24 Exercises in Linguistic Analysis

DBS Software Design for the Hear and the Speak Mode of a Talking Robot

Third Edition
corrected revised expanded
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河宇士

Pen name given to the author by Professor Inseok Yang, President of the Korean Society of Linguistics, Seoul 1982.

Preface

Database Semantics (DBS) takes a new look at linguistic analysis by modeling how communication with natural language works. This requires a *data-driven agent-based* approach, in contradistinction to the widely used substitution-driven sign-based systems. For functional completeness, computational verification, and human-machine interaction, DBS is designed as the language communication and reasoning component of a humanoid robot.

Heuristically, the theory is guided by the principle of *input-output equivalence* with the natural prototype. Input-output equivalence requires the definition of (1) a strictly time-linear derivation order (empirical aspect), (2) separation of the hear and the speak mode (functional aspect), and (3) a representation of *content* as (a) the output of recognition–including the hear mode, (b) the input to action–including the speak mode, and (c) the input and output of reasoning. The agent's main components are (i) an input-output component mediating between concepts and raw data in recognition and action (grounded semantics), (ii) an on-board memory containing a spatio-temporal orientation system and a now front for limiting potential input to current processing, and (iii) an operation component applying to content at the current now front.

Formally, the theory is presented as a *declarative specification*; it shows the *necessary* properties of a software and omits the *accidental* properties of *procedural implementations* in different programming environments such as Lisp, C, Java, and Perl (which have all been used in the evolution of DBS). For larger projects, a declarative specification is essential because it is readable by humans and executable by computers.

The declarative specification of DBS includes (1) the data structure of non-recursive feature structures with ordered attributes, (2) the database schema of a content-addressable variant of a network database, (3) the time-linear algorithm of Left-Associative Grammar integrated with 1 and 2, (4) a computational pattern matching based on type-token matching using restricted variables, (5) the data-driven application of self-organizing operations, and (6) a computational time complexity of linear degree.

To ensure for a given example that the hear mode analysis supplies all the grammatical details needed by the speak mode, DBS adopts the *linguistic laboratory set-up*. It uses the output content produced by the hear mode as input to the speak mode and requires that the speak mode output surface equals the hear mode input surface.

Though a data coverage of 24 isolated[1] linguistic examples may be con-

[1] I.e. outside a dialogue or a text.

sidered small, we know of no other system of comparable functional completeness, grammatical detail, and computational verification. The simple constructions in our sample set have many lexical variants with high frequency of occurrence; the more sophisticated ones are structurally interesting (and challenging), regardless of the number of lexical variants and their statistical frequency.

Second Edition

The title of the second edition is abbreviated as TExer2. The revision of the text benefited from the further evolution of DBS presented in *Computational Cognition* (CC, 2019). Some hear mode operations are improved and their ordering in Sect. 6.3 is corrected.

The linguistic and computational analyses of the English test list (Sect. 1.6) have two obvious directions of extension in the narrow sense. One is additional constructions of English. The other is analogous constructions in other languages, especially non-European languages like Chinese (isolating), Korean (agglutinating), Tagalog (ergative), or Georgian (class of its own). An extension in the wider sense is integration into the behavior control of the robot's cognition, which is driven by the principle of maintaining balance (not truth) in a changing environment.

Third Edition

The title of the third edition is abbreviated as TExer3. Major changes as compared to the second edition are in Sects 1.4, 2.1, 5.4, and 5.5. It is the formal detail which most distinguishes TExer3 from TExer2.

Abbreviations Referring to Preceding and Following Work

SCG Hausser, R. (1984) *Surface Compositional Grammar*, pp. 274, München: Wilhelm Fink Verlag

NEWCAT Hausser, R. (1986) *NEWCAT: Natural Language Parsing Using Left-Associative Grammar*, (Lecture Notes in Computer Science 231), pp. 540, Springer

CoL Hausser, R. (1989) *Computation of Language: An Essay on Syntax, Semantics and Pragmatics in Natural Man-Machine Communication*, Symbolic Computation: Artificial Intelligence, pp. 425, Springer

TCS Hausser, R. (1992) "Complexity in Left-Associative Grammar," *Theoretical Computer Science*, Vol. 106.2:283–308, Amsterdam: Elsevier

FoCL Hausser, R. (1999) *Foundations of Computational Linguistics, Human-Computer Communication in Natural Language, 3rd ed. 2014*, pp. 518, Springer

AIJ Hausser, R. (2001) "Database Semantics for Natural Language." *Artificial Intelligence*, Vol. 130.1:27–74, Amsterdam: Elsevier

L&I'05 Hausser, R. (2005) "Memory-Based Pattern Completion in Database Semantics," *Language and Information*, Vol. 9.1:69–92, Seoul: Korean Society for Language and Information

NLC Hausser, R. (2006) *A Computational Model of Natural Language Communication – Interpretation, Inferencing, and Production in Database Semantics*, Springer, pp. 360;
2nd Ed. 2017, pp. 363, preprint at `lagrammar.net`

L&I'10 Hausser, R. (2010) "Language Production Based on Autonomous Control - A Content-Addressable Memory for a Model of Cognition," in *Language and Information*, Vol. 11:5-31, Seoul: Korean Society for Language and Information

CLaTR Hausser, R. (2011) *Computational Linguistics and Talking Robots, Processing Content in Database Semantics*, pp. 286, Springer;
2nd Ed. 2017, pp. 366, preprint at `lagrammar.net`

L&I'15 Hausser, R. (2015) "From Montague grammar to Database Semantics," in *Language and Information*, Vol 19(2):1-18, Seoul: Korean Society for Language and Information

HBTR Hausser, R. (2016) *How to build a Talking Robot – Linguistics,*

Philosophy, and Artificial Intelligence, pp. 120, Springer, in print

CTGR Hausser, R. (2017) "A computational treatment of generalized reference," *Complex Adaptive Systems Modeling*, Vol. 5(1):1–26, Also available at `http://link.springer.com/article/10.1186/s40294-016-0042-7`. For the original see `lagrammar.net`

CC Hausser, R. (2019) *Computational Cognition: Integrated DBS Software Design for Data-Driven Cognitive Processing*, pp. i–xii, 1–237, `lagrammar.net`

In the following text, references to previous work are to the latest editions. Beginning with 1999, instantiations in the electronic medium, including the present work, make extensive use of `\hyperref` for automatic cross-referencing.

Contents

1. Introduction

This chapter introduces the basic method of linguistic analysis in Database Semantics (DBS). Section 1.1 describes the hear mode mapping from language-dependent surfaces into content. Section 1.2 describes the inverse mapping from content into language-dependent surfaces in the speak mode. Section 1.3 illustrates the elementary, phrasal, and clausal levels of grammatical complexity with examples. Section 1.4 relates the selective activation of a content in the think mode to the distinction between a depth-first and a breadth-first traversal in graph theory. Section 1.5 presents the linguistic laboratory set-up of DBS. Section 1.6 explains the choice and the ordering of the 24 examples.

1.1 Hear Mode: Mapping Surfaces into Content

An agent-based theory of computational linguistics needs to have (i) a data structure for coding content, (ii) an algorithm to map surfaces into content in the hear mode and to map content into surfaces in the speak mode, and (iii) a database schema for the storage and retrieval of content. The data structure of DBS is non-recursive feature structures with ordered attributes called 'proplets.' Most proplets have nine attributes, but a few such as *that* have 10.

1.1.1 Examples of lexical proplets

sur: John	sur: bought	sur: a(n)	sur: new	sur: car	sur: •
noun: [person x]	verb: buy	noun: n_1	adj: new	noun: car	verb: v_1
cat: snp	cat: n′ a′ v	cat: sn′ snp	cat: adn	cat: sn	cat: v′ decl
sem: nm m	sem: ind past	sem: indef sg	sem: pad	sem: sg	sem:
fnc:	arg:	fnc:	mdd:	fnc:	arg:
mdr:	mdr:	mdr:	mdr:	mdr:	mdr:
nc:	nc:	nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:	pc:	pc:
prn:	prn:	prn	prn	prn:	prn:

The second attribute from the top is called the core attribute, e.g. noun, verb, or adj, and its value is called the core value.

Lexical proplets are concatenated into a content by copying values. Consider the following content based on the lexical proplets of 1.1.1:

1.1.2 CONTENT OF John bought a new car .

sur: john	sur:	sur:	sur: new
noun: [person x]	verb: buy	noun: car	adj: new
cat: snp	cat: #n′ #a′ decl	car: snp	cat: adn
sem: nm m	sem: ind past	sem: indef sg	sem: pad
fnc: buy	arg: [person x] car	fnc: buy	mdd: car
mdr:	mdr:	mdr: new	mdr:
nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:
prn: 1	prn: 1	prn: 1	prn: 1

The semantic relation of subject/predicate is coded by copying the core value [person x] of *john* into the first arg slot of *buy* and the core value of *buy* into the fnc slot of *john*. The semantic relation of object\predicate is coded by copying the core value of *car* into the second arg slot of *buy* and the core value of *buy* into the fnc slot *car*, etc.

This form of concatenation is established by the following surface compositional, strictly time-linear (left-associative[1]) hear mode derivation:

1.1.3 TIME-LINEAR HEAR MODE DERIVATION OF A CONTENT

unanalyzed surface

John	bought	a	new	car	.

automatic word form recognition

sur: John	sur: bought	sur: a(n)	sur: new	sur: car	sur: .
noun: [person x]	verb: buy	noun: n_1	adj: new	noun: car	verb: n_1
cat: snp	cat: n' a' v	cat: sn' snp	cat: adn	cat: sn	cat: v' decl
sem: nm m	sem: past ind	sem: indef sg	sem: pad	sem: sg	sem:
fnc:	arg:	fnc:	mdd:	fnc:	arg:
mdr:	mdr:	mdr:	mdr:	mdr:	mdr:
nc:	nc:	nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:	pc:	pc:
prn:	prn:	prn:	prn:	prn:	prn:

syntactic−semantic parsing

	sur: John	sur: bought		
1	noun: [person x]	verb: buy	*cross−copying*	
	cat: snp	cat: n' a' v		
	sem: nm m	sem: past ind		
	fnc:	arg:		
	mdr:	mdr:		
	nc:	nc:		
	pc:	pc:		
	prn: 1	prn:		
	sur: john	sur:	sur: a(n)	
2	noun: [person x]	verb: buy	noun: n_1	*cross−copying*
	cat: snp	cat: #n' a' v	cat: sn' snp	
	sem: nm m	sem: past ind	sem: indef sg	
	fnc: buy	arg: (person x)	fnc:	
	mdr:	mdr:	mdr:	
	nc:	nc:	nc:	
	pc:	pc:	pc:	
	prn: 1	prn: 1	prn:	

3	sur: john noun: [person x] cat: snp sem: nm m fnc: buy mdr: nc: pc: prn: 1	sur: verb: buy cat: #n' #a' v sem: past ind arg: (person x) n_1 mdr: nc: pc: prn: 1	sur: noun: n_1 cat: sn' snp sem: indef sg fnc: buy mdr: nc: pc: prn: 1	sur: new adj: new cat: adn sem: pad mdd: mdr: nc: pc: prn:		*cross−copying*
4	sur: john noun: [person x] cat: snp sem: nm m fnc: buy mdr: nc: pc: prn: 1	sur: verb: buy cat: #n' #a' v sem: past ind arg: (person x) n_1 mdr: nc: pc: prn: 1	sur: noun: n_1 cat: sn' snp sem: indef sg fnc: buy mdr: new nc: pc: prn: 1	sur: adj: new cat: adn sem: pad mdd: n_1 mdr: nc: pc: prn: 1	sur: car noun: car cat: sn sem: sg fnc: mdr: nc: pc: prn:	*absorption with simultaneous substitution*
5	sur: john noun: [person x] cat: snp sem: nm m fnc: buy mdr: nc: pc: prn: 1	sur: verb: buy cat: #n' #a' v sem: past ind arg: (person x) car mdr: nc: pc: prn: 1	sur: noun: car cat: sn' snp sem: indef sg fnc: buy mdr: new nc: pc: prn: 1	sur: adj: new cat: adn sem: pad mdd: car mdr: nc: pc: prn: 1		sur: • verb: n_1 cat: v' decl sem: arg: mdr: nc: pc: prn: *absorption*
result	sur: john noun: [person x] cat: snp sem: nm m fnc: buy mdr: nc: pc: prn: 1	sur: verb: buy cat: #n' #a' decl sem: past ind arg: (person x) car mdr: nc: pc: prn: 1	sur: noun: car cat: sn' snp sem: indef sg fnc: buy mdr: new nc: pc: prn: 1	sur: adj: new cat: adn sem: pad mdd: car mdr: nc: pc: prn: 1		

In addition to cross-copying, hear mode derivations use absorption, with and without simultaneous substitution, as shown in lines 4 and 5, respectively. Also, if a next word proplet cannot find a suitable proplet to connect with, there may be a suspension until a proper candidate arrives.

Cross-copying, absorption, and suspension are performed by operations which are binary in the sense that they always connect two proplets. This is reflected by the names of hear mode operations: they consist of (i) a term characterizing the first input proplet, (ii) a connective which indicates the kind of operation, and (iii) a term characterizing the second input proplet. Cross-copying is indicated by the connective $\times$, as in SBJ$\times$PRD (2.1.2), absorption

[1] Aho and Ullman 1977, p. 47.

by ∪, as in S∪IP (2.1.3), and suspension by ∼, as in ADV∼NOM (3.1.3).

The following application of the hear mode operation SBJ×PRD shows the cross-copying in line 1 of 1.1.3:

1.1.4 Example of applying a hear mode operation

SBJ×PRD (h1)

pattern level

noun: α	verb: β		noun: α	verb: β
cat: NP	cat: NP′ X v	⇒	cat: NP	cat: #NP′ X v
fnc:	arg:		fnc: β	arg: α
prn:K	prn:		prn: K	prn: K

Agreement conditions as in 2.1.2.

⇑ ⇓

content level

sur: John	sur: bought		sur: john	sur:
noun: [person x]	verb: buy		noun: [person x]	verb: buy
cat: snp	cat: n′ a′ v		cat: snp	cat: #n′ a′ v
sem: nm m	sem: ind past		sem: nm m	sem: ind past
fnc:	arg:		fnc: buy	arg: [person x]
mdr:	mdr:		mdr:	mdr:
nc:	nc:		nc:	nc:
pc:	pc:		pc:	pc:
prn: 1	prn:		prn: 1	prn: 1

The operation name is followed by its number, here (h1), in the hear grammar 6.3.1, which lists for each operation the numbers of all its applications.

The *pattern level* shows the operation. The *content level* shows the input (⇑) and the output (⇓). The proplets at the content level relate to the pattern proplets by pattern matching. A pattern proplet matches a content proplet if (i) the attributes of the pattern proplet are a sublist of the attributes of the content proplet and (ii) the values of the pattern proplet match corresponding values of the content proplet. In addition to variable-constant matching there is matching based on the type-token relation (CC 1.6.3).

The operations of DBS are data-driven in the sense that any given input provided by the interface component activates all operations matching it with their trigger pattern. This is in contradistinction to the substitution-driven rules of phrase structure grammar like S→NP VP. Our data-driven method originated as the Lisp code published in NEWCAT (1986) and evolved into the declarative specification of DBS.

The input proplets of the hear mode are stored and connected in the agent's memory, which is realized as a content-addressable computational database called A-memory (formerly called word bank). An A-memory has a two-dimensional database schema.[2] Horizontally, proplets with the same core value are stored in a *token line* in the order of their arrival. Vertically, the token lines are in the alphabetical order induced by their core value.[3] Consider how the content derived in 1.1.3 is stored in a previously empty A-memory:

1.1.5 Database schema of content-addressable A-Memory

member proplets	*now front*	*owner values*
sur: verb: buy cat: #n′ a′ v sem: ind past arg: [person x] car mdr: nc: pc: prn: 1		buy
sur: noun: car car: snp sem: indef sg fnc: buy mdr: new nc: pc: prn: 1		car
sur: john noun: [person x] cat: snp sem: nm m fnc: buy mdr: nc: pc: prn: 1		john
sur: adj: new cat: adn sem: pad mdd: car mdr: nc: pc: prn: 1		new

Because the semantic relations between proplets are coded by address, proplets are order-free (CLaTR 3.2.8) in the sense that the semantic relations between them hold regardless of where they are stored. Therefore the storage of proplets may be organized solely in accordance with the database schema.

The schema of A-memory consists of a table of token lines. Horizontally, each token line contains proplets with the same core value in the order of their arrival. Vertically, the token lines are in the alphabetical order of their core value, enabling string search. The schema is content-addressable (Bachman

[2] The two-dimensional structure of A-memory resembles a classic network database (Elmasri and Navathe 2010), but uses member proplets and owner values instead of member and owner records.

[3] For lookup in the hear mode and production in the speak mode, names are also stored in accordance with their sur marker.

1973) because storage and retrieval do not require a separate index (inverted file, Zobel and Moffat 2006), but rely entirely on the database schema of DBS.[4]

A hear mode operation and the agent's A-memory are integrated as follows: (i) automatic word form recognition stores a next word as a lexical proplet at the now front in the token line of its core value; (ii) called the *trigger proplet*, the next word proplet activates all operations (provided by memory) which match it with their second input pattern; (iii) activated operations look for proplets at the now front which match their first pattern and apply if they find one.

To (a) make room for the next input to be concatenated and (b) limit the number of candidates for activated operations to match, the now front is cleared in regular intervals. The clearance mechanism pushes the proplets currently stored at the now front to the left, as in a pushdown automaton, – or, equivalently, moves the now front and the column of owner values to the right into fresh memory space, leaving the proplets to be cleared behind in what is turning into an area of member proplets, like sediment (loom-like clearance).

This mechanism creates a faithful record of the *time-linear arrival order* of what were - prior to their being connected - lexical next word proplets in their respective token line at the now front. The only way to correct content stored in A-memory is by adding a comment, like a diary entry. The relation between the comment and the content to be corrected is solely by address, leaving the 'sediment' completely untouched.

1.2 Speak Mode: Mapping Content into Surfaces

DBS uses the language-dependent surfaces solely in the automatic word form recognition of the hear mode and the automatic word form production of the speak mode.[5] Otherwise all cognitive operations of the DBS agent work with content, i.e. sets of concatenated proplets in which surfaces, if present, are ignored. Language-specific properties regarding agreement, valency structure, and word order are coded into the proplets' cat and sem slots, making cognition partially language-dependent, but independent of surfaces.

The think mode uses two kinds of operations, (i) selective activation and (ii) inferencing. Selective activation is based on navigating along the semantic relations coded by address between proplets in A-memory. Inferencing takes

[4] The length of a token line for a given core value depends on the number of proplets with that core value. The height of the owner column depends on the number of core value types in the system.

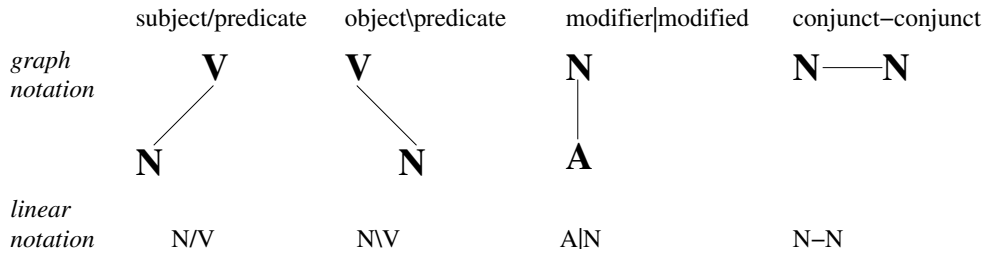
[5] The sur values are deleted in the output of a hear mode operation. A partial exception are proplets of the sign kind name, which retain the surface as a marker, written in lower case and default font instead of helvetica.

activated proplets as input to derive new content. An initial activation is triggered by an external or internal stimulus.

In a complex content, DBS distinguishes four kinds of semantic relations between proplets: (1) subject/predicate, (2) object\predicate, (3) modifier|modified,[6] and (4) conjunct−conjunct. The first three constitute the traditional notions of functor-argument, while the last is coordination. The first two are obligatory, while the latter are optional.

DBS defines a semantic relation of structure as a binary relation between two proplets. Such a relation may be presented in static and in dynamic form. These in turn may be shown (i) graphically and (ii) in linear notation. In static form, the basic semantic relations of structure are written as (i) a letter representing the start proplet (domain item), followed by one of (ii) the connectives /, \, |, and −, and (iii) a letter representing the goal proplet (range item):

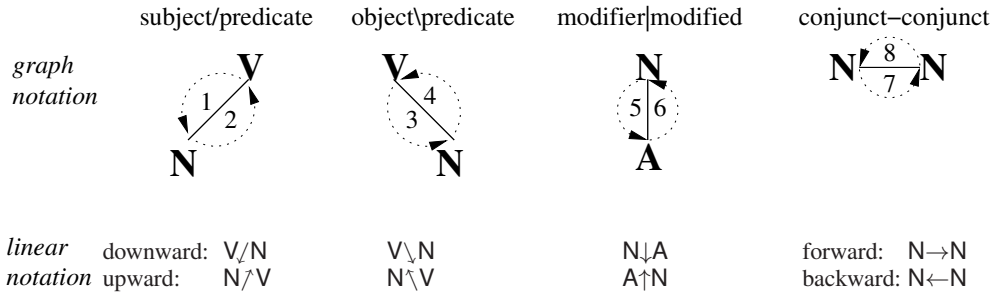
1.2.1 Static presentation of the four semantic relations



If there is a lower node in a binary graph, it precedes in linear notation.

The *direction* of traversing a relation is indicated by numbered arcs in the graph and by extending the slashes into arrows in linear notation, e.g. V↘\N and N↖\V. In linear notation the start node node precedes the goal node.

1.2.2 Dynamic presentation of the four semantic relations



[6] The modifier relation splits in an adverbial and an adnominal version, e.g. A|V and A|N.

Modification and coordination are alike in that they (i) are optional and (ii) allow unlimited iteration. They differ in that repeated modification requires the same semantic role between items (such as location, 1.5.3, 1.5.4), while no such requirement exists for repeated coordination, as in because of the accident (cause) for two days (temporal) in the water (locational) without a life vest (manner).

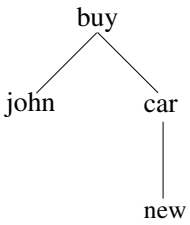
In graphical functor-argument, forward navigation is shown as downward and backward navigation as upward, but in coordination as left-right and right-left.

The semantic relations of structure in complex contents are analyzed as complex graphs. To bring out different aspects of the linguistic analysis underlying the speak mode, DBS uses four different views, called (i) the semantic relations graph (SRG), (ii) the signature, (iii) the numbered arcs graph (NAG), and (iv) the surface realization.

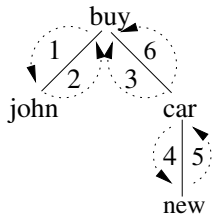
For example, the graph analysis 1.1.3 for the hear mode has the following graph analysis for the speak mode:

1.2.3 Graph analysis underlying the production of 1.1.2

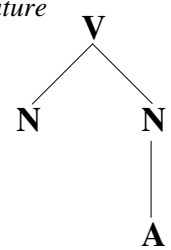
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

1	2	3	4	5	6
John	bought	a	new	car	.
V/N	N/V	V\N	N|A	A|N	N\V

The *(i) SRG, (ii) signature, (iii) NAG*, and *(iv) surface realization* provide different views on a content. The SRG uses the core *values* of the content 1.1.2, while the signature uses the core *attributes*. The NAG adds numbered arcs to the SRG.

The three rows of the (iv) surface realization show for each navigation step (a) the number of the arc traversed, (b) the surface produced, and (c) the nature of the transition. For example, the traversal of arc 1 produces the surface John using the downward navigation V↙N, while the traversal of arc 2 produces the surface bought using the upward navigation N↗V, etc.[7] A transition sequence, e.g. V/N N/V V\N N|A A|N N\V in 1.2.3, must obey the *continuity condition* (NLC 3.6.5), i.e. an operation AxB may be directly followed by an

[7] The surface realization uses, e.g., V/N instead of V↙N because the graphic editor does not provide satisfactory arrows and because the direction is specified by the associated numbered arc.

operation BzC only if the output of AxB is matched by the antecedent of BzC, where A, B, C are patterns and x, y, z are connectives.

The speak mode operations resemble the hear mode (1.1.4) in that they are defined by means of proplet patterns. They differ in that speak mode operations have only one input and one output pattern. Also, the number of speak mode operations applied in the traversal of a well-formed example is always even.

Technically, speak mode operations are think mode operations with a language-dependent lexicalization rule in the sur slot of the output pattern. The following example shows the downward traversal from the predicate to the subject via arc 1 in the NAG of 1.2.3.

1.2.4 Downward traversal with a speak mode operation

$$
\begin{array}{lcccl}
 & \mathbf{V}\swarrow\mathbf{N}\ \text{(s1)} & & & \\
\textit{pattern level} & \begin{bmatrix}\text{verb: } \alpha \\ \text{arg: } \beta\ \overset{..}{\text{X}} \\ \text{prn: K}\end{bmatrix} & \Rightarrow & \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix} & \text{\#-mark } \beta \text{ in the arg slot of proplet } \alpha \\
 & \Uparrow & & \Downarrow & \\
\textit{content level} & \begin{bmatrix}\text{sur:} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x] car} \\ \ldots \\ \text{prn: 1}\end{bmatrix} & & \begin{bmatrix}\text{sur: John} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: buy} \\ \ldots \\ \text{prn: 1}\end{bmatrix} &
\end{array}
$$

The operation name, here V↙N, is followed by the operation number, here s(1). The latter refers to the DBS speak grammar 6.5.1, in which each operation is followed by the reference numbers of all its concrete applications, e.g. 1.2.4.

The corresponding upward traversal (arc 2 in 1.2.3) is provided by N↗V:

1.2.5 Upward traversal with a speak mode operation

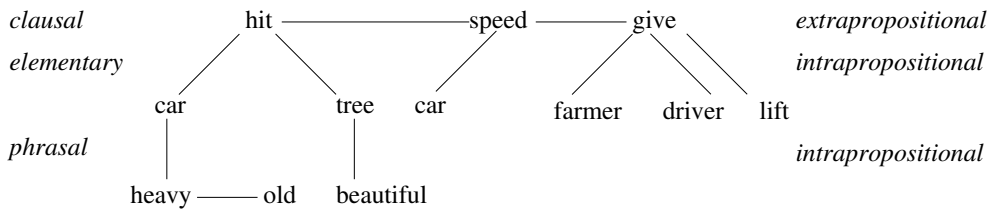
$$
\begin{array}{lcccl}
 & \mathbf{N}\nearrow\mathbf{V}\ \text{(s2)} & & & \\
\textit{pattern level} & \begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y}^{8} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} & \Rightarrow & \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha})^{9} \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K}\end{bmatrix} & \text{\#-mark } \alpha \text{ in the fnc slot of proplet } \beta \\
 & \text{Z is NIL, or elementary and \#-marked} & & & \\
 & \Uparrow & & \Downarrow & \\
\textit{content level} & \begin{bmatrix}\text{sur: john} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 1}\end{bmatrix} & & \begin{bmatrix}\text{sur: bought} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] car} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 1}\end{bmatrix} &
\end{array}
$$

Here, lexverb uses the core value buy and the sem value past to realize bought.

1.3 Three Levels of Grammatical Complexity

In natural language, the four semantic relations represented by /, \, |, and − apply at three levels of grammatical complexity, called elementary, phrasal, and clausal. Consider the DBS graph analysis of the short text The heavy old car hit a beautiful tree. The car had been speeding. A farmer gave the driver a lift., derived in NLC Chaps. 13 (hear mode) and 14 (speak mode).

1.3.1 Clausal, elementary, and phrasal relations



The semantic relations are defined between content proplets, represented by their core value. In other words, the graph is an SRG (1.2.3).

Elementary and phrasal relations are intrapropositional, while clausal relations are extrapropositional. At the clausal level, the predicates of the three propositions are connected by extrapropositional coordination as the conjuncts *hit−speed−give*. The predicates form elementary subject/predicate relations with *car, car,* and *farmer*, respectively, and elementary object\predicate relations with *tree, driver,* and *lift*. The first subject is in the adnominal modifier|modified relation *heavy|car* at the phrasal level; the modifier in turn forms the conjunction *heavy−old* (intrapropositional coordination). Also, the adnominal *beautiful* is in a modifier|modified relation with the object *tree*.

Next consider word order variation for a given content as an instance of paraphrase (FoCL 4.4.6). A classic example is the active-passive alternation,[10] illustrated by the following example using English:

[8] The argument $\hat{\alpha}$ (hat alpha) of lexverb refers to the language-dependent variant of the core value, e.g. German kaufen for buy.

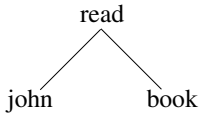
[9] Multiple fnc values are used in subject gapping (Sect. 5.2).

[9] In inferencing (CLaTR Chap. 5), not only the consequent but also the antecedent may be realized in the form of language surfaces.

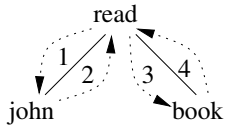
[10] Whether an expression in the active voice and its passive counterpart have the same content or not has been discussed controversially in the literature. Originally generated from the same "deep structure" by a transformation, the meaning equivalence was later cast into doubt based on differences in quantifier scope. For example, Everyone in this room speaks at least two languages (active) and At

1.3.2 Alternation between active and passive in English

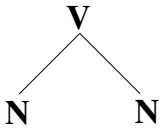
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

a.

1	2	3	4
John	read	a_book	.
V/N	N/V	V\N	N\V

b.

3	4	1	2
A_book	was_read	by_John	.
V\N	N\V	V/N	N/V

The active traverses the arcs of the NAG in the order 1, 2, 3, 4, while the passive traverses them in the order 3, 4, 1, 2.

The content common to the speak mode derivation of the active and the passive variant in 1.3.2 is based on the subject/predicate and object\predicate relations, and defined explicitly as the following set of proplets:

1.3.3 Content common to the active and the passive variant

sur: john	sur:	sur:
noun: [person x]	verb: read	noun: book
cat: snp	cat: #n′ #a′ decl	cat: snp
sem: nm m	sem: ind past	sem: indef sg
fnc: read	arg: [person x] book	fnc: read
mdr:	mdr:	mdr:
nc:	nc:	nc:
pc:	pc:	pc:
prn: 2	prn: 2	prn: 2

The difference between John read a book (surface realization a) and A book was read by John (surface realization b) is accommodated by the lexicalization rules (NLC Sect. 12.4–12.6) embedded into the sur slot of the goal pattern of the navigation operations (1.2.4, 1.2.5).

Another instance of paraphrase is the word order alternation of the indirect and the direct object in English, as The man gave the child an apple vs.

---

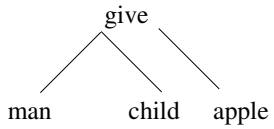
least two languages are spoken by everyone in this room (passive) seem to correspond to the alternative orders of quantifiers postulated by truth-conditional semantics (NLC 6.4.4). The elimination of quantifiers in DBS allows us to treat the literal meaning$_1$ of active and passive as equivalent, moving the alleged scope ambiguity into the inferencing of pragmatics, where it belongs.

It seems to hold in general that expressions with a symmetric alternation like My home is my castle and My castle is my home are based on the same semantic relations of structure, but have nevertheless different pragmatic implications in natural language.

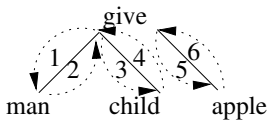
The man gave an apple to the child. Consider the following DBS graph analysis underlying the speak mode realization of both surfaces:

1.3.4 Surface alternation in a three-place verb proposition

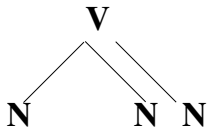
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realizations

a.

1	2	3	4	5	6
The_man	gave	the_child		an_apple	•
V/N	N/V	V\N	N\V	V\N	N\V

b.

1	2	5	6	3	4
The_man	gave	an_apple		to_the_child	•
V/N	N/V	V\N	N\V	V\N	N\V

Variant a is based on the traversal order 1, 2, 3, 4, 5, 6, while variant b is based on the order 1, 2, 5, 6, 3, 4. The prepositional phrase to_the_child is produced by the language-dependent lexicalization rule in the goal pattern of transition 3 of variant b.

While the examples of paraphrase in 1.3.2 and 1.3.4 are within the English language, there are similar kinds of paraphrase also between languages. As an example, consider a content common to corresponding surfaces in English and German:

1.3.5 Content of Peter has read a book.

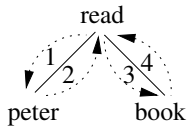
$$\begin{bmatrix} \text{sur: peter} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: read} \\ \text{prn: 79} \end{bmatrix} \begin{bmatrix} \text{sur:} \\ \text{verb: read} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: perf} \\ \text{arg: [person x] book} \\ \text{prn: 79} \end{bmatrix} \begin{bmatrix} \text{sur:} \\ \text{noun: book} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: read} \\ \text{prn:79} \end{bmatrix}$$

Apart from the different word form surfaces of English Peter has read the book and German Peter hat das Buch gelesen. (*Peter has the book read.*), there is a difference in word order. This may be shown with the following DBS graph 1.3.6 underlying the speak mode:

1.3.6 Word order difference between English and German

English word order

(iii) NAG

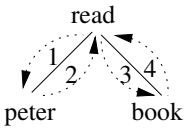


(iv) surface realization

1	2	3	4
Peter	has_read	the_book	.
V/N	N/V	V\N	N\V

German word order

(iii) NAG



(iv) surface realization

1	2	3	4
Peter	hat	das_Buch	gelesen_.
V/N	N/V	V\N	N\V

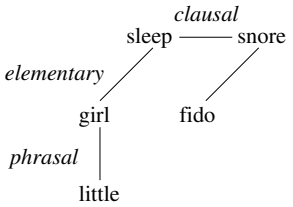
The SRG, the signature, and the NAG are the same for English and German because these graphs characterize the semantic relations in a content, independently of the language-dependent surface realization.

The word order difference between the two languages is provided by the language-dependent lexicalization rules, which segment the two surfaces differently in the traversal of different arcs: In English. the complex verb form has_read is realized in navigation step 2 and the period in step 4. In German, in contrast, hat is realized in step 2 and gelesen_. in step 4 (Satzklammer).[11]

Finally let us turn to a semantic similarity between contents which differs from a proper paraphrase because it is based on the different relations | vs. −. For example, the propositions represented by The little girl slept and Fido snored may be connected extrapropositionally by either the horizontal conjunct−conjunct or the vertical modifier|modifier relation:

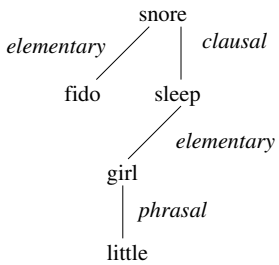
1.3.7 Clausal connection by coordination vs. modification

horizontal connection (conjunct−conjunct)



Corresponding English surfaces:
The little girl slept. Fido snored.

vertical connection (modifier|modified)



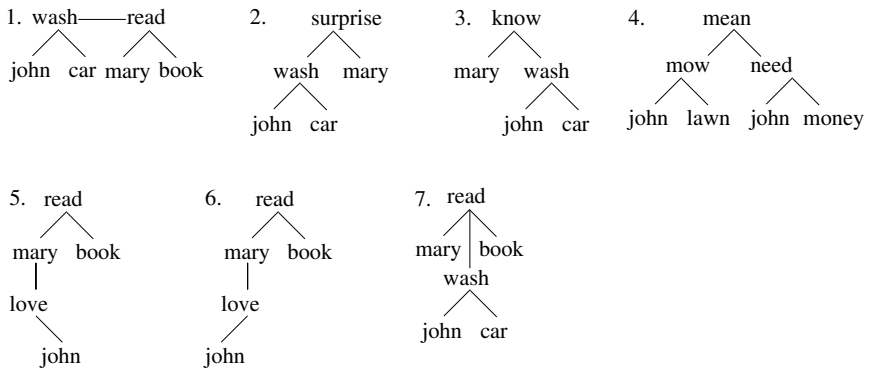
When the little girl slept, Fido snored.

As contents, the constructions are intuitively similar, but they differ syntactically. The extrapropositional alternation is structurally possible because the conjunct−conjunct and modifier|modified relations are both optional.

[11] For a comparison of adnominal subclause word order in English and German see CLaTR Sect. 9.3.

The variety of extrapropositional constructions results from the four different kinds of semantic relations of structure in natural language and is reflected graphically by the semantically interpreted /, \, |, and − lines (edges). Consider the following examples:

1.3.8 Relating two transitive verbs extrapropositionally



1. conjunct−conjunct: John washed the car. Mary read a book.
2. subject/predicate: That John washed the car surprised Mary.
3. object\predicate: Mary knew that John had washed the car.
4. sbj/prd\obj:[12] That J. mows the lawn means that J. needs money.
5. adn. mdr|mdd (subject gap): Mary who loves John read a book.
6. adn. mdr|mdd (object gap): Mary who(m) John loves read a book.
7. adv. modifier|modified: When John washed the car Mary read a book.

Which kind of relation may connect the predicates of two component propositions depends on the verb class. For example, 2 requires a psych verb (Sect. 2.5), while 3 requires a mental state verb (Sect. 2.6). Thus, it is impossible to use the same predicate for constructing all seven[13] constellations.

1.4 Arc Numbering and Traversal Order

The traversal of a DBS graph for selective activation and surface realization in the narrative speak mode is highly constrained. First, the nodes are traversed in accordance with the Continuity Condition (NLC 3.6.5); for example, roughly speaking, if the goal node is N, as in V↙N, the start node of the successor operation must be N as well, as in N↗V. Second, within the DBS laboratory set-up

[12] Verbs which take a clausal subject and a clausal object simultaneously (class 4 in 1.3.8) include *entail, hint, imply, indicate, mean, presuppose,* and *suggest*. Thanks to Prof. Kiyong Lee for pointing it out.

[13] The criteria for establishing word classes are diverse (Levin 2009). For analyzing semantic relations of structure, DBS defines verb classes in terms of their possible valency filler (CLaTR Chap. 15).

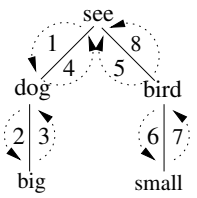
(Sect. 1.5), a speak mode derivation must realize the same surface as interpreted by the corresponding hear mode derivation. Third, the overall structure of the graph is determined empirically by the semantic properties of the input content, automatically determined in the associated hear mode derivation.

As a consequence, there is no choice between different traversals, such as between a depth-first vs. breadth-first traversal in graph theory. The only aspect open to choice is the arc *numbering* in a NAG, which may simulate a depth-first or a breadth-first traversal. For example, the following two NAGs differ only in their arc numbers: the ones on the left are seemingly depth-first, the ones on the right seemingly breadth-first.

1.4.1 Example 1: Arc numbering depth-first vs. breadth-first

Depth first:

(iii) NAG (numbered arcs graph)

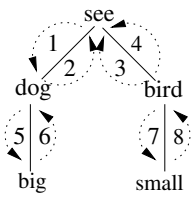


(iv) surface realization

1	2	3	4	5	6	7	8
The	big	dog	saw	the	small	bird	.
V/N	N|A	A|N	N/V	V\N	N|A	A|N	N\V

Breadth first:

(iii) NAG (numbered arcs graph)



(iv) surface realization

1	5	6	2	3	7	8	4
The	big	dog	saw	the	small	bird	.
V/N	N|A	A|N	N/V	V\N	N|A	A|N	N\V

The different arc numbers result in different traversal numbers in the top line of the *(iv) surface realization*s: each number specifies for each associated transition directly underneath in the bottom line in which arc of the NAG the transition takes place. Except for the numbering, the NAG and the surface realization on the left and on the right are the same.

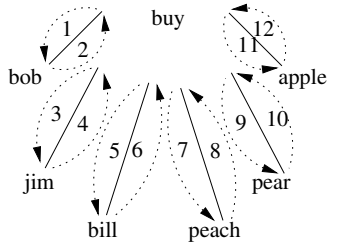
Thus, there is a choice of how to number the arcs, but no choice of how to traverse the NAG for surface production in the speak mode.[14] Linguistically, the arc numbering on the left of 1.4.1 is preferable because it produces a consecutive numbering in the surface realization. There are, however, grammatical constructions for which a depth-first arc numbering does not fit. Consider the following example of predicate gapping (Sect. 5.3):

[14] If the arc numbering were to always follow the surface realization, the distinctions between paraphrases such as active and passive (1.3.2) could not be based on alternative traversals of the same NAG. Also, a consecutive arc numbering following the surface order is impossible in constructions with multiple traversals of the same node as in 1.4.8, 1.4.9, and 1.5.5.

1.4.2 Example 2: Arc numbering depth-first vs. breadth-first

Depth first:

(iii) NAG (numbered arcs graph)



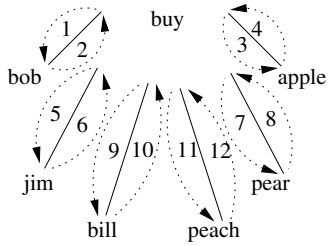
(iv) surface realization

1	2	11	12	3	4
Bob	bought	an_apple		Jim	
V /N	N/V	V\N	N\V	V^p/N	N/V^p

9	10	5	6	7	8
a_pear		and_Bill		a_peach	.
V\N	N\V	V^p/N	N/V^p	V\N	N\V

Breadth first:

(iii) NAG (numbered arcs graph)



(iv) surface realization

1	2	3	4	5	6
Bob	bought	an_apple		Jim	
V /N	N/V	V\N	N\V	V^p/N	N/V^p

7	8	9	10	11	12
a_pear		and_Bill		a_peach	.
V\N	N\V	V^p/N	N/V^p	V\N	N\V

Here it is the breadth-first numbering which results in consecutive numbers in the surface realization, in contradistinction to 1.4.1

In addition to the dichotomy between the depth-first vs. breadth-first arc numbering in a given semantic relations structure, there may also be alternative semantic relation structures for a given surface, as in the following example:

1.4.3 Intra- and extrapropositional verbal coordination

Julia slept. Bob bought, peeled, and ate an apple. Fido snored

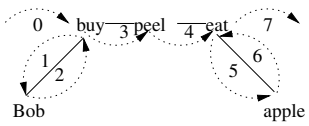
[prn: n] [prn: n+1] [prn: n+2]

The critical transition is from the intrapropositional coordination of proposition [prn: n+1] to [prn: n+2] by means of an extrapropositional coordination. The following solutions have be proposed:

1.4.4 Alternative NAGs for verb coordination

TExer3 proposal

(iii) numbered arc graph (NAG)

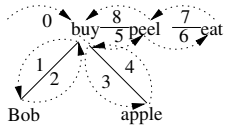


(iv) surface realization

1	2	3	4	5	6
Bob	bought	peeled	and_ate	an_apple	.
V/N^i	N /V	V–V	V–V	V\N	N\V

NLC2 proposal

(iii) numbered arc graph (NAG)



(iv) surface realization

1	2	5	6	7	8	3	4
Bob	bought	peeled	and_ate			an_apple	.
V/N	N/V	V–V	V–V	V–V	V–V	V\N	N\V

The NLC2 analysis on the right takes an intrapropositional perspective by

treating subject (NLC2 8.2.3), predicate (NLC2 8.3.4), object (NLC2 8.2.7), and modifier (CC 15.4.4) coordinations alike. Also, the initial conjunct *buy* is treated as (a) as the representative of the proposition, (b) the point of extrapropositional entrance, and (c) the point of extrapropositional exit.

If there is only a single top verb, which is usually the case, this is easily fulfilled. However, if there are several verbs of equal rank, as in an intrapropositional verb coordination (1.4.3), there is a problem. A first symptom is the absent exit arc in the NLC2 NAG in 1.4.4. At the proplet level, the reason may be located in the nc slot of the initial verb proplet *buy*. Consider the following schematic instantiation:

1.4.5 Intrapropositional verb-verb coordination

$$\begin{bmatrix}\text{verb: buy}\\ \ldots\\ \text{nc: peel}\\ \text{pc:}\\ \text{prn: n}\end{bmatrix}\begin{bmatrix}\text{verb: peel}\\ \ldots\\ \text{nc: eat}\\ \text{pc: buy}\\ \text{prn: n}\end{bmatrix}\begin{bmatrix}\text{verb: eat}\\ \ldots\\ \text{nc:}\\ \text{pc: peel}\\ \text{prn: n}\end{bmatrix}$$

The intrapropositional nature is shown by the shared prn value and the intrapropositional address values of the nc and pc attributes. The nc slot of the first conjunct is filled by the address of the next verbal conjunct peel, which makes it unavailable for any relation to an extrapropositional next verbal conjunct (as would be needed for the NLC analysis in 1.4.3). The nc slot of the last conjunct, however, is available for an extrapropositional coordination with a next proposition.

Next consider an extrapropositional coordination in a similar format as 1.4.5:

1.4.6 Extrapropositional verb-verb coordination

$$\begin{bmatrix}\text{verb: sleep}\\ \text{arg: julia}\\ \text{nc: (sing n+1)}\\ \text{pc:}\\ \text{prn: n}\end{bmatrix}\begin{bmatrix}\text{verb: buy}\\ \text{arg: bob apple}\\ \text{nc: (snore n+2)}\\ \text{pc: (sleep n)}\\ \text{prn: n+1}\end{bmatrix}\begin{bmatrix}\text{verb: snore}\\ \text{arg: fido}\\ \text{nc:}\\ \text{pc: (buy n+1)}\\ \text{prn: n+2}\end{bmatrix}$$

The extrapropositional nature of the coordination is shown by the extrapropositional address values of the nc and pc attributes, and the incremented prn values of the clausal conjuncts. Here the empty pc value in the *sleep* proplet indicates initial position, just as an empty nc value indicates the end of a text.

It is the empty nc value of the intrapropositional coordination 1.4.5 which opens the possibility of the TExer3 analysis on the left of 1.4.4. The first verb of the intrapropositional coordination is the entrance proplet with (1) the subject value bob, (2) the object value apple and (3) the syntactic mood value decl, while the last verb *eat* of the coordination is the exit proplet. The

non-initial conjuncts, here *peel* and *eat*, implicitly share the arg values and explicitly the prn value of the initial verbal conjunct *buy*. The only function *buy* had to relinquish is the role as the exit proplet, which is taken here by the last verbal conjunct *eat* and expressed by the feature [nc: n+2] of *snore*.[15]

The intrapropositional verb coordination in the TExer3 proposal on the left of 1.4.4 and the extrapropositional coordination in 1.4.3 have in common that they are uni-directional, in the direction of time. They may, however, be traversed in the anti-temporal direction by means of the following inference:

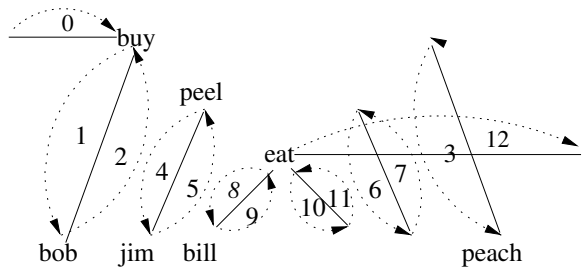
1.4.7 Inference navigating backward through a coordination

$$\begin{bmatrix} \text{verb: } \beta \\ \text{pc: } \alpha \\ \text{prn: n+1} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{verb: } \alpha \\ \text{nc: } \beta \\ \text{prn: n} \end{bmatrix}$$

The considerations for a simple coordination (1.4.5) apply also to another kind of intrapropositional repetition, namely subject and object gapping:

1.4.8 Object gapping in a top level conjunction

(iii) NAG (numbered arcs graph)



(iv) surface realization

0	1	2	3	7	4	5	6	11	8	9	10	11	12
	Bob	bought			Jim	peeled			and_Bill	ate	a_peach	•	
V−V	V/N	N/V	V\N^{o}	N^{o}\V	V/N	N/V	V\N^{o}	N^{o}\V	V/N	N/V	V\N^{f}	N^{f}\V	V−V

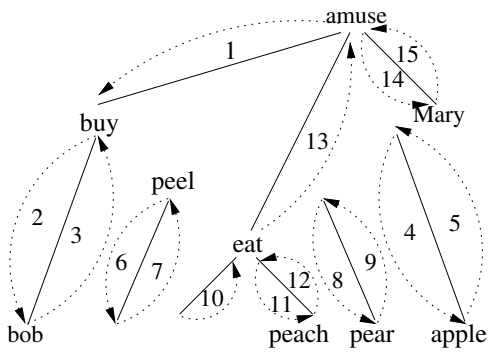
As shown in Sect. 5.4, the relation between the shared item and the gapped items is not run via the nc and pc slots (1.4.6) but via the gap list in the shared item and the repetition of the shared item address in the gapped items. Exiting from *eat* rather than *buy* facilitates continuing to the next proposition by avoiding a lengthy and complicated return via the arcs 10, 7, 4, 2 to the initial verb of the current proposition. Moreover, the last verb is clearly marked in the content's set of proplets by the initial *and* value in the sem slot of *eat*.

[15] That, e.g., *buy* has this function in single predicate constructions is because there it is the entrance and the exit proplet at the same time.

What holds for the paratactic example 1.4.8 holds equally for its hypotactic counterpart:

1.4.9 Subject gapping as a clausal subject

(iii) NAG (numbered arcs graph)



(iv) surface realization

1	2	3	4	5	2	7	8	9	6	10	11	12	13	14	15
That	bob	bought	an_apple			peeled	a_pear			and_ate	a_peach		amused	mary	.
V/V	V/N	N/V	V\N	N\V	V/N	N/V	V\N	N\V	V/N	N\V	V\N	N\V	V/V	V\N	N\V

The navigation activates the top predicate *amuse* from the top level coordination (as in a text, not shown). The depth-first traversals of arc 1 and 2 reach *bob* as the shared item of a subject gapping construction, which happens to serve as the clausal subject of *amuse*. Triggered by the gap list of *bob* (5.2.18), the arc numbering switches from depth-first to breadth-first. After traversing the gapped subject clause, the navigation returns via arc 13 from *eat* to *amuse* (i.e. with V↗V from the clausal subject back to the predicate) and completes the traversal via arcs 14 and 15 in a depth first manner.

1.5 DBS Laboratory Set-Up for Linguistic Analysis

Mapping a content derived in the hear mode from a language surface back into that same surface in the speak mode is called the *DBS laboratory set-up* (NLC 3.5.3, CLaTR Sect. 14.4). For example, the operations 1.2.4 and 1.2.5 realize John and bought from two proplets which were derived in the hear mode derivation 1.1.3 (narrative speak mode).[16]

The linguistic laboratory set-up is defined as follows:

[16] The alternative to the narrative speak mode is the reasoning speak mode, i.e. the verbalization of inferencing.

1.5.1 The DBS Laboratory Set-Up

- Narrow condition
  The hear mode must derive a content from an input surface in such a way that it encodes all grammatical information needed for producing the same surface as output in the speak mode.
- Wide condition
  The optional variants of a speak mode derivation, e.g. 1.3.2, 1.3.4, and 3.5.1, must be syntactically well-formed and semantically equivalent.

The laboratory set-up allows to put the task of controlling the agent's behavior towards maintaining a state of balance vis à vis a continuously changing environment (survival in the agent's ecological niche) temporarily aside. At the same time, a software implementing DBS hear and speak grammars in accordance with the laboratory set-up is prepared from the outset for an autonomous control in the agent's cognition: the constraint provided by the laboratory set-up is simply replaced by guiding the navigation and the inferencing underlying the speak mode (and behavior in general) towards maintaining the agent in a state of balance (6.6.1, 6.6.2; NLC Chap.5; CLaTR Chaps. 5, 6).

The following 24 Sects. 2.1–5.6 are limited to the narrow condition. Each exercise analyzes a sample structure by working off the following to-do list:

1.5.2 The seven **To-do**s of building a DBS grammar

1. **<to-do 1>**
   Definition of the content for an example surface (e.g. 3.3.1)
2. **<to-do 2>**
   Graphical hear mode derivation of the content (e.g. 3.3.2)
3. **<to-do 3>**
   Complete sequence of explicit hear mode operation applications (e.g. 3.3.3–3.3.8)
4. **<to-do 4>**
   Canonical DBS graph analysis underlying production (e.g. 3.3.9)
5. **<to-do 5>**
   List of speak mode operation names with associated surface realizations (e.g. 3.3.10)
6. **<to-do 6>**
   Complete sequence of explicit speak mode operation applications (e.g. 3.3.11–3.3.16)

7. **<to-do 7>**
   Summary of the system extension and comparison of the hear and speak mode operation applications (e.g. 3.3.17)

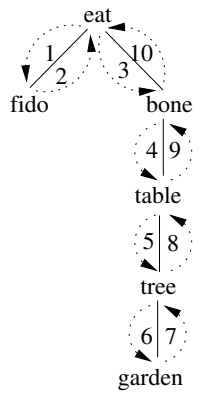
<to-do 1> defines the theoretical space in which the linguistic analysis takes place: the surface is the input to the hear mode and the associated content the output, while the content is the input to the speak mode and the original surface the output. **<to-do 2>** and **<to-do 3>** specify the details of the hear mode, while **<to-do 4>**, **<to-do 5>**, and **<to-do 6>** specify the details of the speak mode. **<to-do 7>** concludes with a comparison of the hear and the speak mode derivations of the example. It lists the additional operations needed for the construction as compared to the preceding example and compares the number of operation applications needed in the hear and the speak mode.

For example, the surface Fido ate the bone on the table under the tree in the garden **.** (5.1.1) consists of n = 14 word form surfaces (including the period as the syntactic mood marker). Therefore, the hear mode interpretation requires a minimum of n-1 = 13 hear mode operations. The associated speak mode derivation, in contrast, requires only 10 operations (5.1.24).

This holds for the adnominal as well as the adverbial reading of the example, as shown by the following graph analyses. The adnominal reading attaches the modifier|modified sequence to the grammatical object (Sect. 5.1):

1.5.3 Graph analysis for producing the adnominal reading

(iii) NAG (numbered arcs graph)



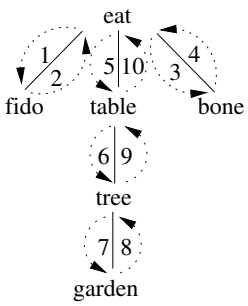
(iv) surface realization

1	2	3	4	5	6	7	8	9	10
Fido	ate	the_bone	on_the_table	under_the_tree	in_the_garden				**.**
V/N	N/V	V\N	N|N	N|N	N|N	N|N	N|N	N|N	N\V

The adverbial reading attaches the modifier|modified sequence to the predicate:

1.5.4 Graph analysis for producing adverbial reading

(iii) NAG (numbered arcs graph)



(iv) surface realization

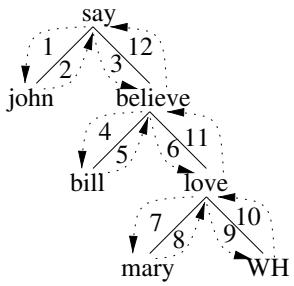
1	2	3	4	5	6	7	8	9	10
Fido	ate	the_bone		on_the_table	under_the_tree	in_the_garden			•
V/N	N/V	V\N	N\V	V|N	N|N	N|N	N|N	N|N	N|N

The reason for the lower number of speak mode operations as compared to the hear mode is the realization of prepositional phrases in a single navigation step.

The example Whom does John say that Bill believes that Mary loves? (5.5.2), in contrast, requires 10 operation applications in the hear mode, but 16 in the speak mode.

1.5.5 DBS graph analysis of an unbounded dependency

(iii) NAG (numbered arcs graph)



(iv) surface realization

3	6	9	10	11	12	1	2	3	4	5	6	7	8	11	12
		Whom				does	John	say	that	Bill	believes	that	Mary	loves	?
V\V	V\V	V\N	N\V	V\V	V\V	V/N	N/V	V\V	V/N	N/V	V\V	V/N	N/V	V\V	V\V

The reason for the higher number of speak mode operations as compared to the hear mode (5.5.33) is the empty traversals for getting to Whom in the lowest

object clause and then back empty to the top clause for a possible navigation to a next proposition, as in a text.[17]

Each time the test list has been extended to an additional example and analyzed in the hear and the speak mode in accordance with the to-do list 1.5.2, the declarative specification is to be tested procedurally by an implementation of the system. Once the complete current test list is debugged such that the hear and the speak mode run without fault, the upscaling cycle is repeated by adding a new construction to the current test list.

1.6 The Test List

This section presents the 24 linguistic examples which will be analyzed in the following chapters. For each example, the grammatical reasons for its construction and its place in the systematic order of presentation are explained.

1.6.1 The examples of Chap. 2

The general topic of this chapter is the obligatory semantic relations of natural language, namely subject/predicate and object\predicate, at the elementary, phrasal, and clausal levels of grammatical complexity (Sect. 1.3).

1. Mary slept[18]. – Mary slept. Fido snored. Sect. 2.1

   After analysis of a minimal declarative sentence, two minimal declaratives are coordinated with extrapropositional coordination to illustrate a minimal text.

2. The old dog had been sleeping. Sect. 2.2

   Like 1, this example is based on the semantic relation of subject/predicate. It differs in that the subject and the predicate are phrasal rather than elementary. The hear mode analysis (2.2.2) shows how the surface, consisting of seven word forms (including the period) is interpreted by adding one analyzed word form after another in a strictly time-linear derivation order, resulting in a content which consists of three proplets. The speak mode

[17] The corresponding declarative sentence John says that Bill believes that Mary loves Tom. uses basically the same speak mode graph (NLC 7.6.1), but the traversals follow the arc numbers consecutively and there are neither empty nor multiple traversals.

[18] An elementary word form like slept is treated as an elementary content.

analysis (2.2.9) shows the time-linear navigation along the semantic relations between these three proplets and the realization of the seven surfaces.

3. I saw you. Sect. 2.3

   This example consists of an elementary subject, predicate, and object. The time-linear hear mode analysis (2.3.2) of the first two word forms is analogous to that of 1. The resulting content consists of three order-free proplets which are connected by the relations subject/predicate and object\predicate. The speak mode analysis (2.3.6) navigates from the predicate to the subject to realize I (pro1), from the subject back to the predicate to realize saw, from the predicate on to the object to realize you, and from the object back to the predicate to realize the period.

4. The big dog saw a small bird. Sect. 2.4

   Like 3, this example is based on the semantic relations subject/predicate and object\predicate. It differs in that the subject and the object are phrasal rather than elementary. The time-linear hear mode analysis of the first four word forms is analogous to that of example 2. Because the hear mode (2.4.2) fuses the determiners the and a(n) with their common noun (function word absorption), the seven word form surface results in a five proplet content. In the speak mode (2.4.10), the function words are realized by lexicalization rules which use such proplet values as def(inite) and indef(inite) as input for realizing the different determiners.

5. That Fido barked amused Mary. Sect. 2.5

   Like 3 and 4 this example is based on the semantic relations subject/predicate and object\predicate. It differs in that the subject is clausal rather than elementary (1) or phrasal (2). The strictly time-linear hear mode interpretation (2.2.2) assembles the subject clause by adding one word form after another and then connects it to the matrix clause predicate with a V/V relation. The speak mode (2.5.8) navigates from the predicate of the matrix clause to the predicate of the subclause to realize That, and from there to the subclause subject to realize Fido. On the return to the subclause predicate, the speak mode realizes barked, and on the return to the matrix predicate it realizes amuse. The time-linear hear and speak mode analysis of the matrix clause remainder is analogous to 4.

6. Mary heard that Fido barked. Sect. 2.6

   This example is also based on the subject/predicate and object\predicate relations. It differs from 5, however, in that it is the object rather than the subject which is clausal. Instead of assembling the object clause before connecting it to the main clause predicate, the hear mode derivation (2.6.2) adds it word form by word form in a strictly time-linear fashion. This is enabled by input and output patterns of the hear mode operations which accommodate the local relations within a subclause regardless of whether it precedes of follows the matrix predicate. The speak mode (2.6.8) navigates from *hear* to *mary* to realize the subject, back to *hear* to realize the predicate, from there to the object clause predicate *bark* to realize that, from there to *fido* to realize the subclause subject, back to *bark* to realize the subclause predicate, and finally back to *hear* to realize the period.

1.6.2 The examples of Chap. 3

The general topic is the optional semantic relations of natural language, namely modifier|modified and conjunct−conjunct, the former at the elementary, phrasal, clausal levels of grammatical complexity, the latter only at the elementary level.[19]

7. *Perhaps* Fido is *still* sleeping *there now*. Sect. 3.1

   Like 1, this example is based on the subject/predicate relation. In addition, the example shows four elementary adverbial modifiers. In the time-linear hear mode derivation (3.1.2), there is no semantic relation between the first two word forms Perhaps Fido. They are suspended until the finite auxiliary arrives, at which point two operations apply in the same derivation step (suspension compensation): one connects *perhaps*, the other *fido*, to the auxiliary. The following adverbial *still* is also connected to the auxiliary. After the auxiliary and the non-finite main verb have been fused (function word absorption), the adverbials *there* and *now* are connected to the predicate. The speak mode (3.1.11) navigates from the predicate to the initial adverbial via V↓A to realize perhaps, back to predicate, on to the subject to realize Fido, back to the predicate to realize is, and so on.

8. Fido ate the bone on the table. Sect. 3.2

   The analysis shows the adverbial (and not the adnominal[20]) interpretation of the phrasal modifier on the table. After interpreting the initial sen-

[20] For a detailed treatment of clausal coordination see NLC Chaps. 11 (hear mode) and 12 (speak mode).

tence in analogy to 4, the hear mode (3.2.3) connects the preposition to the predicate, and then adds the determiner and the noun, fusing them into one proplet representing the prepositional phrase. In the speak mode (3.2.11), the values *on*, def sg, and table of this proplet are used to realize on_the_table from the goal proplet of a single traversal.

9. The dog which saw Mary barked. Sect. 3.3

This example moves from elementary (7) and phrasal (8) adverbial modification to a clausal adnominal modifier, aka a relative clause. By fusing the determiner with *dog* and the subordinating conjunction with *see* (function word absorption), the hear mode maps a seven[21] word form surface into a four proplet content (3.3.2). In the content, *dog* uses see as a modifier, and *see* uses dog as a modified. In addition, the object\predicate relation connects *mary* and *see* (N\V), and the subject/predicate relation connects *dog* and *bark* (N/V). The speak mode (3.3.9) navigates from *bark* to *dog* to realize the dog, from *dog* to *see* to realize which_saw, from *see* to *mary* to realize Mary, back to *see* and on to *bark* to realize barked_.

10. The dog which Mary saw barked. Sect. 3.4

This example differs from 9 in that *mary* is the subject (and not the object) of the adnominal clause; also *dog* functions as the implicit object (and not as the implicit subject) of the subclause. This is expressed by the word order which Mary saw (instead of which saw Mary). As a consequence of this word order there is a suspension in the time-linear hear mode derivation (3.4.2): the subordinating conjunction and *mary* cannot be connected because there is no semantic relation between them. When *see* arrives, (i) it connects with *mary* (subject/predicate) and (ii) fuses with the subordinating conjunction (function word absorption) in the same derivation step (suspension compensation). The speak mode (3.4.9) navigates from *bark* to *dog* to realize the dog, from *dog* to *see* to realize which, from *see* to *mary* to realize Mary, back to *see* to realize saw, and finally back to *bark* to realize barked_.

11. When Fido barked Mary laughed. Sect. 3.5

This example shows a clausal adverbial. In contradistinction to clausal adnominals (9, 10), the position of clausal adverbials is relatively free (NLC

[20] For the analysis of elementary and phrasal adnominal modifiers see NLC Sects. 13.2, 14.2, and 15.3.
[21] Counting the period.

7.5.1, 7.5.4) and they do not contain any gap. The extrapropositional V|V relation between *bark* and *laugh* is coded by the core values laugh in the mdd slot of *bark* and bark in the mdr slot of *laugh*. The time-linear hear mode derivation (3.5.2) begins with a suspension because there is no semantic relation between When and Fido. When *bark* arrives the suspension is compensated by (i) combining *fido* and *bark* with subject/predicate and by (ii) fusing the subordinating conjunction and *bark* (function word absorption). The speak mode derivation (3.5.10) navigates from *laugh* to *bark* to realize When, from *bark* to *fido* to realize Fido, from *fido* back to *bark* to realize barked, from *bark* back to *laugh* and on to *mary* to realize Mary, and from *mary* back to *laugh* to realize laughed_•.

12. Fido, Tucker, and Buster snored loudly. Sect. 3.6

This example illustrates the other optional relation in natural language besides modification, namely coordination, represented formally as conjunct−conjunct. The relation is coded by the core value of *tucker* in the nc (next conjunct) slot of the *fido* proplet and the core value of *fido* in the pc (previous conjunct) slot of the *tucker* proplet, and similarly for the relation between *tucker* and *buster*. In the functor-argument structure derived in the hear mode (3.6.2), only the initial conjunct is used for the subject/predicate relation with the predicate (NLC Sects. 8.1, 8.2), while the conjuncts are connected solely by coordination. The semantic structure underlying the speak mode is shown in 3.6.11

1.6.3 The examples of Chap. 4

The general topic is the different kinds of arguments in the functor-argument relation, such as prepositional object, discontinuous element, infinitive phrase, and the second argument in copula constructions.

13. Julia put the flowers on the table. Sect. 4.1

Modifiers are optional in the sense that an expression without them is still complete, while arguments are obligatory in that an expression without them is incomplete. Prepositional phrases are free to serve as either an optional modifier or an obligatory argument. For example, on the table is an optional modifier in 8, but an obligatory argument here. This is because the verb *put* takes a subject, a direct object, and a prepositional phrase as arguments. The hear mode interpretation (4.1.2) is analogous to 8 except that cat attribute of *put* has the additional valency position mdr′ which gets

canceled when the preposition is added, making the prepositional phrase an argument. The speak mode derivation (4.1.10) is analogous to 8.

14. The letter made Mary happy. Sect. 4.2

The verb *make* is like *put* in that it may take a modifier as an argument. It differs in that it takes an adnominal, here *happy*, rather than a prepositional phrase. As in 13, the obligatory nature of the modifier as a valency filler is expressed by *happy* canceling a mdr′ valency position in the cat slot of the verb. The adnominals combining with *make* are restricted to such mood indicators as {happy, sad, angry, pensive, wary, proud, ...}. For the graphical hear and speak mode derivations see 4.2.2 and 4.2.8, respectively.

15. Fido dug the bone up. Sect. 4.3

This example raises the question of whether the so-called discontinuous element up is part of the verb (separable prefix) or an argument, similar to happy as in discontinuous make...happy. The DBS analysis takes the second approach. However, while the proplet set of 14 includes a *happy* proplet (content word), the proplet set of 15 does not include an *up* proplet (function word); instead, *up* is absorbed into *dig*. For the graphical hear and mode derivations see 4.3.2 and 4.3.8, respectively.

16. John tried to read a book. Sect. 4.4

The transitive verb *try* may take a noun, as in try a cookie, or an infinitive, as in try to read a book (CLaTR Sect. 15.4) as its direct object. In the hear mode (4.4.2), the lexical analysis of the intrapropositional conjunction to has the core attribute verb because it absorbs the infinitive, a fnc attribute because the infinitive serves as an argument of the higher predicate, and an arg attribute for the underlying subject of the infinitive, here *john*. In the speak mode (4.4.9), *read* is related to *try* by V\V and *book* is related to *read* by N\V.

17. Julia is a doctor. Sect. 4.5

The core value of the auxiliary be is a substitution variable, here v_1. When used as a function word in a complex verb construction, the substitution variable is replaced by the core value of the infinite main verb (function word absorption). In the present example, however, the auxiliary is used as a copula taking a noun as its second argument. Citing conflicting morphological evidence of English, the question of whether the second

noun should be analyzed as a nominative or as oblique is answered in favor of the latter. In this way, the hear mode derivation (4.5.2) may be based on the operations SBJ×PRD and PRD×OBJ. The speak mode analysis (4.5.7) is also based on the standard analysis of a transitive sentence.

18. Fido is hungry. Sect. 4.6

The cat values of the auxiliary form is include two valency positions, ns3′ and be′. The first is canceled by the subject, the second by either a noun interpreted as an object, as in 17, or by an adnominal. In the present example, (i) the valency position be′ is canceled by the adnominal *hungry* and (ii) the core values of *v_1* and *hungry* are cross-copied into the respective mdd and mdr slots. This simultaneous valency canceling and cross-copying characterizes *hungry* as an argument (and not as an optional modifier), analogous to 14. For the graphical hear and speak mode derivations see 4.6.2 and 4.6.6, respectively.

1.6.4 The examples of Chap. 5

The general topic is the handling of repetition as iteration.[22] The examples are prepositional clause repetition, subject gapping, predicate gapping, object gapping, unbounded object clause repetition (unbounded dependency), and adnominal subclause repetition.

19. Fido ate the bone on the table under the tree in the garden. Sect. 5.1

The beginning of this example is the same as 8. The difference is the continuation with repeated prepositional phrases. Used as adnominal modifiers, they are attached by cross-copying between the mdr slot of the modified and the mdd slot of the modifier, but being optional without canceling a valency position (unlike 13, 14, and 18). For the graphical hear and speak mode derivations see 5.1.2 and 5.1.12, respectively.

20. Bob bought an apple, ∅ peeled a pear, and ∅ ate a peach. Sect. 5.2

In this example of subject gapping, the hear mode (5.2.3) constructs the gap list *buy, peel, eat* incrementally in the shared subject *bob*. It is a repeating construction because there is no grammatical limit on the number of gapped items. The speak mode (5.2.16) uses the shared subject repeatedly as a valency filler, but with only a single (initial) surface realization.

21. Bob bought an apple, Jim ∅ a pear, ..., and Bill ∅ a peach. Sect. 5.3

    In this example of predicate gapping, the gap list *bob apple, jim pear, bill peach* is constructed incrementally in the shared predicate *buy* by the hear mode (5.3.2). Like all gapping constructions, it is intrapropositional. The speak mode (5.2.16) uses the shared predicate repeatedly as the valency carrier, but with only a single (initial) surface realization.

22. Bob bought ∅, Jim peeled ∅, ..., and Bill ate a peach. Sect. 5.4

    While the shared item in subject and predicate gapping precedes the gaps, the shared item follows the gaps in object gapping, as shown by the shared object *peach* of this example. For building up the gap list *buy, peel, eat*, the hear mode (5.4.5) uses a storage variable and moves its content into the shared object *peach* as soon as it becomes available. As in subject gapping (20), the speak mode (5.4.15) ends the production with the last rather than the first predicate.

23. Whom does John say that Bill believes ... that Mary loves? Sect. 5.5

    This construction instantiates an 'unbounded dependency' between the initial Whom and its grammatical role as the object of the final object sentence. The time-linear hear mode (5.5.2) derivation may continue to add object clauses as long as the verb of last object clause is what is called a *mental state* verb in lexicography. The speak mode (5.5.15) uses two empty traversals (3, 6) to access whom as the object of the last (lowest) object sentence and two (10, 11) to return to the top for continuing.

24. Mary saw the man who loves the woman ... who fed Fido. Sect. 5.6

    In this example of repeating adnominal subclauses (aka relative clauses) with subject gaps, the object noun *man* is in a mdr|mdd relation with *love* (representing the first subclause) and the object noun *woman* is in a mdr|mdd relation with *feed* (representing the second subclause). In the hear mode (5.6.2), the N|V relations between the head noun and the modifier clause are established by cross-copying and based on addresses. The repetition of adnominal subclauses may be continued indefinitely as long as the agents' cognitive reserves permit. The speak mode (5.6.14) returns with five empty traversals (8–12) to the top predicate *see* to realize the period.

The operations defined for the explicit hear and speak mode derivations of each of the 24 examples are summarized as DBS.Hear (Sect. 6.3) and DBS.Speak

(Sect. 6.5). The operations are presented as declarative specifications (CLaTR Sect. 1.5), i.e. at a level of formal detail directly above the software definitions in a general purpose programming language like Lisp, C, Java, or Perl, but without the accidental properties of a procedural implementation.

The linguistic analysis is embedded into the functional flow of agent-based DBS. As a specialization of recognition, the hear mode maps the input of external language surfaces into content. The hear mode operations apply at the now front, where they replace their input with their output. The now front is cleared in regular intervals by moving into free memory space, leaving the content derived behind as permanent sediment (loom-like clearance).

The operations of the think mode consist of (i) selective activation and (ii) inferencing. Selective activation navigates along semantic relations coded by address between items stored in memory. Inferencing refers to old content by address, and derives and stores new content at the now front. By using addresses, neither selective activation nor inferencing touch the stored content. Within the DBS laboratory set-up (Sect. 1.5), which is used here throughout, think mode operations are confined to the selective activation of content derived in the hear mode. For inferencing see CC, Chaps. 4, 7, 8, and 9.

In the speak mode, think mode operations are supplemented with lexicalization rules which are placed in the sur slot of the goal pattern. If a continuation proplet is activated by matching the goal pattern of a think mode operation, the lexicalization rule uses its core, cat, and sem values for language-dependent automatic word form production.

Use of Variables and their Markings

Lower case Greek letters are used as variables for single core or continuation values. For example, [noun: α] may be used to match the core value [noun: dog] (2.2.4), and [mdr: α] to match the continuation value [mdr: old] (2.2.3). These variables require a counterpart at the content level, in contradistinction to uppercase roman letters like X, Y, Z, which are used as variables for zero, one, or more unspecified constant values or substitution variables.

Variables and their constant counterparts may be marked as follows:

1.6.5 The #X-, $\underline{X}$-, $\underset{\cdot\cdot}{X}$, and K-markings of variables

1. #X
   The #-marking of variables is used differently in the hear mode and the speak mode:

   In the hear mode, #-marking is used to cancel valency positions. For example, [cat: #n′ a′ v] indicates that the nominative valency position has been filled, while the accusative position is still open (e.g. 2.3.4).

   In the speak mode, #-marking is applied to continuation values and indicates that they have been traversed at least once. The pattern matching is asymmetric: if a variable is #-marked, the corresponding value at the content level must be #-marked as well (5.5.11, 5.5.16); a variable which is not #-marked, in contrast, may be matched by a #-marked (5.5.29) or an unmarked (5.5.23) value at the content level.

2. $\underline{X}$
   A variable with a solid underline requires at least one matching value at the content level in the hear (2.3.4, 2.4.6, 2.5.6, ..., 5.6.8, 5.6.12) and the speak (5.2.21, 5.2.25) mode.

3. $\underset{\cdot\cdot}{X}$
   A variable with a dotted underline matches values with (2.6.15, 5.5.31, 5.5.32) and without (5.5.21, 5.5.22) an #-marking in the hear (5.2.7, 5.2.10) and the speak mode (2.3.11).

The purpose of 1 is to control the time-linear flow of derivations and to prevent unwanted repetitions, 2 serves to control the application of a couple of operations in gapping constructions, 3 saves an operation.

2. Obligatory Functor-Arguments

In language use, the most basic dichotomy is between the speak mode and the hear mode. The speak mode maps a content into a sequence of unanalyzed surfaces (production) and the hear mode maps a time-linear sequence of unanalyzed surfaces into a content (recognition). Agent-externally, the unanalyzed surfaces are raw data which may be measured and analyzed by Natural Science, but are without any meaning or grammatical properties whatsoever. However, before production and after recognition of the raw data, the surfaces are agent-internal cognitive constructs which are called signs.

2.1 DBS.1: Combining Functor-Argument and Coordination

The cognitive structure of a sign is the association of a language-dependent surface and a content, based on convention.[1] In DBS, a content is built from the concepts of recognition and action, connected by semantic relations of structure. The most basic distinction between these relations is (a) functor-argument and (b) coordination. An example of an intrapropositional functor-argument is the subject/predicate relation in the minimal sentence Mary slept. An example of an extrapropositional coordination is the predicate−predicate relation in the minimal text Mary slept. Fido snored.

Consider an English surface of a minimal functor-argument and its content:

2.1.1 **<to-do 1>**

CONTENT OF THE SURFACE Mary slept**.**

$$\begin{bmatrix} \text{sur: mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: sleep} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 17} \end{bmatrix} \begin{bmatrix} \text{sur:} \\ \text{verb: sleep} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 17} \end{bmatrix}$$

[1] De Saussure [1916](1972), PREMIER PRINCIPE; L'ARBITRAIRE DU SIGNE. (FoCL Sect. 6.2).

The content consist of two proplets. Proplets are defined as non-recursive feature structures with ordered attributes and serve as the data structure of DBS. The proplets of a content are a set (order-free). They are connected by the semantic relations of structure, coded by address.

2.1.2 **<to-do 2>**

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION

unanalyzed surface

Mary slept •

automatic word form recognition

sur: Mary	sur: slept	sur: •
noun: [person x]	verb: sleep	verb: v_1
cat: snp	cat: n' v	cat: v' decl
sem: nm f	sem: past ind	sem:
fnc:	arg:	arg:
prn: 17	prn:	prn:

syntactic−semantic parsing

1	sur: mary	sur: slept	*cross−copying*
	noun: [person x]	verb: sleep	
	cat: snp	cat: n' v	
	sem: nm f	sem: past ind	
	fnc:	arg:	
	prn: 17	prn:	

2	sur: mary	sur:	sur: •	*absorption*
	noun: [person x]	verb: sleep	verb: v_1	
	cat: snp	cat: #n' v	cat: v' decl	
	sem: nm f	sem: past ind	sem:	
	fnc: sleep	arg: [person x]	arg:	
	prn: 17	prn: 17	prn:	

result

sur: mary	sur:
noun: [person x]	verb: sleep
cat: snp	cat: #n' decl
sem: nm f	sem: past ind
fnc: sleep	arg: [person x]
prn: 17	prn: 17

The derivation is *time-linear*, as shown by the addition of exactly one next word in each derivation step (here only two). It is also *surface compositional* because (a) each lexical proplet has a sur value and (b) there are no surfaces without an explicit lexical proplet. And it is *data-driven*.

The sequence of explicit hear mode operation applications begins with SBJ×PRD:

2.1.3 **<to-do 3>**

CROSS-COPYING *mary* AND *sleep* WITH SBJ×PRD (line 1 in 2.1.2)

SBJ×PRD (h1)[2]

pattern level

$$\begin{bmatrix}\text{noun: } \alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:K}\end{bmatrix} \quad \begin{bmatrix}\text{verb: } \beta\\ \text{cat: NP}' \text{ X v}\\ \text{arg:}\\ \text{prn:}\end{bmatrix} \quad \Rightarrow \quad \begin{bmatrix}\text{noun: } \alpha\\ \text{cat: NP}\\ \text{fnc: } \beta\\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{verb: } \beta\\ \text{cat: \#NP}' \text{ X v}\\ \text{arg: } \alpha\\ \text{prn: K}\end{bmatrix}$$

NP ϵ {snp, pnp, s1, s3, p1, sp2, p3}; NP′ ϵ {n′, ns3′, n-s3′, ns1′, ns2p′, ns3′, ns13′}.[3]
If NP = s1, then NP′ ϵ {ns1′, ns13′, n-s3′, n′}
If NP = sp2, then NP′ ϵ {ns2p′, n-s3′, n′}
If NP ϵ {s3, snp}, then NP′ ϵ {ns3′, ns13′, ns3′, n′}
If NP = p1, then NP′ ϵ {ns2p′, n-s3′, n′}
If NP ϵ {p1,p3, pnp}, then NP′ ϵ {ns2p′, n-s3′, n′}

matching frontier ⇑ ⇓

content level

$$\begin{bmatrix}\text{sur: Mary}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm f}\\ \text{fnc:}\\ \ldots^{4}\\ \text{prn: 17}\end{bmatrix} \quad \begin{bmatrix}\text{sur: slept}\\ \text{verb: sleep}\\ \text{cat: n}' \text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \ldots\\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur: mary}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm f}\\ \text{fnc: sleep}\\ \ldots\\ \text{prn: 17}\end{bmatrix} \quad \begin{bmatrix}\text{sur:}\\ \text{verb: sleep}\\ \text{cat: \#n}' \text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x]}\\ \ldots\\ \text{prn: 17}\end{bmatrix}$$

The operation consists of two pattern proplets for matching an input, the connective ⇒, and two pattern proplets for deriving an output. Underneath the pattern level, above the matching frontier, are the agreement conditions, consisting of (i) variable restrictions and (ii) conditions. The agreement condition in 2.1.2 ensures, for example, that pro1 (s1) walk (ns-3′ v) is accepted as grammatical, but pro1 (s1) walks (ns3′ v) is rejected as ungrammatical.

The trigger pattern of a hear mode operation is the second input pattern. In 2.1.3, the input proplet *sleep*, provided by automatic word form recognition, matches the trigger pattern of the SBJ×PRD operation. This activates the operation (data driven) to look at the now front for a matching input proplet for its first input pattern and applies if it finds one.

An output is derived by binding constants of the content level to corresponding variables in the input patterns. For example, in 2.1.2 the constants [person x] and sleep are bound to the variables α and β, which results in adding the values sleep and [person x] to the fnc and arg slots of the output, thus realizing cross-copying computationally.

To complete the content in 2.1.1, the hear mode derivation adds the full stop (period) with the operation S∪IP:

---

[2] The letter h preceding the number in (h1) refers to an operation in the DBS **h**ear grammar in Sect. 6.3. In contrast, the letter s preceding the number (s1) in 2.1.6, for example, refers to an operation of the **s**peak mode grammar in Sect. 6.5.

[3] For the valency positions of English main verbs and auxiliaries see NLC, A.5.1–A.5.6. For the categories of names, pronouns, and determiners as valency fillers see NLC, A.4.1–A.4.3.

2.1.4 ABSORBING • INTO *sleep* WITH S∪IP (line 2 in 2.1.3)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: \#X}' \text{ VT} \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: V\_}n \\ \text{cat: VT}' \text{ SM} \\ \text{fnc:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: \#X}' \text{ SM} \\ \text{prn: K}\end{bmatrix}$$

VT ϵ {v, vi, vimp}, SM ϵ {decl, interrog, impv}. If VT = v, then SM ϵ {decl, interrog}; if VT = vi, then SM = interrog; if VT = vimp, then SM = impv. There is no $\emptyset$ in X.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: sleep} \\ \text{cat: \#n}' \text{ v} \\ \text{sem: ind past} \\ \text{arg: [person x]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 17}\end{bmatrix} \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: v\_2} \\ \text{cat: v}' \text{ decl} \\ \text{sem:} \\ \text{arg:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{verb: sleep} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 17}\end{bmatrix}$$

In 2.1.2, the absorption of the period proplet into the *sleep* proplet is shown by the horizontal arrow (line 2).

Next[4] let us connect two minimal sentences into a minimal text by means of coordinating Mary slept**.** and Fido snored**.**. We start over and begin with the surface of the example and its content:

2.1.5 **<to-do 1>**

CONTENT OF Mary slept**.** Fido snored**.**

$$\begin{bmatrix}\text{sur: mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: sleep} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 17}\end{bmatrix} \begin{bmatrix}\text{sur:} \\ \text{verb: sleep} \\ \text{cat: \#ns3 decl} \\ \text{sem: ind past} \\ \text{arg: [person x]} \\ \text{mdr:} \\ \text{nc: (snore 18)} \\ \text{pc:} \\ \text{prn: 17}\end{bmatrix} \begin{bmatrix}\text{sur:} \\ \text{verb: snore} \\ \text{cat: \#ns3 decl} \\ \text{sem: ind past} \\ \text{arg: [dog y]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc: (sleep 17)} \\ \text{prn: 18}\end{bmatrix} \begin{bmatrix}\text{sur: fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: snore} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 18}\end{bmatrix}$$

The two propositions are distinguished by their prn values 17 and 18. The proplets have nc (next conjunct) and pc (previous conjunct) attributes which may be empty or take intra- or extrapropositional address values. The nc attribute of *sleep* has the extrapropositional address value (snore 18) while pc attribute of *snore* has the extrapropositional address value (sleep 17).

The two propositions are simple, but their time-linear hear mode coordination is not trivial. As a first conceptual orientation consider the derivation graph:

[4] The remaining **<to-do>**s of the minimal sentence are shown as a portion of 2.1.12 ff.

2.1.6 **<to-do 2>**

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION

unanalyzed surface

Mary slept • Fido snored •

automatic word form recognition

sur: Mary	sur: slept	sur: •	sur: fido	sur: snored	sur: •
noun: [p. x]	verb: sleep	verb: v_1	noun: [d. y]	verb: snore	verb: v_2
cat: snp	cat: n' v	cat: v' decl	cat: nm sg m	cat: n' v	cat: v' decl
sem: nm sg f	sem: past ind	sem:	sem: sg	sem: past ind	sem:
fnc:	arg:	arg:	fnc:	arg:	arg:
prn:	prn:	prn:	prn:	prn:	prn:

syntactic−semantic parsing

1

sur: Mary	sur: slept
noun: [p. x]	verb: sleep
cat: snp	cat: n' v
sem: nm sg f	sem: past ind
fnc:	arg:
prn: 17	prn:

cross−copying

2

sur: mary	sur:	sur: •
noun: mary	verb: sleep	verb: v_1
cat: [p. x]	cat: #n' v	cat: v' decl
sem: nm sg f	sem: past ind	sem:
fnc: sleep	arg: [p. x}	arg:
prn: 17	nc:	nc:
	pc:	pc:
	prn: 17	prn:

cross−copying

3

sur: mary	sur:	sur:	sur: fido
noun: [p. x]	verb: sleep	verb: v_1	noun: [d. y]
cat: snp	cat: #n' decl	cat:	cat: snp
sem: nm sg f	sem: past ind	sem:	sem: nm m
fnc:	arg: [p. x}	arg:	fnc:
prn: 17	nc: v_1	nc:	prn:
	pc:	pc: (sleep 17)	
	prn: 17	prn: 18	

cross−copying

4

sur: mary	sur:	sur:	sur: fido	sur: snored
noun: [p. x]	verb: sleep	verb: v_1	~~noun: [d. y]~~	~~verb:~~ snore
cat: snp	cat: #n' decl	cat:	~~cat: snp~~	~~cat:~~ n' v
sem: nm f	sem: ind past	sem:	~~sem: nm m~~	~~sem:~~ past in
fnc: sleep	arg: [p. x}	arg: [d. y}	fnc: v_1	arg:
prn: 17	nc: v_1	nc:	prn: 18	prn:
	pc:	pc: (sleep 17)		
	prn: 17	prn: 18		

absorption with simultaneous substitution

5

sur: mary	sur:	sur:	sur: fido	sur: •
noun: [p. x]	verb: sleep	verb: snore	noun: [d. y]	verb: v_1
cat: snp	cat: #n' decl	cat: #n' v	~~cat: snp~~	~~cat: v~~' decl
sem: nm ag f	sem: ind past	sem: past ind	sem: nm m	sem:
fnc: sleep	arg: [p. x}	arg: [d. y}	fnc: snore	sem:
prn: 17	nc: (snore 18)	nc:	prn: 18	prn:
	pc:	pc: (sleep 17)		
	prn: 17	prn: 18		

absorption

result

sur: mary	sur:	sur:	sur: fido
noun: [p. x]	verb: sleep	verb: snore	noun: [d. y]
cat: snp	cat: #n' decl	cat: #n' decl	cat: snp
sem: nm ag f	sem: ind past	sem: past ind	sem: nm m
fnc: sleep	arg: [p. x}	arg: [d. y}	fnc: snore
prn: 17	nc: (snore 18)	nc:	prn: 18
	pc:	pc: (sleep 17)	
	prn: 17	prn: 18	

The complete sequence of explicit hear mode operation applications begins with SBJ×PRD (as in 2.1.3):

2.1.7 **<to-do 3>**

CROSS-COPYING *mary* AND *sleep* WITH SBJ×PRD (line 1 in 2.1.6)

SBJ×PRD (h1)

pattern level

noun: α	verb: β		noun: α	verb: β
cat: NP	cat: NP′ X v	⇒	cat: NP	cat: #NP′ X v
fnc:	arg:		fnc: β	arg: α
prn:K	prn:		prn: K	prn: K

Agreement conditions as in 2.1.3

⇑ ⇓

content level

sur: Mary	sur: slept		sur: mary	sur:
noun: [person x]	verb: sleep		noun: [person x]	verb: sleep
cat: snp	cat: n′ v		cat: snp	cat: n′ v
sem: nm f	sem: ind past		sem: nm f	sem: ind past
fnc:	arg: [person x]		fnc:	arg: [person x]
...	...		...	...
prn: 17	prn: 17		prn: 17	pc:
				prn: 17

The next input provided by automatic word form recognition is the period. It triggers two operations, S×IP and S∪IP, which apply in parallel but are mutually exclusive: if the input continues, as in a text or dialogue, S×IP succeeds and S∪IP fails (2.1.8). Otherwise S∪IP succeeds and S×IP fails (2.1.11).

2.1.8 CROSS-COPYING *sleep* AND **.** WITH S×IP (line 2 in 2.1.4)

S×IP (h2)

pattern level

verb: β	verb: V_*n*		verb: β	verb: V_*n*
cat: #X′ VT	cat: VT′ SM		cat: #X′ SM	cat:
nc:	nc:	⇒	nc: (V_*n* K+1)	nc:
pc:	pc:		pc:	pc: (β K)
prn: K	prn:		prn: K	prn: K+1

Agreement conditions as in 2.1.4

⇑ ⇓

content level

sur:	sur: **.**		sur:	sur:
verb: sleep	verb: v_1		verb: sleep	verb: v_1
cat: #n′ v	cat: v′ decl		cat: #n′ decl	cat:
sem: ind past	sem:		sem: ind past	sem:
arg: [person x]	arg:		arg: [person x]	arg:
mdr:	mdr:		mdr:	mdr:
nc:	nc:		nc: (v_1 18)	nc:
pc:	pc:		pc:	pc: (sleep 17)
prn: 17	prn:		prn: 17	prn: 18

Cross-copying into the nc and pc slots establishes an extrapropositional coordination between the two propositions.

The IP proplet in the output of 2.1.8 is used for (i) cross-copying with the subject *fido* and (ii) absorbing the predicate *snore* of the second proposition.[5] The operation for cross-copying is called IP×SBJ and defined as follows:

2.1.9 CROSS-COPYING • AND *fido* WITH IP×SBJ (LINE 3)

IP×SBJ (h3)

pattern level

verb: V_*n*	noun: α		verb: V_*n*	noun: α
cat: VT′ SM	cat: NP	⇒	cat: VT′ SM	cat: NP
arg:	fnc:		arg: α	fnc: V_*n*
pc: (β K)	prn:		pc: (β K)	prn:K+1
prn: K+1			prn: K+1	

⇑ ⇓

content level

sur:	sur: Fido	sur:	sur: fido
verb: v_1	noun: [dog y]	verb: v_1	noun: [dog y]
cat: v′ decl	cat: snp	cat: v′ decl	cat: snp
sem:	sem: nm m	sem:	sem: nm m
arg:	fnc:	arg: [dog y]	fnc: v_1
mdr:	mdr:	mdr:	mdr:
nc:	nc:	nc:	nc:
pc: (sleep 17)	pc:	pc: (sleep 17)	pc:
prn: 18	prn:	prn: 18	prn: 18

The verbal shell with the core value v_1 and the arg value [dog y] completes the extrapropositional coordination by absorbing *snore*:

2.1.10 ABSORBING *snore* INTO IP WITH IP∪PRD (line 4)

IP∪PRD (h15)

pattern level

verb: V_*n*	verb: α		verb: α
cat: VT′ SM	cat: NP X VT		cat: #NP X SM
sem:	sem: Y	⇒	sem: Y
arg: Z	arg:		arg: Z
pc (β K)	prn:		(β K)
prn: K+1			prn: K+1

⇑ ⇓

content level

sur:	sur:	sur:
verb: v_1	verb: snore	verb: snore
cat: v′ decl	cat: ns3′ v	cat: #ns3′ decl
sem:	sem: ind past	sem: ind past
arg: [dog y]	arg:	arg: [dog y]
mdr:	mdr:	mdr:
nc:	nc:	nc:
pc: (sleep 17)	pc:	pc: (sleep 17)
prn: 18	prn:	prn: 18

Together, the operations IP×SBJ and IP∪PRD have turned the interpunctuation proplet into the verb of the next proposition.

Finally, automatic word form recognition provides another period as input. This triggers S×IP and S∪IP, which apply in parallel. In contradistinction to

[5] This results in an inversion in the 'derivation order.' It is of no consequence, however, because the proplets in a content are order-free.

2.1.4, the input stream provided by automatic word form recognition dries up and the derivation terminates with S∪IP.

2.1.11 ABSORBING • INTO *snore* WITH S∪IP (line 5 in 2.1.6)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ VT} \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: V\_}n \\ \text{cat: VT}' \text{ SM} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ SM} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: sleep} \\ \text{cat: } \#n' \text{ v} \\ \text{sem: ind past} \\ \text{arg: [dog y]} \\ \ldots \\ \text{prn: 18}\end{bmatrix} \Uparrow \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: v\_2} \\ \text{cat: v}' \text{ decl} \\ \text{sem:} \\ \text{arg:} \\ \ldots \\ \text{prn:}\end{bmatrix} \qquad \Downarrow \begin{bmatrix}\text{sur:} \\ \text{verb: snore} \\ \text{cat: } \#n' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [dog y]} \\ \ldots \\ \text{prn: 18}\end{bmatrix}$$

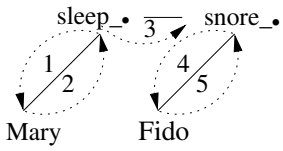
The hear mode derivation of a minimal text is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

2.1.12 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE

(iii) numbered arc graph (NAG)



(iv) surface realization

1	2	3	4	5
Mary	slept_•		Fido	snored_•
V/N^{i}	N/V	V–V	V/N	N/V

Word form production is summarized as follows:

2.1.13 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS[6]

1	2	3	4	5
arc 1:	V↙N	from *sleep* to *mary*	Mary	2.1.14
arc 2:	N↗V	from *mary* to *sleep*	slept_•	2.1.15
arc 3:	V→V	from *sleep* to *snore*		2.1.16
arc 4:	V↙N	from *snore* to *fido*	Fido	2.1.17
arc 5:	N↗V	from *fido* to *snore*	snored_•	2.1.18

Column 1 specifies the arc of the traversal in the associated NAG, 2 names the

[6] The format is a verbose notational variant of the (iv) surface realization in 2.1.11.

operation, 3 describes the traversal, 4 specifies the surface(s) produced, and 5 states the reference number of the explicit operation application.

In summary, automatic word form recognition analyzes raw data as proplets and stores them in the alphabetical order induced by their core value at the now front. If the input is handled by the grammar, an incoming proplet activates at least one hear mode operation by matching its trigger pattern. If there is a proplet at the now front matching its first input pattern that operation applies. Systematic clearance of the now front limits the set of proplets serving as possible input to an initial pattern. Clearance consists in moving the now front into fresh territory of the memory (loomlike clearance, NLC Sect. 11.3), leaving the connected proplets behind in what is becoming an addition to the permanent storage area of the database, like sediment.

The complete sequence of explicit navigation operations begins with V↙N:

2.1.14 **<to-do 6>**

NAVIGATING WITH V↙N FROM *sleep* TO *mary* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: sleep} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x]} \\ \ldots \\ \text{prn: 17} \end{bmatrix} \quad \begin{bmatrix} \text{sur: Mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: sleep} \\ \ldots \\ \text{prn: 17} \end{bmatrix}$$

Based on the N/V relation established in the hear mode between the *sleep* and the *mary* proplets by SBJ×PRD (2.1.3, 2.1.7), the navigation uses the V↙N think-speak mode operation 2.1.14 to travel from V to N.[7] The word form production rule lexnoun in the sur slot of the goal pattern (pattern level) uses the core and the cat values of the goal proplet (content level) to realize the surface Mary in the sur slot of the *mary* proplet.

The next navigation step for activating the content 2.1.5 uses the operation N↗V (2.1.15). Like V↙N, it navigates along the semantic relation N/V established by SBJ×PRD in 2.1.3, but in the opposite direction:

[7] A lower node in a static *(ii) signature* precedes in the corresponding linear notation, e.g. N/V. The linear notation of an arc in the dynamic *(iii) NAG* representation, in contrast, begins with the start node, e.g. V↘N and N↖V.

2.1.15 NAVIGATING WITH N↗V FROM *mary* BACK TO *sleep* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{Y} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: mary} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: sleep} \\ \ldots \\ \text{prn: 17}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: slept\_.} \\ \text{verb: sleep} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#mary} \\ \ldots \\ \text{prn: 17}\end{bmatrix}$$

Lexverb uses sleep, decl, and ind past to produce the surface slept_.

Now the think-speak mode has realized example 2.1.2. For the example 2.1.6, however, the derivation continues with the transition from Mary slept_. to Fido snored_. (extrapropositional coordination).

2.1.16 NAVIGATION WITH V→V FROM *sleep* TO *snore* (arc 3)

V→V (s35)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{nc: } \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{prn: K+1}\end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: sleep} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#mary} \\ \ldots \\ \text{prn: 17}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{verb: snore} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: fido} \\ \ldots \\ \text{prn: 18}\end{bmatrix}$$

The remainder of the speak mode production resembles 2.1.14 and 2.1.15:

2.1.17 NAVIGATING WITH V↙N FROM *snore* TO *fido* (arc 4)

V↙N (s1)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: snore} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [dog y]} \\ \ldots \\ \text{prn: 18}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: Fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: snore} \\ \ldots \\ \text{prn: 18}\end{bmatrix}$$

2.1.18 NAVIGATING WITH N↗V FROM *fido* BACK TO *snore* (arc 5)

$$\begin{array}{ccccc}
 & \mathbf{N{\nearrow}V}\ \text{(s2)} & & & \\
\textit{pattern level} & \begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} & \Rightarrow & \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{Y} \\ \text{prn: K}\end{bmatrix} & \text{\#-mark } \alpha \text{ in the fnc slot of proplet } \beta. \\
 & \text{Z is NIL, or elementary and \#-marked.} & & & \\
 & \Uparrow & & \Downarrow & \\
\textit{content level} & \begin{bmatrix}\text{sur:} \\ \text{noun: fido} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: snore} \\ \ldots \\ \text{prn: 18}\end{bmatrix} & & \begin{bmatrix}\text{sur: snored_}\bullet \\ \text{verb: snore} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#fido} \\ \ldots \\ \text{prn: 18}\end{bmatrix} &
\end{array}$$

The DBS.1 grammar for the coordination of two minimal declaratives required the definition of the hear mode operations SBJ×PRD (h1), S×IP (h2), IP×SBJ (h3), and S∪IP (h18), and the think-speak mode operations V↙N (s1), N↗V (s2), and V→V (s19). They happen to be equal in number, but the incoming and the outgoing surfaces are segmented differently:

2.1.19 **<to-do 7>**

COMPARING SEGMENTATION IN HEAR AND SPEAK MODE

hear mode:

	1		2		3		4		5	
Mary	×	slept	×	•	×	Fido	∪	snored	∪	•

speak mode:

1		2		3	4		5	
V↙N	Mary	N↗V	slept_•	V→V	V↙N	Fido	N↗V	snored_•

In the hear mode, the numerals above the operations correspond to the line numbers in the graphical derivation 2.1.2. In the speak mode, the numerals refer to the corresponding arc numbers of the NAG in 2.1.12. While automatic word form recognition always takes a single surface as input, the number of word forms produced by automatic word form production (output) will vary. Therefore the hear mode interpretation of an example may require a different number of operations than the speak mode production (e.g. 2.2.15, 2.3.12).

2.2 DBS.2: Phrasal Subject and Predicate

The previous section represented the N/V relation with elementary arguments and functors. The present section extends this analysis to a phrasal argument and functor by substituting the elementary subject Fido with phrasal the old dog and the elementary predicate snored with phrasal had been snoring:

2.2.1 **<to-do 1>**

CONTENT OF The old dog had been snoring.

sur:	sur:	sur:
noun: dog	adj: old	verb: snore
cat: snp	cat: adn	cat: #n′ #hv′ #be′ decl
sem: def sg	sem: pad	sem: past perf prog
fnc: snore	mdd: dog	arg: dog
mdr: old	mdr:	mdr:
nc:	nc:	nc:
pc:	pc:	pc:
prn: 2	prn: 2	prn: 2

The function word The is represented by the feature [cat: def sg] in the *dog* proplet and the complex word form had been snoring by the feature [sem: past perf prog] in the *snore* proplet. In this way, the English surfaces may be easily resurrected by automatic word form production in the speak mode (laboratory set-up). The modifier|modified relation is coded by the features [mdr: old] of the *dog* proplet and [mdd: dog] of the *old* proplet.

Proplets accommodate any degree of linguistic detail without jeopardizing linear computational complexity (TCS). In the hear mode, the latter is owed to the surface-compositional time-linear input and data-driven activation:

2.2.2 **<to-do 2>**

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION

unanalyzed surface

The old dog had been snoring •

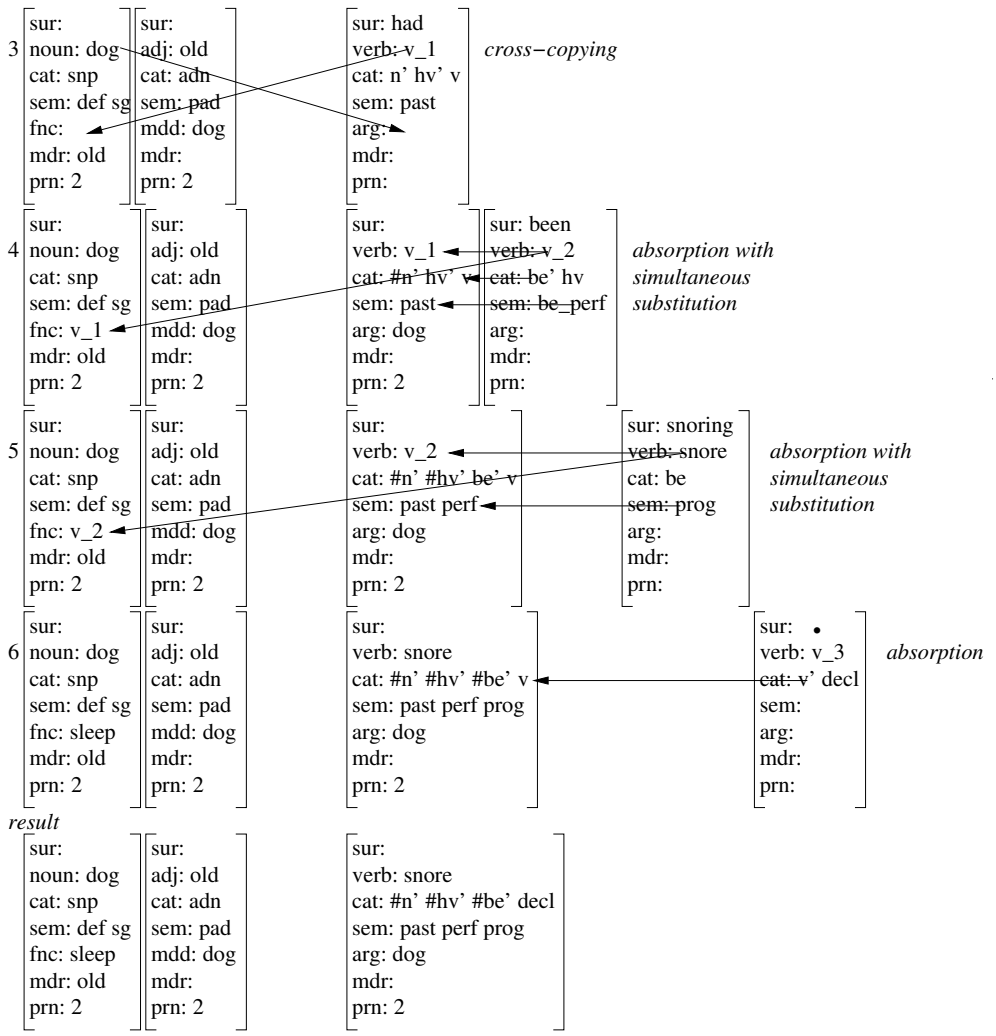
automatic word form recognition

sur: the	sur: old	sur: dog	sur: had	sur: been	sur: snoring	sur: •
noun: n_1	adj: old	noun: dog	verb: v_1	verb: v_2	verb: snore	verb: v_3
cat: nn' np	cat: adn	cat: sn	cat: n' hv' v	cat: be' hv	cat: be	cat: v' decl
sem: def	sem: pad	sem:	sem: past	sem: perf	sem: prog	sem:
fnc:	mdd:	fnc:	arg:	arg:	arg:	arg:
mdr:	mdr:	mdr:	mdr:	mdr:	mdr:	mdr:
prn:	prn:	prn:	prn:	prn:	prn:	prn:

syntactic−semantic parsing

	sur: the	sur: old	
1	noun: n_1	adj: old	*cross−copying*
	cat: nn' np	cat: adn	
	sem: def	sem: pad	
	fnc:	mdd:	
	mdr:	mdr:	
	prn: 2	prn:	

	sur:	sur:	sur: dog	
2	noun: n_1	~~adj: old~~	~~noun: dog~~	*absorption with*
	cat: nn' ~~np~~	~~cat: adn~~	~~cat: sn~~	*simultaneous*
	sem: def	~~sem: pad~~	~~sem: sg~~	*substitution*
	fnc:	mdd: n_1	fnc:	
	mdr: old	mdr:	mdr:	
	prn: 2	prn: 2	prn:	



The first operation to apply is DET×ADN.[8] It is triggered by adnominal *old* matching its second input pattern. The core value of the determiner *the* matching the first input patter is the substitution variable n_1. Cross-copying establishes the modifier|modified relation by writing old into the mdr slot of *the* and n_1 into the mdd slot of *old*:

The complete sequence of explicit hear mode operation applications begins with DET×ADN:

[8] In the headings of hear mode operations, the two input proplets are referred to by the base form of their English surface written in *italics*. For example, the first input proplet of the operation DET×ADN is called *the* in the heading of 2.2.3, though the core value is n_1; the second input proplet of the operation SBJ×PRD in the heading of 5.2.4 is called *buy*, though the example surface is bought in English and would be kaufte in German.

2.2.3 **<to-do 3>**

CROSS-COPYING *the* AND *old* WITH DET×ADN (line 1)

DET×ADN (h55)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\text{ NP}\\ \text{mdr:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{adj: }\alpha\\ \text{cat: ADN}\\ \text{mdd:}\\ \text{nc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\text{ NP}\\ \text{mdr: }\alpha\\ \text{prn:K}\end{bmatrix}\begin{bmatrix}\text{adj: }\alpha\\ \text{cat: ADN}\\ \text{mdd: N\_}n\\ \text{nc:}\\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur: The}\\ \text{noun: n\_1}\\ \text{cat: nn}'\text{ np}\\ \text{sem: def}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 2}\end{bmatrix}\begin{bmatrix}\text{sur: old}\\ \text{adj: old}\\ \text{cat: adn}\\ \text{sem: pad}\\ \text{mdd:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{noun: n\_1}\\ \text{cat: nn}'\text{ np}\\ \text{sem: def}\\ \text{fnc:}\\ \text{mdr: old}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 2}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{adj: old}\\ \text{cat: adn}\\ \text{sem: pad}\\ \text{mdd: n\_1}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 2}\end{bmatrix}$$

With the modifier|modified relation in place, the next operation absorbs the noun *dog* by replacing all instances of the substitution variable n_1:

2.2.4 ABSORBING *dog* INTO *the* WITH DET∪CN (line 2)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\text{ NP}\\ \text{sem: Y}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{sem: Y Z}\\ \text{prn: K}\end{bmatrix}$$

CN′ ϵ {nn′, sn′, pn′}, CN ϵ {sn, pn}, and N ϵ {np, snp, pnp}.
X = adnv or NIL. If CN′ = sn′, then CN = sn. If CN′ = pn′, then CN = pn.
If CN′ = nn′ and CN = sn, then N = snp. If CN′ = nn′ and CN = pn, then N = pnp.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: n\_1}\\ \text{cat: nn}'\text{ np}\\ \text{sem: def}\\ \text{fnc:}\\ \text{mdr: old}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 2}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{adj: old}\\ \text{cat: adn}\\ \text{sem: pad}\\ \text{mdd: n\_1}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 2}\end{bmatrix}\begin{bmatrix}\text{sur: dog}\\ \text{noun: dog}\\ \text{cat: sn}\\ \text{sem: sg}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{noun: dog}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc:}\\ \text{mdr: old}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 2}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{adj: old}\\ \text{cat: adn}\\ \text{sem: pad}\\ \text{mdd: dog}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 2}\end{bmatrix}$$

The two *old* proplets at the content level are added to illustrate the effect of the simultaneous substitution of n_1 with dog (2.2.2, line 2).

The next word proplet *have* with the substitution variable *v_1* as the core value activates the cross-copying operation SBJ×PRD by matching its trigger proplet and finds *dog* at the now front for its first input pattern:

2.2.5 CROSS-COPYING *dog* AND *have* WITH SBJ×PRD (line 3)

SBJ×PRD (h1)

pattern level

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP}'\text{ X v}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ X v}\\ \text{arg: }\alpha\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.2.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: dog}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc:}\\ \text{mdr: old}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 2}\end{bmatrix}\begin{bmatrix}\text{sur: had}\\ \text{verb: v\_1}\\ \text{cat: n}'\text{ hv}'\text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{noun: dog}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc: v\_1}\\ \text{mdr: old}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 2}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat: \#n}'\text{ hv}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: dog}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 2}\end{bmatrix}$$

The SBJ×PRD applications in 2.1.3 and 2.2.5 differ in that here the core value of the verb proplet is the substitution variable v_1, and not a constant.

The following operation combines the finite auxiliary *had* and the non-finite form *been*. It must accommodate the agreement conditions between the three English auxiliaries be, have, and do, and the non-finite verb forms they combine with, as well as their agreement conditions regarding person and number, e.g. am, are, is, was, were, etc., between the finite auxiliary and its nominative argument. Consider the following variants:

John is saying...
John was saying...
John will say...
John has said...
John had said...
John does say...
John did say...
...
I am saying...
you are saying...
he is saying
...
John has been saying
John had been saying
...
John could have been saying
...

The analysis of such paradigms in different natural languages is a challenging routine which requires (a) a declarative specification[9] and (b) an implementation as running software. As an inexhaustible source of topics for academic degrees in computational linguistics, it can be automatically verified based on test lists, and is of permanent practical benefit with easy software maintenance.

[9] Preferably using a distinctive surface-compositional categorization (FoCL Sect. 13.1).

The next word to be added to The old dog has is been:

2.2.6 ABSORBING *be* INTO *have* WITH AUX∪NFV (line 4)

AUX∪NFV (h16)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat: \#W}'\ \text{AUX}'\ \text{VT}\\ \text{sem: X}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: Y AUX}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#W}'\ \text{\#AUX}'\ \text{Y VT}\\ \text{sem: X Z}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions omitted.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat: \#n}'\ \text{hv}'\ \text{v}\\ \text{sem: ind past}\\ \text{arg: dog}\\ \ldots\\ \text{prn: 2}\end{bmatrix}\begin{bmatrix}\text{sur: been}\\ \text{verb: v\_2}\\ \text{cat: be}'\ \text{hv}\\ \text{sem: perf}\\ \text{arg:}\\ \ldots\\ \text{prn:}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: v\_2}\\ \text{cat: \#n}'\ \text{\#hv}'\ \text{be}'\ \text{v}\\ \text{sem: ind past perf}\\ \text{arg: dog}\\ \ldots\\ \text{prn: 2}\end{bmatrix}$$

The core value of *been* is an incremented V_*n* value. For the operation to apply, the AUX′ value (valency position) in the first proplet pattern and the AUX value (valency filler) in the second must agree. At the content level, the two input proplets are fused into one (function word absorption). Their respective cat and sem values are preserved in the output proplet because they contribute to the interpretation and are needed for production in (a) the narrative speak mode and (b) the laboratory set-up.

The next word snoring triggers another application of AUX∪NFV:

2.2.7 ABSORBING *snore* INTO *have be* WITH AUX∪NFV (line 5)

AUX∪NFV (h16)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat: \#W}'\ \text{AUX}'\ \text{VT}\\ \text{sem: X}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: Y AUX}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#W}'\ \text{\#AUX}'\ \text{Y VT}\\ \text{sem: X Z}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions omitted.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_2}\\ \text{cat: \#n}'\ \text{\#hv}'\ \text{be}'\ \text{v}\\ \text{sem: ind past perf}\\ \text{arg: dog}\\ \ldots\\ \text{prn: 2}\end{bmatrix}\begin{bmatrix}\text{sur: snoring}\\ \text{verb: snore}\\ \text{cat: be}\\ \text{sem: prog}\\ \text{arg:}\\ \ldots\\ \text{prn:}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: snore}\\ \text{cat: \#n}'\ \text{\#hv}'\ \text{\#be}'\ \text{v}\\ \text{sem: ind past perf prog}\\ \text{arg: dog}\\ \ldots\\ \text{prn: 2}\end{bmatrix}$$

Here the cat value be of the *snore* proplet cancels the be′ valency position of has_been. Again the two input proplets are fused into one in the output.

The derivation of this isolated example concludes with an application of S∪IP:

2.2.8 CROSS-COPYING *snore* AND • WITH S∪IP (line 6)

S×IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ VT} \\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{verb: V\_}n \\ \text{cat: VT}' \text{ SM}\end{bmatrix} \quad \Rightarrow \quad \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ SM} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: snore} \\ \text{cat: } \#n' \ \#hv' \ \#be' \text{ v} \\ \text{sem: ind past perf prog} \\ \text{arg: dog} \\ \ldots \\ \text{prn: 2}\end{bmatrix} \Uparrow \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: v\_1} \\ \text{cat: v}' \text{ decl} \\ \text{sem:} \\ \text{arg:} \\ \ldots \\ \text{prn:}\end{bmatrix} \qquad \Downarrow \begin{bmatrix}\text{sur:} \\ \text{verb: snore} \\ \text{cat: } \#n' \text{ decl} \\ \text{cat: } \#n' \ \#hv' \ \#be' \text{ decl} \\ \text{sem: ind past perf prog} \\ \ldots \\ \text{prn: 2}\end{bmatrix}$$

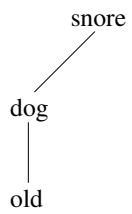
The hear mode derivation of a phrasal subject and predicate is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

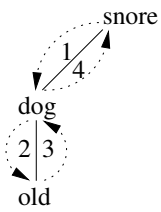
2.2.9 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE

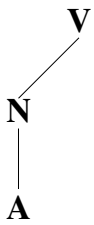
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

1	2	3	4
The	old	dog	has_been_snoring_•
V/N	N|A	A|N	N/V

The content word *old* is connected graphically to *dog* by the A|N relation. The function words has, been, and •, in contrast, were fused with snoring into a single node by the associated hear mode derivation (line 3–5 in 2.2.2)

Word form production is summarized as follows:

2.2.10 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *snore* to *dog*	The	2.2.11
arc 2:	N↓A	from *dog* to *old*	old	2.2.12
arc 3:	A↑N	from *old* to *dog*	dog	2.2.13
arc 4:	N↗V	from *dog* to *snore*	had_been_snoring_.	2.2.14

The surface The old dog is a discontinuous structure, consisting of The ... dog and intervening old. In the speak mode, this phenomenon is treated by utilizing the two directions of traversing an arc. For example, old is realized by the operation N↓A (downward arc 2) and dog by A↑N (upward arc 3). In this construction, each of the four arcs happens to produce a surface, as shown by the surface realization of 2.2.9 and the fourth column of 2.2.10.

For a more detailed grammatical analysis let us turn to the sequence of explicit speak mode operation applications. Leaving verb-less constructions such as answers to questions, headlines, exclamations, etc., aside, a speak mode derivation begins with the top predicate.[10] The complete sequence of explicit navigation operations begins with V↙N:

2.2.11 **<to-do 6>**

NAVIGATING WITH V↙N FROM *snore* TO *dog* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta \text{ X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: snore} \\ \text{cat: \#n}' \text{ \#hv}' \text{ \#be}' \text{ decl} \\ \text{sem: past perf prog} \\ \text{arg: dog} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 2} \end{bmatrix} \quad \begin{bmatrix} \text{sur: The} \\ \text{noun: dog} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc:} \\ \text{mdr: old} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 2} \end{bmatrix}$$

The clause to the right of the operation is called an instruction (6.4.1).

As shown by the value old in the mdr slot of the goal proplet, the noun dog is modified by an elementary adnominal. In this case, the lexicalization rule lexnoun sitting in the sur slot of the V↙N output pattern realizes only the determiner, based on the cat and sem values of the goal proplet. The

[10] If there are several predicates of equal rank, as in subject (1.4.5, Sect. 5.2) and object (1.4.6, Sect. 5.4) gapping, the navigation enters the content with the first and exits with the last.

realization of the common noun surface dog is left to the return navigation A↑N (2.2.13).

The next operation N↓A moves from an N to an A via the modifier|modified relation. The application is controlled by the core attribute noun of the first and adj of the second pattern:

2.2.12 Navigating with N↓A from *dog* to *old* (arc 2)

N↓A (s11)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{mdr: } \gamma \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexadj}(\hat{\gamma}) \\ \text{adj: } \gamma \\ \text{mdd: } \beta \\ \text{prn: K}\end{bmatrix}$$

#-mark γ in the mdr slot of proplet β.

$$\Uparrow \qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: dog} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: snore} \\ \text{mdr: old} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 2}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: old} \\ \text{adj: old} \\ \text{cat: adn} \\ \text{sem: pad} \\ \text{mdd: dog} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 2}\end{bmatrix}$$

Retrieval of the goal proplet *old* from the agent's memory (narrative speak mode) is based on the continuation value old in the mdr slot of *dog*, confirmed by the dog value in the mdd slot of *old*, and on the shared prn value, here 2.

The navigation returns from the adnominal modifier to the noun with A↑N:

2.2.13 Navigating with A↑N from *old* back to *dog* (arc 3)

A↑N (s12)

pattern level

$$\begin{bmatrix}\text{adj: } \gamma \\ \text{mdd: } \beta \\ \text{nc: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{mdr: \#}\gamma \\ \text{prn: K}\end{bmatrix}$$

Z is NIL, or elementary and #-marked.

$$\Uparrow \qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{adj: old} \\ \text{cat: adn} \\ \text{sem: pad} \\ \text{mdd: dog} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 2}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: dog} \\ \text{noun: dog} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: snore} \\ \text{mdr: \#old} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 2}\end{bmatrix}$$

The condition deals with a possible coordination of elementary adnominals ([nc: Z]), as in old, black, sleek, ... The return from an elementary adnominal to the modified noun may occur only if (i) there is no coordination or (ii)

all conjuncts have been #-marked. In 2.2.13, the first condition is fulfilled: the nc slot of *old* is empty.

The last navigation step activating the content 2.2.1 and realizing the surface has_been_snoring_. is performed by the think-speak mode operation N↗V:

2.2.14 NAVIGATING WITH N↗V FROM *dog* BACK TO *snore* (arc 4)

N↗V (s2)

pattern level

noun: β		sur: lexverb($\hat{\alpha}$)	
fnc: α Y	$\Rightarrow$	verb: α	#-mark α in the fnc slot of proplet β.
mdr: Z		arg: #β X	
prn: K		prn: K	

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

sur:	sur: has_been_snoring_.
noun: dog	verb: snore
cat: np	cat: #n′ #hv′ #be′ decl
sem: def sg	sem: past perf prog
fnc: snore	arg: #dog
mdr: #old	mdr:
nc:	nc:
pc:	pc:
prn: 2	prn: 2

Production of the surface has been snoring_. by lexverb($\hat{\alpha}$) is based on the features [verb: snore], [cat: #n′ #hv′ #be′ decl], and [sem: past perf prog] of the output proplet.

In summary, the DBS.2 extension of DBS.1 to a phrasal subject and predicate required the definition of three hear mode operations, namely AUX∪NFV (h16), DET∪CN (h47), and DET×ADN (h55), and two speak mode operations, namely N↓A (s11), and A↑N (s12). The hear mode derivation used six operation applications, while the speak mode derivation used four:

2.2.15 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:	1		2		3		4		5		6	
	The	×	old	∪	dog	×	had	∪	been	∪	snoring	∪	.

speak mode:	1		2		3		4
	V↙N	the	N↓A	old	A↑N	dog	N↗V had_been_snoring_.

The number of speak mode operations is lower than the number of hear mode operations because production of the verb phrase is left to lexverb($\hat{\alpha}$) (2.2.14).

2.3 DBS.3: Elementary Subject/Predicate\Object

The other obligatory functor-argument relation in natural language besides subject/predicate is object\predicate. If there are two objects in English, one is usually the indirect and the other the direct object.

2.3.1 **<to-do 1>**

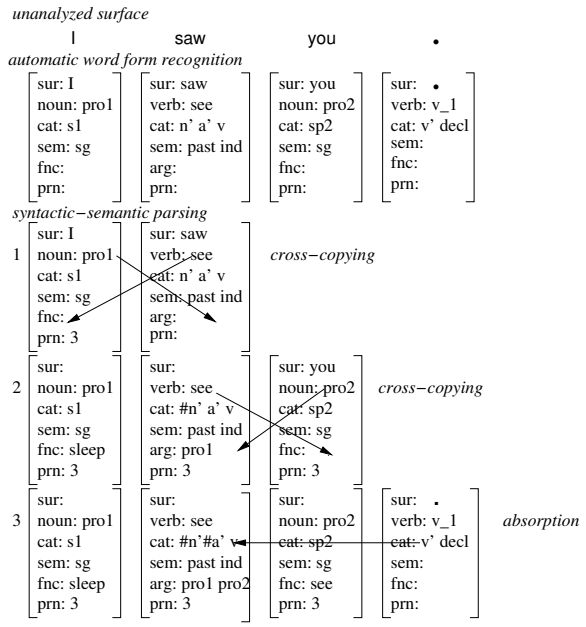
CONTENT OF I saw you.

sur: I	sur: saw	sur: you
noun: pro1	verb: see	noun: pro2
cat: s1	cat: #n #a decl	cat: sp2
sem: sg	sem: ind past	sem: sg
fnc: see	arg: pro1 pro2	fnc: see
...	...	...
prn: 3	prn: 3	prn: 3

The semantic roles of subject vs. direct object vs. indirect object is coded by their order as slots in the predicate's cat and as fillers in the predicate's arg attribute. The first valency position, represented by n′ (with variants for person and number, especially in auxiliaries), is reserved for the subject, the last position, represented by a′, for the direct object, and if there is a position in between represented by d′, it is the indirect object. Accordingly, the *see* proplet in 2.3.1 has the features [cat: #n′ #a′ decl] and [arg: pro1 pro2].

2.3.2 **<to-do 2>**

GRAPHICAL HEAR MODE DERIVATION OF THE CONTENT 2.3.1



result

$$\begin{bmatrix}\text{sur:}\\ \text{noun: pro1}\\ \text{cat: s1}\\ \text{sem: sg}\\ \text{fnc: see}\\ \text{prn: 3}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: see}\\ \text{cat: \#n'\#a' decl}\\ \text{sem: past ind}\\ \text{arg: pro1 pro2}\\ \text{prn: 3}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{noun: pro2}\\ \text{cat: sp2}\\ \text{sem: sg}\\ \text{fnc: see}\\ \text{prn: 3}\end{bmatrix}$$

The derivation resembles 2.1.2, except that there is an additional continuation, i.e. the second cross-copying for adding the grammatical object. In each verb, the number of valency positions for objects is fixed lexically.

The complete sequence of explicit hear mode operation applications begins with SBJ×PRD:

2.3.3 **<to-do 3>**

CROSS-COPYING *pro1* AND *see* WITH SBJ×PRD (LINE 1)

SBJ×PRD (h1)

pattern level

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP}'\text{ X v}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ X v}\\ \text{arg: }\alpha\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions omitted.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: I}\\ \text{noun: pro1}\\ \text{cat: s1}\\ \text{sem: sg}\\ \text{fnc:}\\ \ldots\\ \text{prn: 3}\end{bmatrix}\begin{bmatrix}\text{sur: saw}\\ \text{verb: see}\\ \text{cat: n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \ldots\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{noun: pro1}\\ \text{cat: s1}\\ \text{sem: sg}\\ \text{fnc: see}\\ \ldots\\ \text{prn: 3}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: see}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: pro1}\\ \ldots\\ \text{prn: 3}\end{bmatrix}$$

This application of SBJ×PRD resembles 2.1.3.

The next word *pro2* activates PRD×OBJ by matching its trigger pattern:

2.3.4 CROSS-COPYING *see* AND *you* WITH PRD×OBJ(LINE 2)[11]

PRD×OBJ (h28)

pattern level

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\#\text{X}'}\text{ N}'\text{ Y }\gamma\\ \text{arg: Z}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\text{ N}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\#\text{X}'}\text{ \#N}'\text{ Y }\gamma\\ \text{arg: Z }\alpha\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\text{ N}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}$$

N ϵ {obq, snp, pnp, s1, sp2, p1, p3}, N′ ϵ {d′, a′, be′, hv′}, and CN′ ϵ {NIL, nn′, sn′, pn′}.
γ ϵ {v, vi, vimp, inf}. If N ϵ {s1, sp2, p1, p3}, then N′ = be′; otherwise N′ ϵ {obq, snp, pnp}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: see}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: pro1}\\ \ldots\\ \text{prn: 3}\end{bmatrix}\begin{bmatrix}\text{sur: you}\\ \text{noun: pro2}\\ \text{cat: sp2}\\ \text{sem:}\\ \text{fnc:}\\ \ldots\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{verb: see}\\ \text{cat: \#n}'\text{ \#a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: pro1 pro2}\\ \ldots\\ \text{prn: 3}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{noun: pro2}\\ \text{cat: sp2}\\ \text{sem:}\\ \text{fnc: see}\\ \ldots\\ \text{prn: 3}\end{bmatrix}$$

[11] The agreement condition anticipates the analysis of the copula construction in Sect. 4.5.

The first input pattern matches *see* at the now front and the operation applies.

The #-marking of the nominative valency n′ in the feature [cat: #n′ a′ v] of the first input proplet indicates that this valency slot has been filled (2.3.3). The #-marking of the object valency position a′ in the feature [cat: #n′ #a′ v] of the first output proplet indicates that this valency slot is now filled as well.

Finally, automatic word form recognition provides the isolated example with interpunctuation by activating the S∪IP hear mode operation:

2.3.5 ABSORPTION OF • INTO *see* WITH S∪IP (line 3)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: \#X}' \text{ VT} \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: V\_}n \\ \text{cat: VT}' \text{ SM}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: \#X}' \text{ SM} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: see} \\ \text{cat: \#n}' \text{ v} \\ \text{sem: ind past} \\ \text{arg: pro1} \\ \ldots \\ \text{prn: 3}\end{bmatrix} \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: v\_1} \\ \text{cat: v}' \text{ decl} \\ \text{sem:} \\ \text{arg:} \\ \ldots \\ \text{prn:}\end{bmatrix} \begin{bmatrix}\text{sur:} \\ \text{verb: see} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: pro1} \\ \ldots \\ \text{prn: 3}\end{bmatrix}$$

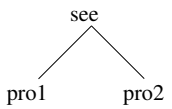
The hear mode derivation of an elementary subject, predicate, object is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

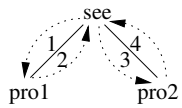
2.3.6 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE

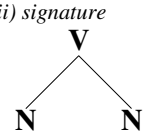
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

1	2	3	4
I	saw	you	•
V/N	N/V	V\N	N\V

As usual (2.1.12, 2.2.9), the (iv) surface realization consists of three lines, with each vertical triple showing the arc number, the surface realized from the goal proplet, and the name of the traversal operation.

Word form production is summarized as follows:

2.3.7 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *see* to *pro1*	I	2.3.8
arc 2:	N↗V	from *pro1* to *see*	saw	2.3.9
arc 3:	V↘N	from *see* to *pro2*	you	2.3.10
arc 4:	N↖V	from *pro2* to *see*	.	2.3.11

The complete sequence of explicit navigation operations begins with V↙N:

2.3.8 **<to-do 6>**

NAVIGATING WITH V↙N FROM *see* TO *pro1* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: see} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{decl} \\ \text{sem: ind past} \\ \text{arg: pro1 pro2} \\ \ldots \\ \text{prn: 3} \end{bmatrix} \quad \begin{bmatrix} \text{sur: I} \\ \text{noun: pro1} \\ \text{cat: s1} \\ \text{sem: sg} \\ \text{fnc: see} \\ \ldots \\ \text{prn: 3} \end{bmatrix}$$

The difference between an intransitive and a transitive verb is buffered by the variable X in the arg slot of the first proplet pattern: X is bound to NIL in 2.1.14, but to pro2 in2.3.8.

To acquire the continuation value in the second arg slot of the verb, here pro2, the think-speak mode navigation returns with the operation N↗V:

2.3.9 NAVIGATING WITH N↗V FROM *pro1* TO *see* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K} \end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{noun: pro1} \\ \text{cat: s1} \\ \text{sem: sg} \\ \text{fnc: see} \\ \ldots \\ \text{prn: 3} \end{bmatrix} \quad \begin{bmatrix} \text{sur: saw} \\ \text{verb: see} \\ \text{cat: \#n}'\ \text{a}'\ \text{decl} \\ \text{sem: ind past} \\ \text{arg: \#pro1 pro2} \\ \ldots \\ \text{prn: 3} \end{bmatrix}$$

The #-marking of the first arg value in the goal proplet resulted from the instruction of V⧸N (2.3.8).[12] The next navigation from the predicate to the object is based on V⧹N:

2.3.10 Navigating with V⧹N from *see* to *pro2* (arc 3)

V⧹N (s3)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: see} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#pro1 pro2} \\ \ldots \\ \text{prn: 3}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: you} \\ \text{noun: pro2} \\ \text{cat: sp2} \\ \text{sem:} \\ \text{fnc: \#see} \\ \ldots \\ \text{prn: 3}\end{bmatrix}$$

The arg value #pro1 is bound to the variable #X in the input pattern [arg: #X β Y], the arg value pro2 to β, and a possible third argument (in a three place verb like give) would be bound to Y.

The return from the object to the predicate with N⧹V is motivated by the need (i) to realize the punctuation mark (period), and (ii) to get into position for navigating to a possible next proposition (1.4.4) by extrapropositional coordination (analogous to 2.1.12, arc 3):

2.3.11 Navigating with N⧹V from *pro2* back to *see* (arc 4)

N⧹V (s4)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{mdr: } \ddot{\text{Z}} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: pro2} \\ \text{cat: sp2} \\ \text{sem:} \\ \text{fnc: \#see} \\ \ldots \\ \text{prn: 3}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: see} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#pro1 \#pro2} \\ \ldots \\ \text{prn: 3}\end{bmatrix}$$

[12] A #-marking instruction applies to an attribute value, here [arg: pro1 pro2], and not to a value *per se*. For example, #-marking a value in an arg slot does not affect the same value in a mdd slot.

The variable $\underset{\cdot\cdot}{\alpha}$ matches constants with or without a #-marking (1.6.5, 3). The #-marking of the second arg value resulted from the instruction of V\N (2.3.10). Lexnoun uses the cat value decl for realizing the period.

The DBS.3 extension of DBS.1 from an example class with elementary subject/predicate to a class with elementary subject/predicate\object required the definition of three operations: PRD×OBJ (h28) for the hear mode, and V\N (s3) and N↖V (s4) for the speak mode. The hear mode derivation used three operation applications, while the speak mode derivation used four:

2.3.12 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:	1		2		3	
	I	×	saw	×	you	∪ •

speak mode:	1		2		3		4	
	V↙N	I	N↗V	saw	V\N	you	N↖V	•

In contradistinction to 2.2.15, the number of speak mode operations is higher than that of the hear mode. The reason is that the speak mode navigation must return to the top predicate, while connecting four words in the hear mode requires only three operation applications.

2.4 DBS.4: Phrasal Subject and Object

In analogy to the upscaling from Sect. 2.1 (elementary subject/predicate) to Sect. 2.2 (phrasal subject/predicate), the present section upscales from Sect. 2.3 (elementary subject and object) to phrasal subject and object:

2.4.1 **<to-do 1>**

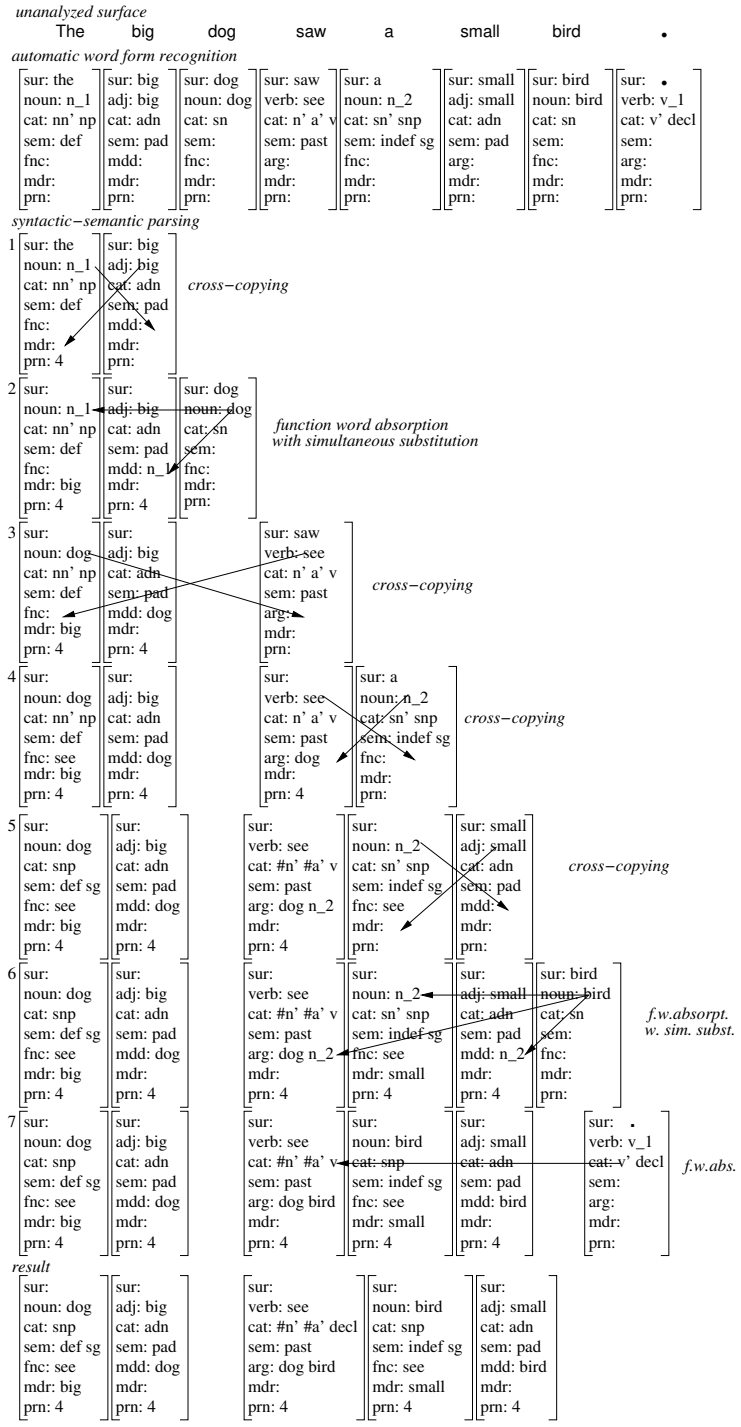
CONTENT OF The big dog saw a small bird.

sur:	sur:	sur:	sur:	sur:
noun: dog	adj: big	verb: see	noun: bird	adj: small
cat: snp	cat: adn	cat: #n #a decl	cat: snp	cat: adn
sem: def sg	sem: pad	sem: ind past	sem: def sg	sem: pad
fnc: see	mdd: dog	arg: dog bird	fnc: see	mdd: bird
mdr: big	mdr:	mdr:	mdr: small	mdr:
nc:	nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:	pc:
prn: 4	prn: 4	prn: 4	prn: 4	prn: 4

The time-linear derivation of the hear mode first composes the phrasal subject in preverbal position and then connects with the predicate (line 3), while the object is first connected to the predicate with its initial item (line 4) and then completed *in situ*:

2.4.2 <to-do 2>

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION



The operations completing the phrasal subject The big dog in preverbal position and putting together the phrasal object the small bird in postverbal position are the same, namely DET×ADN in 2.4.3 and 2.4.7, and DET∪CN in 2.4.4 and 2.4.8.

The complete sequence of explicit hear mode operation applications begins with DET×ADN:

2.4.3 **<to-do 3>**

CROSS-COPYING *the* AND *big* WITH DET×ADN (line 1)

DET×ADN (h55)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\text{ NP}\\ \text{mdr:}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{adj: }\alpha\\ \text{cat: ADN}\\ \text{mdd:}\\ \text{nc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\text{ NP}\\ \text{mdr: }\alpha\\ \text{prn:K}\end{bmatrix}\quad\begin{bmatrix}\text{adj: }\alpha\\ \text{cat: ADN}\\ \text{mdd: N\_}n\\ \text{nc:}\\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\Downarrow$$

content level

$$\begin{bmatrix}\text{sur: The}\\ \text{noun: n\_1}\\ \text{cat: nn}'\text{ np}\\ \text{sem: def}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 4}\end{bmatrix}\quad\begin{bmatrix}\text{sur: big}\\ \text{adj: big}\\ \text{cat: adn}\\ \text{sem: pad}\\ \text{mdd:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{noun: n\_1}\\ \text{cat: nn}'\text{ np}\\ \text{sem: def}\\ \text{fnc:}\\ \text{mdr: big}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 4}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{adj: big}\\ \text{cat: adn}\\ \text{sem: pad}\\ \text{mdd: n\_1}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 4}\end{bmatrix}$$

Next, the phrasal subject is completed with DET∪CN (2.2.4):

2.4.4 ABSORBING *dog* INTO *the* WITH DET∪CN (line 2)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\text{ NP}\\ \text{sem: Y}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{sem: Y Z}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.2.4.

$$\Uparrow\qquad\qquad\qquad\qquad\Uparrow\qquad\qquad\qquad\qquad\Downarrow$$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: n\_1}\\ \text{cat: nn}'\text{ np}\\ \text{sem: def}\\ \text{fnc:}\\ \text{mdr: big}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 4}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{adj: big}\\ \text{cat: adn}\\ \text{sem: pad}\\ \text{mdd: n\_1}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 4}\end{bmatrix}\quad\begin{bmatrix}\text{sur: dog}\\ \text{noun: dog}\\ \text{cat: sn}\\ \text{sem: sg}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{noun: dog}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc:}\\ \text{mdr: big}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 4}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{adj: big}\\ \text{cat: adn}\\ \text{sem:}\\ \text{mdd: dog}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 4}\end{bmatrix}$$

In 2.4.3 the core values of the determiner and *big* were cross-copied. In 2.4.4 the common noun *dog* is absorbed into the determiner and the two input proplets are replaced by one output proplet at the now front. The *big* proplet in the

input and the output is added to show the effect of simultaneous substitution, i.e. the automatic replacement of all instances of a substitution variable, here n_1, at the current now front.

The next step connects the completed phrasal subject and the predicate:

2.4.5 CROSS-COPYING *dog* AND *see* WITH SBJ×PRD (line 3)

SBJ×PRD (h1)

pattern level

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:K}\end{bmatrix}\ \begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP}'\ \text{X v}\\ \text{arg:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}\ \begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\ \text{X v}\\ \text{arg: }\alpha\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.2.

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: dog}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc:}\\ \text{mdr: big}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 4}\end{bmatrix}\ \Uparrow\ \begin{bmatrix}\text{sur: saw}\\ \text{verb: see}\\ \text{cat: n}'\ \text{a}'\ \text{v}\\ \text{sem: ind past}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\qquad \begin{bmatrix}\text{sur:}\\ \text{noun: dog}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc: see}\\ \text{mdr: big}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 4}\end{bmatrix}\ \Downarrow\ \begin{bmatrix}\text{sur:}\\ \text{verb: see}\\ \text{cat: \#n}'\ \text{a}'\ \text{v}\\ \text{sem: ind past}\\ \text{arg: dog}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 4}\end{bmatrix}$$

At this point, the hear mode derivation has interpreted The big dog saw.

The derivation continues with the beginning of the phrasal object. The operation is PRD×OBJ, which was previously used in 2.3.4 for adding an elementary object.

2.4.6 CROSS-COPYING *see* AND *a(n)* WITH PRD×OBJ (line 4)

PRD×OBJ (h28)

pattern level

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\text{\#X}'}\ \text{N}'\ \text{Y }\gamma\\ \text{arg: Z}\\ \text{prn: K}\end{bmatrix}\ \begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\ \text{N}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\text{\#X}'}\ \text{\#N}'\ \text{Y }\gamma\\ \text{arg: Z }\alpha\\ \text{prn: K}\end{bmatrix}\ \begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\ \text{N}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions omitted

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: see}\\ \text{cat: \#n}'\ \text{a}'\ \text{v}\\ \text{sem: ind past}\\ \text{arg: dog}\\ \ldots\\ \text{prn: 4}\end{bmatrix}\ \Uparrow\ \begin{bmatrix}\text{sur: a}\\ \text{noun: n\_2}\\ \text{cat: sn}'\ \text{snp}\\ \text{sem: indef sg}\\ \text{fnc:}\\ \ldots\\ \text{prn:}\end{bmatrix}\qquad \begin{bmatrix}\text{sur:}\\ \text{verb: see}\\ \text{cat: \#n}'\ \text{\#a}'\ \text{v}\\ \text{sem: ind past}\\ \text{arg: dog n\_2}\\ \ldots\\ \text{prn: 4}\end{bmatrix}\ \Downarrow\ \begin{bmatrix}\text{sur:}\\ \text{noun: n\_2}\\ \text{cat: sn}'\ \text{snp}\\ \text{sem: indef sg}\\ \text{fnc: see}\\ \ldots\\ \text{prn: 4}\end{bmatrix}$$

The feature [cat: $\underline{\text{\#X}'}$ N′ Y v] of the verb pattern ensures that the nominative has already been concatenated (canceled valency position(s) $\underline{\text{\#X}'}$[13]) and that there is a free valency position N′ for another noun. The feature [cat: CN′ N]

[13] The underline ensures that #X′ is not bound to NIL (1.6.5, 2).

of the noun pattern matches a determiner proplet beginning a phrasal as well as an elementary noun proplet; in the latter case, CN′ would be bound to NIL.

The next operation continues building the phrasal object with DET×ADN:

2.4.7 CROSS-COPYING *a(n)* AND *small* WITH DET×ADN (line 5)

DET×ADN (h55)

pattern level

noun: N_*n*	adj: α	noun: N_*n*	adj: α
cat: CN′ NP	cat: ADN	cat: CN′ NP	cat: ADN
mdr:	mdd:	mdr: α	mdd: N_*n*
prn: K	nc:	prn: K	nc:
	prn:		prn: K

⇑ ⇓

content level

sur:	sur: small	sur:	sur:
noun: n_2	adj: small	noun: n_2	adj: small
cat: sn′ snp	cat: adn	cat: sn′ snp	cat: adn
sem: indef sg	sem:	sem: indef sg	sem:
fnc: see	mdd:	fnc: see	mdd: n_2
mdr:	mdr:	mdr: small	mdr:
nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:
prn: 4	prn:	prn: 4	prn: 4

The next word proplet *small* matching the second input pattern of DET×ADN activates the operation. It happens to find the proplet *n_2* at the now front (*n_1* has disappeared by absorption in 2.4.4) matching its first input pattern and applies. In the output, the core value of *small* is copied into the mdr slot of *n_2*, and the core value of *n_2* into the mdd slot of *small*.

The next word proplet *bird* matches the second input pattern of the operation DET∪CN, while its first pattern matches the *n_2* proplets at the now front:

2.4.8 ABSORBING *bird* INTO *a(n)* WITH DET∪CN (line 6), absorption

DET∪CN (h47)

pattern level

noun: N_*n*	noun: α	noun: α
cat: CN′ NP	cat: CN	cat: NP
sem: Y	sem: Z	sem: Y Z
prn: K	prn:	prn: K

Agreement conditions as in 2.2.4.

⇑ ⇑ ⇓

content level

sur:	sur:	sur: bird	sur:	sur:
verb: see	noun: n_2	noun: bird	verb: see	noun: bird
cat: #n′ #a′ v	cat: sn′ snp	cat: sn	cat: #n′ #a′ v	cat: snp
sem: ind past	sem: indef sg	sem: sg	sem: ind past	sem: indef sg
arg: dog n_2	fnc: see	fnc:	arg: dog bird	fnc: see
mdr:	mdr: small	mdr:	mdr:	mdr: small
nc:	nc: +a	nc:	nc:	nc:
pc:	pc:	pc:	pc:	pc:
prn: 4	prn: 4	prn:	prn: 4	prn: 4

As shown in 2.4.2, line 6, simultaneous substitution replaces the variable n_2 not only in *a(n)* and *see*, but also in *small* (here omitted) with bird. The phrasal noun in postverbal (object) position is now completed.

Finally, automatic word form recognition provides the isolated example with interpunctuation by activating the S∪IP hear mode operation:

2.4.9 ABSORBING *see* INTO • WITH S∪IP (line 7)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ VT} \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: V\_}n \\ \text{cat: VT}' \text{ SM}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ SM} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: see} \\ \text{cat: } \#n' \text{ v} \\ \text{sem: ind past} \\ \text{arg: dog bird} \\ \ldots \\ \text{prn: 4}\end{bmatrix} \Uparrow \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: v\_1} \\ \text{cat: v}' \text{ decl} \\ \text{sem:} \\ \text{arg:} \\ \ldots \\ \text{prn:}\end{bmatrix} \qquad \Downarrow \begin{bmatrix}\text{sur:} \\ \text{verb: see} \\ \text{cat: } \#n' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: dog bird} \\ \ldots \\ \text{prn: 4}\end{bmatrix}$$

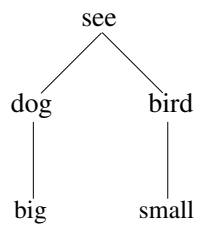
The hear mode derivation of a phrasal subject and object is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

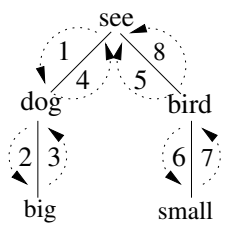
2.4.10 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE

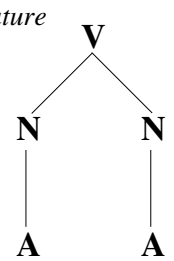
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

1	2	3	4	5	6	7	8
The	big	dog	saw	the	small	bird	•
V/N	N|A	A|N	N/V	V\N	N|A	A|N	N\V

The left branch of the NAG with the arcs 1-4 resembles the graph 2.2.9 for an intransitive construction. The depth first numbering (1.4.1) is consecutive.

Word form production is summarized as follows:

2.4.11 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *see* to *dog*	The	2.4.12
arc 2:	N↓A	from *dog* to *big*	big	2.4.13
arc 3:	A↑N	from *big* to *dog*	dog	2.4.14
arc 4:	N↗V	from *dog* to *see*	saw	2.4.15
arc 5:	V↘N	from *see* to *bird*	a	2.4.16
arc 6:	N↓A	from *bird* to *small*	small	2.4.17
arc 7:	A↑N	from *small* to *bird*	bird	2.4.18
arc 8:	N↖V	from *bird* to *see*	.	2.4.19

The proplets serving as input to the think-speak mode operations are those which have been derived in the hear mode (DBS laboratory set-up).

Activating a next proplet in the agent's memory corresponds to retrieval in a conventional database. However, instead of retrieving an item for a database-external user, autonomous navigation along the semantic relations between proplets constitutes a mental activity of the agent containing the memory. Activated goal proplets, in turn, may be mapped into external surfaces by the language-dependent lexicalization rules stored in the sur slot as the means for inter-agent language communication (automatic word form production).

The complete sequence of explicit navigation operations begins with V↙N:

2.4.12 **<to-do 6>**

NAVIGATING WITH V↙N FROM *see* TO *dog* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: see} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{decl} \\ \text{sem: ind past} \\ \text{arg: dog bird} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 4} \end{bmatrix} \qquad \begin{bmatrix} \text{sur: The} \\ \text{noun: dog} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: see} \\ \text{mdr: big} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 4} \end{bmatrix}$$

As shown by the graph 2.4.10, V↙N moves downward from V to N (arc 1) and realizes the determiner the from the N proplet *dog*.

To realize big, the navigation proceeds with N↓A to the adnominal modifier:

2.4.13 Navigating with N↓A from *dog* to *big* (arc 2)

N↓A (s11)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{mdr: } \gamma \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexadj}(\hat{\gamma}) \\ \text{adj: } \gamma \\ \text{mdd: } \beta \\ \text{prn: K}\end{bmatrix}$$

#-mark γ in the mdr slot of proplet β.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: dog} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: see} \\ \text{mdr: big} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 4}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: big} \\ \text{adj: big} \\ \text{cat: adn} \\ \text{sem: pad} \\ \text{mdd: dog} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 4}\end{bmatrix}$$

The traversal sequence V↙N – N↓A complies with the Continuity Condition of DBS (NLC 3.6.5), according to which a think-speak mode operation AxB may only be followed by an operation BxC which accepts the output of AxB as input. The Continuity Condition is the think-speak mode counterpart to the time-linearity in the hear mode. In fact, the Continuity Condition of the speak mode is the source of the hear mode's time-linear derivation order.

Having realized The big, the only continuation feature currently available is [mdd: dog]:

2.4.14 Navigating with A↑N from *big* back to *dog* (arc 3)

A↑N (s12)

pattern level

$$\begin{bmatrix}\text{adj: } \gamma \\ \text{mdd: } \beta \\ \text{nc: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{mdr: } \#\gamma \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the mdd slot of proplet γ.

Z is NIL, or elementary and #-marked.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{adj: big} \\ \text{cat: adn} \\ \text{sem: pad} \\ \text{mdd: dog} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 4}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: dog} \\ \text{noun: dog} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: see} \\ \text{mdr: \#big} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 4}\end{bmatrix}$$

As shown in the graph 2.4.10, A↑N accesses the N proplet *dog* from below (arc 3) and realizes the common noun dog.

Now, the only continuation feature currently available is [fnc: see]:

2.4.15 NAVIGATING WITH N↗V FROM *dog* BACK TO *see* (arc 4)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: dog} \\ \text{cat: np} \\ \text{sem: def sg} \\ \text{fnc: see} \\ \text{mdr: \#big} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 4}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: saw} \\ \text{verb: see} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{decl} \\ \text{sem: ind past} \\ \text{arg: \#dog bird} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 4}\end{bmatrix}$$

In the graph 2.4.10, N↗V accesses the V proplet *see* from below (arc 4) and realizes the finite main verb saw.

The next step follows arc 5 to the phrasal object with V↘N, similar to 2.3.10:

2.4.16 NAVIGATING WITH V↘N FROM *see* TO *bird* (arc 5)

V↘N (s3)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta\ \text{Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: see} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{decl} \\ \text{sem: ind past} \\ \text{arg: \#dog bird} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 4}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: a(n)} \\ \text{noun: bird} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#see} \\ \text{mdr: small} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 4}\end{bmatrix}$$

In the graph, V↘N accesses the N proplet *bird* from above (arc 5), realizing the indefinite article a(n).

The different surface production of you in 2.3.10 and a(n) in 2.4.16 originates in the lexicalization rule lexnoun. It produces you from the feature [cat: sp2] in the output proplet of 2.3.10 and a(n) from the feature [sem: indef sg] in the output proplet of 2.4.16.

At this point, the speak mode derivation has realized The big dog saw a. The activated *bird* proplet matches the input proplet pattern of the N↓A think-speak operation.

2.4.17 NAVIGATING WITH N↓A FROM *bird* TO *small* (arc 6)

N↓A (s11)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{mdr: } \gamma \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexadj}(\hat{\gamma}) \\ \text{adj: } \gamma \\ \text{mdd: } \beta \\ \text{prn: K} \end{bmatrix}$$

#-mark γ in the mdr slot of proplet β.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{noun: bird} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#see} \\ \text{mdr: small} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 4} \end{bmatrix} \quad \begin{bmatrix} \text{sur: small} \\ \text{adj: small} \\ \text{cat: adn} \\ \text{sem: pad} \\ \text{mdd: bird} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 4} \end{bmatrix}$$

The operation (i) activates the *small* proplet in A-memory and (ii) realizes the surface small from the core value with its lexicalization rule lexadj.

The activated *small* proplet matches the input pattern of the inverse operation A↑N to realize the final surface of discontinuous a...bird:

2.4.18 NAVIGATING WITH A↑N FROM *small* BACK TO *bird* (arc 7)

A↑N (s12)

pattern level

$$\begin{bmatrix} \text{adj: } \gamma \\ \text{mdd: } \beta \\ \text{nc: Z} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{mdr: \#}\gamma \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the mdd slot of proplet γ.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{adj: small} \\ \text{cat: adn} \\ \text{sem: pad} \\ \text{mdd: bird} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 4} \end{bmatrix} \quad \begin{bmatrix} \text{sur: bird} \\ \text{noun: bird} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#see} \\ \text{mdr: \#small} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 4} \end{bmatrix}$$

The following return of the navigation back to the verb with N↖V is used to provide (i) the sur value . (period) with lexverb and to reach (ii) the unique location suitable for a navigation to a possible next proposition (1.3.7, 1.4.4, 2.1.12) by extrapropositional coordination:

2.4.19 NAVIGATING WITH N↖\V FROM *bird* BACK TO *see* (arc 8)

N↖\V (s4)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{mdr: } \ddot{Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta\text{ Y} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

content level

$$\Uparrow \begin{bmatrix}\text{sur:} \\ \text{noun: bird} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#see} \\ \text{mdr: \#small} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 4}\end{bmatrix} \qquad \Downarrow \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: see} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#dog \#bird} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 4}\end{bmatrix}$$

The #-marking of the second arg value bird of the *see* proplet resulted from the instruction of V↘N (2.4.16). It prevents lexnoun to realize bird again, but the variable Y would allow the realization of a third argument in a construction with a three-place (ditransitive) verb.

Applying DBS.4 to an example class with a phrasal subject and object did not require the definition of any additional operations. The hear mode derivation used seven operation applications, while the speak mode derivation used eight:

2.4.20 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

	1		2		3		4		5		6		7	
The	×	big	∪	dog	×	saw	×	a	×	small	∪	bird	∪	•

speak mode:

1	2	3	4	5	6	7	8
V↙N	the N↓A big	A↑N dog	N↗V saw	V↘N a	N↓A small	A↑N bird	N↖V •

The DET-ADN-NOUN sequences require two operation applications in the hear mode interpretation, but their speak mode production requires three.

2.5 DBS.5: Clausal Subject

Functor-argument relations are called intrapropositional if the argument is elementary (Sects. 2.1, 2.3) or phrasal (Sects. 2.2, 2.4). They are called extrapropositional if the argument is clausal, such as a subject, object, adnominal, or adverbial clause. Intra- and extrapropositional functor-argument rela-

tions are alike in that they are binary, i.e. defined by address between two individual, completely self-contained, order-free proplets. They differ in that the proplets of the former share a common prn value, while the latter use different prn values for the different component propositions.

This section complements the intrapropositional constructions of elementary (Sect. 2.1) and phrasal (Sect. 2.2) subjects with a clausal subject construction. Its matrix verb must (i) allow transitive use and (ii) be what is called a 'psych verb' in lexicography, such as *amaze, amuse, anger, annoy, bore, concern, excite, interest, irritate, satisfy, surprise, tire,* and *worry*.

Consider the following example[14] of a subject clause:

2.5.1 **<to-do 1>**

CONTENT OF That Fido barked amused Mary.

sur: fido	sur:	sur:	sur: mary
noun: [dog y]	verb: bark	verb: amuse	noun: [person x]
cat: snp	cat: #n decl	cat: #n #a decl	cat: snp
sem: nm m	sem: *that* ind past	sem: ind past	sem: nm f
fnc: bark	arg: [dog y]	arg: (bark 5) [person x]	fnc: amuse
mdr:	fnc: (amuse 6)	mdr:	mdr:
nc:	mdr:	nc:	nc:
pc:	nc:	pc:	pc:
prn: 5	pc:	prn: 6	prn: 6
	prn: 5		

The subclause and the main clause have different prn values, here 5 and 6. The V/V relation between the two clauses is provided by (i) the additional fnc attribute with the extrapropositional address value (amuse 6) of the verb proplet *bark* and (ii) the extrapropositional address value (bark 5) in the first arg slot of the verb proplet *amuse*.

While the examples in Sects. 2.2–2.4 used the sign kinds *concept*, e.g. dog, and *indexical*, e.g. you, the current example uses the sign kind *name* (CASM). The core value of a name is the referent (concept token) provided in an individual act of baptism rather than the lexicon (concepts) or the agent's on-board orientation system (indexicals). The named referents serving as the core values of the name proplets *mary* and *fido* in 2.5.1 are [person x] and [dog y].

Unlike proplets referring by means of matching (concepts) or pointing (indexicals), which lose their sur value during a hear mode derivation, name proplets retain their sur value in the form of a marker (FoCL 6.1.6), written in default font and lower case, e.g. 'fido' instead of the surface value written in Helvetica, i.e. 'Fido'.[15] Consider the hear mode derivation of 2.5.1:

[14] For convenience, we may refer to a name proplet by its marker in *italics*, e.g. *fido*, instead of its core value, e.g. [dog y].

2.5.2 <to-do 2>

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION

unanalyzed surface

That Fido barked amused Mary •

automatic word form recognition

That	Fido	barked	amused	Mary	•
sur: That	sur: Fido	sur: barked	sur: amused	sur: Mary	sur: •
verb: v_1	noun: [dog x]	verb: bark	verb: amuse	noun: [person y]	verb: v_1
cat:	cat: snp	cat: n' v	cat: n' a' v	cat: snp	cat: v' decl
sem: *that*	sem: nm m	sem: past ind	sem: past	sem: nm f	
arg:	fnc:	arg:	arg:	fnc:	
fnc:	prn:	prn:	prn:	prn:	
prn:					

syntactic−semantic parsing

1

That	Fido
sur: That	sur: Fido
verb: v_1	noun: [dog x]
cat:	cat: snp
sem: *that*	sem: nm m
arg:	fnc:
fnc:	prn:
prn: 5	

cross−copying

2

sur:	sur: fido	sur: barked
verb: v_1	~~noun: [dog x]~~	~~verb:~~ bark
cat:	~~cat: snp~~	cat: n' v
sem: *that*	~~sem: nm m~~	~~sem:~~ past ind
arg: [dog x]	fnc: v_1	arg:
fnc:	prn: 5	prn:
prn: 5		

absorption with simultaneous substitution

3

sur:	sur: fido	sur: amused
verb: bark	noun: [dog x]	~~verb:~~ amuse
cat: #n' v	~~cat: snp~~	cat: n' a' v
sem: *that* past ind	sem: nm m	sem: past ind
arg: [dog x]	fnc: bark	arg:
fnc:	prn: 5	prn:
prn: 5		

cross−copying

4

sur:	sur: fido	sur:	sur: Mary
verb: bark	noun: [dog x]	verb: amuse	noun: [person y]
cat: #n' v	cat: snp	cat: #n' a' v	cat: snp
sem: *that* past ind	sem: nm m	sem: past ind	sem: nm f
arg: [dog x]	fnc: bark	arg: (bark 5)	fnc:
fnc: (amuse 6)	prn: 5	prn: 6	prn:
prn: 5			

cross−copying

5

sur:	sur: fido	sur:	sur: mary	sur: •
verb: bark	noun: [dog x]	verb: amuse	noun: [person y]	verb: v_2
cat: #n' v	cat: snp	cat: #n' #a' v	~~cat: snp~~	~~cat: v~~' decl
sem: *that* past ind	sem: nm m	sem: past ind	sem: nm f	sem:
arg: [dog x]	fnc: bark	arg: (bark 5) [person y]	fnc: amuse	arg:
fnc: (amuse 6)	prn: 5	prn: 6	prn: 6	prn:
prn: 5				

absorption

result

sur:	sur: fido	sur:	sur: mary
verb: bark	noun: [dog x]	verb: amuse	noun: [person y]
cat: #n' v	cat: snp	cat: #n' #a' decl	cat: snp
sem: *that* past ind	sem: nm m	sem: past ind	sem: nm f
arg: [dog x]	fnc: bark	arg: (bark 5) [person y]	fnc: amuse
fnc: (amuse 6)	prn: 5	prn: 6	prn: 6
prn: 5			

Line 1 combines *that* with *fido* by cross-copying. When *bark* arrives in line 2,

the two *v_1* variables in *that* and *fido* are replaced with bark by simultaneous substitution, the cat and sem values of *bark* are absorbed into the *that* proplet becoming the 'new' *bark*, while the 'old' *bark* proplet is discarded. Line 3 adds the verb of the main clause by cross-copying amuse into the fnc slot of the new *bark* and bark into the initial arg slot of *amuse* (clausal subject). Line 4 adds [person x] to the second arg slot of *amuse* as the object.

The complete sequence of explicit hear mode operation applications begins with $\mathsf{PRD}^{\mathsf{obl}} \times \mathsf{SBJ}$:

2.5.3 **<to-do 3>**

CROSS-COPYING *that* AND *fido* WITH $\mathsf{PRD}^{\mathsf{obl}} \times \mathsf{SBJ}$ (line 1)

PRD$^{\text{obl}}\times$**SBJ** (h31)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: } \textit{that}\\ \text{arg:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{fnc:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: V\_}n\\ \text{sem: } \textit{that}\\ \text{arg: }\beta\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{fnc: V\_}n\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.2.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: That}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: } \textit{that}\\ \text{arg:}\\ \text{fnc:}\\ \ldots\\ \text{prn: 5}\end{bmatrix}\begin{bmatrix}\text{sur: Fido}\\ \text{noun: [dog y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc:}\\ \ldots\\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: } \textit{that}\\ \text{arg: [dog y]}\\ \text{fnc:}\\ \ldots\\ \text{prn: 5}\end{bmatrix}\begin{bmatrix}\text{sur: fido}\\ \text{noun: [dog y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc: v\_1}\\ \ldots\\ \text{prn: 5}\end{bmatrix}$$

The function word *that* is lexically defined (NLC A.4.4) with (a) the attribute arg, which is standard for a verb proplet, and (b) an additional fnc attribute, which is usually reserved for nouns, but needed in a subordinating conjunction for the connection to the higher verb.

Based on cross-copying with *fido* (line 1) and absorbing *bark* (line 2), the function word that serves as the pivot of this subclause construction:

2.5.4 ABSORBING *bark* INTO *that* WITH $\mathsf{PRD}^{\mathsf{obl}} \cup \mathsf{PRD}$ (line 2)

PRD$^{\text{obl}}\cup$**PRD** (h19)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: } \textit{that}\\ \text{arg: }\alpha\\ \text{prn:K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP}'\text{ X v}\\ \text{sem: Y}\\ \text{arg:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ X v}\\ \text{sem: } \textit{that}\text{ Y}\\ \text{arg: }\alpha\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.5.3.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: } \textit{that}\\ \text{arg: [dog y]}\\ \text{fnc:}\\ \ldots\\ \text{prn: 5}\end{bmatrix}\begin{bmatrix}\text{sur: barked}\\ \text{verb: bark}\\ \text{cat: n}'\text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \ldots\\ \text{nn prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:}\\ \text{verb: bark}\\ \text{cat: \#n}'\text{ v}\\ \text{sem: } \textit{that}\text{ ind past}\\ \text{arg: [dog y]}\\ \text{fnc:}\\ \ldots\\ \text{prn: 5}\end{bmatrix}$$

The hear mode derivation continues by adding the higher verb *amuse*.

2.5.5 CROSS-COPYING *bark* AND *amused* WITH PRD^{obl}×PRD(LINE 3)

PRD^{obl}×PRD (h5)

pattern level

verb: α	verb: β		verb: α		verb: β
cat: #X′ v	cat: NP’ Y v		cat: #X′ v		cat: #NP’ Y v
sem: *that* Y	arg:	⇒	sem: *that* Y		arg: (α K)
fnc:	prn:		fnc: (β K+1)		prn: K+1
prn: K			prn: K		

NP’ ϵ {ns3′, n-s3′, n′}

⇑ ⇓

content level

sur:	sur: amused	sur:		sur:
verb: bark	verb: amuse	verb: bark		verb: amuse
cat: #n′ v	cat: n′ a′ v	cat: #n′ v		cat: #n′ a′ v
sem: *that* ind past	sem: ind past	sem: *that* ind past		sem: ind past
arg: [dog y]	arg:	arg: [dog y]		arg: (bark 5)
fnc:	mdr:	fnc: (amuse 6)		mdr:
mdr:	nc:	mdr:		nc:
nc:	pc:	nc:		pc:
pc:	prn:	pc:		prn: 6
prn: 5		prn: 5		

The variables K in the prn slot of the first input pattern and K+1 in the second output pattern assign an incremented prn value to the next word proplet, here 6 in the prn slot of *amuse* (operation-based prn incrementation). The cat pattern #X′ v of the first input and output pattern ensures that all valency positions in the subclause have been canceled. The V/V connection between *bark* and *amuse* is established by cross-copying the core value of *bark* into the initial arg slot of *amuse* and the core value of *amuse* into the fnc slot of *bark*.

The grammatical object of *amuse* is *mary*. This continuation is added with standard PRD×OBJ:

2.5.6 CROSS-COPYING *amuse* AND *mary* WITH PRD×OBJ (line 4)

PRD×OBJ (h28)

pattern level

verb: β	noun: α		verb: β	noun: α
cat: <u>#X′</u> N′ Y γ	cat: CN′ N		cat: <u>#X′</u> #N′ Y γ	cat: CN′ N
arg: Z	fnc:	⇒	arg: Z α	fnc: β
prn: K	prn:		prn: K	prn: K

Agreement conditions as in 2.3.4.

⇑ ⇓

content level

sur:	sur: Mary	sur:	sur: mary
verb: amuse	noun: [person x]	verb: amuse	noun: [person x]
cat: #n′ a′ v	cat: snp	cat: #n′ #a′ v	cat: snp
sem: ind past	sem: nm f	sem: ind past	sem: nm f
arg: (bark 5)	fnc:	arg: (bark 5) [person x]	fnc: amuse
mdr:	mdr:	mdr:	mdr:
nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:
prn: 6	prn:	prn: 6	prn: 6

The linguistic example is completed by absorbing the punctuation mark, here • (period), with S∪IP into the top verb:

2.5.7 ABSORBING • INTO *amused* WITH S∪IP (line 5)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ VT} \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: V\_}n \\ \text{cat: VT}' \text{ SM}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ SM} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: amuse} \\ \text{cat: } \#n' \text{ v} \\ \text{sem: ind past} \\ \text{arg: [person x]} \\ \ldots \\ \text{prn: 6}\end{bmatrix} \Uparrow \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: v\_1} \\ \text{cat: v}' \text{ decl} \\ \text{sem:} \\ \text{arg:} \\ \ldots \\ \text{prn:}\end{bmatrix} \qquad \Downarrow \begin{bmatrix}\text{sur:} \\ \text{verb: amuse} \\ \text{cat: } \#n' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x]} \\ \ldots \\ \text{prn: 6}\end{bmatrix}$$

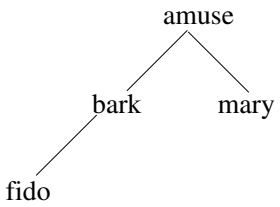
The hear mode derivation of a clausal subject construction is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

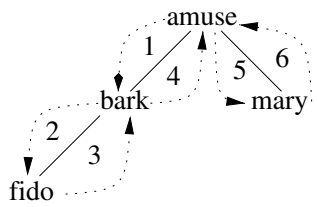
2.5.8 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE

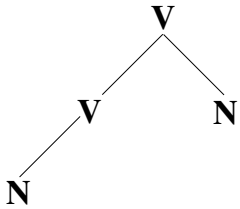
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

1	2	3	4	5	6
That	Fido	barked	amused	Mary	•
V/V	V/N	N/V	V/V	V\N	N\V

Word form production is summarized as follows:

2.5.9 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙V	from *amuse* to *bark*	That	2.5.10
arc 2:	V↙N	from *bark* to *fido*	Fido	2.5.11
arc 3:	N↗V	from *fido* to *bark*	barked	2.5.12
arc 4:	V↗V	from *bark* to *amuse*	amused	2.5.13
arc 5:	V↘N	from *amuse* to *mary*	Mary	2.5.14
arc 6:	N↖V	from *mary* to *amuse*	.	2.5.15

Similar to the discontinuous phrasal noun structure The ... dog (2.2.10), the second surface of discontinuous That ... barked is realized on the return, here by N↗V (arc 3). The extrapropositional subject/predicate transitions V↙V (2.5.10) and V↗V (2.5.13) resemble their intrapropositional counterparts V↙N (2.1.6, 2.2.11, 2.3.8, 2.4.12), and N↗V (2.1.7, 2.2.14, 2.3.11, 2.4.15) insofar as they are strictly binary, i.e. defined by address between two individual, completely self-contained, order-free proplets.

The complete sequence of explicit navigation operations begins with V↙V:

2.5.10 **<to-do 6>**

NAVIGATING WITH V↙V FROM *amuse* TO *bark* (arc 1)

V↙V (s5)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } (\beta\ \text{K})\ \text{X} \\ \text{prn: K+1} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{sem: } \textit{that}\ \text{Z} \\ \text{fnc: } (\alpha\ \text{K+1}) \\ \text{prn: K} \end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: amuse} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{decl} \\ \text{sem: ind past} \\ \text{arg: (bark 5) [person x]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 6} \end{bmatrix} \qquad \begin{bmatrix} \text{sur: That} \\ \text{verb: bark} \\ \text{cat: \#n}'\ \text{v} \\ \text{sem: } \textit{that}\ \text{ind past} \\ \text{arg: [dog y]} \\ \text{fnc: (amuse 6)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 5} \end{bmatrix}$$

The continuation value enabling the application of V↙V is extrapropositional (bark 5) in the arg slot of *amuse*. The goal of the navigation is the verb *bark* representing the subclause. The relation is confirmed (and used for the return in arc 4, 2.5.13) by the continuation value (amuse 6) in the fnc slot of *bark*.

Next the subclause is continued by adding the subject with standard V↙N:

2.5.11 NAVIGATING WITH V↙N FROM *bark* TO *fido* (arc 2)

V↙N (s1)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: bark} \\ \text{cat: \#n}'\ \text{v} \\ \text{sem: } \textit{that}\ \text{ind past} \\ \text{arg: [dog y]} \\ \text{fnc: (amuse 6)} \\ \ldots \\ \text{prn: 5}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: Fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: bark} \\ \ldots \\ \text{prn: 5}\end{bmatrix}$$

The use of V↙N in a subclause is possible because the V pattern disregards the characteristic properties of a subclause verb, such as the presence of an additional fnc feature and a subordinating conjunction, here *that* in the sem slot (compatibility by omission). Lexnoun uses the fido marker preserved in the sur slot of the *fido* proplet (2.5.1) for realizing the surface Fido.

The next think-speak mode operation is N↗V for moving from *fido* to *bark* for realizing the surface barked. It is also a step on the way back to the top predicate *amuse*:

2.5.12 NAVIGATING WITH N↗V FROM *fido* BACK TO *bark* (arc 3)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur: fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: bark} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 5}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: barked} \\ \text{verb: bark} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{decl} \\ \text{sem: } \textit{that}\ \text{ind past} \\ \text{arg: \#[dog y]} \\ \text{fnc: (amuse 6)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 5}\end{bmatrix}$$

The other step needed for the return to the top predicate is based on the operation V↗V. It moves from the clausal subject represented by *bark* to the matrix verb *amuse*:

2.5.13 NAVIGATING WITH V↗V FROM *bark* BACK TO *amuse* (arc 4)

V↗V (s6)

pattern level

$$\begin{bmatrix} \text{verb: } \beta \\ \text{sem: } \textit{that}\ \text{Z} \\ \text{arg: \#X} \\ \text{fnc: } (\alpha\ \text{K+1}) \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: } (\beta\ \text{K})\ \text{X} \\ \text{prn: K+1} \end{bmatrix}$$

#-mark β in the fnc slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: bark} \\ \text{cat: \#n}'\ \text{v} \\ \text{sem: } \textit{that}\ \text{ind past} \\ \text{arg: \#[dog y]} \\ \text{fnc: (amuse 6)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 5} \end{bmatrix} \qquad \begin{bmatrix} \text{sur: amused} \\ \text{verb: amuse} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{decl} \\ \text{sem: ind past} \\ \text{arg: (bark 5) [person x]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 6} \end{bmatrix}$$

By binding the extrapropositional address value (amuse 6) in the fnc slot of *bark* to the variable (α K+1) in the first pattern and using it as the core value of the goal proplet, the operation navigates back to the top predicate. The relation is confirmed by the initial arg value (bark 5) of *amuse*.

The main clause is completed by navigating with standard V↘N to the grammatical object and realizing the main clause object Mary:

2.5.14 NAVIGATING WITH V↘N FROM *amuse* TO *Mary* (arc 5)

V↘N (s3)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: amuse} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{decl} \\ \text{sem: ind past} \\ \text{arg: \#(bark 5) [person x]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 6} \end{bmatrix} \qquad \begin{bmatrix} \text{sur: Mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: \#amuse} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 6} \end{bmatrix}$$

It remains to return to the top verb with N↖V to (i) provide the sur value **.** (period) with lexverb and to (ii) reach the unique location suitable for a possible navigation to a next proposition by extrapropositional coordination (1.4.4).

2.5.15 NAVIGATING WITH N↖\V FROM *Mary* BACK TO *amuse* (arc 6)

N↖\V (s4)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{mdr: } \ddot{Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta\text{ Y} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: \#amuse} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 6}\end{bmatrix} \quad \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: amuse} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#(bark 5) \#[person x]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 6}\end{bmatrix}$$

Extending DBS.4 to an example class with a clausal subject required the definition of the three hear mode operations $\mathsf{PRD}^{\mathsf{obl}} \times \mathsf{PRD}$ (h5), $\mathsf{PRD}^{\mathsf{obl}} \cup \mathsf{PRD}$ (h19), and $\mathsf{PRD}^{\mathsf{obl}} \times \mathsf{SBJ}$ (h31), and the two think-speak mode operations V↙V(s5) and V↗V(s6). The hear mode derivation used five operation applications and the speak mode derivation six:

2.5.16 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

	1		2		3		4		5	
That	×	Fido	∪	barked	×	amused	×	Mary	∪	•

speak mode:

1		2		3		4		5		6	
V↙V	That	V↙N	Fido	N↗V	barked	V↗V	amused	V↘N	Mary	N↖V	•

The numbering of the connective in the hear mode corresponds to the line numbering in 2.5.2.

2.6 DBS.6: Clausal Object

The higher verb of an object clause construction must be (i) transitive and (ii) in the class of what are called ‘mental state verbs’ in lexicography, such as *agree, believe, decide, forget, hear, know, learn, remember, regret, say, see, suspect,* and *want*. The higher subject is the living (e.g. human) experiencer and the object is a clause which describes an event or other cognitive content inducing the mental experience named by the verb.

Following standard procedure, we begin with the content for an example surface as a set of proplets concatenated by address:

2.6.1 **<to-do 1>**

CONTENT OF Mary heard that Fido barked**.**

sur: mary	sur:	sur: fido	sur:
noun: [person x]	verb: hear	noun: [dog y]	verb: bark
cat: snp	cat: #n #a decl	cat: snp	cat: #n decl
sem: nm f	sem: ind past	sem: nm m	sem: *that* ind past
fnc: hear	arg: [person x] (bark 8)	fnc: bark	arg: [dog y]
mdr:	mdr:	mdr:	fnc: (hear 7)
nc:	nc:	nc:	mdr:
pc:	pc:	pc:	nc:
prn: 7	prn: 7	prn: 8	pc:
			prn: 8

In English declaratives, the semantic roles of the subject and the object are expressed by their position: the subject precedes and the object follows the finite verb, regardless of whether they are elementary, phrasal, or clausal. In DBS, this is encoded by the arg value order of the predicate. For example, in 2.5.1 the order is [arg: (bark 5) [person x]] in the *amuse* proplet, with (bark 5) representing the clausal subject, but in 2.6.1 it is [arg: [person x] (bark 8)] in the *hear* proplet, with (bark 8) representing the clausal object.

In the hear mode, the content 2.6.1 is derived from the surface by the following time-linear, surface-compositional, data-driven derivation in canonical DBS graph format:

2.6.2 **<to-do 2>**

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION

unanalyzed surface

Mary	heard	that	Fido	barked	•

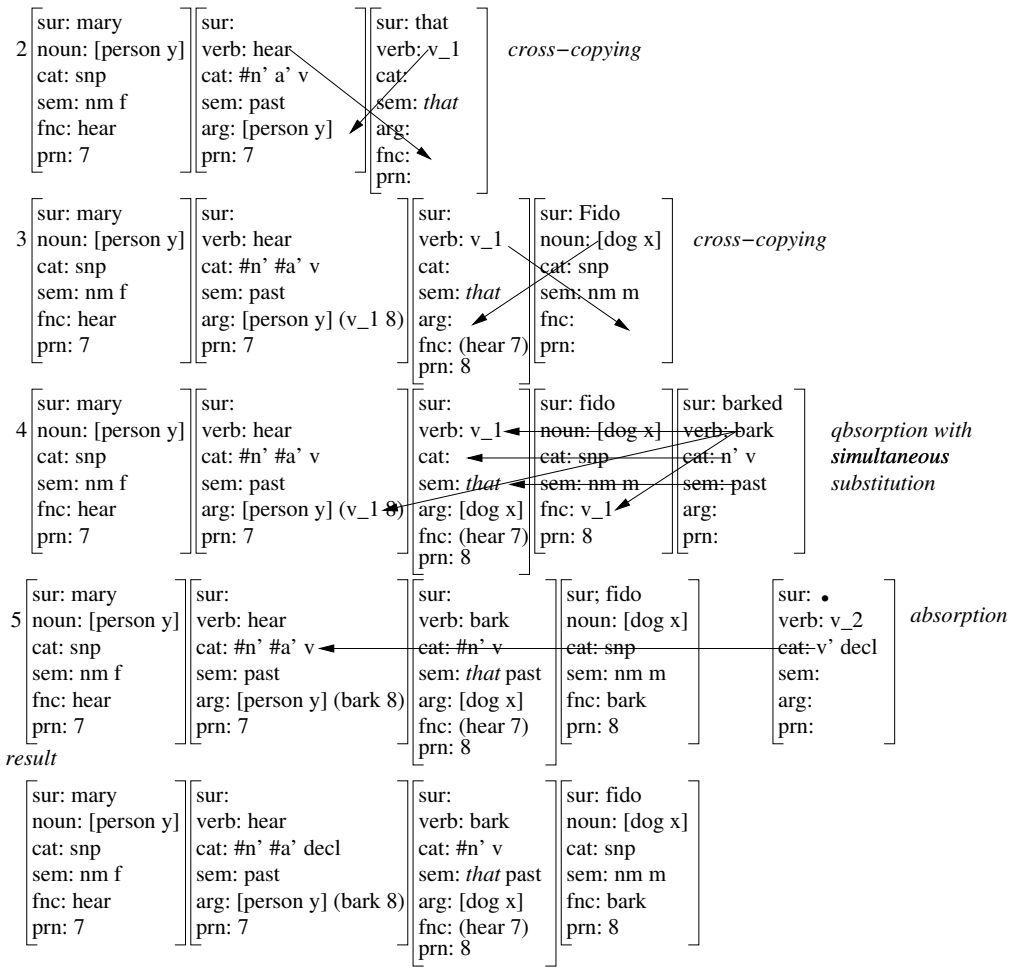
automatic word form recognition

sur: Mary	sur: heard	sur: that	sur: Fido	sur: barked	sur: •
noun: [person y]	verb: hear	verb: v_1	noun: [dog x]	verb: bark	verb: v_2
cat: snp	cat: n' a' v	cat:	cat: snp	cat: n' v	cat: v' decl
sem: nm f	sem: past	sem: *that*	sem: nm m	sem: past	
fnc:	arg:	arg:	fnc:	arg:	
prn:	prn:	fnc:	prn:	prn:	
		prn:			

syntactic−semantic parsing

	sur: Mary	sur: heard
1	noun: [person y]	verb: hear
	cat: snp	cat: n' a' v
	sem: nm f	sem: past
	fnc:	arg:
	prn: 7	prn:

cross−copying



The clausal subject in the previous and the clausal object in the present example are the same, i.e. that Fido barked. English expresses the difference in their grammatical roles with different surface orders, reflected in DBS by the respective application order of the data-driven hear mode operations:

Clausal subject

That $\mathsf{PRD}^{\mathsf{obl}} \times \mathsf{SBJ}$ Fido barked amused Mary.	2.5.3	(h31)
That Fido $\mathsf{PRD}^{\mathsf{obl}} \cup \mathsf{PRD}$ barked amused Mary.	2.5.4	(h19)
That Fido barked $\mathsf{PRD}^{\mathsf{obl}} \times \mathsf{PRD}$ amused Mary.	2.5.5	(h5)

Clausal object

Mary heard $\mathsf{PRD} \times \mathsf{PRD}^{\mathsf{obl}}$ that Fido barked.	2.6.4	(h6)
Mary heard that $\mathsf{PRD}^{\mathsf{obl}} \times \mathsf{SBJ}$ Fido barked.	2.6.5	(h31)
Mary heard that Fido $\mathsf{PRD}^{\mathsf{obl}} \cup \mathsf{PRD}$ barked	2.6.6	(h19)

The diacritic ^{obl} (obligatory) indicates that the constructions would be incomplete without their subject or object subclause (in contradistinction to a clausal

modifier, such as When Fido barked Mary laughed., Sect. 3.5). The variable SBJ refers to the subject of the respective subclause.

The complete sequence of explicit hear mode operation applications begins with SBJ×PRD:

2.6.3 **<to-do 3>**

CROSS-COPYING *mary* AND *heard* WITH SBJ×PRD (line 1)

SBJ×PRD (h1)

pattern level

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP}'\text{ X v}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ X v}\\ \text{arg: }\alpha\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.2.

content level

$$\begin{bmatrix}\text{sur: Mary}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm f}\\ \text{fnc:}\\ \ldots\\ \text{prn: 7}\end{bmatrix}\Uparrow\begin{bmatrix}\text{sur: heard}\\ \text{verb: hear}\\ \text{cat: n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \ldots\\ \text{prn:}\end{bmatrix}\qquad\begin{bmatrix}\text{sur: mary}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm f}\\ \text{fnc: hear}\\ \ldots\\ \text{prn: 7}\end{bmatrix}\Downarrow\begin{bmatrix}\text{sur:}\\ \text{verb: hear}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x]}\\ \ldots\\ \text{prn: 7}\end{bmatrix}$$

Once the subject and the predicate of the main clause are connected there follows the clausal object.

The first step in building the object clause is concatenating the main verb and the subordinating conjunction with PRD×PRD^{obl}:

2.6.4 CROSS-COPYING *hear* AND *that* WITH PRD×PRD^{obl} (line 2)

PRD×PRD^{obl} (h6)

pattern level

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ a}'\text{ V}\\ \text{arg: }\gamma\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\alpha\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ \#a}'\text{ v}\\ \text{arg: }\gamma\text{ (V\_}n\text{ K+1)}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\alpha\\ \text{fnc: (}\beta\text{ K)}\\ \text{prn: K+1}\end{bmatrix}$$

NP′ ϵ {n′, ns3′, n-s3′}. α ϵ {that, what}. V ϵ {v, vi}.

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: hear}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x]}\\ \ldots\\ \text{prn: 7}\end{bmatrix}\Uparrow\begin{bmatrix}\text{sur: that}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: }\textit{that}\\ \text{arg:}\\ \text{fnc:}\\ \ldots\\ \text{prn:}\end{bmatrix}\qquad\begin{bmatrix}\text{sur:}\\ \text{verb: hear}\\ \text{cat: \#n}'\text{ \#a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x] (v\_1 8)}\\ \ldots\\ \text{prn: 7}\end{bmatrix}\Downarrow\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: }\textit{that}\\ \text{arg:}\\ \text{fnc: (hear 7)}\\ \ldots\\ \text{prn: 8}\end{bmatrix}$$

One direction of the V\V relation between *hear* and *bark* is established by copying the core value v_1 of *that* into the second arg slot of *hear*; the other direction is established by copying the core value hear into the fnc slot of *that*. The variables K in the prn slot of the first input pattern and K+1 in the second

output pattern assign an incremented prn value to the next word proplet, here 8 in the prn slot of *that* (extrapropositional). In 2.6.6, all instances of v_1 will be replaced by bark via simultaneous substitution.

Continuing from the subordinating conjunction, the subclause subject is added by the cross-copying operation $\mathsf{PRD}^{\mathsf{obl}} \times \mathsf{SBJ}$:

2.6.5 Cross-copying *that* and *fido* with $\mathsf{PRD}^{\mathsf{obl}} \times \mathsf{SBJ}$ (line 3)

$\mathbf{PRD}^{\mathsf{obl}} \times \mathbf{SBJ}$ (h31)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: } \textit{that}\\ \text{arg:}\\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{noun: } \beta\\ \text{fnc:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: V\_}n\\ \text{sem: } \textit{that}\\ \text{arg: } \beta\\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{noun: } \beta\\ \text{fnc: V\_}n\\ \text{prn: K}\end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: } \textit{that}\\ \text{arg:}\\ \text{fnc: (hear 7)}\\ \ldots\\ \text{prn: 8}\end{bmatrix} \begin{bmatrix}\text{sur: Fido}\\ \text{noun: [dog y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc:}\\ \ldots\\ \text{prn:}\end{bmatrix} \begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: } \textit{that}\\ \text{arg: [dog y]}\\ \text{fnc: (hear 7)}\\ \ldots\\ \text{prn: 8}\end{bmatrix} \begin{bmatrix}\text{sur: fido}\\ \text{noun: [dog y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc: v\_1}\\ \ldots\\ \text{prn: 8}\end{bmatrix}$$

As in Sect. 2.5, the function word *that* serves as the pivot of the subclause construction. In 2.6.5 the subject core value [dog y] of the subclause has been copied to the arg slot of the subordinating conjunction. In this way the subclause subject is already in place when the verb *bark* is added by absorbing it into *that*:

2.6.6 Absorbing *bark* into *that* with $\mathbf{PRD}^{\mathsf{obl}} \cup \mathbf{PRD}$ (line 4)

$\mathbf{PRD}^{\mathsf{obl}} \cup \mathbf{PRD}$ (h19)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: } \textit{that}\\ \text{arg: } \alpha\\ \text{prn:K}\end{bmatrix} \begin{bmatrix}\text{verb: } \beta\\ \text{cat: NP}' \text{ X v}\\ \text{sem: Y}\\ \text{arg:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta\\ \text{cat: \#NP}' \text{ X v}\\ \text{sem: } \textit{that} \text{ Y}\\ \text{arg: } \alpha\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.2.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: } \textit{that}\\ \text{arg: [dog y]}\\ \text{fnc: (hear 7)}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 8}\end{bmatrix} \begin{bmatrix}\text{sur: barked}\\ \text{verb: bark}\\ \text{cat: n}' \text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \begin{bmatrix}\text{sur:}\\ \text{verb: bark}\\ \text{cat: \#n}' \text{ v}\\ \text{sem: } \textit{that} \text{ ind past}\\ \text{arg: [dog y]}\\ \text{fnc: (hear 7)}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 8}\end{bmatrix}$$

This application of $\mathsf{PRD}^{\mathsf{obl}} \cup \mathsf{PRD}$ stores the relevant values of the verb in the subordinating conjunction before discarding the verb proplet. In this way, the subordinating conjunction is turned into the predicate of the subclause.

The hear mode derivation of this isolated linguistic example concludes by adding the interpunctuation with an application of $\mathsf{S} \cup \mathsf{IP}$:

2.6.7 Absorbing . into *hear* with $\mathsf{S} \cup \mathsf{IP}$ (line 5)

S∪IP (h18)

pattern level

$$\begin{bmatrix} \text{verb: } \beta \\ \text{cat: } \#X' \text{ VT} \\ \text{prn: K} \end{bmatrix} \begin{bmatrix} \text{verb: V\_}n \\ \text{cat: VT}' \text{ SM} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{verb: } \beta \\ \text{cat: } \#X' \text{ SM} \\ \text{prn: K} \end{bmatrix}$$

Agreement conditions as in 2.1.4.

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: hear} \\ \text{cat: } \#n' \text{ v} \\ \text{sem: ind past} \\ \text{arg: [person x]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 7} \end{bmatrix} \Uparrow \begin{bmatrix} \text{sur: .} \\ \text{verb: v\_1} \\ \text{cat: v}' \text{ decl} \\ \text{sem:} \\ \text{arg:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:} \end{bmatrix} \Downarrow \begin{bmatrix} \text{sur:} \\ \text{verb: hear} \\ \text{cat: } \#n' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 7} \end{bmatrix}$$

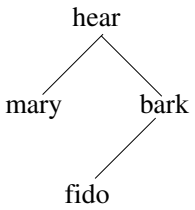
The hear mode derivation of a clausal object construction is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

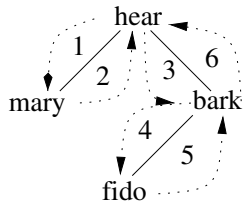
2.6.8 **<to-do 4>**

Graph analysis of the semantic relations of structure

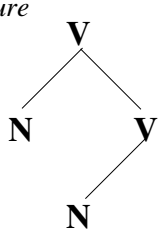
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

1	2	3	4	5	6
Mary	heard	that	Fido	barked	.
V/N	N/V	V\V	V/N	N/V	V\V

The SRG, signature, and NAG differ from those of 2.5.8 in that the lower branch takes the object position (and not the subject position) of the higher clause.

Word form production is summarized as follows:

2.6.9 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *hear* to *mary*	Mary	2.6.10
arc 2:	N↗V	from *mary* to *hear*	heard	2.6.11
arc 3:	V↘V	from *hear* to *bark*	that	2.6.12
arc 4:	V↙N	from *bark* to *fido*	Fido	2.6.13
arc 5:	N↗V	from *fido* to *bark*	barked	2.6.14
arc 6:	V↖V	from *bark* to *hear*	.	2.6.15

The matrix predicate *hear* may take an elementary, phrasal, or clausal object, just as the matrix predicate *amuse* in Sect. 2.5 may take an elementary, phrasal, or clausal subject. The extrapropositional object\predicate relations V↘V (2.6.12) and V↖V (2.6.15) resemble their intrapropositional counterparts V↘N (2.3.10, 2.4.16), and N↖V (2.3.11, 2.4.19) insofar as they are strictly binary, i.e. defined by address between two individual, completely self-contained, order-free proplets. Nonterminal nodes are absolutely absent in DBS.

The complete sequence of explicit navigation operations begins with V↙N:

2.6.10 **<to-do 6>**

NAVIGATING WITH V↙N FROM *hear* TO *mary* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: hear} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x](bark 8)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 7} \end{bmatrix} \Uparrow \qquad \Downarrow \begin{bmatrix} \text{sur: Mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: hear} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 7} \end{bmatrix}$$

Using the continuation value hear of *mary*, the navigation returns to the predicate and realizes heard.

2.6.11 NAVIGATING WITH N↗V FROM *mary* BACK TO *hear* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: hear} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 7}\end{bmatrix} \quad \begin{bmatrix}\text{sur: heard} \\ \text{verb: hear} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{v} \\ \text{sem: } \textit{that}\ \text{ind past} \\ \text{arg: \#[person x] (bark 8)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 7}\end{bmatrix}$$

The condition is fulfilled because the input noun has no mdr (modifier) value, i.e. Z = NIL.

The next operation V↘V is the object sentence counterpart to V↙V in 2.5.10 for a subject sentence. That the higher predicate precedes in an English subject sentence (V↙V) but follows in an object sentence (V↘V) is coded in the respective arg patterns of the higher verb: in V↙V it is [arg: (β K) X], but in V↘V it is [arg: X (β K+1)]:

2.6.12 NAVIGATING WITH V↘V FROM *hear* TO *bark* (arc 3)

V↘V (s7)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: X } (\beta\ \text{K+1}) \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{sem: } \textit{that}\ \text{Z} \\ \text{fnc: } (\alpha\ \text{K}) \\ \text{prn: K+1}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: hear} \\ \text{cat: \#n}'\ \text{\#a v} \\ \text{sem: ind past} \\ \text{arg: \#[person x] (bark 8)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 7}\end{bmatrix} \quad \begin{bmatrix}\text{sur: that} \\ \text{verb: bark} \\ \text{cat: \#n}'\ \text{v} \\ \text{sem: } \textit{that}\ \text{ind past} \\ \text{arg: [dog y]} \\ \text{fnc: \#(hear 7)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 8}\end{bmatrix}$$

Having reached the predicate of the subclause and realized the subordinating conjunction, the navigation continues in the intrapropositional manner shown in Sects. 2.1–2.4. The first step is moving from the predicate to the subject with standard V↙N:

2.6.13 Navigating with V↙N from *bark* to *[dog y]* (arc 4)

V↙N (s1)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: bark} \\ \text{cat: \#n}' \text{ v} \\ \text{sem: } \textit{that} \text{ ind past} \\ \text{arg: [dog y]} \\ \text{fnc: \#(hear 7)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 8}\end{bmatrix} \quad \begin{bmatrix}\text{sur: Fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: bark} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 8}\end{bmatrix}$$

The navigation is enabled by the continuation value [dog y] in the arg slot of *bark*.

Next, the navigation returns to the verb of the subclause to find the address of another valency filler or to continue to the top predicate.

2.6.14 Navigating with N↗V from *Fido* back to *bark* (arc 5)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: bark} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 8}\end{bmatrix} \quad \begin{bmatrix}\text{sur: barked} \\ \text{verb: bark} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: } \textit{that} \text{ ind past} \\ \text{arg: \#[dog y]} \\ \text{fnc: \#(hear 7)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 8}\end{bmatrix}$$

Here, the verb is one-place (intransitive). Therefore, the only option is the return to the matrix verb with V↖V.

Given that *hear* has no nc value, V↖V terminates the think-speak mode derivation with lexverb realizing the period, based on the cat value decl:

2.6.15 NAVIGATING WITH V↖V FROM *bark* BACK TO *hear* (arc 6)

V↖V (s8)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{sem: } \textit{that}\ \text{Z} \\ \text{arg: \#X} \\ \text{fnc: } (\beta\ \text{K})^{16} \\ \text{prn: K+1} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{arg: \#Y \#}(\alpha\ \text{K+1}) \\ \text{prn: K} \end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: bark} \\ \text{cat: \#n}' \text{ v} \\ \text{sem: } \textit{that}\ \text{ind past} \\ \text{arg: \#[dog y]} \\ \text{fnc: \#(hear 7)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 8} \end{bmatrix} \qquad \begin{bmatrix} \text{sur: } \bullet \\ \text{verb: hear} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#(bark 8)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 7} \end{bmatrix}$$

Because the input pattern [arg: #X] of the subclause verb does not specify the number of valency positions, the operation is independent of the number of arguments in the subclause. It is sufficient for all the arg values to be #-marked. Thus, if the subclause verb were two- or three-place, V↖V would proceed from the subclause to the main clause in the same way as in 2.6.15 (after traversing the other valency fillers) – and similarly with V↗V in 2.5.13.

Extending DBS.5 to an example class with a clausal object required the definition of the hear mode operation PRD×PRD^{obl} (h6), and the think-speak mode operationsV↘V (s7) and V↖V (s8).

2.6.16 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

	1		2		3		4		5	
Mary	×	heard	×	that	×	Fido	∪	barked	∪	•

speak mode:

1		2		3		4		5		6	
V↙N	Mary	N↗V	heard	V↘V	that	V↙N	Fido	N↗V	barked	V↖V	•

The object clause with its absorption in the hear mode resembles the subject clause in 2.5.16

[16] A variable with a dotted underline matches values with or without a #-marking at the content level (1.6.5, 3).

3. Optional Modification and Coordination

Modification and coordination have in common that they are optional. They differ in that the modifier|modified relation connects proplets with different core attributes, e.g. adn|noun or adv|verb, while the conjunct−conjunct relation connects proplets with the same core attribute, i.e. noun−noun, verb−verb, or adn−adn.

3.1 DBS.7: Elementary Adverbial Modification

The two main kinds of modification are adverbial and adnominal. In English, the position of adverbial modifiers is comparatively free, while that of adnominal modifiers is fixed. More specifically, elementary adnominals are positioned between the determiner and the noun, while phrasal and clausal adnominals directly follow the modified (with extraposition as an exception, CLaTR 9.3.5).

The topic of this section is the comparatively free order of multiple elementary adverbial modifiers.

3.1.1 **<to-do 1>**

CONTENT OF *Perhaps* Fido is *still* sleeping *there now*.

sur:	sur: fido	sur:	sur:	sur:	sur:
adj: perhaps	noun: [dog y]	verb: sleep	adj: still	adj: there	adj: now
cat: adv	cat: snp	cat: #ns3′ decl	cat: adv	cat: adv	cat: adv
sem: mod[1]	sem: nm m	sem: ind pres prog	sem: tmp	sem: loc	sem: tmp
mdd: sleep	fnc: sleep	arg: [dog y]	mdd: sleep	mdd: sleep	mdd: sleep
mdr:	mdr:	mdr: perh. still there now	mdr:	mdr:	mdr:
nc:	nc:	nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:	pc:	pc:
prn: 9	prn: 9	prn: 9	prn: 9	prn: 9	prn: 9

Adverbial modifiers may be placed (i) before the finite auxiliary, (ii) between the auxiliary and the non-finite main verb, and (iii) following the main verb.

[1] The sem values mod(al), tmp (temporal), and loc(ational) of the elementary adverbials provide a first classification of their meaning. The value mod relates to the ancient distinction between the *possible* and the *necessary* in philosophy. In agent-based DBS, the distinction is reinterpreted as degrees of the agent's certainty.

The order and kind of advs is not controlled by strict grammar rules, but by stylistic recommendations reflecting collocational conventions. These conventions may be recorded by the linguist and introduced, to a degree, into the grammar software by the choice of the examples.[2] The artificial agent using the grammar software may also record current use in the language community to further narrow the placement and choice of advs (learning, CLaTR Chap. 6).

The time-linear hear mode derivation of the content 3.1.1 has the following DBS graph analysis:

3.1.2 **<to-do 2>**

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION

unanalyzed surface

Perhaps Fido is still sleeping there now .

automatic word form recognition

sur: Perhaps	sur: Fido	sur: is	sur: still	sur: sleeping	sur: there	sur: now	sur: .
adj: perhaps	noun: [dog x]	verb: v_1	adj: still	verb: sleep	adj: there	adj: now	verb: v_2
cat: adv	cat: snp	cat: ns3' be' v	cat: adv	cat: be	cat: adv	cat: adv	cat: v' decl
sem: mod	sem: nm m	sem: pres ind	sem: tmp	sem: prog	sem: loc	sem: tmp	sem:
mdd:	fnc:	arg:	mdd:	arg:	mdd:	mdd:	arg:
prn:	prn:	mdr:	prn:	prn:	prn:	prn:	prn:
		prn:					

syntactic−semantic parsing

1	sur: Perhaps adj: perhaps cat: adv sem: mod mdd: prn: 9	sur: Fido noun: [dog x] cat: snp sem: nm m fnc: prn:		*suspension*
2a	sur: adj: perhaps cat: adv sem: mod mdd: prn: 9	sur: fido noun: [dog x] cat: snp sem: nm m fnc: prn: 9	sur: is verb: v_1 cat: ns3' be' v sem: pres ind arg: mdr: prn:	*cross−copying*
2b	sur: adj: perhaps cat: adv sem: mod mdd: prn: 9	sur: fido noun: [dog x] cat: snp sem: nm m fnc: v_1 prn: 9	sur: verb: v_1 cat: ns3' be' v sem: pres ind arg: [dog x] mdr: prn:	*cross−copying*
3	sur: adj: perhaps cat: adv sem: mod mdd: v_1 prn: 9	sur: fido noun: [dog x] cat: snp sem: nm m fnc: v_1 prn: 9	sur: verb: v_1 cat: #ns3' be' v sem: pres ind arg: [dog x] mdr: perhaps prn: 9	sur: still adj: still cat: adv sem: tmp mdd: prn: *cross−copying*

4	sur: adj: perhaps cat: adv sem: mod mdd: v_1 prn: 9	sur: fido noun: [dog x] cat: snp sem: nm m fnc: v_1 prn: 9	sur: verb: v_1 cat: #ns3' be' v sem: pres ind arg: [dog x] mdr: perhaps still prn: 9	sur: adj: still cat: adv sem: tmp mdd: v_1 prn: 9	sur: sleeping verb: sleep cat: be sem: prog arg: prn:	*absorption with simultaneous substitution*
5	sur: adj: perhaps cat: adv sem: mod mdd: sleep prn: 9	sur: fido noun: [dog x] cat: snp sem: nm m fnc: sleep prn: 9	sur: verb: sleep cat: #ns3' v sem: pres prog arg: [dog x] mdr: perhaps still prn: 9	sur: adj: still cat: adv sem: tmp mdd: sleep prn: 9	sur: there adj: there cat: adv sem: loc mdd: prn:	*cross−copying*
6	sur: adj: perhaps cat: adv sem: mod mdd: sleep prn: 9	sur: fido noun: [dog x] cat: snp sem: nm m fnc: sleep prn: 9	sur: verb: sleep cat: #ns3' v sem: pres prog arg: [dog x] mdr: perhaps still there prn: 9	sur: adj: still cat: adv sem: tmp mdd: sleep prn: 9	sur: adj: there cat: adv sem: loc mdd: sleep prn: 9	sur: now adj: now cat: adv sem: tmp mdd: prn:	*cross−cop.*
						absorption
7	sur: adj: perhaps cat: adv sem: mod mdd: sleep prn: 9	sur: fido noun: [dog x] cat: snp sem: nm m fnc: sleep prn: 9	sur: verb: sleep cat: #ns3' v sem: pres prog arg: [dog x] mdr: perhaps still there now prn: 9	sur: adj: still cat: adv sem: tmp mdd: sleep prn: 9	sur: adj: there cat: adv sem: loc mdd: sleep prn: 9	sur: adj: now cat: adv sem: tmp mdd: sleep prn:	• verb: v_2 cat: v' decl sem: mdd: prn:
result	sur: adj: perhaps cat: adv sem: mod mdd: sleep prn: 9	sur: fido noun: [dog x] cat: snp sem: nm m fnc: sleep prn: 9	sur: verb: sleep cat: #ns3' decl sem: pres prog arg: [dog x] mdr: perhaps still there now prn: 9	sur: adj: still cat: adv sem: tmp mdd: sleep prn: 9	sur: adj: there cat: adv sem: loc mdd: sleep prn: 9	sur: adj: now cat: adv sem: tmp mdd: sleep prn:	

The examples 3.1.2 and 2.5.2, 2.6.2 have in common that they begin with a discontinuous relation. They differ in that the relation in 3.1.2 is between two content words, perhaps and Fido, which requires a suspension, but between a function word, i.e. that, and a content word, i.e. bark, in 2.5.2 and 2.6.2, which avoids a suspension.[3]

The complete sequence of explicit hear mode operation applications begins with the suspension operation ADV∼SBJ:

[2] Outside the DBS laboratory set-up, the placement of the advs originates in the speak mode and is transmitted to the hearer by the incoming surfaces. Within the laboratory set-up, the situation is reversed: the linguist provides a surface to the hear mode grammar which derives a content and the speak mode grammar uses that content to replicate the original surface.

[3] In 2.5.2, the subordinating conjunction *that* avoids a suspension by first cross-copying with *fido* (line 1) and then absorbing *bark* (line 2). Similarly in 2.6.2, which avoids a suspension by cross-copying between *that* and *fido* in line 4 and absorbing *bark* into *that* in line 5.

3.1.3 **<to-do 3>**

SUSPENDING *perhaps* AND *fido* WITH ADV∼SBJ (line 1)

ADV∼SBJ (h51)

pattern level

$$\begin{bmatrix}\text{adj: } \alpha\\ \text{cat: adv}\\ \text{mdd:}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: } \beta\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{adj: } \alpha\\ \text{cat: adv}\\ \text{mdd:}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: } \beta\\ \text{fnc:}\\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow\qquad\qquad\qquad\qquad\Downarrow$$

content level

$$\begin{bmatrix}\text{sur: Perhaps}\\ \text{adj: perhaps}\\ \text{cat: adv}\\ \text{sem: mod}\\ \text{mdd:}\\ \ldots\\ \text{prn: 9}\end{bmatrix}\begin{bmatrix}\text{sur: Fido}\\ \text{noun: [dog y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc:}\\ \ldots\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{adj: perhaps}\\ \text{cat: adv}\\ \text{sem: mod}\\ \text{mdd:}\\ \ldots\\ \text{prn: 9}\end{bmatrix}\begin{bmatrix}\text{sur: fido}\\ \text{noun: [dog y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc:}\\ \ldots\\ \text{prn: 9}\end{bmatrix}$$

The application is limited to adding the prn value, here 9, to *fido*:

The suspension is compensated by applying two operations within the next derivation step, SBJ×PRD in line 2a and ADV×FV in line 2b.

3.1.4 CROSS-COPYING *fido* AND *be* WITH SBJ×PRD (line 2a)

SBJ×PRD (h1)

pattern level

$$\begin{bmatrix}\text{noun: } \alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: } \beta\\ \text{cat: NP}'\text{ X v}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{noun: } \alpha\\ \text{cat: NP}\\ \text{fnc: } \beta\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: } \beta\\ \text{cat: \#NP}'\text{ X v}\\ \text{arg: } \alpha\\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow\qquad\qquad\qquad\qquad\Downarrow$$

content level

$$\begin{bmatrix}\text{sur: fido}\\ \text{noun: [dog y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc:}\\ \text{mdr: big}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix}\begin{bmatrix}\text{sur: is}\\ \text{verb: v\_1}\\ \text{cat: ns3}'\text{ be}'\text{ v}\\ \text{sem: ind pres}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur: fido}\\ \text{noun: [dog y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc: v\_1}\\ \text{mdr: big}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat: \#ns3}'\text{ be}'\text{ v}\\ \text{sem: ind pres}\\ \text{arg: [dog y]}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix}$$

3.1.5 CROSS-COPYING *perhaps* AND *v_1* WITH ADV×FV (line 2b)

ADV×FV (h4)

pattern level

$$\begin{bmatrix}\text{adj: } \alpha\\ \text{cat: ADNV}\\ \text{mdd:}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: } \gamma\\ \text{mdr: X}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{adj: } \alpha\\ \text{cat: ADNV}\\ \text{mdd: } \gamma\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: } \gamma\\ \text{mdr: X } \alpha\\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow\qquad\qquad\qquad\qquad\Downarrow$$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{adj: perhaps}\\ \text{cat: adv}\\ \text{sem: mod}\\ \text{mdd:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat: \#ns3}'\text{ be}'\text{ v}\\ \text{sem: ind pres}\\ \text{arg: (x dog)}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{adj: perhaps}\\ \text{cat: adv}\\ \text{sem: mod}\\ \text{mdd: v\_1}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat: \#ns3}'\text{ be}'\text{ v}\\ \text{sem: ind pres}\\ \text{arg: [dog y]}\\ \text{mdr: perhaps}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix}$$

Following the auxiliary, another adverbial is added by FV×ADV:

3.1.6 Cross-copying *be* and *still* with FV×ADV (line 3)

FV×ADV (h56)

pattern level

$$\begin{bmatrix}\text{verb: } \gamma\\ \text{mdr: X}\\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{adj: } \alpha\\ \text{cat: ADV}\\ \text{mdd:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \gamma\\ \text{mdr: X ! } \alpha\\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{adj: } \alpha\\ \text{cat: ADV}\\ \text{mdd: } \gamma\\ \text{prn: K}\end{bmatrix}$$

ADV ϵ {adv, adnv}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat: \#ns3}' \text{ be}' \text{ v}\\ \text{sem: ind pres}\\ \text{arg: [dog y]}\\ \text{mdr: perhaps}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix} \begin{bmatrix}\text{sur: still}\\ \text{adj: still}\\ \text{cat: adv}\\ \text{sem: tmp}\\ \text{mdd:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat: \#ns3}' \text{ be}' \text{ v}\\ \text{sem: ind pres}\\ \text{arg: [dog y]}\\ \text{mdr: perhaps ! still}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix} \begin{bmatrix}\text{sur:}\\ \text{adj: still}\\ \text{cat: adv}\\ \text{sem: tmp}\\ \text{mdd: v\_1}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix}$$

With the finite auxiliary in place, FV×ADV reapplies, this time without a preceding suspension.[4]

In accordance with the DBS laboratory set-up, the hear mode must prepare for the speak mode by coding the information needed for a correct surface realization. To enable lexverb to apply a second time for realizing the separate non-finite part of the verb, FV×ADV introduces the separator '!' before the postverbal values in the mdr slot of the finite auxiliary ([mdr: X ! α]).

Next AUX∪NFV (2.2.7) fuses is and sleeping:

3.1.7 Absorbing *sleep* into *be* with AUX∪NFV (line 4)

AUX∪NFV (h16)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat: \#W}' \text{ AUX}' \text{ VT}\\ \text{sem: X}\\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: } \alpha\\ \text{cat: Y AUX}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \alpha\\ \text{cat: \#W}' \text{ Y VT}\\ \text{sem: X Z}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions omitted.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat: \#ns3}' \text{ be}' \text{ v}\\ \text{sem: ind pres}\\ \text{arg: [dog y]}\\ \text{mdr: perhaps ! still}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix} \begin{bmatrix}\text{sur: sleeping}\\ \text{verb: sleep}\\ \text{cat: be}\\ \text{sem: prog}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:}\\ \text{verb: sleep}\\ \text{cat: \#ns3}' \text{ v}\\ \text{sem: ind pres prog}\\ \text{arg: [dog y]}\\ \text{mdr: perhaps ! still}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix}$$

[4] For the speak mode, however, an adverbial intervening between the finite auxiliary and the non-finite main verb presents a challenge insofar as it creates the discontinuous structure is...sleeping. This is in contradistinction to lexverb realizing a phrasal verb in one single speak mode step, as in 2.2.14. The discontinuous structure at hand resembles the 'Satzklammer' in German (1.3.6).

In lines 5 and 6, FV×ADV (3.1.6) reapplies to add two more adverbials.

3.1.8 CROSS-COPYING *sleep* AND *there* WITH FV×ADV[5] (line 5)

FV×ADV (h56)

pattern level

$$\begin{bmatrix}\text{verb: }\gamma\\ \text{mdr: X}\\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{adj: }\alpha\\ \text{cat: ADV}\\ \text{mdd:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: }\gamma\\ \text{mdr: X ! }\alpha\\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{adj: }\alpha\\ \text{cat: ADV}\\ \text{mdd: }\gamma\\ \text{prn: K}\end{bmatrix}$$

ADV ϵ {adv, adnv}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: sleep}\\ \text{cat: \#ns3}'\text{ v}\\ \text{sem: ind pres prog}\\ \text{arg: [dog y]}\\ \text{mdr: perhaps ! still}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix} \quad \begin{bmatrix}\text{sur: there}\\ \text{adj: there}\\ \text{cat: adv}\\ \text{sem: loc}\\ \text{mdd:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:}\\ \text{verb: sleep}\\ \text{cat: \#ns3}'\text{ v}\\ \text{sem: ind pres}\\ \text{arg: [dog y]}\\ \text{mdr: perhaps ! still there}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix} \quad \begin{bmatrix}\text{sur:}\\ \text{adj: there}\\ \text{cat: adv}\\ \text{sem: loc}\\ \text{mdd: sleep}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix}$$

3.1.9 CROSS-COPYING *sleep* AND *now* WITH FV×ADV (line 6)

FV×ADV (h56)

pattern level

$$\begin{bmatrix}\text{verb: }\gamma\\ \text{mdr: X}\\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{adj: }\alpha\\ \text{cat: ADV}\\ \text{mdd:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: }\gamma\\ \text{mdr: X ! }\alpha\\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{adj: }\alpha\\ \text{cat: ADV}\\ \text{mdd: }\gamma\\ \text{prn: K}\end{bmatrix}$$

ADV ϵ {adv, adnv}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: sleep}\\ \text{cat: \#ns3}'\text{ v}\\ \text{sem: ind pres prog}\\ \text{arg: [dog y]}\\ \text{mdr: perhaps ! still there}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix} \quad \begin{bmatrix}\text{sur: now}\\ \text{adj: now}\\ \text{cat: adv}\\ \text{sem: tmp}\\ \text{mdd:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:}\\ \text{verb: sleep}\\ \text{cat: \#ns3}'\text{ v}\\ \text{sem: ind pres prog}\\ \text{arg: [dog y]}\\ \text{mdr: perhaps ! still there now}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix} \quad \begin{bmatrix}\text{sur:}\\ \text{adj: now}\\ \text{cat: adv}\\ \text{sem: tmp}\\ \text{mdd: sleep}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix}$$

3.1.10 ABSORBING • INTO *sleep* WITH S∪IP (line 7)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#X}'\text{ VT}\\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{verb: V\_}n\\ \text{cat: VT}'\text{ SM}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#X}'\text{ SM}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

$\Uparrow$ $\Downarrow$

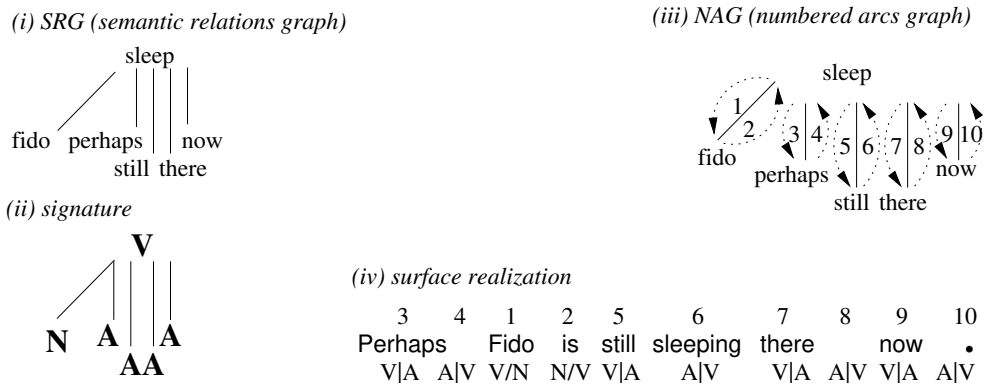
content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: sleep}\\ \text{cat: \#n}'\text{ \#be}'\text{ v}\\ \text{sem: ind pres prog}\\ \text{arg: [dog y]}\\ \text{mdr: perhaps ! still there now}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix} \quad \begin{bmatrix}\text{sur: •}\\ \text{verb: v\_1}\\ \text{cat: v}'\text{ decl}\\ \text{sem:}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:}\\ \text{verb: sleep}\\ \text{cat: \#n}'\text{ \#be}'\text{ decl}\\ \text{sem: ind pres prog}\\ \text{arg: [dog y]}\\ \text{mdr: perhaps ! still there now}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 9}\end{bmatrix}$$

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

3.1.11 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE



In this example, neither the depth-first nor the breadth-first arc numbering (Sect. 1.4) provides a consecutive numbering.

Word form production is summarized as the following list of speak mode operations:

3.1.12 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 3:	V↓A	from *sleep* to *perhaps*	perhaps	3.1.13
arc 4:	A↑V	from *perhaps* to *sleep*		3.1.14
arc 1:	V↙N	from *sleep* to *fido*	Fido	3.1.15
arc 2:	N↗V	from *fido* to *sleep*	is	3.1.16
arc 5:	V↓A	from *sleep* to *still*	still	3.1.17
arc 6:	A↑V	from *still* to *sleep*	sleeping	3.1.18
arc 7:	V↓A	from *sleep* to *there*	there	3.1.19
arc 8:	A↑V	from *there* to *sleep*		3.1.20
arc 9:	V↓A	from *sleep* to *now*	now	3.1.21
arc 10:	A↑V	from *now* to *sleep*	.	3.1.22

Each V↓A downward traversal is directly followed by the corresponding A↑V upward traversal. The sequence satisfies the continuity condition (NLC 3.6.5), which ensures the time-linear derivation order of the think-speak mode directly, and of the hear mode outside the laboratory set-up indirectly.

The complete sequence of explicit navigation operations begins with V↓A:

[5] The !-marker is inserted only once, when FV×ADV applies for the first time

3.1.13 **<to-do 6>**

NAVIGATING WITH V↓A FROM *sleep* TO *perhaps* (arc 3)

V↓A (s9)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{mdr: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexadj}(\hat{\beta}) \\ \text{adj: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the mdr slot of proplet α.

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: sleep} \\ \text{cat: \#ns3}' \text{ \#be}' \text{ decl} \\ \text{sem: ind pres prog} \\ \text{arg: [dog y]} \\ \text{mdr: perhaps ! still there now} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9}\end{bmatrix} \Uparrow \quad \Downarrow \begin{bmatrix}\text{sur: Perhaps} \\ \text{adj: perhaps} \\ \text{cat: adv} \\ \text{sem: mod} \\ \text{mdd: sleep} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9}\end{bmatrix}$$

In this traversal of an initial adverbial, the value assigned to #X is NIL. The instruction #-marks the first unmarked mdr value, i.e. initial *perhaps*, to prevent a re-traversal. Lexadj realizes the surface from the goal proplet.

The navigation returns with A↑V to the verb for a continuation value:

3.1.14 NAVIGATING WITH A↑V FROM *perhaps* BACK TO *sleep* (arc 4)

A↑V (s10)

pattern level

$$\begin{bmatrix}\text{adj: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{mdr: X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{adj: perhaps} \\ \text{cat: adn} \\ \text{sem: mod} \\ \text{mdd: sleep} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9}\end{bmatrix} \Uparrow \quad \Downarrow \begin{bmatrix}\text{sur:} \\ \text{verb: sleep} \\ \text{cat: \#ns3}' \text{ be}' \text{ decl} \\ \text{sem: ind pres prog} \\ \text{arg: [dog y]} \\ \text{mdr: \#perhaps ! still there now} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9}\end{bmatrix}$$

The uncanceled nominative, i.e. [dog y], prevents lexverb from realizing (any part of) the verb.

The *sleep* proplet offers two continuation values, [dog y] for *fido* in the arg slot and still in the mdr slot. The ! in the mdr slot prevents a navigation to *still*; also, more than one adverbial preceding the finite verb would deviate from realizing the original input surface and is against the collocational conventions recorded by the agent. Therefore, the other continuation value [dog y] is accessed with V↙N:

3.1.15 NAVIGATING WITH V↙N FROM *sleep* TO *fido* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: sleep} \\ \text{cat: \#ns3}' \text{ \#be}' \text{ v} \\ \text{sem: ind pres prog} \\ \text{arg: [dog y]} \\ \text{mdr: \#perhaps ! still there now} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9} \end{bmatrix} \quad \begin{bmatrix} \text{sur: Fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: sleep} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9} \end{bmatrix}$$

The instruction #-marks the first (and only) arg value of *sleep* (see the goal proplet in 3.1.16) to prevent another realization of the subject.

At this point, the speak mode derivation has realized Perhaps Fido. The only continuation value of *fido* is sleep:

3.1.16 NAVIGATING WITH N↗V FROM *[dog y]* BACK TO *sleep* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K} \end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur: fido} \\ \text{noun: [dog y]} \\ \text{cat: np} \\ \text{sem: def sg} \\ \text{fnc: sleep} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9} \end{bmatrix} \quad \begin{bmatrix} \text{sur: is} \\ \text{verb: sleep} \\ \text{cat: \#ns3}' \text{ \#be}' \text{ decl} \\ \text{sem: ind pres prog} \\ \text{arg: \#[dog y]} \\ \text{mdr: \#perhaps ! still there now} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9} \end{bmatrix}$$

The condition of N↗V ensures that the noun is either elementary (here [dog y] is not modified) or the modifier has already been traversed (e.g. 2.2.14). Based on the ! separator in the mdr slot sleep, lexverb realizes only the finite auxiliary is, using the #ns3′ and #be′ values stored in the cat slot and the ind pres prog values in the sem slot of *sleep*.

Having decoupled the finite auxiliary and the non-finite main verb by realizing only is, the navigation continues with V↓A to the next adverbial, i.e. the unmarked value still following the separator '!' in the mdr slot of *sleep*.

3.1.17 NAVIGATING WITH V↓A FROM *sleep* TO *still* (arc 5)

V↓A (s9)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{mdr: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexadj}(\hat{\beta}) \\ \text{adj: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the mdr slot of α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: sleep} \\ \text{cat: \#n}' \text{ \#be}' \text{ decl} \\ \text{sem: ind pres prog} \\ \text{arg: \#[dog y]} \\ \text{mdr: \#perhaps ! still there now} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9}\end{bmatrix} \quad \begin{bmatrix}\text{sur: still} \\ \text{adj: still} \\ \text{cat: adn} \\ \text{sem: mod} \\ \text{mdd: sleep} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9}\end{bmatrix}$$

The result of the instruction is shown in the mdr slot of the goal proplet in 3.1.18.

The only continuation value of *still* is sleep. Using A↑V, the navigation returns from *still* to *sleep*.

3.1.18 NAVIGATING WITH A↑V FROM *still* BACK TO *sleep* (arc 6)

A↑V (s10)

pattern level

$$\begin{bmatrix}\text{adj: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{mdr: X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{adj: still} \\ \text{cat: adn} \\ \text{sem: mod} \\ \text{mdd: sleep} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9}\end{bmatrix} \quad \begin{bmatrix}\text{sur: sleeping} \\ \text{verb: sleep} \\ \text{cat: \#n}' \text{ \#be}' \text{ decl} \\ \text{sem: ind pres prog} \\ \text{arg: \#[dog y]} \\ \text{mdr: \#perhaps ! \#still there now} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9}\end{bmatrix}$$

Because squeezing another adverbial between the finite auxiliary and the non-finite main verb would deviate from realizing the original input surface and be against the collocational conventions recorded by the agent, lexverb realizes sleeping using the core value and the prog value in the sem slot.[6]

At this point, the speak mode derivation has realized Perhaps Fido is still sleeping. It remains to add the two adverbials following the non-finite verb:

[6] Here the speak mode realizes the non-finite part of the verb in a transition from an adverbial and not from the finite auxiliary. This is in fulfillment of the Continuity Condition (NLC 3.6.5) in 3.1.17 and 3.1.18.

3.1.19 NAVIGATING WITH V↓A FROM *sleep* TO *there* (arc 7)

V↓A (s9)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{mdr: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexadj}(\hat{\beta}) \\ \text{adj: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the mdr slot of α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: sleep} \\ \text{cat: \#n}' \text{ \#be}' \text{ decl} \\ \text{sem: ind pres prog} \\ \text{arg: \#[dog y]} \\ \text{mdr: \#perhaps ! \#still there now} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9}\end{bmatrix} \quad \begin{bmatrix}\text{sur: there} \\ \text{adj: there} \\ \text{cat: adn} \\ \text{sem: loc} \\ \text{mdd: sleep} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9}\end{bmatrix}$$

The instruction results in #-marking there in the mdr slot of *sleep*, as shown in the output of the following application.

At this point, the navigation has realized Perhaps Fido is still sleeping there, with *there* as the last activated proplet. It remains to realize the last adverbial *now* and conclude with the period. The first step is a return to the verb with A↑V to (i) find the next adverbial without a #-marking as a continuation value:

3.1.20 NAVIGATING WITH A↑V FROM *there* BACK TO *sleep* (arc 8)

A↑V (s10)

pattern level

$$\begin{bmatrix}\text{adj: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{mdr: X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{adj: there} \\ \text{cat: adn} \\ \text{sem: loc} \\ \text{mdd: sleep} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: sleep} \\ \text{cat: \#n}' \text{ \#be}' \text{ decl} \\ \text{sem: ind pres prog} \\ \text{arg: \#[dog y]} \\ \text{mdr: \#perhaps ! \#still \#there now} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9}\end{bmatrix}$$

The value in question is the final adverbial now, still without a #-marking, in the mdr slot of *sleep*. The goal proplet *now* is reached by navigating from *sleep* with V↓A.

3.1.21 NAVIGATING WITH V↓A FROM *sleep* TO *now* (arc 9)

V↓A (s9)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{mdr: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexadj}(\hat{\beta}) \\ \text{adj: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the mdr slot of α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: sleep} \\ \text{cat: \#n}' \text{ \#be}' \text{ decl} \\ \text{sem: ind pres prog} \\ \text{arg: \#[dog y]} \\ \text{mdr: \#perhaps ! \#still \#there now} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: now} \\ \text{adj: now} \\ \text{cat: adn} \\ \text{sem: tmp} \\ \text{mdd: sleep} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9}\end{bmatrix}$$

The result of the instruction is shown in 3.1.22 as the #-marking of now in the mdr slot of *sleep*.

It remains to return to the verb to complete the derivation by adding the period:

3.1.22 NAVIGATING WITH A↑V FROM *now* BACK TO *sleep* (arc 10)

A↑V (s10)

pattern level

$$\begin{bmatrix}\text{adj: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{mdr: X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{adj: now} \\ \text{cat: adn} \\ \text{sem: tmp} \\ \text{mdd: sleep} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: sleep} \\ \text{cat: \#n}' \text{ \#be}' \text{ decl} \\ \text{sem: ind pres prog} \\ \text{arg: \#[dog y]} \\ \text{mdr: \#perhaps ! \#still \#there \#now} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 9}\end{bmatrix}$$

The continuation feature of now is [mdd: sleep]. The lexicalization rule sitting in the sur slot of *sleep* uses the value decl in its cat slot to realize the period.

Extending DBS.6 to an example class with four elementary adverbial modifiers required the definition of the three hear mode operations ADV∼SBJ (h52), ADV×FV (h4), and FV×ADV (h56), and the two speak mode operations V↓A (s9) and A↑V (s10).

Counting the suspension compensation in line 2b, the hear mode derivation used eight operation applications, while the speak mode derivation used ten:

3.1.23 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

	1		2a	2b		3		4		5		6		7	
Perhaps	∼	Fido	×	×	is	×	still	∪	sleeping	×	there	×	now	∪	•

speak mode:

3		4	1		2		5		6						
V↓A	Perhaps	A↑V	V↙N	Fido	N↗V	is	V↓A	still	A↑V	sleeping					
7		8	9		10										
V↓A	there	A↑V	V↓A	now	A↑V	•									

The numbering of the speak mode operations corresponds to the arcs traversed in 3.1.11. The higher number of operation applications in production is caused by the four adverbials, which each require two traversals in the speak mode, but only one concatenation in the hear mode.

3.2 DBS.8: Phrasal Adverbial Modification

In English, the adnominal vs. adverbial use of elementary modifiers may be restricted morphologically, as in beautiful (adnominal) vs. beautifully (adverbial). No such morphological distinction exists for phrasal modifiers like on the table. Syntactically, however, phrasal modifiers in adnominal use must follow the modified noun, while in adverbial use the positioning is relatively free, similar to the elementary adverbials illustrated in the previous section.

If a prepositional phrase is positioned after the verb and a noun (e.g. following the object position), there is an ambiguity between the adnominal and the adverbial use. For example, Fido ate the bone on the table may mean that the bone is on table (adnominal) or that the eating is on the table (adverbial). In DBS, the different readings are coded as the following contents:

3.2.1 **<to-do 1>**

ADNOMINAL CONTENT OF Fido ate the bone on the table**.**

sur: fido	sur:	sur:	sur:	
noun: [dog y]	verb: eat	noun: bone	noun: table	
cat: snp	cat: #n′ #a′ v	cat: snp	cat: adnv snp	
sem: nm f	sem: ind past	sem: def sg	sem: *on* def sg	
fnc: eat	arg: [dog y] bone	fnc: eat	mdd: bone	<
mdr:	mdr:	mdr: table	mdr:	<
nc:	nc:	nc:	nc:	
pc:	pc:	pc:	pc:	
prn: 11	prn: 11	prn: 11	prn: 11	

Here, the mdd value of *table* is bone and the mdr value of *bone* is table.

3.2.2 ADVERBIAL CONTENT OF Fido ate the bone on the table.

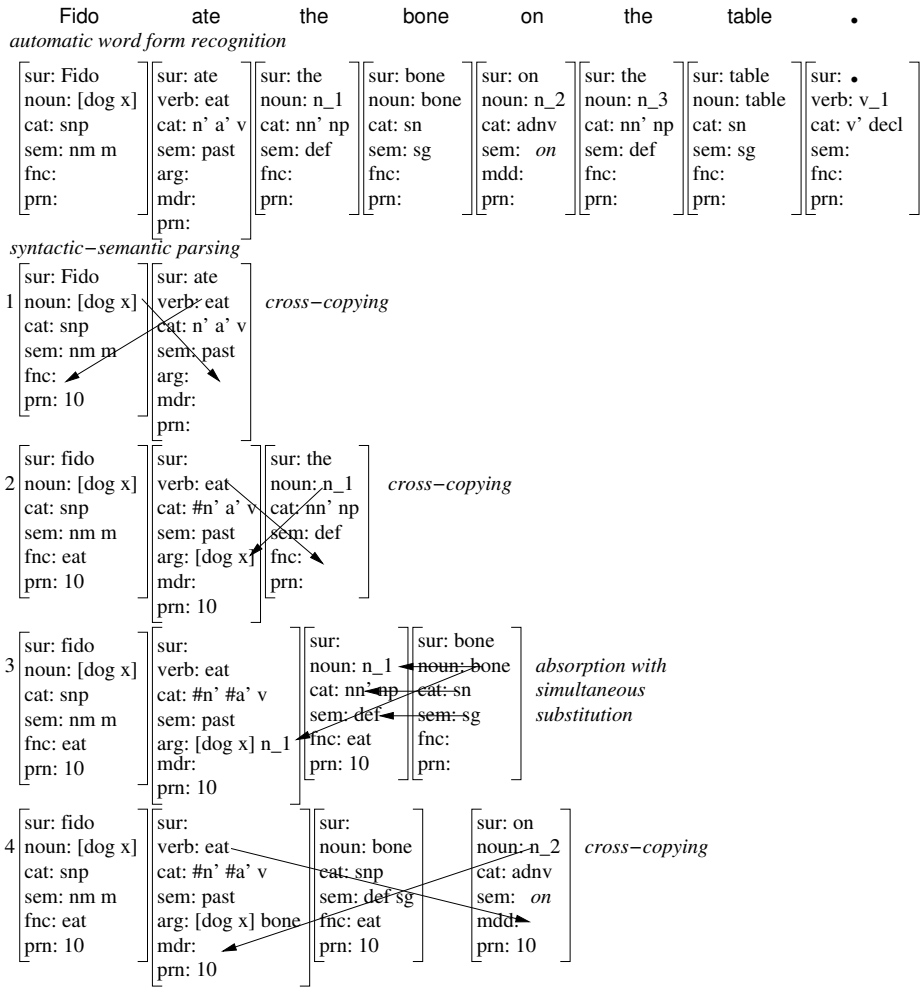
sur: fido	sur:	sur:	sur:	
noun: [dog y]	verb: eat	noun: bone	noun: table	
cat: snp	cat: #n′ #a′ v	cat: snp	cat: adnv snp	
sem: nm f	sem: ind past	sem: def sg	sem: *on* def sg	
fnc: eat	arg: [dog y] bone	fnc: eat	mdd: eat	<
mdr:	mdr: table	mdr:	mdr:	<
nc:	nc:	nc:	nc:	
pc:	pc:	pc:	pc:	
prn: 10	prn: 10	prn: 10	prn: 10	

Here the mdd value of *table* is eat and the mdr value of *eat* is table.

The adverbial reading has the following hear mode graph analysis:

3.2.3 **<to-do 2>**

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION



5	sur: fido noun: [dog x] cat: snp sem: nm m fnc: eat prn: 10	sur: verb: eat cat: #n' #a' v sem: past arg: [dog x] bone mdr: n_2 prn: 10	sur: noun: bone cat: snp sem: def sg fnc: eat prn: 10	sur: noun: n_2 cat: adnv sem: *on* mdd: eat prn: 10	sur: the ~~noun: n~~_3 ~~cat: nn~~' np ~~sem: def~~ fnc: prn:	*absorption with simultaneous substitution*
6	sur: fido noun: [dog x] cat: snp sem: nm m fnc: eat prn: 10	sur: verb: eat cat: #n' #a' v sem: past arg: [dog x] bone mdr: n_3 prn: 10	sur: noun: bone cat: snp sem: def sg fnc: eat prn: 10	sur: noun: n_3 cat: adnv nn'~~np~~ ~~sem:~~ *on* def mdd: eat prn: 10	sur: table ~~noun: table~~ ~~cat: sn~~ ~~sem: sg~~ fnc: prn:	*absorption with simultaneous substitution*
7	sur: fido noun: [dog x] cat: snp sem: nm m fnc: eat prn: 10	sur: verb: eat cat: #n' #a' v sem: past arg: [dog x] bone mdr: table prn: 10	sur: noun: bone ~~cat: snp~~ sem: def sg fnc: eat prn: 10	sur: noun: table ~~cat: adnv snp~~ sem: *on* def sg mdd: eat prn: 10	sur: • verb: v_1 ~~cat: v~~' decl sem: arg: prn:	*absorption*
result	sur: fido noun: [dog x] cat: snp sem: nm m fnc: eat prn: 10	sur: verb: eat cat: #n' #a' decl sem: past arg: [dog x] bone mdr: table prn: 10	sur: noun: bone cat: snp sem: def sg fnc: eat prn: 10	sur: • noun: table cat: adnv snp sem: *on* def sg mdd: eat prn: 10		

The initial declarative sentence continues with a prepositional phrase which is attached to the verb via cross-copying between the respective mdr and mdd slots in line 4. The preposition *on* matches the second input pattern of the operation PRD×PREP^{opt} (3.2.7), which finds the verb *eat* at the now front matching its first input pattern and applies (data-driven).

The complete sequence of explicit hear mode operation applications begins with SBJ×PRD:

3.2.4 **<to-do 3>**

CROSS-COPYING *fido* AND *ate* WITH SBJ×PRD (line 1)

SBJ×PRD (h1)

pattern level

noun: α	verb: β		noun: α	verb: β
cat: NP	cat: NP′ X v	⇒	cat: NP	cat: #NP′ X v
fnc:	arg:		fnc: β	arg: α
prn:K	prn:		prn: K	prn: K

Agreement conditions as in 2.1.2.

⇑ ⇓

content level

sur: Fido	sur: ate		sur: fido	sur:
noun: [dog y]	verb: eat		noun: [dog y]	verb: eat
cat: snp	cat: ns3′ a′ v		cat: snp	cat: #ns3′ a′ v
sem: nm m	sem: ind past		sem: nm m	sem: ind past
fnc:	arg:		fnc: eat	arg: [dog y]
mdr: big	mdr:		mdr:	mdr:
prn: 10	prn:		prn: 10	prn: 10

The second hear mode operation to apply is standard PRD×OBJ:

3.2.5 CROSS-COPYING *eat* AND *the* WITH PRD×OBJ (line 2)

PRD×OBJ (h28)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \underline{\#X'}\ N'\ Y\ \gamma \\ \text{arg: } Z \\ \text{prn: } K\end{bmatrix}\begin{bmatrix}\text{noun: } \alpha \\ \text{cat: } CN'\ NP \\ \text{fnc:} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \underline{\#X'}\ \#N'\ Y\ \gamma \\ \text{arg: } Z\ \alpha \\ \text{prn: } K\end{bmatrix}\begin{bmatrix}\text{noun: } \alpha \\ \text{cat: } CN'\ NP \\ \text{fnc: } \beta \\ \text{prn: } K\end{bmatrix}$$

Agreement conditions as in 2.3.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: } \#n'\ a'\ v \\ \text{sem: ind past} \\ \text{arg: [dog y]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 10}\end{bmatrix}\begin{bmatrix}\text{sur: the} \\ \text{noun: n\_1} \\ \text{cat: } nn'\ np \\ \text{sem: def sg} \\ \text{fnc: eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: } \#n'\ \#a'\ v \\ \text{sem: ind past} \\ \text{arg: [dog y] n\_1} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 10}\end{bmatrix}\begin{bmatrix}\text{sur:} \\ \text{noun: n\_1} \\ \text{cat: } nn'\ np \\ \text{sem: def} \\ \text{fnc: eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 10}\end{bmatrix}$$

The underline of the variable $\underline{\#X'}$ ensures that there is at least one #-marked counterpart (here the subject) in the matching input (1.6.5, 2).

The grammatical object is completed with standard DET∪CN:

3.2.6 ABSORBING *bone* INTO *the* WITH DET∪CN (line 3)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n \\ \text{cat: } CN'\ NP \\ \text{sem: Y} \\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: } \alpha \\ \text{cat: CN} \\ \text{sem: Z} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: NP} \\ \text{sem: Y Z} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.2.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: n\_1} \\ \text{cat: } nn'\ np \\ \text{sem: def} \\ \text{fnc: eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 10}\end{bmatrix}\begin{bmatrix}\text{sur: bone} \\ \text{noun: bone} \\ \text{cat: sn} \\ \text{sem: sg} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{noun: bone} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 10}\end{bmatrix}$$

At this point, the hear mode derivation has interpreted the example up to Fido ate the bone.

The next operation is called PRD×PREP^{opt}. PRD matches the finite verb, the connective × indicates cross-copying, and PREP^{opt} matches a preposition as (the beginning of) an optional phrasal modifier.[7]

[7] The operation PRD×PREP^{obl} (4.1.6) is also adverbial, but cancels a valency position in a verb like *put* as an obligatory argument.

3.2.7 CROSS-COPYING *eat* AND *on* WITH PRD×PREP^{opt} (line 4)

PRD×PREP^{opt} (h35)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha\\ \text{mdr:}\\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{mdd:}\\ \text{prn:}\end{bmatrix} \quad \Rightarrow \quad \begin{bmatrix}\text{verb: } \alpha\\ \text{mdr: N\_}n\\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{mdd: } \alpha\\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow \qquad\qquad\qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: eat}\\ \text{cat: \#n}'\ \text{\#a}'\ \text{v}\\ \text{sem: ind past}\\ \text{arg: [dog y] bone}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 10}\end{bmatrix} \quad \begin{bmatrix}\text{sur: on}\\ \text{noun: n\_2}\\ \text{cat: adnv}\\ \text{sem: } on\\ \text{mdd:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:}\\ \text{verb: eat}\\ \text{cat: \#n}'\ \text{\#a}'\ \text{v}\\ \text{sem: ind past}\\ \text{arg: [dog y] bone}\\ \text{mdr: n\_2}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 10}\end{bmatrix} \quad \begin{bmatrix}\text{sur:}\\ \text{noun: n\_2}\\ \text{cat: adnv}\\ \text{sem: } on\\ \text{mdd: eat}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 10}\end{bmatrix}$$

The adverbial modifier relation between the prepositional phrase and the finite verb is established by cross-copying the core value of the preposition, here n_2, into the mdr slot of the verb *eat* and the core value of *eat* into the mdd slot of the preposition. The cat value adnv indicates that a prepositional phrase may be used adnominally (adn) or adverbially (adv). The kind of the preposition, here *on* in contradistinction to, e.g., *in, under, below,* etc., is specified in the lexical entry as the initial value of the sem attribute.

The first step in assembling the remainder of the prepositional phrase (CLaTR 7.2.5) is based on the operation PREP∪NP:

3.2.8 ABSORBING *the* INTO *on* WITH PREP∪NP (line 5)

PREP∪NP (h48)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{sem: X}\\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{noun: } \alpha\\ \text{cat: CN}'\ \text{NP}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix} \quad \Rightarrow \quad \begin{bmatrix}\text{noun: } \alpha\\ \text{cat: adnv CN}'\ \text{NP}\\ \text{sem: X Z}\\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow \qquad\qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: n\_2}\\ \text{cat: adnv}\\ \text{sem: } on\\ \text{mdd: eat}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 10}\end{bmatrix} \quad \begin{bmatrix}\text{sur: the}\\ \text{noun: n\_3}\\ \text{cat: nn}'\ \text{np}\\ \text{sem: def sg}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:}\\ \text{noun: n\_3}\\ \text{cat: adnv nn}'\ \text{np}\\ \text{sem: } on\ \text{def sg}\\ \text{mdd: eat}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 10}\end{bmatrix}$$

Function word absorption in combination with simultaneous substitution automatically replaces all occurrences of the variable n_2 (originating lexically in the preposition) with the incremented variable n_3 (originating in the lexical lookup of the determiner). Also, the cat and sem values of the two input proplets are combined in the single output proplet.

The time-linear assembling of the prepositional phrase is completed with the application of DET∪CN:

3.2.9 ABSORBING *table* INTO *on the* WITH DET∪CN (line 6)

DET∪CN (h47)

pattern level

noun: N_*n*	noun: α		noun: α
cat: CN′ NP	cat: CN	⇒	cat: NP
sem: Y	sem: Z		sem: Y Z
prn: K	prn:		prn: K

Agreement conditions as in 2.2.4.

⇑ ⇓

content level

sur:	sur: table	sur:
noun: n_3	noun: table	noun: table
cat: adnv[8] nn′ np	cat: sn	cat: adnv snp
sem: *on* def sg	sem: sg	sem: *on* def sg
mdd: eat	fnc:	mdd: eat
mdr:	mdr:	mdr:
nc:	nc:	nc:
pc:	pc:	pc:
prn: 10	prn:	prn: 10

Grammatically there is no upper limit on repeating the addition of prepositional phrases.[9] Here, however, the hear mode derivation is completed with the application of standard S∪IP for adding the period:

3.2.10 ABSORBING • INTO *eat* WITH S∪IP (line 7)

S∪IP (h18)

pattern level

verb: β	verb: V_*n*		verb: β
cat: #X′ VT	cat: VT′ SM	⇒	cat: #X′ SM
prn: K			prn: K

Agreement conditions as in 2.1.4.

⇑ ⇓

content level

sur:	sur: •	sur: •
verb: eat	verb: v_1	verb: eat
cat: #n′ #a′ v	cat: v′ decl	cat: #n′ #be′ decl
sem: ind past	sem:	sem: ind past
arg: [dog y]	arg:	arg: [dog y]
mdr: table	mdr:	mdr: table
nc:	nc:	nc:
pc:	pc:	pc:
prn: 10	prn:	prn: 10

The hear mode derivation of a phrasal adverbial modification is now complete.

---

[9] The initial adnv value in the cat slot of the preposition-determiner combination originated lexically in the preposition (3.2.7, 3.2.8). It may be accommodated by DET∪CN by using an initial cat variable X which is restricted to adnv or NIL (omitted).

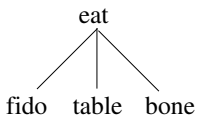
[9] As an example see on the table under the tree in the garden in Sect. 5.1; the semantic relation between the stacked items is modification: under the tree modifies table and in the garden modifies tree. The alternative reading is coordination as the semantically less restricted relation (NLC, Sects. 15.2, 15.3).

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

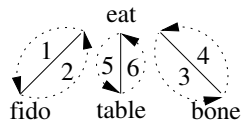
3.2.11 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE

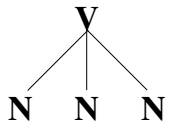
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

1	2	3	4	5	6
Fido	ate	the_bone		on_the_table	.
V/N	N/V	V\N	N\V	V|N	N|V

Based on the breadth-first arc numbering (Sect. 1.4), the transition numbers in the surface realization are consecutive.

Word form production is summarized as the following list of speak mode operations:

3.2.12 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *eat* to *fido*	Fido	3.2.13
arc 2:	N↗V	from *fido* to *eat*	ate	3.2.14
arc 3:	V↘N	from *eat* to *bone*	the_bone	3.2.15
arc 4:	N↖V	from *bone* to *eat*		3.2.16
arc 5:	V↓N	from *eat* to *table*	on_the_table	3.2.17
arc 6:	N↑V	from *table* to *eat*	.	3.2.18

In a text, the navigation accesses the top predicate, here *eat*, from an extrapropositional coordination (1.4.4) and continues with standard V↙N to the initial value in its arg slot to realize Fido (arc 1). From there, it returns with N↗V from *fido* to *eat* to realize ate (arc 2). The initial declarative sentence is concluded with the V↘N traversal and realization of the object (arc 3), and the empty return to the predicate (arc 4). From there, the adverbial modifier phrase is accessed via V↓N and realized (arc 5). The final return via N↑V to the predicate (arc 6) gets into position for accessing a possible next proposition by an extrapropositional relation between the top verbs (1.3.7) and provides the appropriate interpunctuation.

The complete sequence of explicit navigation operations begins with V↙N:

3.2.13 **<to-do 6>**

NAVIGATING WITH V↙N FROM *eat* TO *dog* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [dog y] bone} \\ \text{mdr: table} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 10}\end{bmatrix} \quad \begin{bmatrix}\text{sur: Fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 10}\end{bmatrix}$$

Lexnoun realizes the surface Fido from the marker ‘fido,’ which the hear mode operation 3.2.4 stored in the sur slot of the name proplet. The name surface covers the name marker temporarily until the surface is moved to the agent’s interface component for word form realization, revealing the marker again.

3.2.14 NAVIGATING WITH N↗V FROM *dog* BACK TO *eat* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: fido} \\ \text{noun: [dog y]} \\ \text{cat: np} \\ \text{sem: def sg} \\ \text{fnc: eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 10}\end{bmatrix} \quad \begin{bmatrix}\text{sur: ate} \\ \text{verb: eat} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[dog y] bone} \\ \text{mdr: table} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 10}\end{bmatrix}$$

At this point, the speak mode has realized Fido ate.

The realization of the subject and the predicate continues with the traversal of the grammatical object, navigating from *eat* to *bone* and back, based on the standard V↘N and N↖V operations. While the V↘N traversal realizes the_bone, the N↖V traversal is empty[10]:

[10] If an adnominal intervenes between the determiner and the noun, as in 2.4.16–2.4.19, V↘N would realize the determiner and N↖V the common noun.

3.2.15 NAVIGATING WITH V↘N FROM *eat* TO *bone* (arc 3)

V↘N (s3)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{prn: } \ddot{\text{K}}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[dog y] bone} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 10}\end{bmatrix} \quad \begin{bmatrix}\text{sur: the\_bone} \\ \text{noun: bone} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 10}\end{bmatrix}$$

The #-marking of the valency positions in the cat slot of *eat* stem from the hear mode operation patterns SBJ×PRD (3.2.4) and PRD×OBJ (3.2.5). The #-marking of the initial arg value [dog y], in contrast, stems from the instruction of the speak mode operation 3.2.13.

3.2.16 NAVIGATING WITH N↖V FROM *bone* BACK TO *eat* (arc 4)

N↖V (s4)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{mdr: } \ddot{\text{Z}} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: bone} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: \#eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn 10}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[dog y] \#bone} \\ \text{mdr: table} \\ \text{nc:} \\ \text{pc:} \\ \text{prn 10}\end{bmatrix}$$

The #-marking of second arg value bone of *eat* resulted from the instruction in 3.2.15. Lexverb in the sur slot of the goal proplet is prevented from realizing an interpunctuation sign by the presence of the unmarked continuation value table in the mdr slot of *eat*.

The navigation continues with the traversal of the phrasal adverbial modifier. That the modification is adverbial rather than adnominal is indicated by the source node V. The phrasal nature of the modifier is indicated by the goal node N (instead of A):

3.2.17 NAVIGATING WITH V↓N FROM *eat* TO *table* (arc 5)

V↓N (s13)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{mdr: X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the mdr slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[dog y] \#bone} \\ \text{mdr: table} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 10}\end{bmatrix} \quad \begin{bmatrix}\text{sur: on\_the\_table} \\ \text{noun: table} \\ \text{cat: adnv snp} \\ \text{sem: } \textit{on} \text{ def sg} \\ \text{mdd: eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 10}\end{bmatrix}$$

The realization of the surface on_the_table by lexverb is based on the sem values *on*, def, sg, and the core value table.

Using the mdd value of the goal proplet, the navigation returns to the verb with N↑V, here *eat*.[11] Without any untraversed continuation values in the *eat* proplet, lexverb uses the cat value decl to realize the period:

3.2.18 NAVIGATING WITH N↑V FROM *table* BACK TO *eat* (arc 6)

N↑V (s14)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{mdr: X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: table} \\ \text{cat: adnv snp} \\ \text{sem: } \textit{on} \text{ def sg} \\ \text{mdd: eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 10}\end{bmatrix} \quad \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: eat} \\ \text{cat: \#ns3}' \text{ \#be}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[dog y] \#bone} \\ \text{mdr: \#table} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 10}\end{bmatrix}$$

Extending DBS.7 to a class of examples with an optional phrasal adverbial modifier in postverbal position required the definition of four additional operations, namely PRD×PREP^{opt} (h39) and PREP∪NP (h48) for the hear mode, and V↓N (s13) and N↑V (s14) for the speak mode. The hear mode derivation used seven operation applications, while the speak mode derivation used six:

3.2.19 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

	1		2		3		4		5		6		7	
Fido	×	ate	×	the	∪	bone	×	on	∪	the	∪	table	∪	•

speak mode:

1	2	3	4	5	6	
V↙N Fido	N↗V ate	V↘N the_bone	N↖V	V↓A on_the_table	A↑V	•

The numbering of the speak mode operations corresponds to the breadth first arc numbering in 3.2.11. The hear mode derivation runs straight through without any suspension; the speak mode derivation has one empty traversal.

3.3 DBS.9: Clausal Adnominal Modifier with Subject Gap

Having analyzed examples with an elementary (Sect. 3.1, suspension) and a phrasal modifier (Sect. 3.2, absorption), let us turn to clausal modifiers. Clausal adnominal modifiers (aka relative clauses) may occur with a subject gap, as in The dog which saw Mary barked, and with an object gap, as in The dog which Mary saw barked.

3.3.1 **<to-do 1>**

CONTENT OF The dog which saw Mary barked**.**

sur:	sur:	sur: mary	sur:
noun: dog	verb: see	noun: [person x]	verb: bark
cat: snp	cat: #n′ #a′ v	cat: snp	cat: #n′ decl
sem: def sg	sem: *which* ind past	sem: nm f	sem: ind past
fnc: bark	arg: ∅ [person x]	fnc: see	arg: dog
mdr: (see 13)	mdd: [dog 12)	mdr:	mdr:
nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:
prn: 12	prn: 13	prn: 13	prn: 12

The extrapropositional nature of the construction is reflected by the use of two prn values, 12 and 13.

One direction of the relation between the subclause and the main clause is coded by the feature [mdr: (see 13)] of *dog*. The other direction is coded by the feature [mdd: [dog 12)] of *see*. The characteristic subject gap is shown by the gap marker ∅ in the feature [arg: ∅ [person y]] of *see*; the implicit filler of the gap is shown by the feature [mdd: [dog 12)] directly underneath.

3.3.2 <to-do 2>

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION

unanalyzed surface

The dog which saw Mary barked •

automatic word form recognition

The	dog	which	saw	Mary	barked	•
sur: the	sur: dog	sur: which	sur: saw	sur: Mary	sur: barked	sur: •
noun: n_1	noun: dog	verb: v_1	verb: see	noun: [person y]	verb: bark	verb: v_2
cat: nn' np	cat: sn	cat:	cat: n' a' v	cat: snp	cat: n' v	cat: v' decl
sem: def	sem: sg −mf	sem: *which*	sem: past	sem: nm f	sem: past	sem:
fnc:	fnc:	arg: ∅	arg:	fnc:	arg:	arg:
mdr:	prn:	mdd:	prn:	prn:	prn:	prn:
prn:		prn:				

syntactic−semantic parsing

1 *absorption*

sur: the	sur: dog
noun: n_1	~~noun:~~ dog
cat: nn' ~~np~~	~~cat:~~ sn
sem: def	~~sem:~~ sg −mf
fnc:	fnc:
mdr:	prn:
prn: 12	

2 *cross−copying*

sur:	sur: which
noun: dog	verb: v_1
cat: snp	cat:
sem: def sg −mf	sem: *which*
fnc:	arg: ∅
mdr:	mdd:
prn: 12	prn:

3 *absorption with simultaneous substitution*

sur:	sur:	sur: saw
noun: dog	verb: v_1	~~verb: see~~
cat: snp	cat:	~~cat:~~ n' a' v
sem: def sg −mf	sem: *which*	~~sem:~~ past
fnc:	arg: ∅	arg:
mdr: (v_1 ~~13~~)	mdd: (dog 12)	prn: 13
prn: 12	prn: 13	

4 *cross−copying*

sur:	sur:	sur: Mary
noun: dog	verb: see	noun: [person y]
cat: snp	cat: #n a' v	cat: snp
sem: def sg −mf	sem: *which* past	sem: nm f
fnc:	arg: ∅	fnc:
mdr: (see 13)	mdd: (dog 12)	prn:
prn: 12	prn: 13	

5 *cross−copying*

sur:	sur:	sur: mary	sur: barked
noun: dog	verb: see	noun: [person y]	verb: bark
cat: snp	cat: n' #a' v	cat: snp	cat: n' v
sem: def sg −mf	sem: *which* past	sem: nm f	sem: past
fnc:	arg: ∅ [person y]	fnc: see	arg:
mdr: (see 13)	mdd: (dog 12)	prn: 13	prn:
prn: 12	prn: 13		

6 *absorption*

sur:	sur:	sur: mary	sur:	sur: •
noun: dog	verb: see	noun: [person y]	verb: bark	verb: v_2
cat: snp	cat: n' #a' v	cat: snp	cat: #n' v	~~cat:~~ v' decl
sem: def sg −mf	sem: *which* past	sem: nm f	sem: past	sem:
fnc: bark	arg: ∅ [person y]	fnc: see	arg: dog	arg:
mdr: (see 13)	mdd: (dog 12)	prn: 13	prn: 12	prn:
prn: 12	prn: 13			

result

sur:	sur:	sur: mary	sur:
noun: dog	verb: see	noun: [person y]	verb: bark
cat: snp	cat: n' #a' v	cat: snp	cat: #n' decl
sem: def sg −mf	sem: *which* past	sem: nm f	sem: past
fnc: bark	arg: ∅ [person y]	fnc: see	arg: dog
mdr: (see 13)	mdd: (dog 12)	prn: 13	prn: 12
prn: 12	prn: 13		

The addition of the subordinating conjunction which in line 2 leaves it open whether the adnominal clause will have a subject or an object gap. This is because which has no morphological case marking.[12] The issue is decided in line 3 (shown in line 4) with the arrival of the verb. It is absorbed into the subordinating conjunction, whereby the gap marker $\emptyset$ in the cat slot of which is switched from lexically neutral to subject position (3.3.5).

The adnominal clause is completed in line 4 with the object Mary. In line 5, the head noun *dog* of the adnominal clause is connected to the predicate *bark* of the matrix clause by cross-copying their core values into the respective fnc and arg slots. In short, the adnominal clause represented by *see* is connected to *dog* with the modifier|modified relation (3.3.4) and the head noun *dog* is related to *bark* with the subject/predicate relation (3.3.9).

The complete sequence of explicit hear mode operation applications begins with DET∪CN:

3.3.3 **<to-do 3>**

ABSORBING *dog* INTO *The* WITH DET∪CN (line 1)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\ \text{NP}\\ \text{sem: Y}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{sem: Y Z}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.2.4.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur: The}\\ \text{noun: n\_1}\\ \text{cat: nn}'\ \text{np}\\ \text{sem: def}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 12}\end{bmatrix}\begin{bmatrix}\text{sur: dog}\\ \text{noun: dog}\\ \text{cat: sn}\\ \text{sem: sg}\\ \text{fnc:}\\ \ldots\\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:}\\ \text{noun: dog}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 12}\end{bmatrix}$$

Next, the operation CN×PRD^{which} connects *dog* and lexical *v_1* (which) by cross-copying the core values into the respective mdr and mdd slots:

[12] The difference between which and who may be coded as ±human (not shown). The use of who as oblique is represented here by using the optional case marking, i.e. who(m) (5.5.2).

3.3.4 CROSS-COPYING *dog* AND *which* WITH $\mathbf{CN}\times\mathbf{PRD}^{which}$ (line 2)

$\mathbf{CN}\times\mathbf{PRD}^{which}$ (h12)

pattern level

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{mdr:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: }\beta\\ \text{arg: }\emptyset\\ \text{mdd:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{mdr: (V\_n K+1)}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: }\beta\\ \text{arg: }\emptyset\\ \text{mdd: }(\alpha\text{ K})\\ \text{prn: K+1}\end{bmatrix}$$

$\beta \in$ {which, who}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: dog}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 12}\end{bmatrix}\begin{bmatrix}\text{sur: which}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: }\textit{which}\\ \text{arg: }\emptyset\\ \text{mdd:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:}\\ \text{noun: dog}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc:}\\ \text{mdr: v\_1}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 12}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: }\textit{which}\\ \text{arg: }\emptyset\\ \text{mdd: [dog 12)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 13}\end{bmatrix}$$

The gap marker $\emptyset$ in middle position (neutral) indicates that the choice between a subject or an object gap is still open. This is decided when automatic word form recognition provides the next item: it is a subject gap if the next item is a verb, as in the dog which saw, and an object gap if the next item is a noun, as in the dog which Mary (data-driven).

In our example, the next word is the verb form saw. Its proplet is absorbed by the operation PRD^{who}[13]$\cup\mathsf{PRD}$ into the conjunction which:

3.3.5 ABSORBING *see* INTO *who* WITH $\mathsf{PRD}^{who}\cup\mathsf{PRD}$ (line 3)

$\mathbf{PRD}^{who}\cup\mathbf{PRD}$ (h22)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: }\alpha\\ \text{arg: }\emptyset\\ \text{mdd: }(\gamma\text{ K-1})\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP X v}\\ \text{sem: Y}\\ \text{arg:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP X v}\\ \text{sem: }\alpha\text{ Y}\\ \text{arg: }\emptyset\\ \text{mdd: }(\gamma\text{ K-1})\\ \text{prn: K}\end{bmatrix}$$

$\alpha \in$ {who, which}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: }\textit{which}\\ \text{arg: }\emptyset\\ \text{mdd: [dog 12)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 13}\end{bmatrix}\begin{bmatrix}\text{sur: saw}\\ \text{verb: see}\\ \text{cat: n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:}\\ \text{verb: see}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: }\textit{which}\text{ ind past}\\ \text{arg: }\emptyset\\ \text{mdd: [dog 12)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 13}\end{bmatrix}$$

[13] We use who as the diacritic indicating a subject gap, who(m) indicating an object gap, and which for undecided (3.3.4).

The operation moves ∅ from its lexical middle position (undecided, neutral) in the arg slot of which to subject position, fixing the interpretation to subject gap. So far, the hear mode derivation has interpreted The dog which saw.

The next word is Mary; it serves as the object of the subclause and is connected to saw by cross-copying:

3.3.6 CROSS-COPYING *see* AND *mary* WITH PRD×OBJ (line 4)

PRD×OBJ (h28)

pattern level

verb: β	noun: α	verb: β	noun: α
cat: $\underline{\#X'}$ N′ Y γ	cat: CN′ NP	cat: $\underline{\#X'}$ #N′ Y γ	cat: CN′ NP
arg: Z	fnc:	arg: Z α	fnc: β
prn: K	prn:	prn: K	prn: K

⇒

Agreement conditions as in 2.3.4.

⇑ ⇓

content level

sur:	sur: Mary	sur:	sur: mary
verb: see	noun: [person x]	verb: see	noun: [person x]
cat: #n′ a′ v	cat: snp	cat: #n′ #a′ v	cat: snp
sem: *which* ind past	sem: nm f	sem: *which* ind past	sem: nm f
arg: ∅	fnc:	arg: ∅ [person x]	fnc: see
mdd: [dog 12)	mdr:	mdd: [dog 12)	mdr:
nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:
prn: 13	prn:	prn: 13	prn: 13

Now the next word is barked. It matches and activates the second input pattern of SBJ×PRD, which finds *dog* with the prn value 12 at the now front matching its first input pattern and applies:

3.3.7 CROSS-COPYING *dog* AND *barked* WITH SBJ×PRD (line 5)

SBJ×PRD (h1)

pattern level

noun: α	verb: β	noun: α	verb: β
cat: NP	cat: NP′ X v	cat: NP	cat: #NP′ X v
fnc:	arg:	fnc: β	arg: α
prn:K	prn:	prn: K	prn: K

⇒

Agreement conditions as in 2.1.2.

⇑ ⇓

content level

sur:	sur: barked	sur:	sur: barked
noun: dog	verb: bark	noun: dog	verb: bark
cat: snp	cat: n′ v	cat: snp	cat: #n′ v
sem: def sg	sem: ind past	sem: def sg	sem: ind past
fnc	arg:	fnc: bark	arg: dog
mdr: (see 13)	mdr:	mdr: (see 13)	mdr:
nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:
prn: 12	prn:	prn: 12	prn: 12

Like an elementary or phrasal noun, clausal the dog which saw Mary may serve not only as a subject, but also as a direct or indirect object.

The hear mode derivation of 3.3.1 is completed with an application of S∪IP:

3.3.8 ABSORBING • INTO *bark* WITH S∪IP (line 6)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ VT} \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: V\_}n \\ \text{cat: VT}' \text{ SM}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ SM} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: bark} \\ \text{cat: } \#n' \text{ v} \\ \text{sem: ind past} \\ \text{arg: [dog y]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 12}\end{bmatrix} \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: v\_1} \\ \text{cat: v}' \text{ decl} \\ \text{sem:} \\ \text{arg:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{verb: bark} \\ \text{cat: } \#n' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [dog y]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 12}\end{bmatrix}$$

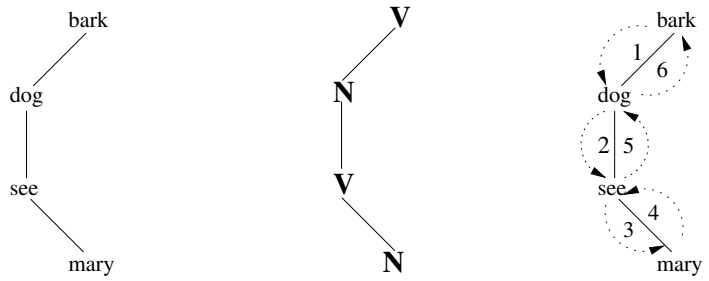
Using the cat value decl of the lexical punctuation sign, the output of S∪IP characterizes the top verb *bark*, and thus the complete grammatical construction which it represents, as a declarative. The hear mode derivation of a clausal adnominal modifier with subject gap is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

3.3.9 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE

(i) SRG (semantic relations graph) *(ii) signature* *(iii) NAG (numbered arcs graph)*



(iv) surface realization

1	2	3	4	5	6
The_dog	which_saw	Mary			barked_ •
V/N	N|V	V\N	N\V	V|N	N/V

The modifier role of the relative clause is shown graphically by the | line between *see* and *dog*. The subject gap is shown by the absent subject/predicate branch below *see* (NLC 7.3.1). The arc numbering is depth-first. The traversal order, indicated by the surface realization, is consecutive.

Word form production is summarized as the following list of speak mode operations:

3.3.10 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *bark* to *dog*	The_dog	3.3.11
arc 2:	N↓V	from *dog* to *see*	which_saw	3.3.12
arc 3:	V↘N	from *see* to *mary*	Mary	3.3.13
arc 4:	N↖V	from *mary* to *see*		3.3.14
arc 5:	V↑N	from *see* to *dog*		3.3.15
arc 6:	N↗V	from *dog* to *bark*	barked_.	3.3.16

It is clearly shown that the continuity condition, and thus the time-linearity of the think-speak mode derivation, is fulfilled.

The navigation begins with V↙N, traveling along arc 1 from the main clause verb to the subject and realizes the surface The_dog. The traversal continues along arc 2 with N↓V from the subject to the beginning of an adnominal clause with a subject gap and realizes which_saw. V↘N traverses arc 3 and produces Mary as the object of the adnominal subclause. Returning empty back up along arcs 4–6, the traversal concludes with N↗V and realizes barked_.

The complete sequence of explicit navigation operations begins with V↙N:

3.3.11 **<to-do 6>**

NAVIGATING WITH V↙N FROM *bark* TO *dog* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$$\Uparrow \qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: bark} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: dog} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 12} \end{bmatrix} \qquad \begin{bmatrix} \text{sur: The\_dog} \\ \text{noun: dog} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: bark} \\ \text{mdr: (see 13)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 12} \end{bmatrix}$$

The lexicalization rule lexnoun in the sur slot of the output pattern realizes the surface The_ dog from the core and sem values of the output proplet.

The next operation is N↓V (3.3.12), which has V↑N (3.3.15) as its counterpart.[14] Both use the semantic relation of modification and connect the adnominal subclause extrapropositionally with the head noun in the main clause:

3.3.12 NAVIGATING WITH N↓V FROM *dog* TO *see* (arc 2)

N↓V (s15)

pattern level

noun: α		sur: lexverb($\hat{\beta}$)	
mdr: (β K+1)	$\Rightarrow$	verb: β	#-mark α in the mdd slot of proplet β.
prn: K		mdd: (α K)	
		prn: K+1	

$\Uparrow$ $\Downarrow$

content level

sur:	sur: which_saw
noun: dog	verb: see
cat: snp	cat: #n′ #a′ v
sem: def sg	sem: *which* ind past
fnc: bark	arg: ∅ [person x]
mdr: (see 13)	mdd: [dog 12)
nc:	nc:
pc:	pc:
prn: 12	prn: 13

The extrapropositional transition from the head noun *dog* to the subclause beginning with *which_saw* is shown by the different prn variables K and K+1 at the pattern level, and the matching constants 12 and 13 at the content level, which were assigned by the hear mode in 3.3.4. Using the features [verb: see], [sem: *which* past ind], and [arg: ∅ [person x]], lexverb realizes the English surface which_saw.

After reaching the verb of the adnominal subclause, the navigation travels with intrapropositional V↘N to the object and realizes the surface Mary:

3.3.13 NAVIGATING WITH V↘N FROM *see* TO *mary* (arc 3)

V↘N (s3)

pattern level

verb: α		sur: lexnoun($\hat{\beta}$)	
arg: #X β Y	$\Rightarrow$	noun: β	#-mark β in the arg slot of proplet α.
prn: K		fnc: α	
		prn: K	

$\Uparrow$ $\Downarrow$

content level

sur:	sur: Mary
verb: see	noun: [person x]
cat: #n′ #a′ decl	cat: snp
sem: ind past	sem: nm f
arg: ∅ [person x]	fnc: see
mdd: #[dog 14)	mdr:
nc:	nc:
pc:	pc:
prn: 13	prn: 13

At this point, the speak mode has realized The dog which saw Mary.

To complete the traversal of the adnominal subclause, the navigation returns from the lower object *mary* to the lower predicate *see* (3.3.9), using standard N↖\V.

3.3.14 NAVIGATING WITH N↖\V FROM *mary* BACK TO *see* (arc 4)

N↖\V (s4)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{prn: } \ddot{K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta\text{ Y} \\ \text{prn: K}\end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: see} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 13}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: see} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: } \emptyset \text{ \#[person x]} \\ \text{mdd: \#[dog 14)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 13}\end{bmatrix}$$

The traversal is ‘empty’ in the sense that no surface is produced by lexverb.

It remains to complete the main clause by adding bark_.. The first step is a return from the subclause verb *see* with the prn value 13 to the head noun *dog* in the main clause with the prn value 12, using V↑N:

3.3.15 NAVIGATING WITH V↑N FROM *see* BACK TO *dog* (arc 5)

V↑N (s16)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{mdd: \#(}\alpha\text{ K)} \\ \text{prn: K+1}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{mdr: \#(}\beta\text{ K+1)} \\ \text{prn: K}\end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: see} \\ \text{cat: \#n}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{which} \text{ ind past} \\ \text{arg: } \emptyset \text{ \#[person x]} \\ \text{mdd: \#[dog 12)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 13}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{noun: dog} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: bark} \\ \text{mdr: \#(see 13)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 12}\end{bmatrix}$$

The continuation value is #[dog 12) in the mdd slot of the input proplet. The traversal is empty.

[14] The operations N↓V and V↑N handle the extrapropositional transition from a main clause to a adnominal subclause and back. They differ from V↓N (3.2.17, 4.1.16) and N↑V (3.2.18, 4.1.17), which handle the intrapropositional connection between the predicate and a prepositional phrase in adverbial use.

Finally, the navigation returns from the head noun of the adnominal subclause to the top verb *bark*. In this example, the full stop proplet is used for providing the syntactic mood by changing the cat value v into decl, after which it is discarded. However, if there is a next sentence following, the full stop proplet (period) has the additional function of managing the transition.

3.3.16 NAVIGATING WITH N↗V FROM *dog* BACK TO *bark* (arc 6)

N↗V (s4)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\text{ Y} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: dog} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: bark} \\ \text{mdr: \#(see 13)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 12}\end{bmatrix} \quad \begin{bmatrix}\text{sur: barked\_}\bullet \\ \text{verb: bark} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#dog} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 12}\end{bmatrix}$$

Lexverb uses the core value bark, the sem value ind past, the #-marking of the arg value, and the cat value decl(arative) of the goal proplet to realize the surface of the top verb together with the punctuation sign.

Extending DBS.8 to a clausal adnominal modifier with a subject gap required the definition of the hear mode operations CN×PRD^{which} (h9) and PRD^{who}∪PRD (h18), and of the speak mode operations N↓V (s15) and V↑N (s16).

3.3.17 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

1		2		3		4		5		6	
The	∪	dog	×	which	∪	saw	×	Mary	×	barked	∪	•

speak mode:

1	2	3	4	5	6
V↙N The_dog	N↓V which_saw	V↘N Mary	N↖V	V↑N	N↗V barked_•

The hear mode derivation runs straight through without any suspension. The speak mode derivation has two empty traversals.

3.4 DBS.10: Clausal Adnominal Modifier with Object Gap

The grammatical counterpart[15] to subject gapping is object gapping, e.g. The dog which Mary saw barked. As in Sect. 3.3, the function word which is the pivot of the subclause construction; it cross-copies with *mary* and absorbs *see*, thus avoiding suspension. We begin with an example surface and its content:

3.4.1 **<to-do 1>**

CONTENT OF The dog which Mary saw barked .

sur:	sur: mary	sur:	sur:
noun: dog	noun: [person x]	verb: see	verb: bark
cat: snp	cat: snp	cat: #n′ #a′ v	cat: #n′ decl
sem: def sg	sem: nm f	sem: *which* ind past	sem: ind past
fnc: bark	fnc: see	arg: [person x] ∅	arg: dog
mdr: (see 15)	mdr:	mdd: [dog 14)	mdr:
nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:
prn: 14	prn: 15	prn: 15	nprn: 14

As contents, the only difference between this object gap construction and the subject gap construction 3.3.1 is in the respective arg feature of *see*: it is [arg: ∅ [person x]] in the subject gap content, but [arg: [person x] ∅] in the object gap content. In the English surface, this difference is coded by the word order, e.g. dog which [saw Mary] vs. dog which [Mary saw]. In addition, the surfaces of the two constructions may differ in an optional case marking, as in man who [saw Mary] vs. man who(m) [Mary saw].

Let us continue with the time-linear hear mode derivation in canonical DBS graph format, followed by point 3, i.e. the sequence of explicit hear mode operation applications which derive 3.4.1.

3.4.2 **<to-do 2>**

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION

unanalyzed surface

The dog which Mary saw barked .

automatic word form recognition

sur: the	sur: dog	sur: which	sur: Mary	sur: saw	sur: barked	sur: .
noun: n_1	noun: dog	verb: v_1	noun: (person y)	verb: see	verb: bark	verb: v_2
cat: nn’ np	cat: sn	cat:	cat: snp	cat: n’ a’ v	cat: n’ v	cat: v’ decl
sem: def	sem: sg –mf	sem: *which*	sem: nm f	sem: past	sem: past	
fnc:	fnc:	arg: ∅	fnc:	arg:	arg:	
mdr:	prn:	mdd:	prn:	prn:	prn:	
prn:		prn:				

[15] There are additional adnominal clause constructions, especially with prepositions as in The room in which ... or The person about who(m) ....

syntactic−semantic parsing

1	sur: the noun: n_1 cat: nn' ~~np~~ sem: def fnc: mdr: prn: 14	sur: dog ~~noun:~~ dog ~~cat:~~ sn ~~sem:~~ sg −mf fnc: prn:	*absorption*	
2	sur: noun: dog cat: snp sem: def sg −mf fnc: mdr: prn: 14	sur: which verb: v_1 cat: sem: *which* arg: ∅ mdd: prn:	*cross−copying*	
3	sur: noun: dog cat: snp sem: def sg −mf fnc: mdr: (v_1 15) prn: 14	sur: verb: v_1 cat: sem: *which* arg: ∅ mdd: (dog 14) prn: 15	sur: Mary noun: [person y] cat: snp sem: nm f fnc: prn:	*cross−copying*
4	sur: noun: dog cat: snp sem: def sg −mf fnc: mdr: (v_1 15) prn: 14	sur: verb: v_1 cat: sem: *which* arg: [person y] ∅ mdd: (dog 14) prn: 15	sur: mary ~~noun: [person y]~~ ~~cat: snp~~ ~~sem: nm f~~ fnc: see prn: 15	sur: saw ~~verb: see~~ ~~cat: #~~n' a' v ~~sem:~~ past arg: prn:	*absorption with simultaneous substitution*
5	sur: noun: dog cat: snp sem: def sg −mf fnc: mdr: (see 15) prn: 14	sur: verb: see cat: #n' #a' v ~~sem:~~ *which* past arg: [person y] ∅ mdd: (dog 14) prn: 15	sur: mary noun: [person y] cat: snp sem: nm f fnc: see prn: 15	sur: barked ~~verb:~~ bark cat: n' v sem: past arg: prn:	*cross−copying*
3	sur: noun: dog cat: snp sem: def sg −mf fnc: mdr: (v_1 15) prn: 14	sur: verb: v_1 cat: sem: *which* arg: ∅ mdd: (dog 14) prn: 15	sur: Mary noun: [person y] cat: snp sem: nm f fnc: prn:	*cross−copying*	
4	sur: noun: dog cat: snp sem: def sg −mf fnc: mdr: (v_1 15) prn: 14	sur: verb: v_1 cat: sem: *which* arg: [person y] ∅ mdd: (dog 14) prn: 15	sur: mary ~~noun: [person y]~~ ~~cat: snp~~ ~~sem: nm f~~ fnc: see prn: 15	sur: saw ~~verb: see~~ ~~cat: #~~n' a' v ~~sem:~~ past arg: prn:	*absorption with simultaneous substitution*

The analysis uses the same lexical analysis of the subordinating conjunction which as 3.3.2. It works for a subject as well as an object gap by having the gap marker ∅ in undecided (middle) position of the arg attribute (line 2).

The complete sequence of explicit hear mode operations begins with DET∪CN:

3.4.3 **<to-do 3>**

ABSORBING *dog* INTO *the* WITH DET∪CN (line 1)

DET∪CN (h47)

pattern level

noun: N_*n*	noun: α		noun: α
cat: CN′ NP	cat: CN	⇒	cat: NP
sem: Y	sem: Z		sem: Y Z
prn: K	prn:		prn: K

Agreement condition as in 2.2.4.

⇑ ⇓

content level

sur: The	sur: dog	sur:
noun: n_1	noun: dog	noun: dog
cat: nn′ np	cat: sn	cat: snp
sem: def	sem: sg	sem: def sg
fnc:	fnc:	fnc:
mdr:	mdr:	mdr:
nc:	nc:	nc:
pc:	pc:	pc:
prn: 14	prn:	prn: 14

The feature [cat: nn′ np] of the definite articles leaves the grammatical number of the resulting noun phrase open. It is decided by the feature [cat: sg] of dog.

Next *dog* cross-copies with the subordinating conjunction *which*. As in 3.3.4, it is left open whether the relative clause has a subject or an object gap:

3.4.4 CROSS-COPYING *dog* AND *which* WITH CN×PRD^{which} (line 2)

CN×PRD^{which} (h12)

pattern level

noun: α	verb: V_*n*		noun: α	verb: V_*n*
cat: NP	sem: β		cat: NP	sem: β
mdr:	arg: $\emptyset$	⇒	mdr: (V_n K+1)	arg: $\emptyset$
prn: K	mdd:		prn: K	mdd: (α K)
	prn:			prn: K+1

$\beta \in$ {who, which}

⇑ ⇓

content level

sur:	sur: which	sur:	sur:
noun: dog	verb: v_1	noun: dog	verb: v_1
cat: snp	cat:	cat: snp	cat:
sem: def sg	sem: *which*	sem: def sg	sem: *which*
fnc:	arg: $\emptyset$	fnc:	arg: $\emptyset$
mdr:	mdd:	mdr: (v_1 15)	mdd: [dog 14)
nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:
prn: 14	prn:	prn: 14	prn: 15

At the pattern level, the subordinating conjunction with a grammatical arg role, aka ”relative pronoun”, has the substitution variable V_*n* as its core value. It is matched by the core value v_1 of *which* at the content level. In the input and the output, the $\emptyset$ is in the middle (undecided, neutral) position of the second proplet’s arg slot. The choice between a subject and an object gap is decided in the next step by whether the following item is a noun or a verb.

In the present example, the following item is the noun *Mary*, resulting in an object gap construction even if *who* rather than *whom* is used:

3.4.5 CROSS-COPYING *who(m)* AND *mary* WITH PRD$^{who(m)}\times$SBJ (line 3)

PRD$^{who(m)}\times$SBJ (h43)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\alpha\\ \text{arg: }\emptyset\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\beta\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\alpha\\ \text{arg: }\beta\ \ \emptyset\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\beta\\ \text{fnc: V\_}n\\ \text{prn: K}\end{bmatrix}$$

$\alpha \in$ {who, who(m), which}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: }\textit{which}\\ \text{arg: }\emptyset\\ \text{mdd: [dog 14)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 15}\end{bmatrix}\begin{bmatrix}\text{sur: Mary}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm f}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: }\textit{who(m)}\\ \text{arg: [person x] }\emptyset\\ \text{mdd: [dog 14)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 15}\end{bmatrix}\begin{bmatrix}\text{sur: mary}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm f}\\ \text{fnc: v\_1}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 15}\end{bmatrix}$$

The operation cross-copies [person x] into the subject position of the verb's arg slot, thereby pushing $\emptyset$ from the middle (neutral) to the object position.

The next input item is a verb which must be transitive, here the ind past form of see. It is absorbed into the subordinating conjunction.

3.4.6 ABSORBING *see* INTO *which* WITH PRD$^{who(m)}\cup$PRD (line 4)

PRD$^{who(m)}\cup$PRD (h23)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: }\alpha\\ \text{arg: }\beta\ \ \emptyset\\ \text{mdd: }(\gamma\text{ K-1})\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\delta\\ \text{cat: NP X v}\\ \text{sem: Y}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{verb: }\delta\\ \text{cat: NP X v}\\ \text{sem: }\alpha\text{ Y}\\ \text{arg: }\beta\ \ \emptyset\\ \text{mdd: }(\gamma\text{ K-1})\\ \text{prn: K}\end{bmatrix}$$

$\alpha \in$ {who, who(m), which}; NP $\in$ {n′, ns3′, n-s3′}.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: }\textit{which}\\ \text{arg: [person x] }\emptyset\\ \text{mdd: [dog 14)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 15}\end{bmatrix}\begin{bmatrix}\text{sur: saw}\\ \text{verb: see}\\ \text{cat: n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{verb: see}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: }\textit{which}\text{ ind past}\\ \text{arg: [person x] }\emptyset\\ \text{mdd: [dog 14)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 15}\end{bmatrix}$$

The simultaneous substitution of the variable v_1 with see applies to all instances, here also to the one in the initial proplet (3.4.2, line 4).

The hear mode derivation has now interpreted The dog which Mary saw. It remains to complete the main clause The dog ... barked. Provided by automatic word form recognition, barked as the trigger proplet activates the operation SBJ×PRD by matching its second input pattern. Its first input pattern finds matching *dog* at the now front and applies (data driven):

3.4.7 CROSS-COPYING *dog* AND *barked* WITH SBJ×PRD (line 5)

SBJ×PRD (h1)

pattern level

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP}'\text{ X v}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ X v}\\ \text{arg: }\alpha\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.2.

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: dog}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc}\\ \text{mdr: (see 15)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 14}\end{bmatrix}\Uparrow\begin{bmatrix}\text{sur: barked}\\ \text{verb: bark}\\ \text{cat: n}'\text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\qquad\begin{bmatrix}\text{sur:}\\ \text{noun: dog}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc: bark}\\ \text{mdr: (see 13)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 14}\end{bmatrix}\Downarrow\begin{bmatrix}\text{sur: barked}\\ \text{verb: bark}\\ \text{cat: \#n}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: dog}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 14}\end{bmatrix}$$

Like an elementary or phrasal noun, the dog which saw Mary may serve not only as a subject, but also as a direct object, e.g. Bill fed the dog which saw Mary, or as an indirect object, e.g. Bill gave the dog which saw Mary to Suzy.

The hear mode derivation 3.4.2 is completed with an application of S∪IP:

3.4.8 ABSORBING • INTO *bark* WITH **S∪IP**

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#X}'\text{ VT}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: V\_}n\\ \text{cat: VT}'\text{ SM}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#X}'\text{ SM}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: bark}\\ \text{cat: \#n}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [dog y]}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 14}\end{bmatrix}\Uparrow\begin{bmatrix}\text{sur: }\bullet\\ \text{verb: v\_1}\\ \text{cat: v}'\text{ decl}\\ \text{sem:}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\qquad\Downarrow\begin{bmatrix}\text{sur:}\\ \text{verb: bark}\\ \text{cat: \#n}'\text{ decl}\\ \text{sem: ind past}\\ \text{arg: [dog y]}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 14}\end{bmatrix}$$

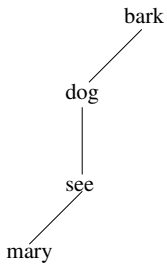
The hear mode derivation of a clausal adnominal modifier with object gap is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

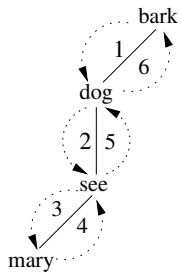
3.4.9 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE

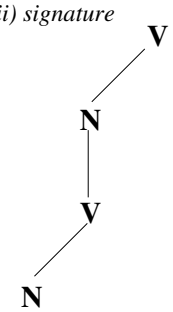
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

1	2	3	4	5	6	
The_dog	which	Mary	saw		barked_	.
V/N	N|V	V/N	N/V	V|N	N/V	

The modifier role of the relative clause is shown graphically by the | line between *see* and *dog*. The object gap is shown by the absent object\predicate branch below *see* (NLC 7.3.1). The arc numbering is depth-first.

Word form production is summarized as the following list of speak mode operations:

3.4.10 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *bark* to *dog*	The_dog	3.4.11
arc 2:	N↓V	from *dog* to *see*	which	3.3.12
arc 3:	V↘N	from *see* to *mary*	mary	3.3.13
arc 4:	N↖V	from *mary* to *see*	saw	3.3.14
arc 5:	V↑N	from *see* to *dog*		3.3.15
arc 6:	N↗V	from *dog* to *bark*	barked_.	3.3.16

The navigation begins with V↙N, traveling from the top verb to the subject and realizing its surface. For this operation application it makes no difference

whether or not the goal proplet serves as the modified of a clausal adnominal modifier. This is because the semantic relations between proplets are strictly binary (1.2.1, 1.2.2), such that a V↙N traversal of arc 1, for example, is unaffected by a subsequent N↓V traversal of arc 2 (compatibility by omission).

The complete sequence of explicit navigation operations begins with V↙N:

3.4.11 **<to-do 6>**

NAVIGATING WITH V↙N FROM *bark* TO *dog* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: bark} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: dog} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 14}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: The\_dog} \\ \text{noun: dog} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: bark} \\ \text{mdr: (see 15)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 14}\end{bmatrix}$$

The lexicalization rule lexnoun in the sur slot of the output pattern realizes the surface The_ dog from the core and sem values of the output proplet.

The next operation N↓V has V↑N (3.3.15) as its counterpart. Both use the relation of modification and connect the adnominal subclause extrapropositionally with the head noun in the main clause, but differ in their direction:

3.4.12 NAVIGATING WITH N↓V FROM *dog* TO *see* (arc 2)

N↓V (s15)

pattern level

$$\begin{bmatrix}\text{noun: } \alpha \\ \text{mdr: } (\beta\ \text{K+1}) \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{mdd: } (\alpha\ \text{K}) \\ \text{prn: K+1}\end{bmatrix}$$

#-mark α in the mdd slot of proplet β.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: dog} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: bark} \\ \text{mdr: (see 15)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 14}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: which} \\ \text{verb: see} \\ \text{cat: \#n}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{which} \text{ ind past} \\ \text{arg: [person x] } \emptyset \\ \text{mdd: [dog 14)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 15}\end{bmatrix}$$

The vertical matching and binding between the mdr variable (β K+1) and the continuation value (see 15) is a prerequisite for N↓V to apply successfully. The same holds for the incremented prn value 15, which was assigned by the hear mode operation NP×PRD$^{who(m)}$ in 3.4.4 and is now required by the patterns [mdr: (β K+1)] and [prn: K+1]. Using the features [sem: *which* ind past] and [arg: ∅ [person x]], lexverb realizes which.

After reaching the verb of the adnominal subclause, the navigation travels with intrapropositional V↘N to the object and realizes the surface Mary:

3.4.13 Navigating with V↘N from *see* to *mary* (arc 3)

V↘N (s3)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: } \ddot{\text{K}}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: see} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x] } \emptyset \\ \text{mdd: \#[dog 14)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 15}\end{bmatrix} \quad \begin{bmatrix}\text{sur: Mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: see} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 15}\end{bmatrix}$$

To complete the traversal of the adnominal subclause, standard N↖V returns from the lower object *mary* to the lower predicate *see*.

3.4.14 Navigating with N↖V from *mary* back to *see* (arc 4)

N↖V (s4)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: } \ddot{\text{K}}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: see} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 15}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: see} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] } \emptyset \\ \text{mdd: \#[dog 14)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 14}\end{bmatrix}$$

The traversal is ‘empty’ in the sense that no surface is produced by lexverb.

The next navigation step uses V↑N to return from the subclause verb *see* with the prn value 15 to the head noun *dog* in the main clause with the prn value 14:

3.4.15 NAVIGATING WITH V↑N FROM *see* BACK TO *dog* (arc 5)

V↑N (s16)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{mdd: \#}(\alpha\ \text{K}) \\ \text{prn: K+1}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{mdr: \#}(\beta\ \text{K+1}) \\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: see} \\ \text{cat: \#n}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{which} \text{ ind past} \\ \text{arg: \#[person x] } \emptyset \\ \text{mdd: \#[dog 14)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 15}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{noun: dog} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: bark} \\ \text{mdr: \#(see 15)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 14}\end{bmatrix}$$

The continuation value used by the operation is the mdd value #[dog 14).

Finally, the navigation returns from the head noun of the adnominal subclause to the top verb *bark*, completing the think-speak mode derivation:

3.4.16 NAVIGATING WITH N↗V FROM *dog* BACK TO *bark* (arc 6)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{Y} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is #-marked or NIL.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: dog} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: bark} \\ \text{mdr: \#(see 15)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 14}\end{bmatrix} \quad \begin{bmatrix}\text{sur: barked\_}\bullet \\ \text{verb: bark} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#dog} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 14}\end{bmatrix}$$

Lexverb uses the core value bark, the sem value ind past, the #-marking of the initial arg value, and the cat value decl(arative) of the goal proplet to realize the surface of the top verb together with the punctuation sign.

The DBS 10 extension of DBS.8 to a clausal adnominal modifier with an object gap required the definition of the hear mode operation $\text{PRD}^{who(m)} \cup \text{PRD}$ (h18), and of the speak mode operations N↓V (s15) and V↑N (s16). The hear and the speak mode derivation used six operation applications each.

3.4.17 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

	1		2		3		4		5		6	
The	∪	dog	×	which	×	Mary	∪	saw	×	barked	∪	.

speak mode:

1		2		3		4		5	6	
V↙N	The_dog	N↓V	which	V↘N	Mary	N↖V	saw	V↑N	N↗V	barked_.

The hear mode derivation runs straight through. The speak mode derivation has one empty traversal.

3.5 DBS.11: Clausal Adverbial Modification

Clausal adverbial modification complements the DBS analysis of clausal adnominal modification presented in Sects. 3.3 (subject gap) and 3.4 (object gap). In comparison, clausal adverbial modification has (i) no gap and (ii) a relatively free word order.

The following example shows two surface variants for the same content. The derivation of the variant in which the subclause precedes the main clause requires suspension; of the variant in which it follows, absorption is sufficient:

3.5.1 **<to-do 1>**

CONTENT[16] OF When Fido barked Mary laughed. AND
Mary laughed when Fido barked .

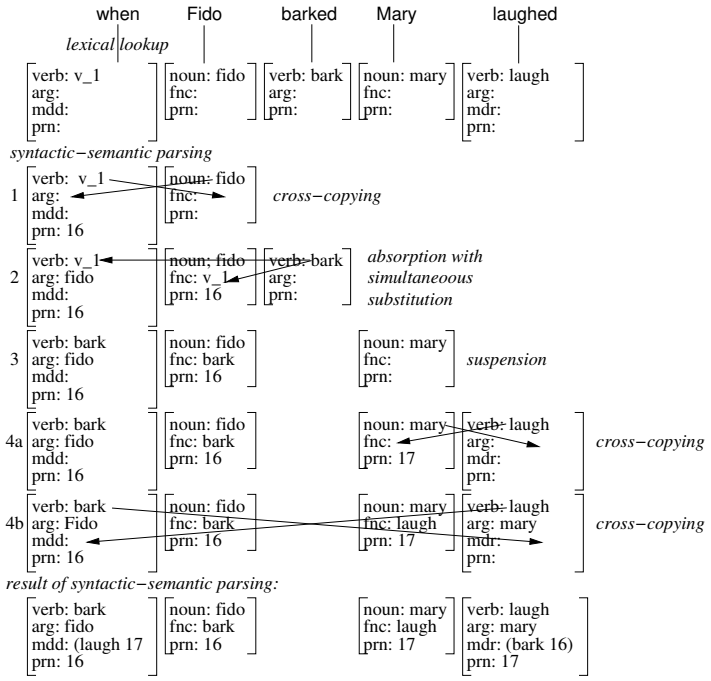
sur:	sur: fido	sur:	sur: mary
verb: bark	noun: [dog y]	verb: laugh	noun: [person x]
cat: #n′ v	cat: snp	cat: #n′ decl	cat: snp
sem: *when* ind past	sem: nm m	sem: ind past	sem: nm f
arg: [dog y]	fnc: bark	arg: [person x]	fnc: laugh
mdd: (laugh 17)	mdr:	mdr: (bark 16)	mdr:
mdr:	nc:	nc:	nc:
nc:	pc:	pc:	pc:
pc:	prn: 16	prn: 17	prn: 17
prn: 16			

If the subclause precedes, there exists no semantic relation between the subclause verb barked and the main clause subject mary. This requires a suspension (line 3):

[16] To be neutral with respect to the two surfaces, the order-free proplets of their shared content are shown in the alphabetical order of their core values (and not in the derivation order of the hear mode).

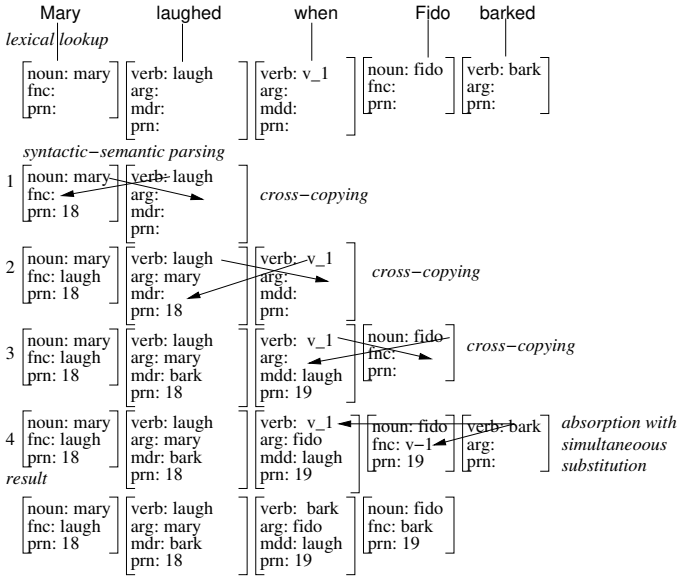
3.5.2 **<to-do 2>**

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION



If the subclause follows the main clause, the position of when between laugh and bark supports cross-copying in line 3 and absorption in line 4:

3.5.3 INTERPRETATION OF Mary laughed when Fido barked



The complete sequence of explicit hear mode operations begins with PRD$^{\text{opt}}\times$SBJ:

3.5.4 **<to-do 3>**

CROSS-COPYING *When* AND *fido* WITH PRD$^{\text{opt}}\times$SBJ (line 1)

PRD$^{\text{opt}}\times$SBJ (h36)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\gamma\\ \text{arg:}\\ \text{mdd:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{fnc:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\gamma\\ \text{arg: }\beta\\ \text{mdd:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{fnc: V\_}n\\ \text{prn: K}\end{bmatrix}$$

$\gamma \in$ {what, when, where, how, why}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: When}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: }\textit{when}\\ \text{arg:}\\ \text{mdd:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 16}\end{bmatrix}\begin{bmatrix}\text{sur: Fido}\\ \text{noun: [dog y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat: snp}\\ \text{sem: }\textit{when}\\ \text{arg: [dog y]}\\ \text{mdd:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 16}\end{bmatrix}\begin{bmatrix}\text{sur: fido}\\ \text{noun: [dog y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc: v\_1}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 16}\end{bmatrix}$$

3.5.5 ABSORBING *bark* INTO *when* WITH PRD$^{\text{opt}}\cup$PRD (LINE 2)

PRD$^{opt}\cup$PRD (h53)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: }\gamma\\ \text{arg: }\beta\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP' X v}\\ \text{sem: }\gamma\\ \text{arg:}\\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP' X v}\\ \text{sem: }\gamma\text{ Y}\\ \text{arg: }\beta\\ \text{prn: K}\end{bmatrix}$$

$\gamma \in$ {what, when, where, how, why}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: }\textit{when}\\ \text{arg: [dog y]}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 16}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: bark}\\ \text{cat: n}'\text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 16}\end{bmatrix} \quad \begin{bmatrix}\text{sur:}\\ \text{verb: bark}\\ \text{cat: \#n}'\text{ v}\\ \text{sem: }\textit{when}\text{ ind past}\\ \text{arg: [dog y]}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 16}\end{bmatrix}$$

At this point, the time-linear hear mode derivation has interpreted the input up to When Fido barked.

The next proplet provided by automatic word form recognition is the main clause subject *mary*. It is added to the set of proplets at the current now front by suspension:

3.5.6 SUSPENDING *bark* AND *mary* WITH PRD$^{\text{opt}}\sim$SBJ (line 3)

PRD$^{\text{opt}}\sim$SBJ (h54)

pattern level

$$\begin{bmatrix}\text{verb: }\beta\\ \text{sem: }\gamma\text{ Z}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{verb: }\beta\\ \text{sem: }\gamma\text{ Z}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{prn: K+1}\end{bmatrix}$$

$\gamma\ \epsilon$ {what, when, where, how, why}, NP ϵ {snp, pnp, s1, s3, p1, sp2, p3}.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: bark}\\ \text{cat: \#n}'\text{ v}\\ \text{sem: }\textit{when}\text{ ind past}\\ \text{arg: [dog y]}\\ \text{mdd:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 16}\end{bmatrix}\begin{bmatrix}\text{sur: Mary}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm f}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{verb: bark}\\ \text{cat: \#n}'\text{ v}\\ \text{sem: }\textit{when}\text{ ind past}\\ \text{arg: [dog y]}\\ \text{mdd:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 16}\end{bmatrix}\begin{bmatrix}\text{sur: mary}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm f}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 17}\end{bmatrix}$$

The suspension operation is limited to assigning a prn value to the second input proplet, albeit an incremented one.

The next word proplet *laugh* activates two hear mode operations, (i) standard SBJ$\times$PRD for the subject/predicate relation between *mary* and *laugh* in the main clause (line 4a) and (ii) PRD$^{when}\times$PRD for establishing the modifier|modified relation between the adverbial modifier clause and the higher predicate by cross-copying between *bark* and *laugh* (line 4b):

3.5.7 CROSS-COPYING *mary* AND *laugh* WITH SBJ$\times$PRD (line 4a)

SBJ$\times$PRD (h1)

pattern level

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP}'\text{ X v}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ X v}\\ \text{arg: }\alpha\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.2.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: mary}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm f}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 17}\end{bmatrix}\begin{bmatrix}\text{sur: laughed}\\ \text{verb: laugh}\\ \text{cat: n}'\text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur: mary}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm f}\\ \text{fnc: laugh}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 17}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: laugh}\\ \text{cat: \#n}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x]}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 17}\end{bmatrix}$$

Standard SBJ$\times$PRD is activated by matching the next word *laugh* with its second input pattern. It applies by finding *mary* at the now front matching its first input pattern. Thus, the preceding modifier clause is not in the picture.

The application of one operation does not prohibit the simultaneous application of another, here PRD$^{\text{opt}}\times$PRD (line 4b). Like SBJ$\times$PRD, it is activated

by the next word *laugh* matching its second input pattern. Unlike SBJ×PRD, PRD^{opt}×PRD finds *bark* at the now front matching its first input pattern:

3.5.8 CROSS-COPYING *bark* AND *laugh* WITH PRD^{opt}×PRD (line 4b)

PRD^{opt}×PRD (h7)

pattern level

$$\begin{bmatrix}\text{verb: }\alpha\\ \text{mdd:}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\beta\\ \text{mdr:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\begin{bmatrix}\text{verb: }\alpha\\ \text{mdd: }(\beta\text{ K+1})\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\beta\\ \text{mdr: }(\alpha\text{ K})\\ \text{prn: K+1}\end{bmatrix}$$

$$\Uparrow\qquad\qquad\qquad\qquad\Downarrow$$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: bark}\\ \text{cat: \#n}'\text{ v}\\ \text{sem: }\textit{when}\text{ ind past}\\ \text{arg: [dog y]}\\ \text{mdd:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 16}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: laugh}\\ \text{cat: \#n}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x]}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{verb: bark}\\ \text{cat: \#n}'\text{ v}\\ \text{sem: }\textit{when}\text{ ind past}\\ \text{arg: [dog y]}\\ \text{mdd: (laugh 17)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 16}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: laugh}\\ \text{cat: \#n}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x]}\\ \text{mdr: (bark 16)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 17}\end{bmatrix}$$

In short, applying more than one operation in a single derivation step, here line 4a and 4b, does not require any special software provisions, but follows directly from the data-driven operation application in DBS.

At this point, the time-linear hear mode derivation has interpreted When Fido barked Mary laughed. The isolated linguistic example is completed by adding the period proplet **.**, which is supplied by automatic word form recognition (in the medium of writing):

3.5.9 ABSORBING **.** INTO *laugh* WITH S∪IP (LINE 5)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#X}'\text{ VT}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: V\_}n\\ \text{cat: VT}'\text{ SM}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#X}'\text{ SM}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

$$\Uparrow\qquad\qquad\qquad\Downarrow$$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: laugh}\\ \text{cat: \#n}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x]}\\ \text{mdr: (bark 16)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 17}\end{bmatrix}\begin{bmatrix}\text{sur: }\bullet\\ \text{verb: v\_1}\\ \text{cat: v}'\text{ decl}\\ \text{sem:}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\qquad\begin{bmatrix}\text{sur:}\\ \text{verb: laugh}\\ \text{cat: \#n}'\text{ decl}\\ \text{sem: ind past}\\ \text{arg:[person x]}\\ \text{mdr: (bark 16)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 17}\end{bmatrix}$$

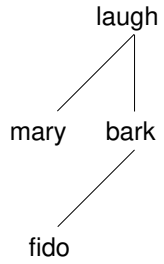
The hear mode derivation of a clausal adverbial modification is now complete.

Th DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

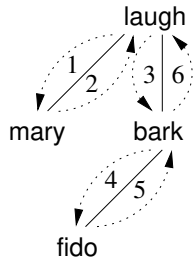
3.5.10 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE

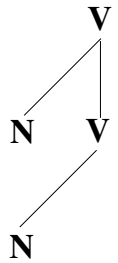
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

	1	2	3	4	5	6
(a)	Mary	laughed	when	Fido	barked	.
	V/N	N/V	V|V	V/N	N/V	V|V

	3	4	5	6	1	2
(b)	When	Fido	barked		Mary	laughed_.
	V|V	V/N	N/V	V|V	V/N	N/V

In variant (a) of the surface realization, the depth-first arc numbering is consecutive.

Word form production is summarized as the following list of speak mode operations:

3.5.11 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 3:	V↓V	from *laugh* to *bark*	When	3.5.12
arc 4:	V↙N	from *bark* to *fido*	Fido	3.5.13
arc 5:	N↗V	from *fido* to *bark*	barked	3.5.14
arc 6:	V↑V	from *bark* to *laugh*		3.5.15
arc 1:	V↙N	from *laugh* to *mary*	Mary	3.5.16
arc 2:	N↗V	from *mary* to *laugh*	laughed_.	3.5.17

The complete sequence of explicit navigation operations begins with V↓V. It resembles the first navigation step V↙V of the subject clause example 2.5.9 in that it moves from the top verb to the verb representing an initial subclause. They differ in that V↙N navigates to a clausal subject argument, while V↓V navigates to a clausal adverbial modifier.

3.5.12 **<to-do 6>**

NAVIGATING WITH V↓V FROM *laugh* TO *bark* (arc 3)

V↓V (s17)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{mdr: X } \beta \text{ Y} \\ \text{prn: K+1}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the mdd slot of proplet β.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: laugh} \\ \text{cat: \#n}' \text{ v} \\ \text{sem: ind past} \\ \text{arg: [person x]} \\ \text{mdr: (bark 16)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 17}\end{bmatrix} \quad \begin{bmatrix}\text{sur: When} \\ \text{verb: bark} \\ \text{cat: \#n}' \text{ v} \\ \text{sem: } \textit{when} \text{ ind past} \\ \text{arg: [dog y]} \\ \text{mdd: (laugh 17)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 16}\end{bmatrix}$$

3.5.13 NAVIGATING WITH V↙N FROM *bark* TO *fido* (arc 4)

V↙N (s1)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: } \beta \text{ X} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: bark} \\ \text{cat: \#n}' \text{ v} \\ \text{sem: } \textit{when} \text{ ind past} \\ \text{arg: [dog y]} \\ \text{mdd: \#(laugh 17)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 16}\end{bmatrix} \quad \begin{bmatrix}\text{sur: Fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: bark} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 16}\end{bmatrix}$$

3.5.14 NAVIGATING WITH N↗V FROM *fido* BACK TO *bark* (arc 5)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha \text{ Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta \text{ X} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: bark} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 16}\end{bmatrix} \quad \begin{bmatrix}\text{sur: barked} \\ \text{verb: bark} \\ \text{cat: \#n}' \text{ v} \\ \text{sem: } \textit{when} \text{ ind past} \\ \text{arg: \#[dog y]} \\ \text{mdd: (laugh 17)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 16}\end{bmatrix}$$

3.5.15 NAVIGATING WITH V↑V FROM *bark* BACK TO *laugh* (arc 6)

V↑V (s18)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{mdd: X \#}\beta\text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{mdr: } \alpha \\ \text{prn: K+1}\end{bmatrix}$$

#-mark α in the mdr slot of proplet β.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: bark} \\ \text{cat: \#n}' \text{ v} \\ \text{sem: } \textit{when} \text{ ind past} \\ \text{arg: \#[dog y]} \\ \text{mdd: \#(laugh 17)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 16}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: laugh} \\ \text{cat: \#n}' \text{ v} \\ \text{sem: ind past} \\ \text{arg: [person x]} \\ \text{mdr: (bark 16)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 17}\end{bmatrix}$$

3.5.16 NAVIGATING WITH V↙N FROM *laugh* TO *Mary* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: } \beta\text{ X} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: laugh} \\ \text{cat: \#n}' \text{ v} \\ \text{sem: ind past} \\ \text{arg: [person x]} \\ \text{mdr: \#(bark 16)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 17}\end{bmatrix} \quad \begin{bmatrix}\text{sur: Mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: laugh} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 17}\end{bmatrix}$$

3.5.17 NAVIGATING WITH N↗V FROM *Mary* BACK TO *laugh* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\text{ Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\text{ X} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: laugh} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 17}\end{bmatrix} \quad \begin{bmatrix}\text{sur: laughed\_}\bullet \\ \text{verb: laugh} \\ \text{cat: \#n}' \text{ v} \\ \text{sem: ind past} \\ \text{arg: \#[person x]} \\ \text{mdr: \#(bark 16)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 17}\end{bmatrix}$$

Extending DBS.10 to an example class with clausal adverbial modification required the definition of four additional operations, namely $\mathsf{PRD}^{opt}{\sim}\mathsf{SBJ}$ (h54) and $\mathsf{PRD}^{opt}{\times}\mathsf{PRD}$ (h7) for the hear mode, and $\mathsf{V}{\downarrow}\mathsf{V}$ (s17) and $\mathsf{V}{\uparrow}\mathsf{V}$ (s18) for the think-speak mode. Counting the suspension in line 3 and its compensations in lines 4a and 4b, the hear mode derivation used six operation applications, just like the speak mode derivation:

3.5.18 COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

	1		2		3		4a	4b		5	
When	×	Fido	∪	barked	∼	Mary	×	×	laughed	∪	•

speak mode:

3		4		5		6	1		2	
V↓V	When	V↙N	Fido	N↗V	barked	V↑V	V↙N	Mary	N↗V	laughed_•

The numbering of the speak mode operations corresponds to the arcs traversed in 3.5.10. There is one suspension in the hear mode derivation and one empty traversal in the speak mode derivation.

3.6 DBS.12: Coordination

The functor-argument relations of subject/predicate, object\predicate, adnominal|noun, and adverbial|verb, at the elementary, phrasal, and clausal levels of grammatical complexity combine a 'lower' proplet with a 'higher' one (hypotaxis). The conjunct–conjunct relation, in contrast, combines two proplets at the same level (parataxis), intra- and extrapropositionally.

Consider the following example of an intrapropositional noun coordination serving as a subject and its content as a set of proplets concatenated by address:

3.6.1 **<to-do 1>**
CONTENT OF Fido, Tucker, and Buster snored loudly.

sur: fido	sur: tucker	sur: buster	sur:	sur:
noun: [dog x]	noun: [dog y]	noun: [dog z]	verb: snore	adj: loud
cat: snp	cat: snp	cat: snp	cat: #n′ decl	cat: adv
sem: nm m	sem: nm m	sem: *and* nm m	sem: ind past	sem: pad
fnc: snore	fnc:	fnc:	arg: [dog y]	mdd: snore
mdr:	mdr:	mdr:	mdr: loud	mdr:
nc: [dog y]	nc: [dog z]	nc:	nc:	nc:
pc:	pc: [dog x]	pc: [dog y]	pc:	pc:
prn: 18@	prn: 18	prn: 18	prn: 18	prn: 18

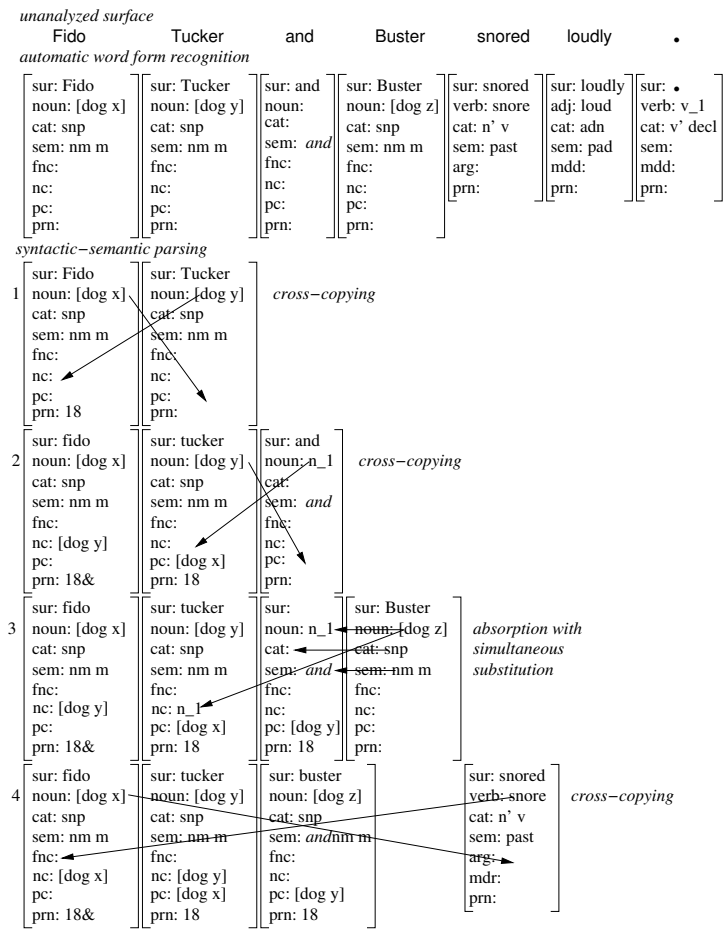
The connection between the conjuncts is coded by the nc (next conjunct) and pc (previous conjunct) values: the first conjunct points forward to the second

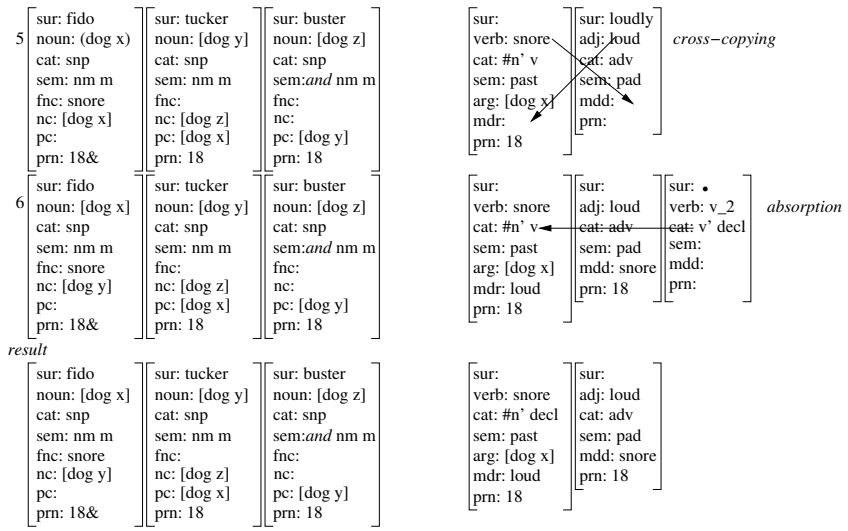
conjunct via its nc value, the second conjunct points forward to the third via its nc value and backward to the first via its pc value. The initial conjunct has an empty pc slot, just as the final conjunct has an empty nc slot.

A chain of conjuncts is integrated into the functor-argument structure by using only the initial conjunct with an @-marked prn value (NLC Sects. 8.2, 8.3). For example, the core value of the @-marked *fido* proplet appears in the arg slot of *snore* and the core value of *snore* appears in the fnc slot of the *fido* proplet. The core values of the non-initial conjunct proplets *tucker* and *buster*, in contrast, do not appear in the arg slot of *snore* and snore does not appear in the fnc slots of the non-initial *tucker* and *buster* proplets. To find the modified or the predicate of a non-initial conjunct, the search has to go to the initial conjunct by moving back the chain (NLC Sect. 8.1, last paragraph).

3.6.2 **<to-do 2>**

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION





The subject is a noun coordination. The conjuncts consist of name proplets. The verb is one-place and is modified by a clause-final elementary adverb. The apparent distance between the subject and the verb in line 4 is not a problem because proplets at the now front are order-free and accessed by string search of their attributes and values, and not by location.

The conjunction and specifies the kind of coordination (e.g. and vs. or) and announces the arrival of the last conjunct.[17] Suspension is avoided by analyzing and as a proplet shell which absorbs the final conjunct. Because absorption requires the slot and the filler proplet to be of the same grammatical kind, coordination words have three lexical proplet variants, such as the following:

3.6.3 Three lexical variants of the function word and

noun	*verb*	*adj*
sur:	sur:	sur:
noun: α	verb: α	adj: α
cat:	cat:	cat:
sem: *and*	sem: *and*	sem: *and*
fnc: β	arg: β	mdd: β
mdr:	mdr:	mdr:
nc:	nc:	nc:
pc:	pc:	pc:
prn:	prn:	prn:

For example, the variant used in 3.6.2, line 2, is noun, in 5.2.3, line 7, verb, in 5.3.2, line 7, noun, and in 5.4.5, line 4, verb.

[17] The conjunction but not may initiate a second coordination, as in Fido, Tucker, and Buster, but not Bailey, Molly, and Daisy.

The complete sequence of explicit hear mode operation applications begins with the coordination of the conjuncts Fido and Tucker, provided by automatic word form recognition. The initial coordination operation is called $\mathsf{N}_1 \times \mathsf{N}$.

3.6.4 **<to-do 3>**

CROSS-COPYING *fido* AND *tucker* WITH $\mathsf{N}_1 \times \mathsf{N}$ (line 1)

$$
\begin{array}{lcccccc}
 & \mathbf{N}_1 \times \mathbf{N}\ \text{(h41)} & & & & & \\
\textit{pattern level} & \begin{bmatrix}\text{noun: } \alpha \\ \text{nc:} \\ \text{pc:} \\ \text{prn: K}\end{bmatrix} & \begin{bmatrix}\text{noun: } \beta \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} & \Rightarrow & \begin{bmatrix}\text{noun: } \alpha \\ \text{nc: } \beta \\ \text{pc:} \\ \text{prn: K@}\end{bmatrix} & \begin{bmatrix}\text{noun: } \beta \\ \text{nc:} \\ \text{pc: } \alpha \\ \text{prn: K}\end{bmatrix} \\
 & & \Uparrow & & & \Downarrow & \\
\textit{content level} & \begin{bmatrix}\text{sur: Fido} \\ \text{noun: [dog x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 18}\end{bmatrix} & \begin{bmatrix}\text{sur: Tucker} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} & & \begin{bmatrix}\text{sur: fido} \\ \text{noun: [dog x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc: [dog y]} \\ \text{pc:} \\ \text{prn: 18@}\end{bmatrix} & \begin{bmatrix}\text{sur: tucker} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc: [dog x]} \\ \text{prn: 18}\end{bmatrix}
\end{array}
$$

The operation cross-copies the core values into the respective nc and pc slots of the first two conjuncts and marks the prn value of the initial conjunct with @ (because only the initial conjunct will be connected to the functor-argument structure, NLC 8.1.4).

If there are more than two conjuncts in a noun coordination, the nonfinal ones are connected by a coordination operation called $\mathsf{N} \times \mathsf{N}$, which resembles $\mathsf{N}_1 \times \mathsf{N}$ except that no @-marker is introduced. The coordination of verbs and adjectives is based on similar operations, though with different core attributes.

In the hear mode, the approaching end of a coordination is announced by a coordinating conjunction, such as and or or. Because the conjuncts must all be of the same grammatical kind, here noun, the core attribute of the conjunction is already known at this point. This allows to choose the variant of the conjunction (3.6.3) which is required for absorbing the final conjunct in 3.6.6.

3.6.5 CROSS-COPYING *tucker* AND *and* WITH $\mathsf{N} \times \mathsf{CNJ}^{\mathsf{N}}$ (line 2)

$$
\begin{array}{lcccccc}
 & \mathbf{N} \times \mathbf{CNJ}^{\mathbf{N}}\ \text{(h42)} & & & & & \\
\textit{pattern level} & \begin{bmatrix}\text{noun: } \alpha \\ \text{sem: X} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: K}\end{bmatrix} & \begin{bmatrix}\text{noun: N\_}n \\ \text{sem: } \beta \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} & \Rightarrow & \begin{bmatrix}\text{noun: } \alpha \\ \text{sem: X} \\ \text{nc: N\_}n \\ \text{pc:} \\ \text{prn: K}\end{bmatrix} & \begin{bmatrix}\text{noun: N\_}n \\ \text{sem: } \beta \\ \text{nc:} \\ \text{pc: } \alpha \\ \text{prn: K}\end{bmatrix} \\
 & \beta \in \{\text{and, or}\} & & & & & \\
 & & \Uparrow & & & \Downarrow &
\end{array}
$$

content level

sur: tucker	sur: and	sur: tucker	sur:
noun: [dog y]	noun: N_*n*	noun: [dog y]	noun: n_1
cat: snp	cat:	cat: snp	cat:
sem: nm m	sem: *and*	sem: nm m	sem: *and*
fnc:	fnc:	fnc:	fnc:
mdr:	mdr:	mdr:	mdr:
nc:	nc:	nc: n_1	nc:
pc:	pc:	pc:	pc: [dog y]
prn: 18	prn:	prn: 18	prn: 18

The operation CNJ∪N absorbs the final conjunct into the coordination:

3.6.6 ABSORBING *buster* INTO *and* WITH CNJ∪N (line 3)

SBJ^{and}**∪SBJ** (h50)

pattern level

noun: N_*n*	noun: α		noun: α
sem: β	sem: X	⇒	sem: β X
prn: K	prn:		prn: K

$\beta \in$ {and, or}

⇑ ⇓

content level

sur:	sur: Buster	sur: buster
noun: n_1	noun: [dog z]	noun: [dog z]
cat:	cat: snp	cat: snp
sem: *and*	sem: nm m	sem: *and* nm m
fnc:	fnc:	fnc:
mdr:	mdr:	mdr:
nc:	nc:	nc:
pc: [dog y]	pc:	pc: [dog y]
prn: 18	prn:	prn: 18

In line 3, the absorption discards the original buster proplet, as shown in line 4.

Next, automatic word form recognition provides the finite verb form snored as the trigger proplet which activates standard SBJ×PRD by matching its second input pattern:

3.6.7 CROSS-COPYING *fido* AND *snored* WITH SBJ×PRD (line 4)

SBJ×PRD (h1)

pattern level

noun: α	verb: β	noun: α	verb: β
cat: NP	cat: NP′ X v	cat: NP	cat: #NP′ X v
fnc:	arg:	fnc: β	arg: α
prn:K	prn:	prn: K	prn: K

Agreement conditions as in 2.1.2.

⇑ ⇓

content level

sur: fido	sur: snored	sur: fido	sur:
noun: [dog y]	verb: snore	noun: [dog y]	verb: snore
cat: snp	cat: n′ v	cat: snp	cat: #n′ v
sem: nm m	sem: ind pres	sem: nm m	sem: ind past
fnc:	arg:	fnc: snore	arg: [dog y]
nc: [dog y]	prn:	nc: [dog y]	prn: 18
pc:		pc:	
prn: 18@		prn: 18@	

Because the subject is a noun coordination, the operation SBJ×PRD cross-

copies only the initial conjunct, recognizable by its empty pc slot and @-marker of the prn value, into the initial arg slot of the verb,

The optional elementary adj loudly provided by automatic word form recognition is added with FV×ADV:

3.6.8 CROSS-COPYING *snore* AND loudly WITH FV×ADV (line 5)

FV×ADV (h56)

pattern level

$$\begin{bmatrix}\text{verb: } \gamma\\ \text{mdr: X}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{adj: } \alpha\\ \text{cat: ADV}\\ \text{mdd:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{verb: } \gamma\\ \text{mdr: X ! } \alpha\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{adj: } \alpha\\ \text{cat: ADV}\\ \text{mdd: } \gamma\\ \text{prn: K}\end{bmatrix}$$

ADV ϵ {adv, adnv}

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: snore}\\ \text{cat: \#n}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [dog y]}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 18}\end{bmatrix}\Uparrow\begin{bmatrix}\text{sur: loudly}\\ \text{adj: loud}\\ \text{cat: adv}\\ \text{sem: pad}\\ \text{mdd:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\qquad\begin{bmatrix}\text{sur:}\\ \text{verb: snore}\\ \text{cat: \#n}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [dog y]}\\ \text{mdr: loud}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 18}\end{bmatrix}\Downarrow\begin{bmatrix}\text{sur:}\\ \text{adj: loud}\\ \text{cat: adv}\\ \text{sem: pad}\\ \text{mdd: snore}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 18}\end{bmatrix}$$

The hear mode derivation of this isolated linguistic example concludes by adding the interpunctuation with S∪IP:

3.6.9 ABSORBING • INTO *snore* WITH S∪IP (line 6)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: } \beta\\ \text{cat: \#X}'\text{ VT}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: V\_}n\\ \text{cat: VT}'\text{ SM}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{verb: } \beta\\ \text{cat: \#X}'\text{ SM}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

content level

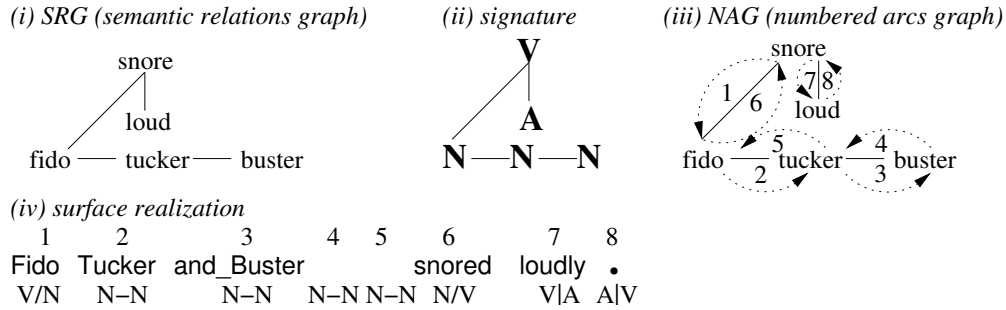
$$\begin{bmatrix}\text{sur:}\\ \text{verb: snore}\\ \text{cat: \#n}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [dog y]}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 18}\end{bmatrix}\Uparrow\begin{bmatrix}\text{sur: } \bullet\\ \text{verb: v\_1}\\ \text{cat: v}'\text{ decl}\\ \text{sem:}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\qquad\Downarrow\begin{bmatrix}\text{sur:}\\ \text{verb: snore}\\ \text{cat: \#n}'\text{ decl}\\ \text{sem: ind past}\\ \text{arg: [dog y]}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 18}\end{bmatrix}$$

The hear mode derivation of an elementary nominal coordination is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

3.6.10 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE



The depth-first numbering of the NAG results in a consecutive numbering in the surface realization.

Word form production is summarized as the following list of speak mode operations:

3.6.11 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *snore* to *fido*	Fido	3.6.12
arc 2:	N→N	from *fido* to *tucker*	Tucker	3.6.13
arc 3:	N→N	from *tucker* to *buster*	and_Buster	3.6.14
arc 4:	N←N	from *buster* to *tucker*		3.6.15
arc 5:	N←N	from *tucker* to *fido*		3.6.16
arc 6:	N↗V	from *fido* to *snore*	snored	3.6.17
arc 7:	V↓A	from *snore* to *loud*	loudly	3.6.18
arc 8:	A↑V	from *loud* to *snore*	•	3.6.19

The next to-do is the complete sequence of explicit think-speak mode operation applications. It begins with the traversal of arc 1 with standard V↙N:

3.6.12 **<to-do 6>**

NAVIGATING WITH V↙N FROM *snore* TO *fido* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: snore} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [dog y]} \\ \text{mdr: loud} \\ \text{prn: 18} \end{bmatrix} \qquad \begin{bmatrix} \text{sur: Fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: snore} \\ \text{mdr:} \\ \text{nc: [dog y]} \\ \text{pc:} \\ \text{prn: 18@} \end{bmatrix}$$

The prn variable K of the goal proplet matches the constant 18@ because the @-marker (which was provided by the hear mode) is asymmetric (1.6.5, 4).

Using the continuation feature [nc: [dog y]] of the goal proplet, the navigation enters the coordination and traverses arc 2 with the operation N→N:

3.6.13 NAVIGATING WITH N→N FROM *fido* TO *tucker* (arc 2)

N→N (s23)

pattern level

$$\begin{bmatrix} \text{noun: } \alpha \\ \text{nc: } \beta \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{pc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur: fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc:} \\ \text{nc: [dog y]} \\ \text{pc:} \\ \text{prn: 18@} \end{bmatrix} \quad \begin{bmatrix} \text{sur: Tucker} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc:} \\ \text{nc: [dog z]} \\ \text{pc: [dog y]} \\ \text{prn: 18} \end{bmatrix}$$

Lexnoun in the sur slot of the output proplet uses the name marker tucker (hidden by the lex-rule) for realizing the surface Tucker.

The operation N→N uses the continuation feature [nc: [dog z]] of the above goal proplet to traverses arc 3:

3.6.14 NAVIGATING WITH N→N FROM *tucker* TO *buster* (arc 3)

N→N (s23)

pattern level

$$\begin{bmatrix} \text{noun: } \alpha \\ \text{nc: } \beta \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{pc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur: tucker} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc: [dog z]} \\ \text{pc: [dog y]} \\ \text{prn: 18} \end{bmatrix} \quad \begin{bmatrix} \text{sur: and\_Buster} \\ \text{noun: [dog z]} \\ \text{cat: snp} \\ \text{sem: } \textit{and} \text{ nm m} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc: [dog y]} \\ \text{prn: 18} \end{bmatrix}$$

As a name, the sur slot of the goal proplet contains the marker 'buster.' Together with the initial sem value *and*, it is used by lexnoun to realize the surface and_Buster.

At this point, the navigation has traversed the proplets *fido tucker buster* via their nc values and the end of the coordination has been reached. This is shown

by the goal proplet having neither an mdr nor an nc continuation value. To return to the top verb, the think-speak mode operation N←N applies as follows:

3.6.15 NAVIGATING WITH N←N FROM *buster* BACK TO *tucker* (arc 4)

N←N (s24)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{pc: } \alpha \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{nc: } \beta \\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: [dog z]} \\ \text{cat: snp} \\ \text{sem: } \textit{and} \text{ nm m} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc: [dog y]} \\ \text{prn: 18}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc: [dog z]} \\ \text{pc: [dog y]} \\ \text{prn: 18}\end{bmatrix}$$

In contradistinction to N→N (3.6.13, 3.6.14), which uses the nc value of its start proplet to move forward, N←N uses the pc value of its start proplet to move backward. There is no surface realization.

To get back to the initial conjunct, N←N applies once more:

3.6.16 NAVIGATING WITH N←N FROM *tucker* BACK TO *fido* (arc 5)

N←N (s24)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{pc: } \alpha \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{nc: } \beta \\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc: [dog z]} \\ \text{pc: [dog y]} \\ \text{prn: 18}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: snore} \\ \text{mdr:} \\ \text{nc: [dog y]} \\ \text{pc:} \\ \text{prn: 18@}\end{bmatrix}$$

As the initial conjunct, the proplet *fido* provides the continuation value snore, enabling the operation N↗V to return to the predicate:

3.6.17 NAVIGATING WITH N↗V FROM *fido* BACK TO *snore* (arc 6)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha \text{ Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta \text{ X} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: snore} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 18\&}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: snored} \\ \text{verb: snore} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[dog y]} \\ \text{mdr: loud} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 18}\end{bmatrix}$$

The #-marking of the initial arg value resulted from the instruction in 3.6.13.

It remains to traverse and realize the adverbial loudly with the operation V↓A and to return to the verb to realize the period with the operation A↑V. The operations have been introduced in 3.1.13 and 3.1.14 with an example in which an elementary adverb is in sentence-initial position; here, in contrast, the elementary adverb is sentence-final.

3.6.18 NAVIGATING WITH V↓A FROM *snore* TO *loud* (arc 7)

V↓A (s9)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{mdr: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexadj}(\hat{\beta}) \\ \text{adj: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the mdr slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: snore} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[dog y]} \\ \text{mdr: loud} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 18}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: loudly} \\ \text{adj: loud} \\ \text{cat: adv} \\ \text{sem: pad} \\ \text{mdd: snore} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 18}\end{bmatrix}$$

To realize the punctuation sign and to enable a potential continuation to a next proposition (NLC Chap. 12), the navigation travels back to the predicate with A↑V:

3.6.19 NAVIGATING WITH A↑V FROM *loud* BACK TO *snore* (arc 8)

A↑V (s10)

pattern level

$$\begin{bmatrix} \text{adj: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{mdr: X } \beta \text{ Y} \\ \text{prn: K} \end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{adj: loud} \\ \text{cat: adv} \\ \text{sem: pad} \\ \text{mdd: snore} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 18} \end{bmatrix} \qquad \begin{bmatrix} \text{sur: } \bullet \\ \text{verb: snore} \\ \text{cat: \#n}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[dog y] mdr: \#loud} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 18} \end{bmatrix}$$

Using the cat value decl of *snore*, lexverb realizes the period.

Extending DBS.11 to an example class with an intrapropositional noun coordination required the definition of the four hear mode operations N×N (h29), N_1×N (h41), N×CNJ^N (h42), and CNJ∪N (h36), and the two speak mode operations N→N (s23) and N←N (s24). The hear mode derivation used six operation applications, and the speak mode derivation used eight:

3.6.20 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

1		2		3		4		5		6	
Fido	×	Tucker	×	and	∪	Buster	×	snored	×	loudly	∪	.

speak mode:

1		2		3		4	5
V↙N	Fido	N→N	Tucker	N→N	and_Buster	N←V	N←N

6		7		8	
N↗V	snored	V↓A	loudly	A↑V	.

In the hear mode, adding a conjunct requires one operation application (excepting the last one with the conjunction), but its speak mode production requires two.

4. Valency

The valency (Tesnière 1959) slots of a verb may take two kinds of obligatory filler (complement), (i) argument and (ii) modifier. For example, John crossed requires a 2nd argument such as the street in order to be complete; and Julia put the flowers requires an adverbial modifier such as on the table.

In DBS, the valency slots for arguments and modifiers are specified alike as cat values of lexical verb proplets. Filler values, in contrast, concatenate proplets into content by writing the arguments into the arg slot and the modifiers into the mdr slot of verbs. While arguments are obligatory, modifiers may be (a) obligatory or optional, and (b) adnominal or adverbial.

4.1 DBS.13: Phrasal Modifier in Obligatory Use

Whether an adverbial modifier is optional or obligatory depends on the verb. For example, the verb *put* takes a modifier as an obligatory complement, as in Julia put the flowers on the table: the construction is grammatically incomplete without the prepositional phrase on the table. A verb allowing the same prepositional phrase as an optional modifier is *eat*. For example, Fido ate the bone on the table (3.2.2) does not become grammatically incomplete if the prepositional phrase is omitted.

The following content shows *put* as a three place verb taking two arguments and one modifier as obligatory complements:

4.1.1 **<to-do 1>**

CONTENT OF Julia put the flowers on the table**.**

sur: julia	sur:	sur:	sur:
noun: [person x]	verb: put	noun: flower	noun: table
cat: snp	cat: #n′ #a′ #mdr′ decl	cat: pnp	cat: adnv snp
sem: nm f	sem: ind past	sem: def pl	sem: *on* def sg
fnc: put	arg: [person x] flower	fnc: put	mdd: put
mdr:	mdr: table	mdr:	mdr:
nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:
prn: 19	prn: 19	prn: 19	prn: 19

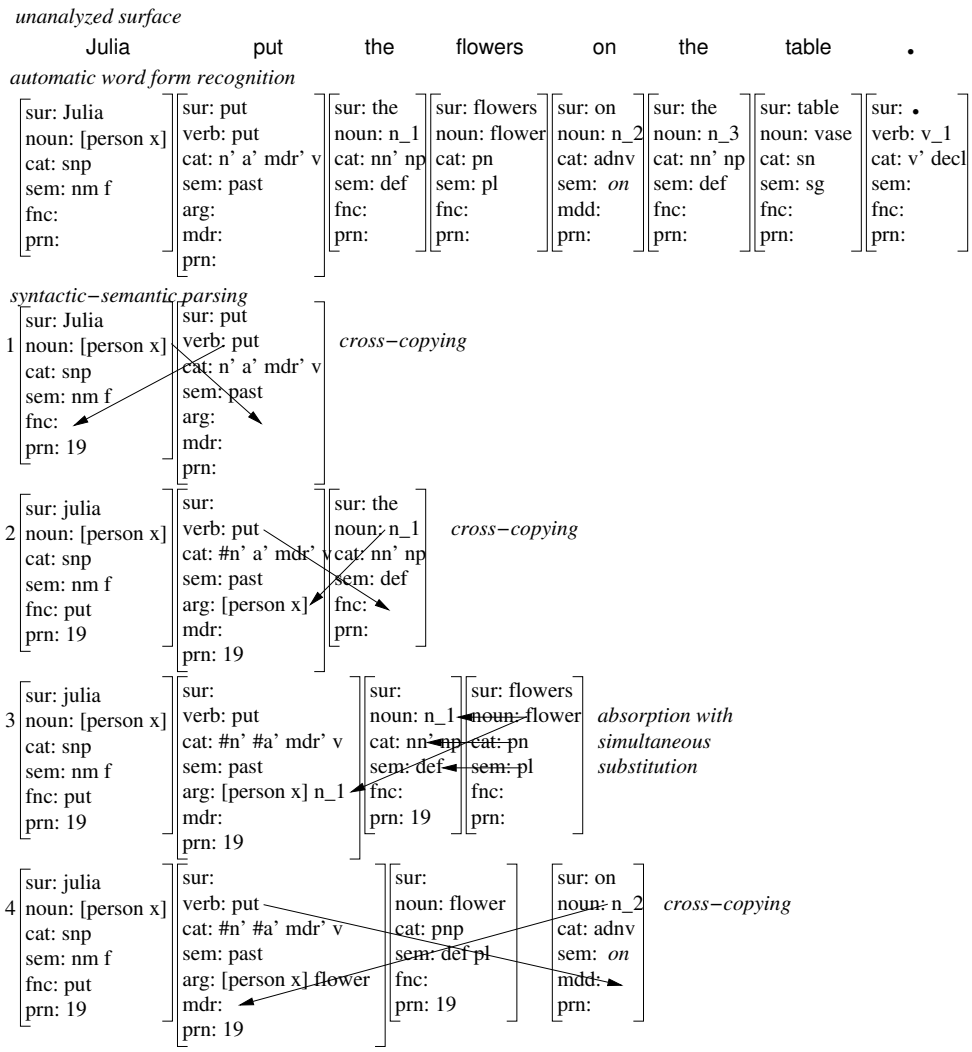
The connection between the verb and the prepositional phrase is based (i) on cross-copying, used for establishing obligatory as well as optional semantic relations, and (ii) on specifying and #-canceling valency positions in the cat slot of the valency carrier, which is limited to obligatory complements.

For example, in 4.1.1 there is an mdr′ valency position in the third cat slot of the verb. Writing the value table into the verb's mdr slot cancels this valency position by #-marking. Thus the lexical feature [cat: n′ a′ mdr′ v] of *put* ends up in 4.1.1 as [cat: #n′ #a′ #mdr′ decl].

As a first conceptual orientation consider the derivation graph:

4.1.2 **<to-do 2>**

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION



5	sur: julia noun: [person x] cat: snp sem: nm f fnc: put prn: 19	sur: verb: put cat: #n' #a' #mdr' v sem: past arg: [person x] flower mdr: n_2 prn: 19	sur: noun: flower cat: pnp sem: def pl fnc: prn: 19	sur: noun: n_2 cat: adnv sem: *on* mdd: put prn: 19	sur: the ~~noun:~~ n_3 ~~cat:~~ nn' np ~~sem:~~ def fnc: prn:	*absorption with simultaneous substitution*
6	sur: julia noun: [person x] cat: snp sem: nm f fnc: put prn: 19	sur: verb: put cat: #n' #a' #mdr' v sem: past arg: [person x] flower mdr: n_3 prn: 19	sur: noun: flower cat: pnp sem: def pl ~~fnc:~~ prn: 19	sur: noun: n_3 cat: adnv nn' np sem: *on* def mdd: put prn: 19	sur: table ~~noun:~~ table ~~cat:~~ sn ~~sem:~~ sg fnc: prn:	*absorption with simultaneous substitution*
7	sur: julia noun: [person x] cat: snp sem: nm f fnc: put prn: 19	sur: verb: put cat: #n' #a' #mdr' v sem: past arg: [person x] flower mdr: table prn: 19	sur: noun: flower ~~cat: pnp~~ sem: def pl fnc: prn: 19	sur: noun: table ~~cat: adnv nn' np~~ sem: *on* def sg mdd: put prn: 19	sur: • verb: v_1 ~~cat:~~ v' decl sem: ind arg: mdr: prn:	*absorption*
result	sur: julia noun: [person x] cat: snp sem: nm f fnc: put prn: 19	sur: verb: put cat: #n' #a' #mdr' decl sem: past arg: [person x] flower mdr: table prn: 19	sur: noun: flower cat: pnp sem: def pl fnc: prn: 19	sur: noun: table cat: adnv nn' np sem: *on* def sg mdd: put prn: 19		

The crucial step is in line 4. It consists in (i) the cross-copying between the verb and the preposition, and (ii) the concomitant canceling of the mdr′ valency position in the cat slot of *put* (result shown in line 5).

The complete sequence of explicit hear mode operation applications begins with SBJ×PRD:

4.1.3 **<to-do 3>**

CROSS-COPYING *julia* AND *put* WITH SBJ×PRD (line 1)

SBJ×PRD (h1)

pattern level

noun: α	verb: β		noun: α	verb: β
cat: NP	cat: NP′ X v	⇒	cat: NP	cat: #NP′ X v
fnc:	arg:		fnc: β	arg: α
prn:K	prn:		prn: K	prn: K

Agreement conditions as in 2.1.2.

⇑ ⇓

content level

sur: Julia	sur: put	sur: julia	sur:
noun: [person x]	verb: put	noun: [person x]	verb: put
cat: snp	cat: n′ a′ mdr′ v	cat: snp	cat: #n′ a′ mdr′ v
sem: nm f	sem: ind past	sem: nm f	sem: ind past
fnc:	arg:	fnc: put	arg: [person x]
mdr:	mdr:	mdr:	mdr:
nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:
prn: 19	prn:	prn: 19	prn: 19

4.1.4 Cross-copying *put* and *the* with PRD×OBJ (line 2)

PRD×OBJ (h28)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \underline{\#X'}\ \text{N}'\ \text{Y}\ \gamma \\ \text{arg: Z} \\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: } \alpha \\ \text{cat: CN}'\ \text{NP} \\ \text{fnc:} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \underline{\#X'}\ \#\text{N}'\ \text{Y}\ \gamma \\ \text{arg: Z}\ \alpha \\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: } \alpha \\ \text{cat: CN}'\ \text{NP} \\ \text{fnc: } \beta \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.3.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: put} \\ \text{cat: \#n}'\ \text{a}'\ \text{mdr}'\ \text{v} \\ \text{sem: ind past} \\ \text{arg: [person x]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 19}\end{bmatrix}\begin{bmatrix}\text{sur: the} \\ \text{noun: n\_1} \\ \text{cat: nn}'\ \text{np} \\ \text{sem: def} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{verb: put} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{mdr}'\ \text{v} \\ \text{sem: ind past} \\ \text{arg: [person x] n\_1} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 19}\end{bmatrix}\begin{bmatrix}\text{sur:} \\ \text{noun: n\_1} \\ \text{cat: nn}'\ \text{np} \\ \text{sem: def} \\ \text{fnc: put} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 19}\end{bmatrix}$$

4.1.5 Absorbing *flower* into *the* with DET∪CN (line 3)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n \\ \text{cat: CN}'\ \text{NP} \\ \text{sem: Y} \\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: } \alpha \\ \text{cat: CN} \\ \text{sem: Z} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: NP} \\ \text{sem: Y Z} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.2.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: n\_1} \\ \text{cat: nn}'\ \text{np} \\ \text{sem: def} \\ \text{fnc: put} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 19}\end{bmatrix}\begin{bmatrix}\text{sur: flowers} \\ \text{noun: flower} \\ \text{cat: pn} \\ \text{sem: pl} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{noun: flower} \\ \text{cat: pnp} \\ \text{sem: def pl} \\ \text{fnc: put} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 19}\end{bmatrix}$$

Up to this point, the hear mode derivation interpreted Julia put the flowers.

Next applies PRD×PREP^{obl}. Like PRD×PREP^{opt} (3.2.7), PRD×PREP^{obl} connects the finite verb form and the modifier (here a preposition as the beginning of a phrasal modifier) by cross-copying the core values into the respective mdd and mdr slots. PRD×PREP^{obl} requires an mdr′ valency position in the cat slot of the verb to be canceled by #-marking, unlike PRD×PREP^{opt}.

These details are coded in the transition from the input patterns to the output patterns of the PRD×PREP^{obl} operation, which is phrasal in contradistinction to elementary PRD×ADN (h57) and clausal PRD^{opt}×PRD (h7). The operations attaching adverbial modifiers of elementary, phrasal, and clausal complexity must be defined separately because their trigger patterns have the different core attributes adj (Sect. 3.1), noun (Sect. 4.1), and verb (Sect. 3.5).

4.1.6 CROSS-COPYING *put* AND *on* WITH **PRD×PREP**$^{\textbf{obl}}$ (line 4)

PRD×PREP$^{\textbf{obl}}$ (h32)

pattern level

verb: α	noun: N_*n*		verb: α	noun: N_*n*
cat: #X mdr′ v	cat: adnv	⇒	cat: #X #mdr′ v	cat: adnv
mdr:	mdd:		mdr: N_*n*	mdd: α
prn: K	prn:		prn: K	prn: K

⇑ ⇓

content level

sur:	sur: on		sur:	sur:
verb: put	noun: n_2		verb: put	noun: n_2
cat: #n′ #a′ mdr′ v	cat: adnv		cat: #n′ #a′ #mdr′ v	cat: adnv
sem: ind past	sem: *on*		sem: ind past	sem: *on*
arg: [person x] flower	mdd:		arg: [person x] flower	mdd: put
mdr:	mdr:		mdr: n_2	mdr:
nc:	nc:		nc:	nc:
pc:	pc:		pc:	pc:
prn: 19	prn:		prn: 19	prn: 19

The feature [cat: #X mdr′ v] of the first input pattern specifies a verb taking a modifier as its last complement. The second input pattern requires a preposition, as specified by the core attribute noun[1] and the cat value adnv. In the two output proplets, the core value n_2 of the preposition is cross-copied into the mdr slot of the verb and the core value put bof the verb into the mdd slot of the preposition. The first output pattern #-cancels the valency position mdr′, as specified by the output feature [cat: #X #mdr′ v].

The next word continues the preposition into a prepositional phrase by adding the. The article is absorbed into the preposition by simultaneous substitution replacing n_2 with n_3 and by fusing the cat values of the two input proplets in the output proplet, similar to 3.2.8:

4.1.7 ABSORBING *the* INTO *on* WITH PREP∪NP (line 5)

PREP∪NP (h48)

pattern level

noun: N_*n*	noun: α		noun: α
cat: adnv	cat: CN′ NP	⇒	cat: adnv CN′ NP
sem: X	sem: Z		sem: X Z
prn: K	prn:		prn: K

⇑ ⇓

content level

sur:	sur: the		sur:
noun: n_2	noun: n_3		noun: n_3
cat: adnv	cat: nn′ np		cat: adnv nn′ np
sem: *on*	sem: def sg		sem: *on* def sg
mdd: put	fnc:		mdd: put
mdr:	mdr:		mdr:
nc:	nc:		nc:
pc:	pc:		pc:
prn: 19	prn:		prn: 19

[1] What is treated in English by preposition-noun combinations is treated in many other languages by case markings on nouns, e.g. declination in classical Latin.

This operation may also combine a preposition with an elementary noun, as in Paris or to you. Here, however, the addition of a determiner requires the addition of a noun, with or without adnominal modifiers.

The input continues with the next word table. DET∪CN applies similar to 3.2.9:

4.1.8 ABSORBING *table* INTO *on the* WITH DET∪CN (line 6)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\ \text{NP}\\ \text{sem: Y}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{sem: Y Z}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.2.4.

$$\Uparrow\qquad\qquad\Downarrow$$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: n\_3}\\ \text{cat: adnv}^2\ \text{nn}'\ \text{np}\\ \text{sem: } on \text{ def sg}\\ \text{mdd: put}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 19}\end{bmatrix}\quad\begin{bmatrix}\text{sur: table}\\ \text{noun: table}\\ \text{cat: sn}\\ \text{sem: sg}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{noun: table}\\ \text{cat: adnv snp}\\ \text{sem: } on \text{ def sg}\\ \text{mdd: put}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 19}\end{bmatrix}$$

Simultaneous substitution replaces all instances of n_3 with table.

The hear mode derivation of this isolated linguistic example concludes by adding the interpunctuation with S∪IP:

4.1.9 ABSORBING • INTO *put* WITH S∪IP (line 7)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#X}'\ \text{VT}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: V\_}n\\ \text{cat: VT}'\ \text{SM}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#X}'\ \text{SM}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

$$\Uparrow\qquad\qquad\Downarrow$$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: put}\\ \text{cat: \#n}'\ \text{\#a}'\ \text{\#mdr}'\ \text{v}\\ \text{sem: ind past}\\ \text{arg: [person x] flower}\\ \text{mdr: table}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 19}\end{bmatrix}\quad\begin{bmatrix}\text{sur: }\bullet\\ \text{verb: v\_1}\\ \text{cat: v}'\ \text{decl}\\ \text{sem: ind}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{verb: put}\\ \text{cat: \#n}'\ \text{\#a}'\ \text{\#mdr}'\ \text{decl}\\ \text{sem: ind past}\\ \text{arg: [person x] flower}\\ \text{mdr: table}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 19}\end{bmatrix}$$

[2] To accommodate the optional adnv segment for the preposition in the pattern matching of DET∪CN, an additional variable for a single cat value is required. Though easily implemented, it is a complication for the reader and therefore omitted.

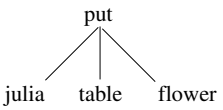
The hear mode derivation as a sequence of explicit hear mode operations is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure, using a breadth-first arc numbering:

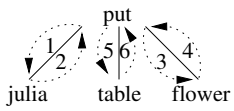
4.1.10 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE

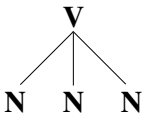
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

1	2	3	4	5	6
Julia	put	the_flowers		on_the_table	.
V/N	N/V	V\N	N\V	V|N	N|V

Word form production is summarized as follows:

4.1.11 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *put* to *julia*	Julia	4.1.12
arc 2:	N↗V	from *julia* to *put*	put	4.1.13
arc 3:	V↙N	from *put* to *flower*	the_flowers	4.1.14
arc 4:	N↗V	from *flower* to *put*		4.1.15
arc 5:	V↓N	from *put* to *table*	on_the_table	4.1.16
arc 6:	N↑V	from *table* to *put*	.	4.1.17

The complete sequence of explicit navigation operations begins with V↙N:

4.1.12 **<to-do 6>**

NAVIGATING WITH V↙N FROM *put* TO *julia* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: put} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{\#mdr}'\ \text{decl} \\ \text{sem: ind past} \\ \text{arg: [person x] flower} \\ \text{mdr: table} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 19} \end{bmatrix} \quad \begin{bmatrix} \text{sur: Julia} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: put} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 19} \end{bmatrix}$$

4.1.13 NAVIGATING WITH N↗V FROM *julia* BACK TO *put* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β. Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: julia} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: put} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 19}\end{bmatrix} \begin{bmatrix}\text{sur: put} \\ \text{verb: put} \\ \text{cat: \#n}' \text{ \#a}' \text{ \#mdr}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] flower} \\ \text{mdr: table} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 19}\end{bmatrix}$$

4.1.14 NAVIGATING WITH V↘N FROM *put* TO *flower* (arc 3)

V↘N (s3)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta\ \text{Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: } \dot{\text{K}}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: put} \\ \text{cat: \#n}' \text{ \#a}' \text{ \#mdr}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] flower} \\ \text{mdr: table} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 19}\end{bmatrix} \begin{bmatrix}\text{sur: the\_flowers} \\ \text{noun: flower} \\ \text{cat: pnp} \\ \text{sem: def pl} \\ \text{fnc: \#put} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 19}\end{bmatrix}$$

4.1.15 NAVIGATING WITH N↖V FROM *flower* BACK TO *put* (arc 4)

N↖V (s4)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{mdr: } \ddot{\text{Z}} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta\ \text{Y} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: flower} \\ \text{cat: pnp} \\ \text{sem: def pl} \\ \text{fnc: \#put} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn 19}\end{bmatrix} \begin{bmatrix}\text{sur:} \\ \text{verb: put} \\ \text{cat: \#n}' \text{ \#a}' \text{ \#mdr}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#flower} \\ \text{mdr: table} \\ \text{nc:} \\ \text{pc:} \\ \text{prn 19}\end{bmatrix}$$

The next step navigates from the verb to the prepositional phrase with V↓N,

similar to 3.2.17. The operation ignores the difference between an obligatory complement vs. an optional modifier by omitting the cat feature in its input (compatibility by omission).

4.1.16 Navigating with V↓N from *put* to *table* (arc 5)

V↓N (s13)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{mdr: X } \beta \text{ Y} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: put} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ \#mdr}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#flower} \\ \text{mdr: table} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 19} \end{bmatrix} \quad \begin{bmatrix} \text{sur: on\_the\_table} \\ \text{noun: table} \\ \text{cat: adnp} \\ \text{sem: } \textit{on} \text{ def sg} \\ \text{mdd: put} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 19} \end{bmatrix}$$

Lexnoun uses the features [noun: table] and [sem: *on* def sg].

The final return via N↑V to the predicate (arc 6) gets into position for accessing a possible next proposition by an extrapropositional relation between the top verbs (1.3.7) and provides the appropriate interpunctuation.

4.1.17 Navigating with N↑V from *table* back to *put* (arc 6)

N↑V (s14)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{mdr: X } \beta \text{ Y} \\ \text{prn: K} \end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{noun: table} \\ \text{cat: adnp} \\ \text{sem: } \textit{on} \text{ def sg} \\ \text{mdd: put} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 19} \end{bmatrix} \quad \begin{bmatrix} \text{sur: } \bullet \\ \text{verb: put} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ \#mdr}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#flower} \\ \text{mdr: \#table} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 19} \end{bmatrix}$$

Verbs like *put* may also take elementary modifiers as their obligatory complement, as in Julia put the flowers aside.

Extending DBS.12 to a class of examples with an obligatory modifier complement required the definition of the hear mode operations PRD×PREP^{obl} (h32) and PREP∪NP (h48).

4.1.18 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

1	2	3	4	5	6	7
Julia ×	put ×	the ∪	flowers ×	on ∪	the ∪	table ∪ .

speak mode:

1	2	3	4	5	6
V↙N Julia	N↗V put	V↘N the_flowers	N↖V	V↓N on_the_table	N↑V .

The hear mode derivation used seven operation applications, and the speak mode derivation used six. The hear mode derivation runs straight through. The breadth-first numbering of the speak mode operations corresponds to the arcs traversed in 4.1.10. There is one empty traversal.

4.2 DBS.14: Elementary Modifier in Obligatory Use

An example of a verb taking an adnominal as its third complement is The letter made Mary happy, with make taking the complements letter, Mary, and happy. As a complement, happy, like phrasal a happy woman, is not part of the verb make, unlike up in Fido dug the bone up (Sect. 4.3). However, *make* in combination with an elementary adnominal seems to be restricted to such 'mood' adnominals as {*angry, happy, pensive, proud, sad, tired, wary, ...*}.

4.2.1 **<to-do 1>**

CONTENT OF The letter made Mary happy.

sur:	sur:	sur: mary	sur:
noun: letter	verb: make	noun: [person x]	adj: happy
cat: snp	cat: #n′ #a′ #mdr′ decl	cat: snp	cat: adn
sem: def sg	sem: ind past	sem: nm f	sem: pad
fnc: make	arg: letter [person x]	fnc: make	mdd: make
mdr:	mdr: happy	mdr:	mdr:
nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:
prn: 20	prn: 20	prn: 20	prn: 20

The content resembles 4.1.1 except that the modifier here is an elementary adnominal instead of a prepositional phrase. Happy is an obligatory complement insofar as it #-cancels the mdr′ valency position in the cat attribute of make. It differs from nominal arguments (nouns), however, because it is not stored in the arg but in the mdr slot of the finite verb.

As a first conceptual orientation consider the derivation graph:

4.2.2 <to-do 2>

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION

unanalyzed surface

The letter made Mary happy .

automatic word form recognition

sur: the	sur: letter	sur: made	sur: Mary	sur: happy	sur: .
noun: n_1	noun: letter	verb: make	noun: [person x]	adj: happy	verb: v_1
cat: nn' np	cat: sn	cat: n' a' mdr' v	cat: snp	cat: adn	cat: v' decl
sem: def	sem: sg	sem: past	sem: nm f	sem: pad	sem:
fnc:	fnc:	arg:	fnc:	mdd:	mdd:
prn:	prn:	mdr:	prn:	prn:	prn:
		prn:			

syntactic−semantic parsing

1 *absorption*

sur: the	sur: letter
noun: n_1	~~noun:~~ letter
cat: nn' ~~np~~	~~cat:~~ sn
sem: def	~~sem:~~ sg
fnc:	fnc:
prn: 20	prn:

2 *cross−copying*

sur:	sur: made
noun: letter	verb: make
cat: snp	cat: n' a' mdr' v
sem: def sg	sem: past
fnc:	arg:
prn: 20	mdr:
	prn:

3 *cross−copying*

sur:	sur:	sur: Mary
noun: letter	verb: make	noun: [person x]
cat: snp	cat: #n' a' mdr' v	cat: snp
sem: def sg	sem: past	sem: nm f
fnc: make	arg: letter	fnc:
prn: 20	mdr:	prn:
	prn: 20	

4 *cross−copying*

sur:	sur:	sur: mary	sur: happy
noun: letter	verb: make	noun: [person x]	~~adj:~~ happy
cat: snp	cat: #n' #a' mdr' v	~~cat:~~ snp	cat: adn
sem: def sg	sem: past	~~sem:~~ nm f	sem: pad
fnc: make	arg: letter [person y]	fnc: make	~~mdd:~~
prn: 20	mdr:	prn: 20	prn:
	prn: 20		

5 *absorption*

sur:	sur:	sur: mary	sur:	sur: .
noun: letter	verb: make	noun: [person x]	adj: happy	verb: v_1
cat: snp	cat: #n' #a' #mdr' v	~~cat:~~ snp	~~cat:~~ adn	~~cat:~~ v' decl
sem: def sg	sem: past	sem: nm f	sem: pad	sem:
fnc: make	arg: letter [person y]	fnc: make	mdd: make	mdd:
prn: 20	mdr: happy	prn: 20	prn: 20	prn:
	prn: 20			

result

sur:	sur:	sur: mary	sur:
noun: letter	verb: make	noun: [person x]	adj: happy
cat: snp	cat: #n' #a' #mdr' decl	cat: snp	cat: adn
sem: def sg	sem: past	sem: nm f	sem: pad
fnc: make	arg: letter [person y]	fnc: make	mdd: make
prn: 20	mdr: happy	prn: 20	prn: 20
	prn: 20		

The derivation is two lines shorter than 4.1.2 because the modifier complement is elementary happy rather than phrasal on the table.

The complete sequence of explicit hear mode operation applications begins with DET∪CN:

4.2.3 **<to-do 3>**

ABSORBING *letter* INTO *the* WITH DET∪CN (line 1)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\text{ NP}\\ \text{sem: Y}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{sem: Y Z}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.2.4.

content level

$$\begin{bmatrix}\text{sur: The}\\ \text{noun: n\_1}\\ \text{cat: nn}'\text{ np}\\ \text{sem: def}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 20}\end{bmatrix}\Uparrow\begin{bmatrix}\text{sur: letter}\\ \text{noun: letter}\\ \text{cat: sn}\\ \text{sem: sg}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \qquad \Downarrow\begin{bmatrix}\text{sur:}\\ \text{noun: letter}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 20}\end{bmatrix}$$

The next word provided by automatic word form recognition is *make*. As the trigger proplet, it matches the second input pattern of SBJ×PRD, which finds *letter*[3] at the now front matching its first input pattern and applies as follows:

4.2.4 CROSS-COPYING *letter* AND *made* WITH SBJ×PRD (line 2)

SBJ×PRD (h1)

pattern level

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP}'\text{ X v}\\ \text{arg:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ X v}\\ \text{arg: }\alpha\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.2.

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: letter}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 20}\end{bmatrix}\Uparrow\begin{bmatrix}\text{sur: made}\\ \text{verb: make}\\ \text{cat: n}'\text{ a}'\text{ mdr}'\text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \qquad \Downarrow\begin{bmatrix}\text{sur:}\\ \text{noun: letter}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc: make}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 20}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: make}\\ \text{cat: \#n}'\ a'\text{ mdr}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: letter}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 20}\end{bmatrix}$$

[3] Another example is John made Mary happy, in which make...happy is used with an animate subject.

The next word provided by automatic word form recognition is the direct object Mary:

4.2.5 Cross-copying *make* and *mary* with PRD×OBJ (line 3)

PRD×OBJ (h28)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \underline{\#X'}\ N'\ Y\ \gamma \\ \text{arg: } Z \\ \text{prn: } K\end{bmatrix}\begin{bmatrix}\text{noun: } \alpha \\ \text{cat: } CN'\ NP \\ \text{fnc: } \\ \text{prn: }\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \underline{\#X'}\ \#N'\ Y\ \gamma \\ \text{arg: } Z\ \alpha \\ \text{prn: } K\end{bmatrix}\begin{bmatrix}\text{noun: } \alpha \\ \text{cat: } CN'\ NP \\ \text{fnc: } \beta \\ \text{prn: } K\end{bmatrix}$$

Agreement conditions as in 2.3.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: } \\ \text{verb: make} \\ \text{cat: } \#n'\ a'\ mdr'\ v \\ \text{sem: ind past} \\ \text{arg: letter} \\ \text{mdr: } \\ \text{nc: } \\ \text{pc: } \\ \text{prn: 20}\end{bmatrix}\begin{bmatrix}\text{sur: Mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: } \\ \text{mdr: } \\ \text{nc: } \\ \text{pc: } \\ \text{prn: }\end{bmatrix} \quad \begin{bmatrix}\text{sur: } \\ \text{verb: make} \\ \text{cat: } \#n'\ \#a'\ mdr'\ v \\ \text{sem: ind past} \\ \text{arg: letter [person x]} \\ \text{mdr: } \\ \text{nc: } \\ \text{pc: } \\ \text{prn: 20}\end{bmatrix}\begin{bmatrix}\text{sur: mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: make} \\ \text{mdr: } \\ \text{nc: } \\ \text{pc: } \\ \text{prn: 20}\end{bmatrix}$$

With a name as the second input proplet, CN′ in the corresponding cat pattern is bound to NIL.

The obligatory modifier complement happy is added by the operation PRD×ADN. It differs from PRD×PREP^{obl} (4.1.6) in that its trigger proplet is restricted to an elementary adnominal:

4.2.6 Cross-copying *make* and *happy* with PRD×ADN (line 4)

PRD×ADN (h57)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{cat: } \#X\ \gamma'\ Y \\ \text{mdr: } \\ \text{prn: } K\end{bmatrix}\begin{bmatrix}\text{adj: } \beta \\ \text{cat: ADN} \\ \text{mdd: } \\ \text{prn: } K\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \alpha \\ \text{cat: } \#X\ \#\gamma'\ Y \\ \text{mdr: } \beta \\ \text{prn: } K\end{bmatrix}\begin{bmatrix}\text{adj: } \beta \\ \text{cat: ADN} \\ \text{mdd: } \alpha \\ \text{prn: } K\end{bmatrix}$$

$\gamma \in \{mdr', be'\}$. If $\gamma = mdr'$, then ADN = adn; otherwise ADN $\in$ {adn, adnv}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: } \\ \text{verb: make} \\ \text{cat: } \#n'\ \#a'\ mdr'\ v \\ \text{sem: ind past} \\ \text{arg: letter [person x]} \\ \text{mdr: } \\ \text{nc: } \\ \text{pc: } \\ \text{prn: 20}\end{bmatrix}\begin{bmatrix}\text{sur: happy} \\ \text{adj: happy} \\ \text{cat: adn} \\ \text{sem: pad} \\ \text{mdd: } \\ \text{mdr: } \\ \text{nc: } \\ \text{pc: } \\ \text{prn: }\end{bmatrix} \quad \begin{bmatrix}\text{sur: } \\ \text{verb: make} \\ \text{cat: } \#n'\ \#a'\ \#mdr'\ v \\ \text{sem: ind past} \\ \text{arg: letter [person x]} \\ \text{mdr: happy} \\ \text{nc: } \\ \text{pc: } \\ \text{prn: 20}\end{bmatrix}\begin{bmatrix}\text{sur: } \\ \text{adj: happy} \\ \text{cat: adn} \\ \text{sem: pad} \\ \text{mdd: make} \\ \text{mdr: } \\ \text{nc: } \\ \text{pc: } \\ \text{prn: 20}\end{bmatrix}$$

The added modifier is an adnominal rather than an adverbial because it must be, for example, happy and not happily. Analogous to PRD×PREP^{obl} (h33), PRD×ADN (i) cross-copies the core values of the verb and the adnominal into the respective mdr and mdd slots, and (ii) cancels the mdr′ valency position in the third cat slot of the verb, thus characterizing *happy* as obligatory.

The derivation of this isolated linguistic example is completed by adding the interpunctuation with S∪IP:

4.2.7 ABSORBING • INTO *make* WITH S∪IP (line 5)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ VT} \\ \text{prn: K}\end{bmatrix} \qquad \begin{bmatrix}\text{verb: V\_}n \\ \text{cat: VT}' \text{ SM}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \beta \\ \text{cat: } \#X' \text{ SM} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: make} \\ \text{cat: } \#n' \ \#a' \ \#mdr' \text{ v} \\ \text{sem: ind past} \\ \text{arg: letter [person x]} \\ \text{mdr: happy} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 20}\end{bmatrix} \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: v\_1} \\ \text{cat: v}' \text{ decl} \\ \text{sem:} \\ \text{arg:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{verb: make} \\ \text{cat: } \#n' \ \#a' \ \#mdr' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: letter [person x]} \\ \text{mdr: happy} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 20}\end{bmatrix}$$

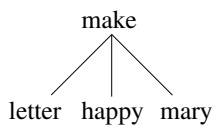
The hear mode derivation of an elementary modifier in obligatory use is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

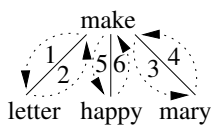
4.2.8 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE

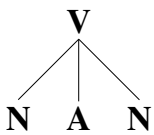
(i) SRG (semantic relations graph)



(iii) NRG (numbered arcs graph)



(ii) signature



(iv) surface realization

1	2	3	4	5	6
The_letter	made	Mary		happy	•
V/N	N/V	V\N	N\V	V|A	A|V

Compared to the graph 4.1.10 for Julia put the flowers on the table, the (ii) signature node representing the modifier complement is A rather than N. The respective NAGs show the same breadth-first arc numbering.

Word form production is summarized as the following list of speak mode operations:

4.2.9 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *make* to *letter*	The_letter	4.2.10
arc 2:	N↗V	from *letter* to *make*	made	4.2.11
arc 3:	V↙N	from *make* to *mary*	Mary	4.2.12
arc 4:	N↗V	from *mary* to *make*		4.2.13
arc 5:	V↓A	from *make* to *happy*	happy	4.2.14
arc 6:	A↑V	from *happy* to *make*	.	4.2.15

The complete sequence of explicit navigation operations begins with V↙N:

4.2.10 **<to-do 6>**

NAVIGATING WITH V↙N FROM *make* TO *letter* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: make} \\ \text{cat: \#n}' \text{ \#a}' \text{ \#mdr}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: letter [person x]} \\ \text{mdr: happy} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 20} \end{bmatrix} \quad \begin{bmatrix} \text{sur: The\_letter} \\ \text{noun: letter} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: make} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 20} \end{bmatrix}$$

4.2.11 NAVIGATING WITH N↗V FROM *letter* BACK TO *make* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K} \end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{noun: letter} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: make} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 20} \end{bmatrix} \quad \begin{bmatrix} \text{sur: made} \\ \text{verb: make} \\ \text{cat: \#n}' \text{ \#a}' \text{ \#mdr}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#letter [person x]} \\ \text{mdr: happy} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 20} \end{bmatrix}$$

4.2.12 NAVIGATING WITH V⤵N FROM *make* TO *[person x]* (arc 3)

V⤵N (s3)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{prn: } \ddot{\text{K}}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: make} \\ \text{cat: \#n}' \text{ \#a}' \text{ \#mdr}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#letter [person x]} \\ \text{mdr: happy} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 20}\end{bmatrix} \quad \begin{bmatrix}\text{sur: Mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: \#make} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 20}\end{bmatrix}$$

Up to this point, the think-speak mode navigation has realized The letter made Mary. The following return to the predicate with standard N⤴V provides access to the continuation feature [mdr: happy] in the goal proplet:

4.2.13 NAVIGATING WITH N⤴V FROM *mary* BACK TO *make* (arc 4)

N⤴V (s4)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{mdr: } \ddot{\text{Z}} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: \#make} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 20}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: make} \\ \text{cat: \#n}' \text{ \#a}' \text{ \#mdr}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#letter \#[person x]} \\ \text{mdr: happy} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 20}\end{bmatrix}$$

This derivation step requires no special operation because standard N⤴V ignores the continuation feature [mdr: happy] in the output proplet by omitting the mdr attribute.

For the next operation V↓A, however, the feature [mdr: #X β Y] is an essential part of the start pattern. In contradistinction to V↓N (4.1.16), the core attribute of the goal pattern is adj instead of noun. The obligatory nature of complementing *make* with an adnominal is indicated by the mdr slot in the category of *make*, which was #-marked in the hear mode (4.2.6).

Using the mdr value happy in the start proplet *make*, the following operation application reaches the elementary modifier complement:

4.2.14 NAVIGATING WITH V↓A FROM *make* TO *happy* (arc 5)

V↓A (s9)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{mdr: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexadj}(\hat{\beta}) \\ \text{adj: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the mdr slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: make} \\ \text{cat: \#n}' \text{ \#a}' \text{ \#mdr}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#letter \#[person x]} \\ \text{mdr: happy} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 20}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: happy} \\ \text{adj: happy} \\ \text{cat: adn} \\ \text{sem: pad} \\ \text{mdd: make} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 20}\end{bmatrix}$$

For realizing happy, lexadj uses the core value, the cat value adn, and the sem value pad (for adjective in the positive).

A return to the verb with A↑V (3.1.14), as the inverse of V↓A, completes the think-speak mode derivation:

4.2.15 NAVIGATING WITH A↑V FROM *make* BACK TO *happy* (arc 6)

A↑V (s10)

pattern level

$$\begin{bmatrix}\text{adj: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{mdr: X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{adj: happy} \\ \text{cat: adn} \\ \text{sem: pad} \\ \text{mdd: \#make} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 20}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: make} \\ \text{cat: \#n}' \text{ \#a}' \text{ \#mdr}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#letter \#[person x]} \\ \text{mdr: \#happy} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 20}\end{bmatrix}$$

Without any untraversed continuation values in the *make* proplet, lexverb uses the cat value decl to realize the period. In a text, the address of the successor's top predicate would be the nbc value of *make*.

Extending DBS.13 to an example class with a copula taking an obligatory adnominal required the definition of the hear mode operation PRD×ADN (h57). The hear mode derivation used five operation applications, and the speak mode derivation used six:

4.2.16 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

	1		2		3		4		5	
The	∪	letter	×	made	×	Mary	×	happy	∪	•

speak mode:

1		2		3		4	5		6	
V↙N	The_letter	N↗V	made	V↘N	Mary	N↖V	V↓A	happy	A↑V	•

The hear mode derivation runs straight through. The numbering of the speak mode operations corresponds to the breadth-first arc numbering in 4.2.8; there is one empty traversal.

4.3 DBS.15: Bare Preposition in Obligatory Use

While make...happy consists of two content words, there are also grammatical structures consisting of a content and a function word, for example dig...up.[4] Called "discontinuous element" in English grammar, up raises the question of whether it should be treated as a complement of the verb, like happy, or as a part of the verb, called "separable prefix."[5]

In line with our analysis of prepositional (Sect. 4.1) and adnominal (Sect. 4.2) complements, the following analysis of English treats the discontinuous element up as a complement, and not as a part, of the verb. Accordingly, put...up, put...down, put...on, put...in, put...out,b etc. are not treated as different verbs, each with a separate entry in the lexicon, but as the single verb put which takes a discontinuous element from an explicitly defined variable restriction, just like make...happy, make...sad, make...angry, etc.

As complements, aside, up, down, etc. are called *bare prepositions* and used to cancel a valency position in the cat feature of, e.g., put. That they are obligatory is shown by the grammatical incompleteness of Fido dug the bone. As function words, they are absorbed without being represented in the content as separate proplets (unlike content words like happy, sad, etc).

The following content shows the verb *dig* taking the bare preposition up:

[4] At least since 1953 (Bar-Hillel 1964, p. 102) this construction has played a central role in the question of how to accommodate "constituent structure" in context-free PS Grammar (FoCL p. 160; CLaTR Sect. 12.2).

[5] In German grammar, verbs with a "separable prefix" (*trennbare Verben*) are traditionally written as single entries in the lexicon, e.g. ausgraben (*up_dig*), eingraben (*in_dig*), etc. However, these combined forms are used only in subordinate clauses, e.g. als Fido den Knochen ausgrub (*when Fido the bone up_dug*). In main clauses, in contrast, two separate surface parts are used, with the object intervening, e.g. Fido grub den Knochen aus (*Fido dug the bone up*). In the 1960s there was a heated debate of which form should be used in the "deep structure" (Bach 1962, Bierwisch 1963).

4.3.1 **<to-do 1>**

CONTENT OF Fido dug the bone up.

sur: fido	sur:	sur:
noun: [dog y]	verb: dig	noun: bone
cat: snp	cat: #n′ #a′ #bp′ decl	cat: snp
sem: nm m	sem: *up* ind past	sem: def sg
fnc: dig	arg: [dog y] bone	fnc: dig
mdr:	mdr:	mdr:
nc:	nc:	nc:
pc:	pc:	pc:
prn: 21	prn: 21	prn: 21

As a first conceptual orientation consider the derivation graph:

4.3.2 **<to-do 2>**

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION

unanalyzed surface

Fido dug the bone up .

automatic word form recognition

sur: Fido	sur: dug	sur: the	sur: bone	sur: up	sur: .
noun: [dog x]	verb: dig	noun: n_1	noun: bone	noun: n_2	verb: v_1
cat: snp	cat: n’ a’ bp’ v	cat: nn’ np	cat: sn	cat: adnv	cat: v’ decl
sem: nm m	sem: past	sem: def	sem: sg	sem: *up*	sem:
fnc:	arg:	fnc:	fnc:	mdd:	mdd:
prn:	prn:	prn:	prn:	prn:	prn:

syntactic−semantic parsing

1	sur: Fido noun: [dog x] cat: snp sem: nm m fnc: prn: 21	sur: dug verb: dig cat: n’ a’ bp’ v sem: past arg: prn:	*cross−copying*
2	sur: fido noun: [dog x] cat: snp sem: nm m fnc: dig prn: 21	sur: verb: dig cat: #n’ a’ bp’ v sem: past arg: [dog x] prn: 21	sur: the noun: n_1 cat: nn’ np sem: def fnc: prn: *cross−copying*
3	sur: fido noun: [dog x] cat: snp sem: nm m fnc: dig prn: 21	sur: verb: dig cat: #n’ #a’ bp’ v sem: past arg: [dog x] n_1 prn: 21	sur: noun: n_1 cat: nn’ np sem: def fnc: dig prn: 21 / sur: bone ~~noun:~~ bone ~~cat:~~ sn ~~sem:~~ sg fnc: prn: *absorption with simultaneous substitution*
4	sur: fido noun: [dog x] cat: snp sem: nm m fnc: dig prn: 21	sur: verb: dig cat: #n’ #a’ bp’ v sem: past arg: [dog x] bone prn: 21	sur: noun: bone ~~cat: nn’ np~~ ~~sem: def~~ fnc: dig prn: 21 / sur: up noun: n_2 ~~cat:~~ adnv ~~sem:~~ *up* mdd: prn: *absorption*

5	sur: fido noun: [dog x] cat: snp sem: nm m fnc: dig prn: 21	sur: verb: dig cat: #n' #a' #bp' v sem: *up* past arg: [dog x] bone prn: 21	sur: noun: bone ~~cat: nn' np~~ sem: def fnc: dig prn: 21	sur: • verb: v_1 ~~cat: v~~' decl sem: fnc: prn:	*absorption*

result

sur: fido noun: [dog x] cat: snp sem: nm m fnc: dig prn: 21	sur: verb: dig cat: #n' #a' #bp' decl sem: *up* past arg: [dog x] bone prn: 21	sur: noun: bone cat: nn' np sem: def fnc: dig prn: 21

The bare preposition up is absorbed in line 4. It fills the valency position bp′ in the third cat slot of *dig* and writes its sem value up into the initial sem slot of the verb. As the *up* proplet is absorbed into dig, no separate proplet is left behind, unlike *table* in 4.1.1 and *happy* in 4.2.1.

The complete sequence of explicit hear mode operation applications begins with SBJ×PRD:

4.3.3 **<to-do 3>**

CROSS-COPYING *fido* AND *dig* WITH SBJ×PRD (line 1)

SBJ×PRD (h1)

pattern level

noun: α cat: NP fnc: prn:K	verb: β cat: NP′ X v arg: prn:	⇒	noun: α cat: NP fnc: β prn: K	verb: β cat: #NP′ X v arg: α prn: K

Agreement conditions as in 2.1.2.

content level

sur: Fido noun: [dog y] cat: snp sem: nm m fnc: mdr: nc: pc: prn: 21	⇑ sur: dug verb: dig cat: n′ a′ bp′ v sem: ind past arg: mdr: nc: pc: prn:	sur: fido noun: [dog y] cat: snp sem: nm m fnc: dig mdr: nc: pc: prn: 21	⇓ sur: verb: dig cat: #n′ a′ bp′ v sem: ind past arg: [dog y] mdr: nc: pc: prn: 21

For SBJ×PRD to apply, (i) the cat feature of the first input proplet must match the cat feature in the first input pattern (vertical) and (ii) the cat value corresponding to NP in the first input proplet must agree with the cat value corresponding to NP′ in the second input pattern (horizontal). The same principle of canceling valency positions in their order from left to right in the verb's cat slot is used in the following application of PRD×OBJ:

4.3.4 CROSS-COPYING *dig* AND *the* WITH PRD×OBJ (LINE 2)

PRD×OBJ (h28)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \underline{\#X'}\ \text{N}'\ \text{Y}\ \gamma \\ \text{arg: Z} \\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: } \alpha \\ \text{cat: CN}'\ \text{NP} \\ \text{fnc:} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \underline{\#X'}\ \#\text{N}'\ \text{Y}\ \gamma \\ \text{arg: Z}\ \alpha \\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: } \alpha \\ \text{cat: CN}'\ \text{NP} \\ \text{fnc: } \beta \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.3.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: dig} \\ \text{cat: \#n}'\ \text{a}'\ \text{bp}'\ \text{v} \\ \text{sem: ind past} \\ \text{arg: [dog y]} \\ \ldots \\ \text{prn: 21}\end{bmatrix}\begin{bmatrix}\text{sur: the} \\ \text{noun: n\_1} \\ \text{cat: nn}'\ \text{np} \\ \text{sem: def} \\ \text{fnc:} \\ \ldots \\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{verb: dig} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{bp}'\ \text{v} \\ \text{sem: ind past} \\ \text{arg: [dog y] n\_1} \\ \ldots \\ \text{prn: 21}\end{bmatrix}\begin{bmatrix}\text{sur:} \\ \text{noun: n\_1} \\ \text{cat: nn}'\ \text{np} \\ \text{sem: def} \\ \text{fnc: dig} \\ \ldots \\ \text{prn: 21}\end{bmatrix}$$

The object is completed with DET∪CN absorbing bone into the determiner:

4.3.5 ABSORBING *bone* INTO *the* WITH DET∪CN (line 3)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n \\ \text{cat: CN}'\ \text{NP} \\ \text{sem: Y} \\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: } \alpha \\ \text{cat: CN} \\ \text{sem: Z} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: NP} \\ \text{sem: Y Z} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.2.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: n\_1} \\ \text{cat: nn}'\ \text{np} \\ \text{sem: def} \\ \text{fnc: dig} \\ \ldots \\ \text{prn: 21}\end{bmatrix}\begin{bmatrix}\text{sur: bone} \\ \text{noun: bone} \\ \text{cat: sn} \\ \text{sem: sg} \\ \text{fnc:} \\ \ldots \\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{noun: bone} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: dig} \\ \ldots \\ \text{prn: 21}\end{bmatrix}$$

Next, automatic word form recognition provides the bare preposition up. It is absorbed into *dig* by PRD∪BP:

4.3.6 ABSORBING *up* INTO *dig* WITH PRD∪BP (line 4)

PRD∪BP (h49)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{cat: \#X}\ \beta'\ \text{v} \\ \text{sem: Y} \\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{adv: A\_}n \\ \text{cat: adnv} \\ \text{sem: } \beta \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \alpha \\ \text{cat: \#X \#}\beta'\ \text{v} \\ \text{sem: } \beta\ \text{Y} \\ \text{prn: K}\end{bmatrix}$$

where $\beta \in$ {aside, in, out, up, down, ...}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: dig} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{bp}'\ \text{v} \\ \text{sem: ind past} \\ \text{arg: [dog y] bone} \\ \ldots \\ \text{prn: 21}\end{bmatrix}\begin{bmatrix}\text{sur: up} \\ \text{noun: n\_2} \\ \text{cat: adnv} \\ \text{sem: } up \\ \text{mdd:} \\ \ldots \\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{verb: dig} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{\#bp}'\ \text{v} \\ \text{sem: } up\ \text{ind past} \\ \text{arg: [dog y] bone} \\ \ldots \\ \text{prn: 21}\end{bmatrix}$$

The bare preposition *up* is shown as the first value in the sem slot of *dig*. Though PRD∪BP resembles PRD×ADN (4.2.6) and PRD×PREP^{obl} (4.1.6) in that it adds a modifier, it differs in that it absorbs the discontinuous element as a function word, instead of cross-copying between content words.[6]

With all three valency positions in the cat slot of *dig* #-canceled, it remains to complete this linguistic example by adding the period with S∪IP:

4.3.7 ABSORBING • INTO *dig* WITH S∪IP (line 5)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ VT} \\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{verb: V\_}n \\ \text{cat: VT}' \text{ SM}\end{bmatrix} \quad \Rightarrow \quad \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ SM} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: dig} \\ \text{cat: } \#n' \ \#a' \ \#bp' \text{ v} \\ \text{sem: } \textit{up} \text{ ind past} \\ \text{arg: [dog y] bone} \\ \ldots \\ \text{prn: 21}\end{bmatrix} \quad \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: v\_1} \\ \text{cat: v}' \text{ decl} \\ \text{sem:} \\ \text{arg:} \\ \ldots \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: dig} \\ \text{cat: } \#n' \ \#a' \ \#bp' \text{ decl} \\ \text{sem: } \textit{up} \text{ ind past} \\ \text{arg: [dog y] bone} \\ \ldots \\ \text{prn: 21}\end{bmatrix}$$

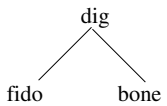
The hear mode derivation of a construction with a bare preposition (aka "discontinuous element") is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

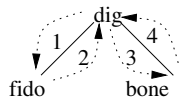
4.3.8 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE

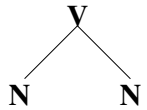
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

1	2	3	4
Fido	dug	the_bone	up_.
V/N	N/V	V\N	N\V

The graph differs from 4.1.10 for Julia put the flowers on the table and from 4.2.8 for The letter made Mary happy in that there is neither a V↓N

[6] In accordance with surface compositionality, there is a lexical *up* proplet in the input of 4.3.6, but as a function word it is absorbed. This is in contradistinction to the adnominal happy as the modifier complement of make in Sect. 4.2 and the prepositional phrase on the table as the modifier complement of put in Sect. 4.1, which remain as proplets in the resulting contents.

nor a N↑V relation. Instead, lexverb realizes up_• from the sem and cat values of the verb in arc 4. Verbs taking bare prepositions are quite selective in what they accept as obligatory arguments, but the variable restrictions on bare prepositions for each lexical verb entry may be easily determined empirically by wide scope corpus analysis.

Word form production for the example is summarized as the following list of speak mode operations:

4.3.9 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *dig* to *fido*	Fido	4.3.10
arc 2:	N↗V	from *fido* to *dig*	dug	4.3.11
arc 3:	V↘N	from *dig* to *bone*	the_bone	4.3.12
arc 4:	N↖V	from *bone* to *dig*	up_•	4.3.13

The complete sequence of explicit navigation operations begins with V↙N:

4.3.10 **<to-do 6>**

NAVIGATING WITH V↙N FROM *dig* TO *fido* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: dig} \\ \text{cat: \#n}' \text{ \#a}' \text{ \#bp}' \text{ decl} \\ \text{sem: } \textit{up} \text{ ind past} \\ \text{arg: [dog y] bone} \\ \ldots \\ \text{prn: 21} \end{bmatrix} \quad \begin{bmatrix} \text{sur: Fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: dig} \\ \ldots \\ \text{prn: 21} \end{bmatrix}$$

4.3.11 NAVIGATING WITH N↗V FROM *fido* BACK TO *dig* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K} \end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur: fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: dig} \\ \ldots \\ \text{prn: 21} \end{bmatrix} \quad \begin{bmatrix} \text{sur: dug} \\ \text{verb: dig} \\ \text{cat: \#n}' \text{ \#a}' \text{ \#bp}' \text{ decl} \\ \text{sem: } \textit{up} \text{ ind past} \\ \text{arg: \#[dog y] bone} \\ \ldots \\ \text{prn: 21} \end{bmatrix}$$

4.3.12 NAVIGATING WITH V↘N FROM *dig* TO *bone* (arc 3)

V↘N (s3)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: dig} \\ \text{cat: \#n}' \text{ \#a}' \text{ \#bp}' \text{ decl} \\ \text{sem: } \textit{up} \text{ ind past} \\ \text{arg: \#[dog y] bone} \\ \ldots \\ \text{prn: 21}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: the\_bone} \\ \text{noun: bone} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: \#dig} \\ \ldots \\ \text{prn: 21}\end{bmatrix}$$

4.3.13 NAVIGATING WITH N↖V FROM *bone* BACK TO *dig* (arc 4)

N↖V (s4)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{mdr: } \ddot{\text{Z}} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: bone} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: \#dig} \\ \ldots \\ \text{prn: 21}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: up\_}\bullet \\ \text{verb: dig} \\ \text{cat: \#n}' \text{ \#a}' \text{ \#bp}' \text{ decl} \\ \text{sem: } \textit{up} \text{ ind past} \\ \text{arg: \#[dog y] \#bone} \\ \ldots \\ \text{prn: 21}\end{bmatrix}$$

The sem value *up* and the cat value decl are used by lexverb to realize up_•.

Extending DBS.14 to an example class with a verb taking a discontinuous bare preposition required the definition of the additional hear mode operation PRD×NP (h48). The hear mode derivation used five operation applications, and the speak mode derivation used four:

4.3.14 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

1	2	3	4	5
Fido×	dug ×	the ∪	bone ∪	up ∪ •

speak mode:

1	2	3	4
V↙N Fido	N↗V dug	V↘N the_bone	N↖V up_•

The hear and the speak mode derivations run straight through.

4.4 DBS.16: Infinitives with Subject vs. Object Control

The function word to may be used as a preposition, as in the train to Katzwang, or as a conjunction, as in the infinitives John tried to sing (subject control) and John asked Mary to sing (object control). As a conjunction, lexical to has (i) the core feature [verb: v_1], (ii) the continuation feature [arg: ∅] with ∅ firmly in subject position, and (iii) an additional fnc attribute for connecting to the matrix verb.

In an infinitive with subject control, the matrix verb must be transitive, i.e. two- or three-place, whereby ∅ equals the subject. For example, in John tried to sing or John promised Mary to sing the implicit subject of sing is John.

4.4.1 **<to-do 1>**

CONTENT OF John tried to sing **.** (subject control)

$$\begin{bmatrix}\text{sur: john}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc: try}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 24}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: try}\\ \text{cat: \#n}'\ \text{\#a}'\ \text{decl}\\ \text{sem: ind past}\\ \text{arg: [person x] sing}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 24}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: sing}\\ \text{cat: n-s3}'\ \text{inf}\\ \text{sem: } \textit{to} \text{ ind pres}\\ \text{arg: } \emptyset\\ \text{fnc: try}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 24}\end{bmatrix}$$

The gap marker ∅ of the infinitive *sing* implicitly equals [person x] in *try*.

In an infinitive with object control, the matrix verb must be three-place (ditransitive), i.e. take a subject and two objects, whereby the second object is the infinitive. The construction is called object control because, for example, in John persuaded Mary to sing the implicit subject of sing is Mary.

4.4.2 CONTENT OF John persuaded Mary to sing **.** (object control)

$$\begin{bmatrix}\text{sur: john}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc: try}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 25}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: persuade}\\ \text{cat: \#n}'\ \text{\#a}'\ \text{decl}\\ \text{sem: ind past}\\ \text{arg: [person x] (person y) sing}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 25}\end{bmatrix}\begin{bmatrix}\text{sur: mary}\\ \text{noun: (person y)}\\ \text{cat: snp}\\ \text{sem: nm f}\\ \text{fnc: sing}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 25}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: sing}\\ \text{cat: n-s3}'\ \text{inf}\\ \text{sem: } \textit{to} \text{ ind pres}\\ \text{arg: } \emptyset\\ \text{fnc: persuade}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 25}\end{bmatrix}$$

Here the ∅ in the arg slot's subject position of the *sing* infinitive equals the other object, i.e. (person y), of the three-place verb *persuade*.

Subject and object control infinitives may be combined as follows:

4.4.3 John promised Susy to persuade Mary to sing.

sur: john	sur:	sur: suzy	sur:	sur: mary	sur:
noun: (p. x)	verb: promise	noun: (p. y)	verb: persuade	noun: (p. z)	verb: sing
cat: snp	cat: #s3n′ #d′ #a′ decl	cat: snp	cat: ns-3′ a′ a′ inf	cat: snp	cat: n′ inf
sem: nm m sg	sem: ind past	sem: nm f sg	sem: *to* ind pres	sem: nm f	sem: *to* ind pres
fnc: promise	arg: (p. x) (p. y) persuade	fnc: promise	arg: ∅ (p. z) sing	fnc: sing	arg: ∅
mdr:	mdr:	mdr:	fnc: promise	mdr:	fnc: persuade
nc:	nc:	nc:	mdr:	nc:	mdr:
pc:	pc:	pc:	nc:	pc:	nc:
prn: 26	prn: 26	prn: 26	pc:	prn: 26	pc:
			prn: 26		prn: 26

The two infinitives are (i) to persuade Mary with the matrix promise and (ii) to sing with the matrix persuade. The ∅ of the first shows up in the arg slot of persuade and equals the subject [person x] in the arg slot of promise. The ∅ of the second infinitive shows up in the arg slot of sing and equals the other object (person z) in the arg slot of persuade. The initial *to* value in the sem slot of infinitive verbs is used in the speak mode for surface realization. There is only one prn value, indicating an intrapropositional construction.[7]

In the remainder of this section, we concentrate on the subject control example 4.4.1. As a first conceptual orientation consider the derivation graph:

4.4.4 **<to-do 2>**

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION

unanalyzed surface

John tried to sing •

automatic word form recognition

sur: John	sur: tried	sur: to	sur: sing	sur: •
noun: (person x)	verb: try	verb: v_1	verb: sing	verb: v_2
cat: snp	cat: n’ a’ v	cat: inf	cat: n−s3’ v	cat: v’ decl
sem: nm m	sem: pres	fnc:	sem: pres	sem:
fnc:	arg:	arg: ∅	arg:	arg:
prn:	prn:	prn:	prn:	prn:

syntactic−semantic parsing

1	sur: John	sur: tried		
	noun: (person x)	verb: try	*cross−copying*	
	cat: snp	cat: n’ a’ v		
	sem: nm m	sem: pres		
	fnc:	arg:		
	prn: 24	prn:		
2	sur: john	sur:	sur: to	
	noun: (person x)	verb: try	verb: v_1	*cross−copying*
	cat: snp	cat: #n’ a’ v	cat: inf	
	sem: nm m	sem: pres	sem:	
	fnc: try	arg: (person x)	arg: ∅	
	prn: 24	prn: 24	fnc:	
			prn:	

[7] Sag (1997) treats subclauses vs. infinitives without the distinction between extrapropositional (clausal) and intrapropositional (phrasal) constructions.

3	sur: john noun: (person x) cat: snp sem: nm m fnc: try prn: 24	sur: verb: try cat: #n' #a' v sem: pres arg: (person x) v_1 prn: 24	sur: verb: v_1 cat: inf sem: *to* arg: ∅ fnc: try prn: 24	sur :sing ~~verb:~~ sing ~~cat: n−s3'~~ v ~~sem:~~ pres ind arg: prn:	*absorption with simultaneous substitution*
4	sur: john noun: (person x) cat: snp sem: nm m fnc: try prn: 24	sur: verb: try cat: #n' #a' sem: pres arg: (person x) sing prn: 24	sur: verb: sing ~~cat: n−s3' inf~~ sem: *to* pres ind arg: ∅ fnc: try prn: 24	sur: • verb: v_2 ~~cat: v' decl~~ sem: arg: prn:	*absorption*
result	sur: john noun: (person x) cat: snp sem: nm m fnc: try prn: 24	sur: verb: try cat: #n' #a' decl sem: pres arg: (person x) sing prn: 24	sur: verb: sing cat: n−s3' inf sem: *to* pres ind arg: ∅ fnc: try prn: 24		

That the ∅ marker originating in the *to* proplet is lexically fixed to subject position is in contradistinction to the ∅ markers of clausal adnominal modifiers (aka "relative clauses"), as in 3.3.2 (lines 3, 4) and 3.4.2 (lines 3, 4), which originate lexically in neutral position and are later switched to subject or object, depending on the core attribute noun vs. verb of the successor.

In the hear mode of infinitives, in contrast, the choice between the implicit subject vs. object depends on the preceding verb, e.g. promise vs. persuade. Adnominal clauses and infinitives are alike, however, in that both use the gap marker ∅ and their derivations depend on the concretely given surface order.[8]

The complete sequence of explicit hear mode operation applications begins with SBJ×PRD:

4.4.5 **<to-do 3>**

CROSS-COPYING *john* AND *try* WITH SBJ×PRD (line 1)

SBJ×PRD (h1)

pattern level

noun: α	verb: β		noun: α	verb: β
cat: NP	cat: NP′ X v	⇒	cat: NP	cat: #NP′ X v
fnc:	arg:		fnc: β	arg: α
prn:K	prn:		prn: K	prn: K

Agreement conditions as in 2.1.2.

⇑ ⇓

content level

sur: John	sur: tried	sur: john	sur:
noun: [person x]	verb: try	noun: [person x]	verb: try
cat: snp	cat: n′ a′ v	cat: snp	cat: #n′ a′ v
sem: nm m	sem: ind past	sem: nm m	sem: ind past
fnc:	arg:	fnc: try	arg: [person x]
...	...	...	...
prn: 24	prn:	prn: 24	prn: 24

Try has the valency slot a′ for the direct object. As a verb of the *promise* class (cf. variable restriction in 4.4.6), the a′ slot may be #-canceled by a noun (e.g. tried a cookie) or by the conjunction to of an infinitive (e.g. tried to sing).

4.4.6 CROSS-COPYING *try* AND *to* WITH PRD×INF^{try} (line 2)

PRD×INF^{try} (h13)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{cat: \#NOM}' \text{ a}' \text{ v} \\ \text{arg: } \beta \\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: v\_1} \\ \text{cat: inf} \\ \text{fnc:} \\ \text{arg: } \emptyset \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \alpha \\ \text{cat: \#NOM}' \text{ \#a}' \text{ v} \\ \text{arg: } \beta \text{ v\_1} \\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: v\_1} \\ \text{cat: inf} \\ \text{fnc: } \alpha \\ \text{arg:}\emptyset \\ \text{prn: K}\end{bmatrix}$$

$\alpha \in$ {begin, can afford, choose, decide, expect, forget, learn, like, manage, need, offer, plan, prepare, promise, refuse, start, try, want}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: try} \\ \text{cat: \#n}' \text{ a}' \text{ v} \\ \text{sem: ind past} \\ \text{arg: [person x]} \\ \ldots \\ \text{prn: 24}\end{bmatrix}\begin{bmatrix}\text{sur: to} \\ \text{verb: v\_1} \\ \text{cat: inf} \\ \text{sem: } \textit{to} \\ \text{fnc:} \\ \text{arg:}\emptyset \\ \ldots \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: try} \\ \text{cat: \#n}' \text{ \#a}' \text{ v} \\ \text{sem: ind past} \\ \text{arg: [person x] v\_1} \\ \ldots \\ \text{prn: 24}\end{bmatrix}\begin{bmatrix}\text{sur:} \\ \text{verb: v\_1} \\ \text{cat: inf} \\ \text{sem: } \textit{to} \\ \text{fnc: try} \\ \text{arg:}\emptyset \\ \ldots \\ \text{prn: 24}\end{bmatrix}$$

The empty slot marker $\emptyset$ in the arg slot of to is lexically in subject position.[9]

The following absorption of *sing* replaces all occurrences of v_1, here two (cf. 4.4.4, line 3), fuses the cat values of the input, supplies the sem values. and retains the $\emptyset$ marker:

4.4.7 ABSORBING *sing* INTO *to* WITH INF∪V (line 3)

INF∪NFV (h17)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n \\ \text{cat: inf} \\ \text{arg: } \beta \\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: } \alpha \\ \text{cat: n-s3}' \text{ X v} \\ \text{arg:} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \alpha \\ \text{cat: \#n-s3}' \text{ X inf} \\ \text{arg: } \beta \\ \text{prn: K}\end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: v\_1} \\ \text{cat: inf} \\ \text{sem: } \textit{to} \\ \text{fnc: try} \\ \text{arg: } \emptyset \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 24}\end{bmatrix}\begin{bmatrix}\text{sur: sing} \\ \text{verb: sing} \\ \text{cat: n-s3}' \text{ v} \\ \text{sem: ind pres} \\ \text{arg:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: sing} \\ \text{cat: \#n-s3}' \text{ inf} \\ \text{sem: } \textit{to} \text{ ind pres} \\ \text{fnc: try} \\ \text{arg:}\emptyset \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 24}\end{bmatrix}$$

[9] The variable restriction of the corresponding operation **PRD×INF**^{persuade} for object control (not shown) includes {advise, allow, appoint, ask, beg, choose, convince, encourage, expect, forbid, force, invite, need, permit, persuade, select, teach, tell, urge, want, would like}. For more differentiated classes of variable restrictions on infinitives see CLaTR Sect. 15.4.

In accordance with surface compositionality, the form sing is analyzed in the input with the standard lexical feature [cat: n-s3′ v] for the unmarked present tense (NLC A.5.1). The #-marking of the nominative valency position in the cat slot of the output prepares for a possible PRD×OBJ alternative.

The hear mode derivation concludes with adding the period:

4.4.8 ABSORBING • INTO *try* WITH S∪IP (line 3)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: \#X}' \text{ VT} \\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{verb: V\_}n \\ \text{cat: VT}' \text{ SM}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: \#X}' \text{ SM} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

$\Uparrow$ $\Downarrow$

content level

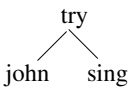
$$\begin{bmatrix}\text{sur:} \\ \text{verb: try} \\ \text{cat: \#n}' \text{ \#a}' \text{ v} \\ \text{sem: ind past} \\ \text{arg: [person x] sing} \\ \ldots \\ \text{prn: 24}\end{bmatrix} \quad \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: v\_1} \\ \text{cat: v}' \text{ decl} \\ \text{sem:} \\ \text{arg:} \\ \ldots \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: try} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x] sing} \\ \ldots \\ \text{prn: 24}\end{bmatrix}$$

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

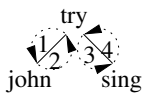
4.4.9 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE

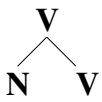
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

1	2	3	4
John	tried	to__sing	•
V/N	N/V	V\V	V\V

The \ line in V\V characterizes the infinitive as a grammatical object.

Word form production is summarized as follows:

4.4.10 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *try* to *john*	John	4.4.11
arc 2:	N↗V	from *john* to *try*	tried	4.4.12
arc 3:	V↘INF^{try}	from *try* to *sing*	to_sing	4.4.13
arc 4:	V↖V	from *sing* to *try*	•	4.4.14

The complete sequence of explicit navigation operations begins with V↙N:

4.4.11 **<to-do 6>**

NAVIGATING WITH V↙N FROM *try* TO *john* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: try} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x] sing} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 24} \end{bmatrix} \quad \begin{bmatrix} \text{sur: John} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: try} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 24} \end{bmatrix}$$

Based on the name marker in the goal proplet, the surface output is John.

Using the continuation feature [fnc: try] of the goal proplet *john*, the navigation returns with N↗V to the top verb and realizes tried:

4.4.12 NAVIGATING WITH N↗V FROM *john* BACK TO *try* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K} \end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur: john} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: try} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 24} \end{bmatrix} \quad \begin{bmatrix} \text{sur: tried} \\ \text{verb: try} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x] sing} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 24} \end{bmatrix}$$

Up to this point, the speak mode navigation ignores the verbal object value sing in the arg slot of *try*. The next navigation operation, however, requires the second argument of *try* to be a verb (cf. core attribute of the goal pattern):

4.4.13 NAVIGATING WITH V\↘INF^{try} FROM *try* TO *sing* (arc 3)

V\↘INF^{try} (s36)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: } \#\gamma\ \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{cat: \#NP \#X inf} \\ \text{sem: } \textit{to}\ \text{Z} \\ \text{arg: } \emptyset\ \text{Y} \\ \text{fnc: } \#\alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\alpha \in$ {begin, can afford, choose, decide, expect, forget, learn, like, manage, need, offer, plan, prepare, refuse, start, try, want.}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: try} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] sing} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 24}\end{bmatrix} \quad \begin{bmatrix}\text{sur: to\_sing} \\ \text{verb: sing} \\ \text{cat: \#n-s3}' \text{ v} \\ \text{sem: } \textit{to} \\ \text{arg: } \emptyset \\ \text{fnc: \#try} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 24}\end{bmatrix}$$

The variable γ in the initial arg slot of α indicates "subject control" of the *try*-class. The arg value $\emptyset$ and the additional fnc attribute of *sing* originated lexically from the intrapropositional conjunction to in the hear mode (4.4.4, line 2).

Finally, the navigation returns to try and realizes the surface **.** from the decl value in the cat slot of the goal proplet.

4.4.14 NAVIGATING WITH INF↖\V FROM *read* BACK TO *try* (arc 6)

INF↖\V (s37)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: \#X v} \\ \text{sem: } \textit{to}\text{\#X} \\ \text{arg: } \emptyset\ \text{\#Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\gamma}) \\ \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K}\end{bmatrix}$$

$\gamma \in$ {that, when, where, how, why}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: to\_sing} \\ \text{verb: sing} \\ \text{cat: \#n-s3}' \text{ v} \\ \text{sem: } \textit{to} \\ \text{arg: } \emptyset \\ \text{fnc: \#try} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 24}\end{bmatrix} \quad \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: try} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#sing} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 24}\end{bmatrix}$$

Once the verb of an infinitival object has been added by fusing it with to (4.4.5), the continuation of the infinitival phrase is free: the infinitive phrase may range from a bare one-place verb, as in John tried to sing to more complex constructions, such as John tried to read a book or John tried to give Mary a cookie.

Extending DBS.15 to an example class with an infinitival object in current DBS.16 required the definition of the two hear mode operations $\mathsf{PRD}\times\mathsf{INF}^{try}$ (h13) and $\mathsf{INF}\cup\mathsf{NFV}$ (h17), and the two speak mode operations $\mathsf{V}\backslash_{\searrow}\mathsf{INF}^{try}$ (s36), and $\mathsf{INF}\nwarrow\mathsf{V}$ (s37).

4.4.15 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

	1		2		3		4	
John	$\times$	tried	$\times$	to	$\cup$	sing	$\times$	$\bullet$

speak mode:

1		2		3		4	
$\mathrm{V}/_{\swarrow}\mathrm{N}$	John	$\mathrm{N}/_{\nearrow}\mathrm{V}$	tried	$\mathrm{V}\backslash_{\searrow}\mathrm{INF}^{try}$	to_sing	$\mathrm{INF}\nwarrow\mathrm{V}$	$\bullet$

The hear mode and the speak mode derivations used four operation applications each, but differ in their segmentation.

4.5 DBS.17: Nominal Copula Construction

The English auxiliary *be* may be used in complex verb constructions (Sects. 2.2, 3.1) or as a copula. In either case, *be* is like an almost empty verb shell which specifies tense and mood, and requires subject agreement,[10] but lacks a more substantial content beyond some general notion of equation.

As an auxiliary, as in was running, *be* takes a non-finite form of a main verb form, e.g. the present participle (gerund), as a more differentiated content. As a copula, *be* takes a second noun, as in is a doctor, or an adnominal, as in is hungry, as its second complement.

Regarding the grammatical role of a second noun, English syntax provides no clear criterion as to whether it is a nominative or an oblique.[11] For example, when looking at an old foto, one may point at a person and say ‘This is me.’ On the phone, in contrast, one may reply with ‘This is I.’ In consequence we use standard $\mathsf{PRD}\times\mathsf{OBJ}$ for connecting the second noun.

As an example consider the following content with *be* taking a second noun as an argument, which has been called ‘predicative’ in English grammar:

4.5.1 **<to-do 1>**

CONTENT OF Julia is a doctor.

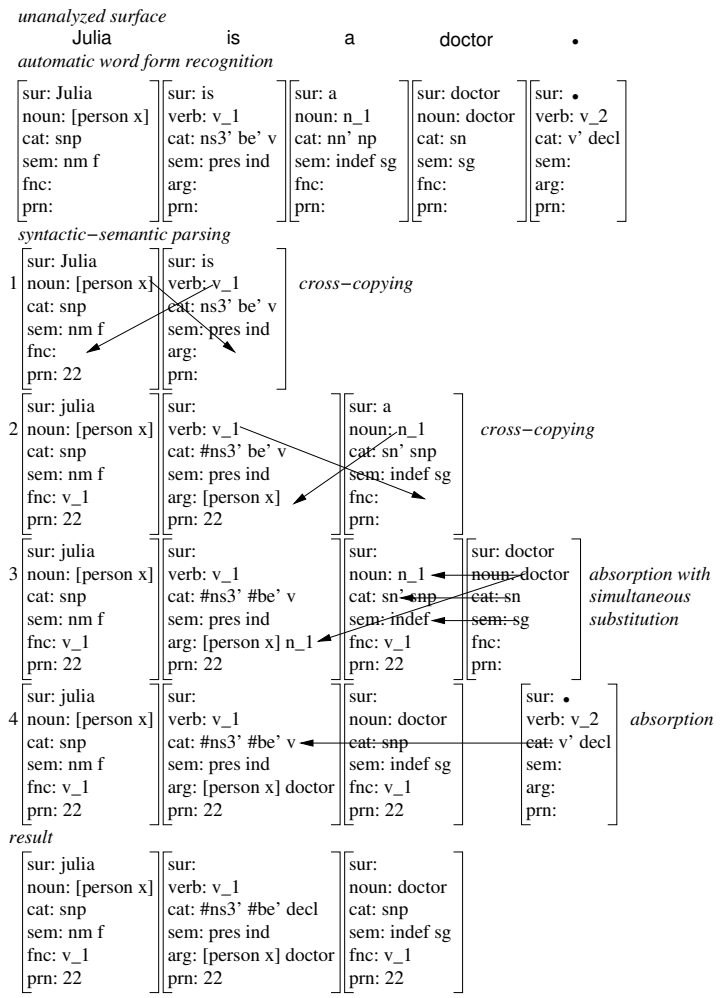
sur: julia	sur:	sur:
noun: [person x]	verb: v_1	noun: doctor
cat: snp	cat: #ns3′ #be′ decl	cat: snp
sem: nm f	sem: ind pres	sem: indef sg
fnc: v_1	arg: [person x] doctor	fnc: v_1
...	...	...
prn: 22	prn: 22	prn: 22

The core value of the proplet representing is is the substitution variable v_1; the equation quality is coded by the valency position be′ in the cat slot.

As a first conceptual orientation consider the derivation graph:

4.5.2 **<to-do 2>**

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION



The valency position be′ is filled by the second noun *doctor* in lines 2 and 3. The auxiliary character of the copula is represented by the substitution variable *v_1* serving as the core value. The kind of copula is coded in the cat slot by the valency position be′, distinguishing it from hv′ and do′ (CLaTR 6.6.8). The core value of *doctor* is copied into the second arg slot of be, i.e. the standard object position.

The complete sequence of explicit hear mode operation applications begins with SBJ×PRD:

4.5.3 **<to-do 3>**

CROSS-COPYING *Julia* AND *be* WITH SBJ×PRD (line 1)

SBJ×PRD (h1)

pattern level

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP}'\text{ X v}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ X v}\\ \text{arg: }\alpha\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.2.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: Julia}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm f}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 22}\end{bmatrix}\quad\begin{bmatrix}\text{sur: is}\\ \text{verb: v\_1}\\ \text{cat: ns3}'\text{ be}'\text{ v}\\ \text{sem: ind pres}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur: julia}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm f}\\ \text{fnc: v\_1}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 22}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat: \#ns3}'\text{ be}'\text{ v}\\ \text{sem: ind pres}\\ \text{arg: [person x]}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 22}\end{bmatrix}$$

The #-canceling of the ns3′ value in the *v_1* proplet enables the PRD×OBJ operation to apply next. The agreement between the valency position be′ in the cat slot of the copula and the associated second nominal filler is accommodated by the variable restrictions of 2.3.4.

---

[10] In addition, there are the auxiliaries *have* and *do* in English (FoCL Sect. 17.4), as well as the modals *can, could, may, might, must, ought, shall, should, will,* and *would*. An example of using have as an auxiliary is John has bought a car; an example of using have as a copula is John has a car (general relation of ownership). An example of using do as an auxiliary is emphatic John does like Mary; an example of do as a copula is Mary does the boogie-woogie.

[11] In German, the second noun is morphologically a clear nominative, called Gleichsetzungsnominativ in the grammar literature. For example, it is Das bin ich•, but not *Das bin mich•, *Das bin mir•, *Das ist mich•, or *Das ist mir•, which are all clearly ungrammatical. Yet there is Wie ist Dir?, which is archaic but grammatical and documented (Brömel 1794, p. 15) – in contradistinction to *Wie bist Du?, which uses a Gleichsetzungsnominativ but is not employed in German, despite the English analog. However, Where am I?/Wo bin ich?, Where is she?/Wo ist sie?, etc., work alike.

4.5.4 Cross-copying *be* and *a(n)* with PRD×OBJ (line 2)

PRD×OBJ (h28)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \underline{\#X'}\ N'\ Y\ \gamma \\ \text{arg: } Z \\ \text{prn: } K\end{bmatrix} \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: } CN'\ NP \\ \text{fnc:} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \underline{\#X'}\ \#N'\ Y\ \gamma \\ \text{arg: } Z\ \alpha \\ \text{prn: } K\end{bmatrix} \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: } CN'\ NP \\ \text{fnc: } \beta \\ \text{prn: } K\end{bmatrix}$$

Variable restriction as in 2.3.4.

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: v\_1} \\ \text{cat: \#ns3}'\ \text{be}'\ \text{v} \\ \text{sem: ind pres} \\ \text{arg: [person x]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 22}\end{bmatrix} \Uparrow \begin{bmatrix}\text{sur: a(n)} \\ \text{noun: n\_1} \\ \text{cat: sn}'\ \text{snp} \\ \text{sem: indef sg} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: v\_1} \\ \text{cat: \#ns3}'\ \text{\#be}'\ \text{v} \\ \text{sem: ind pres} \\ \text{arg: [person x] n\_1} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 22}\end{bmatrix} \Downarrow \begin{bmatrix}\text{sur:} \\ \text{noun: n\_1} \\ \text{cat: sn}'\ \text{snp} \\ \text{sem: indef sg} \\ \text{fnc: v\_1} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 22}\end{bmatrix}$$

With the second valency position be′ in the cat slot of *v_1* canceled by the determiner of a second nominal argument (and not by an adnominal modifier like hungry as in 4.6.1), it remains to complete the noun.

Automatic word form recognition provides the common noun doctor as the next word and standard DET∪CN applies as follows:

4.5.5 Absorbing *doctor* into *a(n)* with DET∪CN (line 3)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n \\ \text{cat: } CN'\ NP \\ \text{sem: } Y \\ \text{prn: } K\end{bmatrix} \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: CN} \\ \text{sem: } Z \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: NP} \\ \text{sem: } Y\ Z \\ \text{prn: } K\end{bmatrix}$$

Agreement conditions as in 2.2.4.

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: n\_1} \\ \text{cat: sn}'\ \text{snp} \\ \text{sem: indef} \\ \text{fnc: v\_1} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 22}\end{bmatrix} \Uparrow \begin{bmatrix}\text{sur: doctor} \\ \text{noun: doctor} \\ \text{cat: sn} \\ \text{sem: sg} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \Downarrow \begin{bmatrix}\text{sur:} \\ \text{noun: doctor} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: v\_1} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 22}\end{bmatrix}$$

In summary, the case role of post-copula nouns is left undecided because (i) determiner-noun combinations and names have no concrete morphological case marking in English and (ii) those which do, i.e. pronouns like she vs. her, provide conflicting evidence. Therefore, we rely on English word order and treat non-initial arguments in declarative sentences generally as grammatical objects, even if they are pronouns with a case-marking for nominative.

The hear mode derivation concludes with standard S∪IP adding the inter-punctuation, here the period :

4.5.6 ABSORBING • INTO *v_1* WITH S∪IP (line 7)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ VT} \\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{verb: V\_}n \\ \text{cat: VT}' \text{ SM}\end{bmatrix} \quad \Rightarrow \quad \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ SM} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: v\_1} \\ \text{cat: } \#ns3' \ \#be' \text{ v} \\ \text{sem: ind pres} \\ \text{arg: [person x] doctor} \\ \text{dots} \\ \text{prn: 22}\end{bmatrix} \Uparrow \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: v\_1} \\ \text{cat: v}' \text{ decl} \\ \text{sem:} \\ \text{arg:} \\ \text{dots} \\ \text{prn:}\end{bmatrix} \qquad \Downarrow \begin{bmatrix}\text{sur:} \\ \text{verb: v\_1} \\ \text{cat: } \#ns3' \ \#be' \text{ decl} \\ \text{sem: ind pres} \\ \text{arg: [person x] doctor} \\ \ldots \\ \text{prn: 22}\end{bmatrix}$$

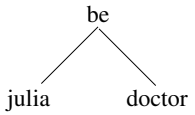
The hear mode derivation of an adnominal copula construction is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

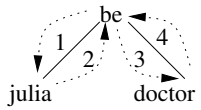
4.5.7 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE

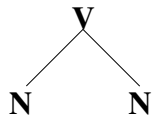
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

1	2	3	4
Julia	is	a_doctor	•
V/N	N/V	V\N	N\V

The graphs (i)–(iii) show the copula with the subject and a second noun, connected by \ as an object. The relations in the third line of the *(iv) surface realization* resemble those of a simple transitive verb structure such as 2.3.6.

Word form production is summarized as follows:

4.5.8 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *be* to *julia*	Julia	4.5.9
barc 2:	N↗V	from *julia* to *be*	is	4.5.10
arc 3:	V↘N	from *is* to *doctor*	a_doctor	4.5.11
arc 4:	N↖V	from *doctor* to *be*	•	4.5.12

The complete sequence of explicit navigation operations begins with V↙N:

4.5.9 **<to-do 6>**

NAVIGATING WITH V↙N FROM *v_1* TO *julia* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta \text{ X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: v\_1} \\ \text{cat: \#ns3}' \text{ \#be}' \text{ decl} \\ \text{sem: ind pres} \\ \text{arg: [person x] doctor} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 22} \end{bmatrix} \qquad \begin{bmatrix} \text{sur: Julia} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: v\_1} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 22} \end{bmatrix}$$

There is no need to adjust V↙N for this application because the variable α is not defined to exclude a substitution variable like *v_1* as a possible value to be bound to.

The same holds for N↗V, which applies next:

4.5.10 NAVIGATING WITH N↗V FROM *julia* BACK TO *v_1* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: } \alpha \text{ Y} \\ \text{mdr: Z} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta \text{ X} \\ \text{prn: K} \end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur: julia} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: v\_1} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 22} \end{bmatrix} \qquad \begin{bmatrix} \text{sur: is} \\ \text{verb: v\_1} \\ \text{cat: \#ns3}' \text{ \#be}' \text{ decl} \\ \text{sem: ind pres} \\ \text{arg: \#[person x] doctor} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 22} \end{bmatrix}$$

Using the sole continuation feature [fnc: v_1], the navigation returns to the copula. Using the cat value be′ and the sem value pres of the goal proplet, lexverb realizes the surface is.

With the first arg value [person x] #-marked, the only continuation value for the navigation to proceed from the copula is the second arg value doctor using V↘N:

4.5.11 NAVIGATING WITH V\↘N FROM *v_1* TO *doctor* (arc 3)

V\↘N (s3)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \underset{\cdot}{\alpha} \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: v\_1} \\ \text{cat: \#ns3}' \text{ \#be}' \text{ decl} \\ \text{sem: ind pres} \\ \text{arg: \#[person x] doctor} \\ \ldots \\ \text{b prn: 22} \end{bmatrix} \qquad \begin{bmatrix} \text{sur: a\_doctor} \\ \text{noun: doctor} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#v\_1} \\ \ldots \\ \text{prn: 22} \end{bmatrix}$$

Lexnoun realizes the surface a_doctor from the sem values indef sg and the core value doctor.

Finally, the navigation returns to the copula with N↖\V:

4.5.12 NAVIGATING WITH N↖\V FROM *doctor* BACK TO *v_1* (arc 4)

N↖\V (s4)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: } \underset{\cdot}{\alpha} \\ \text{mdr: } \underset{\cdot}{\text{Z}} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta \text{ Y} \\ \text{prn: K} \end{bmatrix}$$

where Z is #-marked or NIL.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{noun: doctor} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#v\_1} \\ \ldots \\ \text{prn: 22} \end{bmatrix} \qquad \begin{bmatrix} \text{sur: } \bullet \\ \text{verb: v\_1} \\ \text{cat: \#ns3}' \text{ \#be}' \text{ decl} \\ \text{sem: ind pres} \\ \text{arg: \#[person x] \#doctor} \\ \ldots \\ \text{prn: 22} \end{bmatrix}$$

Using the cat value decl of the goal proplet, lexverb realizes the surface •.

Applying DBS.16 to an example class with the copula be taking a noun did not require the definition of any additional operations. The hear and the speak mode derivations used four operation applications each, but the surface segmentation is different:

4.5.13 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

	1		2		3		4	
Julia	×	is	×	a	∪	doctor	×	•

speak mode:

1	2	3	4
V↙N Julia	N↗V is	V\↘N a_doctor	N↖\V •

The hear and the speak mode derivations run straight through.

4.6 DBS.18: Adnominal Copula Construction

The previous section analyzed the expression Julia is a doctor., i.e. the copula be with a noun as the second complement. We turn now to analyzing the expression Fido is hungry, i.e. the copula be with an elementary adnominal as the second complement. Nominal and adjectival copula constructions have in common that the second complement is obligatory.

In analogy to 4.1.1 and 4.2.1, the obligatory nature of the modifier as a complement is expressed by the cat value adn of *hungry* canceling the valency position be′ of the copula in addition to cross-copying the core values into the mdr and mdd slots of the predicate and the object.

4.6.1 **<to-do 1>**

CONTENT OF Fido is hungry.

sur: fido	sur:	sur:
noun: [dog y]	verb: v_1	adj: hungry
cat: snp	cat: #ns3′ #be′ decl	cat: adn
sem: nm m	sem: ind pres	sem: pad
fnc: v_1	arg: [dog y]	fnc:
mdr:	mdr: hungry	mdd: v_1
nc:	nc:	nc:
pc:	pc:	pc:
prn: 23	prn: 23	prn: 23

As a first conceptual orientation consider the derivation graph:

4.6.2 **<to-do 2>**

GRAPH ANALYSIS OF HEAR MODE INTERPRETATION

unanalyzed surface

Fido is hungry •

automatic word form recognition

sur: Fido	sur: is	sur: hungry	sur: •
noun: (dog x)	verb: v_1	adj: hungry	verb: v_2
cat: snp	cat: ns3' be' v	cat: adn	cat: v' decl
sem: nm m	sem: pres	sem: pad	sem:
fnc:	arg:	mdd:	arg:
mdr:	mdr:	mdr:	mdr:
prn:	prn:	prn:	prn:

syntactic–semantic parsing

1	sur: Fido	sur: is		
	noun: (dog x)	verb: v_1		*cross–copying*
	cat: snp	cat: ns3' be' v		
	sem: nm m	sem: pres		
	fnc:	arg:		
	mdr:	mdr:		
	prn: 23	prn:		
2	sur: Fido	sur:	sur: hungry	
	noun: (dog x)	verb: v_1	adj: hungry	*cross–copying*
	cat: snp	cat: #ns3' be' v	cat: adn	
	sem: nm m	sem: pres	sem: pad	
	fnc: v_1	arg: (dog x)	mdd:	
	mdr:	mdr:	mdr:	
	prn: 23	prn: 23	prn:	

3	sur: Fido noun: [dog x] cat: snp sem: nm m fnc: v_1 mdr: prn: 23	sur: verb: v_1 cat: #ns3' #be' v sem: pres ind arg: [dog x] mdr: hungry prn: 23	sur: adj: hungry ~~cat: adn~~ sem: pad mdd: v_1 mdr: prn: 23	sur: • verb: v_2 ~~cat: v'~~ decl sem: arg: mdr: prn:	*absorption*

result

sur: Fido noun: [dog x] cat: snp sem: nm m fnc: v_1 mdr: prn: 23	sur: verb: v_1 cat: #ns3' #be' decl sem: pres ind arg: [dog x] mdr: hungry prn: 23	sur: adj: hungry cat: adn sem: pad mdd: v_1 mdr: prn: 23

The explicit hear mode operation applications begin with SBJ×PRD:

4.6.3 **<to-do 3>**

CROSS-COPYING *fido* AND *be* WITH SBJ×PRD (line 1)

SBJ×PRD (h1)

pattern level

noun: α cat: NP fnc: prn:K	verb: β cat: NP′ Y v arg: bprn:	⇒	noun: α cat: NP fnc: β prn: K	verb: β cat: #NP′ Y v arg: α prn: K

Agreement conditions as in 2.1.2.

⇑ ⇓

content level

sur: Fido noun: [dog y] cat: snp sem: nm m fnc: ... prn: 23	sur: is verb: v_1 cat: ns3′ be′ v sem: ind pres arg: ... prn:	sur: fido noun: [dog y] cat: snp sem: nm m fnc: v_1 ... prn: 23	sur: verb: v_1 cat: #ns3′ be′ v sem: ind pres arg: [dog y] ... prn: 23

Next, automatic word form recognition provides the adn *hungry*. It is combined with the copula by the operation PRD×ADN (4.2.6):

4.6.4 CROSS-COPYING *be* AND *hungry* WITH PRD×ADN (line 2)

PRD×ADN (h57)

pattern level

verb: α cat: #X γ' Y mdr: prn: K	adj: β cat: ADN mdd: prn: K	⇒	verb: α cat: #X #γ' Y mdr: β prn: K	adj: β cat: ADN mdd: α prn: K

$\gamma \in$ {mdr′, be′}. If γ = mdr′, then ADN = adn; otherwise ADN $\in$ {adn, adnv}

⇑ ⇓

content level

sur: verb: v_1 cat: #ns3′ be′ v sem: ind pres arg: [dog y] mdr: nc: pc: prn: 23	sur: hungry adj: hungry cat: adn sem: pad mdd: mdr: nc: pc: prn:	sur: verb: v_1 cat: #ns3′ #be′ v sem: ind pres arg: [dog y] mdr: hungry nc: pc: prn: 23	sur: hungry adj: hungry cat: adn sem: pad mdd: v_1 mdr: nc: pc: prn: 23

The operation #-cancels the valency slot be′ in the copula with the filler adn and cross-copies the core values of *be* and *hungry* into their respective mdr and mdd slots. The restriction of the variable γ to mdr′ and be′ allows the use of PRD×ADN in 4.2.6 and 4.6.4. The restriction of ADN to {adn, adnv} in the case of be′ accommodates also phrasal modifiers, as in Fido is in the kitchen.

In summary, the use of nouns vs. modifiers as complements is parallel in a main verb and a copula: noun complements are stored in the arg slot (2.4.2, line 4; 4.5.2, line 2) while modifier complements are stored in the mdr slot (4.1.2, line 4; 4.2.2, line 4; 4.6.2, line 2). Furthermore, modifiers used as complements cancel a valency position in the cat slot of the predicate (4.1.2, line 4; 4.6.2, line 2), while optional modifiers do not (3.1.5, 3.1.6, 3.1.8, 3.1.9; 3.2.7).

The hear mode derivation concludes with standard S∪IP:

4.6.5 ABSORBING • INTO *be* WITH S∪IP (line 3)

S∪IP18)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ VT} \\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{verb: V\_}n \\ \text{cat: VT}' \text{ SM}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ SM} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

$\Uparrow$ $\Downarrow$

content level

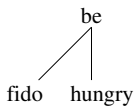
$$\begin{bmatrix}\text{sur:} \\ \text{verb: v\_1} \\ \text{cat: } \#ns3' \ \#be' \text{ v} \\ \text{sem: ind pres} \\ \text{arg: [dog y]} \\ \text{mdr: hungry} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 23}\end{bmatrix} \quad \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: v\_1} \\ \text{cat: v}' \text{ decl} \\ \text{sem:} \\ \text{arg:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: v\_1} \\ \text{cat: } \#ns3' \ \#be' \text{ decl} \\ \text{sem: ind pres} \\ \text{arg: [dog y]} \\ \text{mdr: hungry} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 23}\end{bmatrix}$$

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

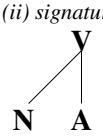
4.6.6 **<to-do 4>**

GRAPH ANALYSIS OF THE SEMANTIC RELATIONS OF STRUCTURE

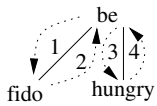
(i) SRG (semantic relations graph)



(ii) signature



(iii) NAG (numbered arcs graph)



(iv) surface realization

1	2	3	4
Fido	is	hungry	•
V/N	N/V	V|A	A|V

Comparison with 4.5.7 for Julia is a doctor clearly shows the semantic difference between the two constructions.

Word form production is summarized as follows:

4.6.7 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *be* to *fido*	Fido	4.6.8
arc 2:	N↗V	from *fido* to *be*	is	4.6.9
arc 3:	V↓A	from *be* to *hungry*	hungry	4.6.10
arc 4:	A↑V	from *hungry* to *be*	.	4.6.11

The complete sequence of explicit navigation operations begins with V↙N:

4.6.8 **<to-do 6>**

NAVIGATING WITH V↙N FROM *v_1* TO *fido* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: v\_1} \\ \text{cat: \#ns3}' \text{ \#be}' \text{ decl} \\ \text{sem: ind pres} \\ \text{arg: [dog y]} \\ \text{mdr: hungry} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 23} \end{bmatrix} \quad \begin{bmatrix} \text{sur: Fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: v\_1} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 23} \end{bmatrix}$$

The next operation returns to the verb and realizes is:

4.6.9 NAVIGATING WITH N↗V FROM *fido* BACK TO *v_1* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K} \end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur: fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: v\_1} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 23} \end{bmatrix} \quad \begin{bmatrix} \text{sur: is} \\ \text{verb: v\_1} \\ \text{cat: \#ns3}' \text{ \#be}' \text{ decl} \\ \text{sem: ind pres} \\ \text{arg: \#[dog y]} \\ \text{mdr: hungry} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 23} \end{bmatrix}$$

The navigation continues with V↓A and realizes hungry.

4.6.10 NAVIGATING WITH V↓A FROM *v_1* TO *hungry* (arc 3)

V↓A (s9)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{mdr: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexadj}(\hat{\beta}) \\ \text{adj: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the mdr slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: v\_1} \\ \text{cat: \#ns3}' \text{ \#be}' \text{ decl} \\ \text{sem: ind pres} \\ \text{arg: \#[dog y]} \\ \text{mdr: hungry} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 23}\end{bmatrix} \quad \begin{bmatrix}\text{sur: hungry} \\ \text{adj: hungry} \\ \text{cat: adn} \\ \text{sem: pad} \\ \text{mdd: \#v\_1} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 23}\end{bmatrix}$$

With the following application of A↑V the navigation returns to the copula as the top verb, allowing realization of the period with lexverb:

4.6.11 NAVIGATING WITH A↑V FROM *hungry* BACK TO *v_1* (arc 4)

A↑V (s10)

pattern level

$$\begin{bmatrix}\text{adj: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{mdr: X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{adj: hungry} \\ \text{cat: adn} \\ \text{sem: pad} \\ \text{mdr: \#v\_1} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 23}\end{bmatrix} \quad \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: v\_1} \\ \text{cat: \#ns3}' \text{ \#be}' \text{ decl} \\ \text{sem: ind pres} \\ \text{arg: \#[dog y]} \\ \text{mdr: \#hungry} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 23}\end{bmatrix}$$

Extending DBS.17 to an example class with the copula be taking an adnominal did not require the definition of any additional operation. The hear derivation used three operation applications and the speak mode used four:

4.6.12 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

	1		2		3	
Fido	×	is	×	hungry	∪	•

speak mode:

1	2	3	4
V↙N Fido	N↗V is	V↓A hungry	A↑V •

The hear and the speak mode derivations run straight through.

5. Unbounded Repetition

In computer science, there are two methods of repetition, (a) *iteration* and (b) *recursion*. They are equivalent computationally in that every recursive function may be rewritten as an iteration and vice versa.[1] They differ conceptually, however, in that iteration computes possible continuations as a flat chaining while recursion computes possible substitution as a repeated embedding, as in fractals. Substitution-driven sign-based linguistics claims recursion to be innate,[2] without considering iteration. Data-driven agent-based DBS, in contrast, uses time-linear iteration for repetition; there is no use of recursion.

5.1 DBS.19: Prepositional Phrases

A simple example of unbounded repetition in natural language are prepositional phrases. They start with the modification of a noun (adnominal reading, 1.5.3) or a verb (adverbial reading, 1.5.4), and continue by modifying the preceding modified, as in the following example:

5.1.1 **<to-do 1>**

Fido ate the bone on the table under the tree in the garden...

sur: fido	sur:	sur:	sur:	sur:	sur:
noun: [dog y]	verb: eat	noun: bone	noun: table	noun: tree	noun: garden
cat: snp	cat: n′ a′ v	cat: snp	cat: snp	cat: snp	cat: snp
sem: nm f	sem: ind past	sem: def sg	sem: *on* def sg	sem: *under* def sg	sem: *in* def sg
fnc: eat	arg: [dog y] bone	fnc: eat	mdd: bone	mdd: table	mdd: tree
mdr:	mdr:	mdr: table	mdr: tree	mdr: garden	mdr:
nc:	nc:	nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:	pc:	pc:
prn: 25	prn: 25	prn: 25	prn: 25	prn: 25	prn: 25

The noun bone is modified by the first prepositional phrase *table*,[3] connected

[1] The choice depends on the application and associated considerations of efficiency (Lanzman 2007).

[2] Hauser, Chomsky, and Fitch (2002). The claim has been challenged by Everett (2005) with evidence that the Pirahã language does not use embedding and is therefore not recursive.

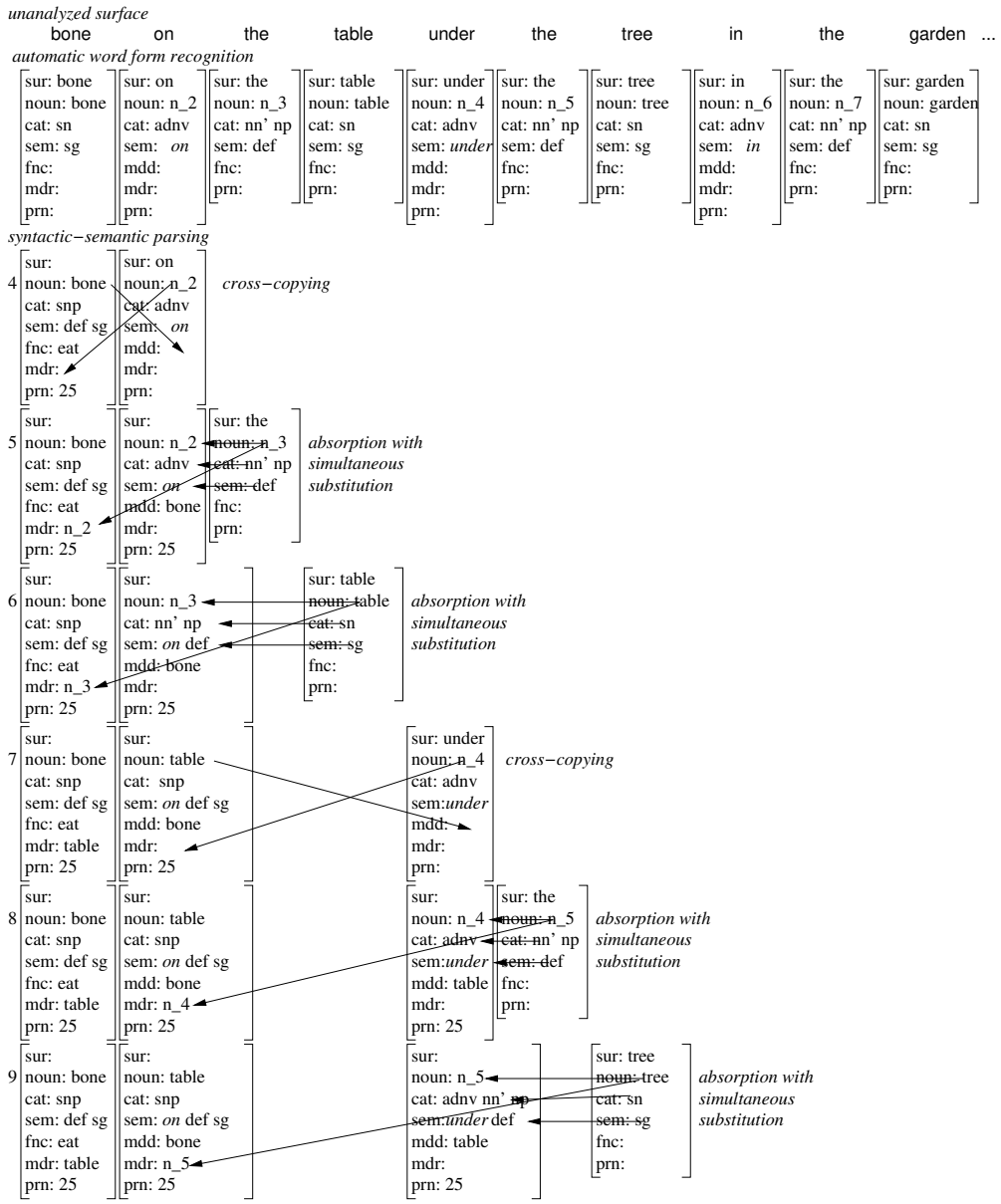
[3] DBS distinguishes elementary, phrasal, and clausal modifiers in terms of their respective core attributes adv, noun, and verb.

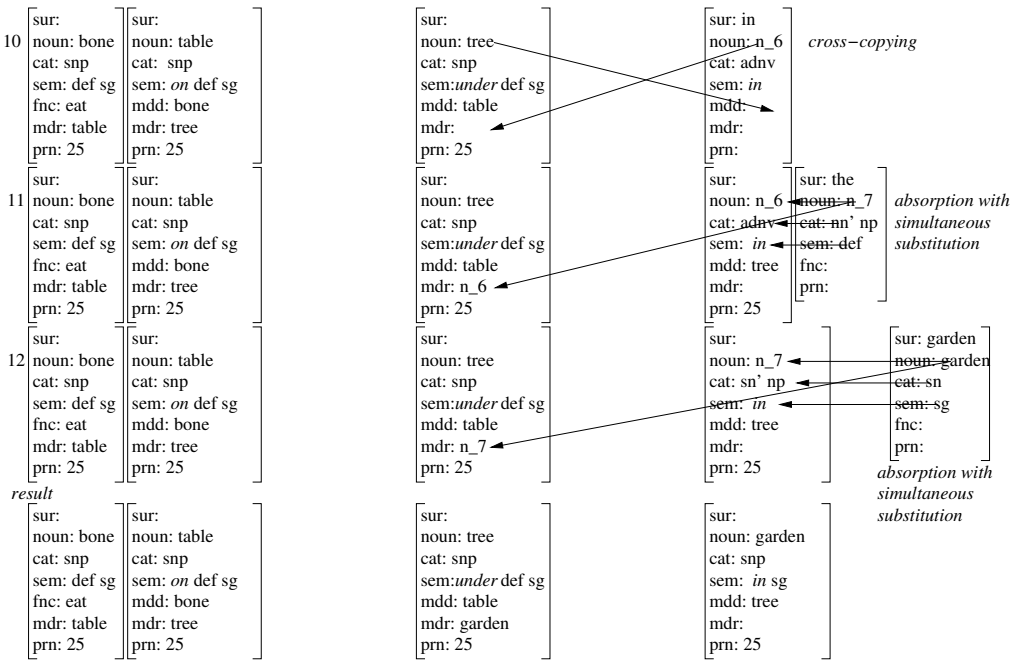
by cross-copying the core values into the respective mdr and mdd slots. *Table*, in turn, is modified by the second prepositional phrase *tree*, etc. The repeating relation is modification because the location table is modified by the location under the tree which is modified by the location in the garden.

As a first conceptual orientation consider the derivation graph:[4]

5.1.2 **<to-do 2>**

GRAPHICAL HEAR MODE DERIVATION OF THE CONTENT 5.1.1



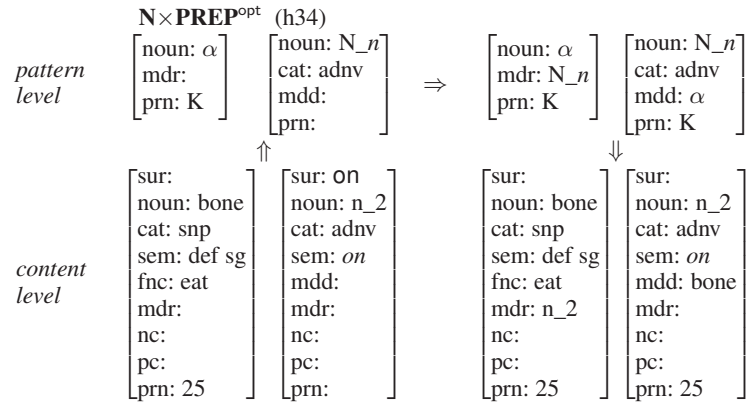


That the unlimited addition of prepositional phrases does not require recursion is shown by the cross-copyings in lines 4, 7, and 10, and by the following data-driven sequence of hear mode operations, specifically by the applications of N×PREP^{opt} in 5.1.3, 5.1.6, and 5.1.9, which code inter-proplet relations by address, and not by embedding. There is no suspension (unlike 3.1.3).

The explicit sequence of hear mode operations begins with cross-copying between the modified *bone* and the modifier *on*:

5.1.3 **<to-do 3>**

CROSS-COPYING *bone* AND *on* WITH N×PREP^{opt} (line 4)



[4] For the beginning of the example see 3.2.3. The modification in line 4 of 5.1.2 is adnominal N×PREP^{opt}, in contradistinction to line 4 in 3.2.3, which is adverbial PRD×PREP^{opt} (3.2.7).

Combining *bone* and *on* is the beginning of a prepositional modifier in adnominal use, in contradistinction to the adverbial alternative, which would combine *eat* and *on*, as shown in 1.5.4.

The next operation to apply is PREP∪NP (3.2.8). It absorbs the determiner into the preposition (CLaTR 7.2.5):

5.1.4 ABSORBING *the* INTO *on* WITH PREP∪NP (line 5)

PREP∪NP (h48)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{sem: X}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\text{ NP}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: }\alpha\\ \text{cat: adnv CN}'\text{ NP}\\ \text{sem: X Z}\\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: n\_2}\\ \text{cat: adnv}\\ \text{sem: }on\\ \text{mdd: bone}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 25}\end{bmatrix}\begin{bmatrix}\text{sur: the}\\ \text{noun: n\_3}\\ \text{cat: nn}'\text{ np}\\ \text{sem: def}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:}\\ \text{noun: n\_3}\\ \text{cat: adnv nn}'\text{ np}\\ \text{sem: }on\text{ def}\\ \text{mdd: bone}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 25}\end{bmatrix}$$

DET∪CN[5] completes the prepositional phrase by absorbing table:

5.1.5 ABSORBING *table* INTO *on the* WITH DET∪CN (line 6)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\text{ NP}\\ \text{sem: Y}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{sem: Y Z}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.2.4.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: n\_3}\\ \text{cat: adnv nn}'\text{ np}\\ \text{sem: }on\text{ def}\\ \text{mdd: bone}\\ \ldots\\ \text{prn: 25}\end{bmatrix}\begin{bmatrix}\text{sur: table}\\ \text{noun: table}\\ \text{cat: sn}\\ \text{sem: sg}\\ \text{fnc:}\\ \ldots\\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:}\\ \text{noun: table}\\ \text{cat: adnv snp}\\ \text{sem: }on\text{ def sg}\\ \text{mdd: bone}\\ \ldots\\ \text{prn: 25}\end{bmatrix}$$

When automatic word form recognition provides a second preposition, here *under*, N×PREP^{opt} concatenates *table* and *under* in the same way as *bone* and *on* in 5.1.3. Cross-copying the core values into the respective mdr and mdd slots characterizes the semantic relation as modification. Absence of an mdr′ valency in the cat(egory) of eat (3.2.3) characterizes the relation as optional.

[5] To accommodate the optional adnv segment for the preposition, the cat slot in the initial pattern proplet requires an additional variable (omitted).

The preposition *under* is the beginning of a repeating prepositional phrase. For the iteration of phrasal modifiers, DBS combines the preceding prepositional phrase, represented by the noun proplet *table*, and the next preposition by cross-copying, resulting in the feature [mdr: n_4] in *table* and the feature [mdd: table] in *under*:

5.1.6 CROSS-COPYING *table* AND *under* WITH N×PREP^{opt} (line 7)

N×PREP^{opt} (h34)

pattern level

$$\begin{bmatrix}\text{noun: } \alpha \\ \text{mdr:} \\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{noun: N\_}n \\ \text{cat: adnv} \\ \text{mdd:} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{mdr: N\_}n \\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{noun: N\_}n \\ \text{cat: adnv} \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow \qquad\qquad\qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: table} \\ \text{cat: adnv snp} \\ \text{sem: } \textit{on} \text{ def sg} \\ \text{mdd: bone} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix} \quad \begin{bmatrix}\text{sur: under} \\ \text{noun: n\_4} \\ \text{cat: adnv} \\ \text{sem: } \textit{under} \\ \text{mdd:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{noun: table} \\ \text{cat: adnv snp} \\ \text{sem: } \textit{on} \text{ def sg} \\ \text{mdd: bone} \\ \text{mdr: n\_4} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{noun: n\_4} \\ \text{cat: adnv} \\ \text{sem: } \textit{under} \\ \text{mdd: table} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix}$$

The prepositional phrase is continued by adding the determiner with PREP∪NP:

5.1.7 ABSORBING *the* INTO *under* WITH PREP∪NP (line 8)

PREP∪NP (h48)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n \\ \text{cat: adnv} \\ \text{sem: X} \\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: CN}' \text{ NP} \\ \text{sem: Z} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: adnv CN}' \text{ NP} \\ \text{sem: X Z} \\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow \qquad\qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: n\_4} \\ \text{cat: adnv} \\ \text{sem: } \textit{under} \\ \text{mdd: table} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix} \quad \begin{bmatrix}\text{sur: the} \\ \text{noun: n\_5} \\ \text{cat: nn}' \text{ np} \\ \text{sem: def} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{noun: n\_5} \\ \text{cat: adnv nn}' \text{ np} \\ \text{sem: } \textit{under} \text{ def} \\ \text{mdd: table} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix}$$

The second input pattern would also accept an elementary noun, as in to you or in Paris. Here, however, the prepositional phrase must be completed with an application of DET∪CN.[6]

[6] The incrementation of the N_*n* substitution variable from n_2 to n_7 is seen best in the top line (automatic word form recognition) of 5.1.2. Automatic incrementation is needed to keep track of different determiners, as in the German example Der die das Kind fütternde Frau liebende Mann..., which may be contrived but is grammatical.

5.1.8 ABSORBING *tree* INTO *under the* WITH DET∪CN (line 9)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\text{ NP}\\ \text{sem: Y}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{sem: Y Z}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.2.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: n\_5}\\ \text{cat: adnv nn}'\text{ np}\\ \text{sem: }\textit{under}\text{ def}\\ \text{mdd: table}\\ \ldots\\ \text{prn: 25}\end{bmatrix}\quad\begin{bmatrix}\text{sur: tree}\\ \text{noun: tree}\\ \text{cat: sn}\\ \text{sem: sg}\\ \text{fnc:}\\ \ldots\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{noun: tree}\\ \text{cat: adnv snp}\\ \text{sem: }\textit{under}\text{ def sg}\\ \text{mdd: table}\\ \ldots\\ \text{prn: 25}\end{bmatrix}$$

The unbounded repetition of modification with prepositional phrases continues by adding the third preposition *in* to *(under the) tree*:

5.1.9 CROSS-COPYING *tree* AND *in* WITH N×PREP^{opt} (line 10)

N×PREP^{opt} (h34)

pattern level

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{mdr:}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{mdd:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{mdr: N\_}n\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{mdd: }\alpha\\ \text{prn: K}\end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: tree}\\ \text{cat: adnv snp}\\ \text{sem: }\textit{under}\text{ def sg}\\ \text{mdd: table}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 25}\end{bmatrix}\quad\begin{bmatrix}\text{sur: in}\\ \text{noun: n\_6}\\ \text{cat: adnv}\\ \text{sem: }\textit{in}\\ \text{mdd:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{noun: tree}\\ \text{cat: adnv snp}\\ \text{sem: }\textit{under}\text{ def sg}\\ \text{mdd: table}\\ \text{mdr: n\_6}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 25}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{noun: n\_6}\\ \text{cat: adnv}\\ \text{sem: }\textit{in}\\ \text{mdd: tree}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 25}\end{bmatrix}$$

5.1.10 ABSORBING *the* INTO *in* WITH PREP∪NP (line 11)

PREP∪NP (h48)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{sem: X}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\text{ NP}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: adnv CN}'\text{ NP}\\ \text{sem: X Z}\\ \text{prn: K}\end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: n\_6}\\ \text{cat: adnv}\\ \text{sem: }\textit{in}\\ \text{mdd: tree}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 25}\end{bmatrix}\quad\begin{bmatrix}\text{sur: the}\\ \text{noun: n\_7}\\ \text{cat: nn}'\text{ np}\\ \text{sem: def}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{noun: n\_7}\\ \text{cat: adnv nn}'\text{ np}\\ \text{sem: }\textit{in}\text{ def}\\ \text{mdd: tree}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 25}\end{bmatrix}$$

5.1.11 ABSORBING *garden* INTO *in the* WITH DET∪CN (line 12)

DET∪CN (h47)

pattern level

noun: N_*n*	noun: α		noun: α
cat: CN′ NP	cat: CN	⇒	cat: NP
sem: Y	sem: Z		sem: Y Z
prn: K	prn:		prn: K

Agreement conditions as in 2.2.4.

⇑ ⇓

content level

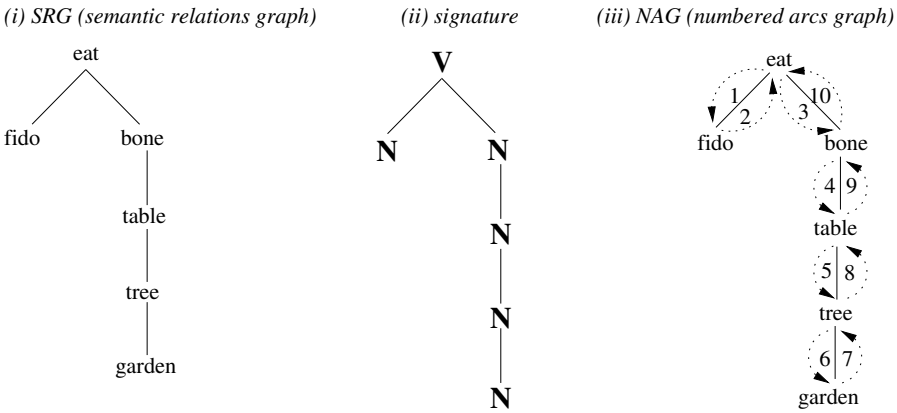
sur:	sur: garden	sur:
noun: n_7	noun: garden	noun: garden
cat: adnv nn′ np	cat: sn	cat: adnv snp
sem: *in* def	sem: sg	sem: *in* def sg
mdd: tree	fnc:	mdd: tree
mdr:	mdr:	mdr:
nc:	nc:	nc:
pc:	pc:	pc:
prn: 25	prn:	prn: 25

The hear mode derivation of repeating prepositional phrases is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

5.1.12 **<to-do 4>**

GRAPH ANALYSIS UNDERLYING PRODUCTION OF 5.1.1



(iv) surface realization

1	2	3	4	5	6	7	8	9	10
Fido	ate	the_bone	on_the_table	under_the_tree	in_the_garden				•
V/N	N/V	V\N	N|N	N|N	N|N	N|N	N|N	N|N	N\V

The unbounded repetition of prepositional phrases, here two, is based on the local, binary N|N relation between the modifier and the modified, coded by address. Comparison with 3.6.10 shows the semantic difference between the intrapropositional repetition of modification vs. coordination.

Word form production is summarized as the following list of speak mode operations:

5.1.13 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *eat* to *fido*	Fido	5.1.14
arc 2:	N↗V	from *fido* to *eat*	ate	5.1.15
arc 3:	V↘N	from *eat* to *bone*	the_bone	5.1.16
arc 4:	N↓N	from *bone* to *table*	on_the_table	5.1.17
arc 5:	N↓N	from *table* to *tree*	under_the_tree	5.1.18
arc 6:	N↓N	from *tree* to *garden*	in_the_garden	5.1.19
arc 7:	N↑N	from *garden* to *tree*		5.1.20
arc 8:	N↑N	from *tree* to *table*		5.1.21
arc 9:	N↑N	from *table* to *bone*		5.1.22
arc 10:	N↖V	from *bone* to *eat*	•	5.1.23

The complete sequence of explicit navigation operations begins with V↙N:

5.1.14 **<to-do 6>**

NAVIGATING WITH V↙N FROM *eat* TO *fido* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: eat} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [dog y] bone} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25} \end{bmatrix} \quad \begin{bmatrix} \text{sur: Fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25} \end{bmatrix}$$

5.1.15 NAVIGATING WITH N↗V FROM *fido* BACK TO *eat* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{Y} \\ \text{prn: K} \end{bmatrix}$$

#-mark α in the fnc slot of proplet β

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur: fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25} \end{bmatrix} \quad \begin{bmatrix} \text{sur: ate} \\ \text{verb: eat} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[dog y] bone} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25} \end{bmatrix}$$

5.1.16 NAVIGATING WITH V↘N FROM *eat* TO *bone* (arc 3)

V↘N (s3)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[dog y] bone} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix} \quad \begin{bmatrix}\text{sur: the\_bone} \\ \text{noun: bone} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: \#eat} \\ \text{mdr: table} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix}$$

The following three navigation steps move from *bone* to *table*, from table to *tree*, and from *tree* to *garden*:

5.1.17 NAVIGATING WITH N↓N FROM *bone* TO *table* (arc 4)

N↓N (s21)

pattern level

$$\begin{bmatrix}\text{noun: } \alpha \\ \text{mdr: } \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the mdr slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: bone} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: \#eat} \\ \text{mdr: table} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix} \quad \begin{bmatrix}\text{sur: on\_the\_table} \\ \text{noun: table} \\ \text{cat: snp} \\ \text{sem: } \textit{on} \text{ def sg} \\ \text{mdd: bone} \\ \text{mdr: tree} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix}$$

5.1.18 NAVIGATING WITH N↓N FROM *table* TO *tree* (arc 5)

N↓N (s21)

pattern level

$$\begin{bmatrix}\text{noun: } \alpha \\ \text{mdr: } \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the mdr slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: table} \\ \text{cat: snp} \\ \text{sem: } \textit{on} \text{ def sg} \\ \text{mdd: \#bone} \\ \text{mdr: tree} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix} \quad \begin{bmatrix}\text{sur: under\_the\_tree} \\ \text{noun: tree} \\ \text{cat: snp} \\ \text{sem: } \textit{under} \text{ def sg} \\ \text{mdd: \#table} \\ \text{mdr: garden} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix}$$

5.1.19 NAVIGATING WITH N↓N FROM *tree* TO *garden* (arc 6)

N↓N (s21)

pattern level

$$\begin{bmatrix}\text{noun: } \alpha \\ \text{mdr: } \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the mdr slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: tree} \\ \text{cat: snp} \\ \text{sem: } \textit{under} \text{ def sg} \\ \text{mdd: \#table} \\ \text{mdr: garden} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix} \quad \begin{bmatrix}\text{sur: in\_the\_garden} \\ \text{noun: garden} \\ \text{cat: snp} \\ \text{sem: } \textit{in} \text{ def sg} \\ \text{mdd: \#tree} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix}$$

The navigation returns empty to the modified from *garden* back to *tree* (arc 7), from *tree* back to *table* (arc 8), and from *table* back to *bone* (arc 9).

5.1.20 NAVIGATING WITH N↑N FROM *garden* BACK TO *tree* (arc 7)

N↑N (s22)

pattern level

$$\begin{bmatrix}\text{noun: } \alpha \\ \text{mdd: } \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{mdr: } \alpha \\ \text{prn: K}\end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: garden} \\ \text{cat: snp} \\ \text{sem: } \textit{in} \text{ def sg} \\ \text{mdd: \#tree} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{noun: tree} \\ \text{cat: snp} \\ \text{sem: } \textit{under} \text{ def sg} \\ \text{mdd: \#table} \\ \text{mdr: \#garden} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix}$$

5.1.21 NAVIGATING WITH N↑N FROM *tree* BACK TO *table* (arc 8)

N↑N (s22)

pattern level

$$\begin{bmatrix}\text{noun: } \alpha \\ \text{mdd: } \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{mdr: } \alpha \\ \text{prn: K}\end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: tree} \\ \text{cat: snp} \\ \text{sem: } \textit{under} \text{ def sg} \\ \text{mdd: \#table} \\ \text{mdr: \#garden} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{noun: table} \\ \text{cat: snp} \\ \text{sem: } \textit{on} \text{ def sg} \\ \text{mdd: \#bone} \\ \text{mdr: \#tree} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix}$$

5.1.22 NAVIGATING WITH N↑N FROM *table* BACK TO *bone* (arc 9)

N↑N (s22)

pattern level

$$\begin{bmatrix}\text{noun: } \alpha \\ \text{mdd: } \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{mdr: } \alpha \\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: table} \\ \text{cat: snp} \\ \text{sem: } \textit{on} \text{ def sg} \\ \text{mdd: \#bone} \\ \text{mdr: \#tree} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{noun: bone} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: \#eat} \\ \text{mdr: \#table} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 25}\end{bmatrix}$$

The speak mode operations N↓N and N↑N traversing the initial modification of *bone* (5.1.17, 5.1.22) and those traversing the repetitions (5.1.18–5.1.21) are the same, and correspondingly for N×PREP^{opt} in the hear mode.

The last traversal is from *bone* back to the top verb *eat*:

5.1.23 NAVIGATING WITH N↖\V FROM *bone* BACK TO *eat* (arc 10)

N↖\V (s4)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{mdr: } \ddot{Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta\text{ Y} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: bone} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: \#eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn 25}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: eat} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[dog y] \#bone} \\ \text{mdr: \#table} \\ \text{nc:} \\ \text{pc:} \\ \text{prn 25}\end{bmatrix}$$

Using the cat value decl of the goal proplet, lexverb realizes the surface •.

Extending DBS.18 to an example class of repeating prepositional phrases required the definition of the hear operation N×PREP^{opt} (h34), and of the two speak mode operations N↓N (s21) and N↑N (s22). Including the three lines which were omitted at the beginning of 5.1.2 for reasons of space (but presented in Sect. 3.2), the hear mode derivation used 13 operation applications, while the speak mode derivation used ten:

5.1.24 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

	1		2		3		4		5		6		7		8
Fido	×	ate	×	the	∪	bone	×	on	∪	the	∪	table	×	under	∪

	9		10		11		12		13	
the	∪	tree	×	in	∪	the	∪	garden	∪	•

speak mode:

1		2		3		4		5	
V↙/N	Fido	N↗V	ate	V↘\N	the_bone	N↓N	on_the_table	N↓N	under_the_tree

6		7	8	9	10	
N↓N	in_the_garden	N↑N	N↑N	N↑N	N↖\V	•

Even though the speak mode requires two navigation steps for each modifier, it has fewer applications than the hear mode because the three words of a prepositional phrase are produced in one step from a single proplet by the lexicalization rule. The hear mode, in contrast, needs three applications for attaching and composing a prepositional phrase.

5.2 DBS.20: Subject Gapping

In linguistics, a grammatical construction in which a single *shared* item is in a semantic relation with a sequence of n ($1 \leq n$) *gapped* items (repetition) is called *gapping*. Basic examples are (i) subject gapping, (ii) predicate gapping, and (iii) object gapping, which have the following pretheoretical structure:

5.2.1 PRETHEORETICAL COMPARISON OF THREE GAPPING KINDS

subject gapping	*predicate gapping*	*object gapping*
Bob buy apple	Bob **buy** apple	Bob buy ∅
∅ peel pear	Jim ∅ pear	Jim peel ∅
and ∅ eat peach	*and* Bill ∅ peach	*and* Bill eat **peach**

The shared item is shown in bold face, while the gapped items are indicated by the gap marker ∅. In subject (present section) and predicate (Sect. 5.3) gapping, the shared item, i.e. the filler, precedes the gapped items, i.e. the slots. In object gapping (Sect. 5.4), in contrast, the gapped items (slots) precede the shared item (filler).

The following example shows the content of a subject gapping:

5.2.2 **<to-do 1>**

Bob bought an apple, ∅ peeled a pear, and ∅ ate a peach**.**

sur: bob	sur:	sur:	sur:	sur:	sur:
noun: [person x]	verb: buy	noun: apple	verb: peel	noun: pear	verb: eat
cat: snp	cat: #n′ #a′ v	cat: snp	cat: #n′ #a′ v	cat: snp	cat: #n′ #a′ decl
sem: nm m	sem: ind past	sem: indef sg	sem: ind past	sem: indef sg	sem: *and* ind past
fnc: buy	arg: [person x] apple	fnc: buy	arg: [person x] pear	fnc: peel	arg: [person x] peach
peel	mdr:	mdr:	mdr:	mdr:	mdr:
eat	nc:	nc:	nc:	nc:	nc:
mdr:	pc:	pc:	pc:	pc:	pc:
nc:	prn: 32	prn: 32	prn: 32	prn: 32	prn: 32
pc:					
prn: 32					

sur:	sur:
noun: peach	
cat: snp	
sem: indef sg	
fnc: eat	
mdr:	
nc:	
pc:	
prn: 32	

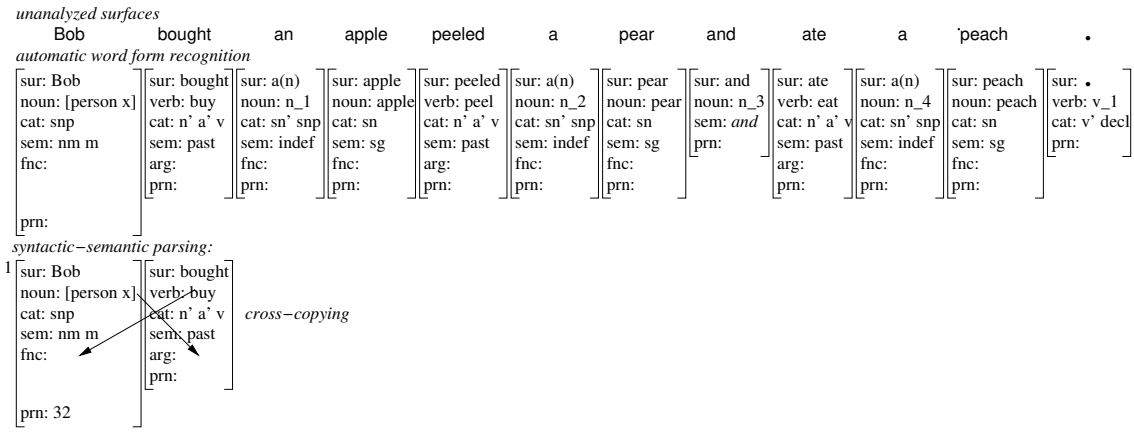
b

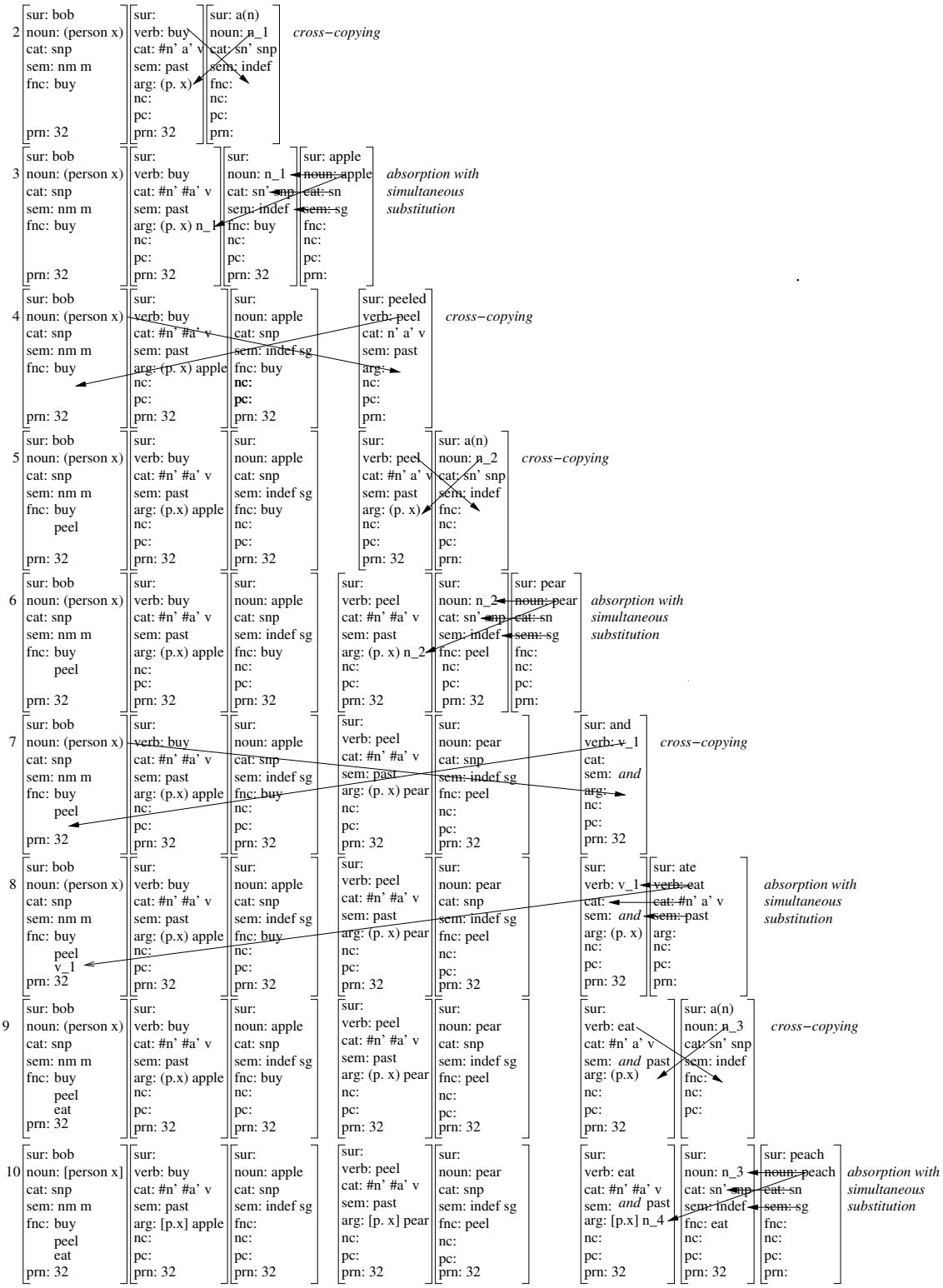
The semantic relations between the shared item *bob* and the gapped items ∅ *peel pair* and ∅ *eat peach* are not run via the nc and pc slots (which are empty), but via the gap list in the shared item and the repetition of the shared item's address, here [person x], in the verbs of the gapped items (arg slot, initial position). In this way, the semantic relations of structure are complete even in a gapping construction.

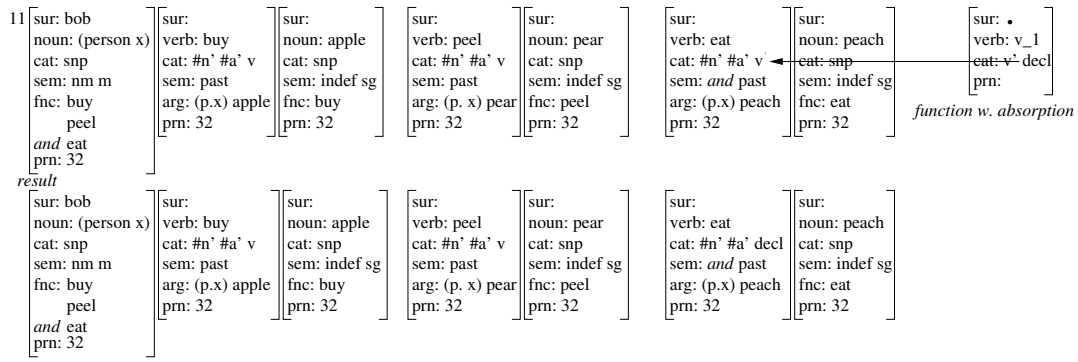
As a first conceptual orientation consider the derivation graph:

5.2.3 **<to-do 2>**

GRAPHICAL HEAR MODE DERIVATION OF THE CONTENT 5.2.2




2
sur: bob
noun: (person x)
cat: snp
sem: nm m
fnc: buy
prn: 32
sur:
verb: buy
cat: #n' a' v
sem: past
arg: (p. x)
nc:
pc:
prn: 32
sur: a(n)
noun: n_1
cat: sn' snp
sem: indef
fnc:
nc:
pc:
prn:
cross−copying
3
sur: bob
noun: (person x)
cat: snp
sem: nm m
fnc: buy
prn: 32
sur:
verb: buy
cat: #n' #a' v
sem: past
arg: (p. x) n_1
nc:
pc:
prn: 32
sur:
noun: n_1
cat: sn' snp
sem: indef
fnc: buy
nc:
pc:
prn: 32
sur: apple
noun: apple
cat: sn
sem: sg
fnc:
nc:
pc:
prn:
absorption with simultaneous substitution
4
sur: bob
noun: (person x)
cat: snp
sem: nm m
fnc: buy
prn: 32
sur:
verb: buy
cat: #n' #a' v
sem: past
arg: (p. x) apple
nc:
pc:
prn: 32
sur:
noun: apple
cat: snp
sem: indef sg
fnc: buy
nc:
pc:
prn: 32
sur: peeled
verb: peel
cat: n' a' v
sem: past
arg:
nc:
pc:
prn:
cross−copying
5
sur: bob
noun: (person x)
cat: snp
sem: nm m
fnc: buy
peel
prn: 32
sur:
verb: buy
cat: #n' #a' v
sem: past
arg: (p.x) apple
nc:
pc:
prn: 32
sur:
noun: apple
cat: snp
sem: indef sg
fnc: buy
nc:
pc:
prn: 32
sur:
verb: peel
cat: #n' a' v
sem: past
arg: (p. x)
nc:
pc:
prn: 32
sur: a(n)
noun: n_2
cat: sn' snp
sem: indef
fnc:
nc:
pc:
prn:
cross−copying
6
sur: bob
noun: (person x)
cat: snp
sem: nm m
fnc: buy
peel
prn: 32
sur:
verb: buy
cat: #n' #a' v
sem: past
arg: (p.x) apple
nc:
pc:
prn: 32
sur:
noun: apple
cat: snp
sem: indef sg
fnc: buy
nc:
pc:
prn: 32
sur:
verb: peel
cat: #n' #a' v
sem: past
arg: (p. x) n_2
nc:
pc:
prn: 32
sur:
noun: n_2
cat: sn' snp
sem: indef
fnc: peel
nc:
pc:
prn: 32
sur: pear
noun: pear
cat: sn
sem: sg
fnc:
nc:
pc:
prn:
absorption with simultaneous substitution
7
sur: bob
noun: (person x)
cat: snp
sem: nm m
fnc: buy
peel
prn: 32
sur:
verb: buy
cat: #n' #a' v
sem: past
arg: (p.x) apple
nc:
pc:
prn: 32
sur:
noun: apple
cat: snp
sem: indef sg
fnc: buy
nc:
pc:
prn: 32
sur:
verb: peel
cat: #n' #a' v
sem: past
arg: (p. x) pear
nc:
pc:
prn: 32
sur:
noun: pear
cat: snp
sem: indef sg
fnc: peel
nc:
pc:
prn: 32
sur: and
verb: v_1
cat:
sem: and
arg:
nc:
pc:
prn: 32
cross−copying
8
sur: bob
noun: (person x)
cat: snp
sem: nm m
fnc: buy
peel
v_1
prn: 32
sur:
verb: buy
cat: #n' #a' v
sem: past
arg: (p.x) apple
nc:
pc:
prn: 32
sur:
noun: apple
cat: snp
sem: indef sg
fnc: buy
nc:
pc:
prn: 32
sur:
verb: peel
cat: #n' #a' v
sem: past
arg: (p. x) pear
nc:
pc:
prn: 32
sur:
noun: pear
cat: snp
sem: indef sg
fnc: peel
nc:
pc:
prn: 32
sur:
verb: v_1
cat:
sem: and
arg: (p. x)
nc:
pc:
prn: 32
sur: ate
verb: eat
cat: #n' a' v
sem: past
arg:
nc:
pc:
prn:
absorption with simultaneous substitution
9
sur: bob
noun: (person x)
cat: snp
sem: nm m
fnc: buy
peel
eat
prn: 32
sur:
verb: buy
cat: #n' #a' v
sem: past
arg: (p.x) apple
nc:
pc:
prn: 32
sur:
noun: apple
cat: snp
sem: indef sg
fnc: buy
nc:
pc:
prn: 32
sur:
verb: peel
cat: #n' #a' v
sem: past
arg: (p. x) pear
nc:
pc:
prn: 32
sur:
noun: pear
cat: snp
sem: indef sg
fnc: peel
nc:
pc:
prn: 32
sur:
verb: eat
cat: #n' a' v
sem: and past
arg: (p.x)
nc:
pc:
prn: 32
sur: a(n)
noun: n_3
cat: sn' snp
sem: indef
fnc:
nc:
pc:
cross−copying
10
sur: bob
noun: [person x]
cat: snp
sem: nm m
fnc: buy
peel
eat
prn: 32
sur:
verb: buy
cat: #n' #a' v
sem: past
arg: [p.x] apple
nc:
pc:
prn: 32
sur:
noun: apple
cat: snp
sem: indef sg
fnc:
nc:
pc:
prn: 32
sur:
verb: peel
cat: #n' #a' v
sem: past
arg: [p. x] pear
nc:
pc:
prn: 32
sur:
noun: pear
cat: snp
sem: indef sg
fnc: peel
nc:
pc:
prn: 32
sur:
verb: eat
cat: #n' #a' v
sem: and past
arg: [p.x] n_4
nc:
pc:
prn: 32
sur:
noun: n_3
cat: sn' snp
sem: indef
fnc: eat
nc:
pc:
prn: 32
sur: peach
noun: peach
cat: sn
sem: sg
fnc:
nc:
pc:
prn:
absorption with simultaneous substitution



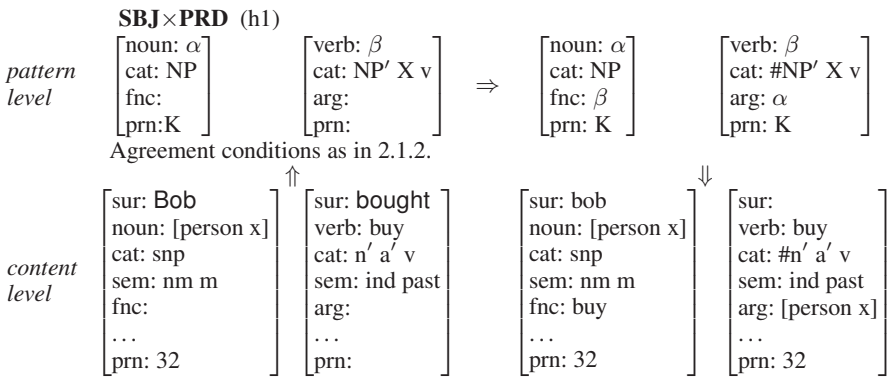
The derivation begins with an almost complete sentence, here Bob ate an apple (lines 1–3). It is only when the following item is a finite verb, here peeled, that the DBS.hear grammar settles on a gapping construction.

As indicated by the use of a single prn value, here32, the gapping construction is intrapropositional. Therefore the proplets of the initial sentence have not been cleared from the now front when the gapped items arrive. This facilitates establishing the semantic N/V relation between the shared item Bob and the gapped items peeled and ate. The core values of the additional verbs are stored as the gap list in the fnc slot of the shared subject *bob*, and the core value of *bob* is copied into the initial (subject) arg slot of the additional verbs.

The complete sequence of explicit hear mode operation applications begins with SBJ×PRD:

5.2.4 **<to-do 3>**

CROSS-COPYING *bob* AND *buy* WITH SBJ×PRD (line 1)



The next concatenation adds (the beginning of) the grammatical object:

5.2.5 CROSS-COPYING *buy* AND *a(n)* WITH PRD×OBJ (line 2)

PRD×OBJ (h28)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \underline{\#X'}\ N'\ Y\ \gamma \\ \text{arg: } Z \\ \text{prn: } K\end{bmatrix}\begin{bmatrix}\text{noun: } \alpha \\ \text{cat: } CN'\ NP \\ \text{fnc:} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \underline{\#X'}\ \#N'\ Y\ \gamma \\ \text{arg: } Z\ \alpha \\ \text{prn: } K\end{bmatrix}\begin{bmatrix}\text{noun: } \alpha \\ \text{cat: } CN'\ NP \\ \text{fnc: } \beta \\ \text{prn: } K\end{bmatrix}$$

Agreement conditions as in 4.5.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: buy} \\ \text{cat: } \#n'\ a'\ v \\ \text{sem: ind past} \\ \text{arg: [person x]} \\ \ldots \\ \text{prn: 32}\end{bmatrix}\begin{bmatrix}\text{sur: a(n)} \\ \text{noun: n\_1} \\ \text{cat: } sn'\ snp \\ \text{sem: indef sg} \\ \text{fnc:} \\ \ldots \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: buy} \\ \text{cat: } \#n'\ \#a'\ v \\ \text{sem: ind past} \\ \text{arg: [person x] n\_1} \\ \ldots \\ \text{prn: 32}\end{bmatrix}\begin{bmatrix}\text{sur:} \\ \text{noun: n\_1} \\ \text{cat: } sn'\ snp \\ \text{sem: indef sg} \\ \text{fnc: buy} \\ \ldots \\ \text{prn: 32}\end{bmatrix}$$

The grammatical object is completed by absorbing the noun into the determiner:

5.2.6 ABSORBING *apple* INTO *a(n)* WITH DET∪CN (line 3)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n \\ \text{cat: } CN'\ NP \\ \text{sem: } Y \\ \text{prn: } K\end{bmatrix}\begin{bmatrix}\text{noun: } \alpha \\ \text{cat: } CN \\ \text{sem: } Z \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: } NP \\ \text{sem: } Y\ Z \\ \text{prn: } K\end{bmatrix}$$

Agreement conditions as in 2.2.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: n\_1} \\ \text{cat: } sn'\ snp \\ \text{sem: indef sg} \\ \text{fnc: buy} \\ \ldots \\ \text{prn: 32}\end{bmatrix}\begin{bmatrix}\text{sur: apple} \\ \text{noun: apple} \\ \text{cat: sn} \\ \text{sem: sg} \\ \text{fnc:} \\ \text{dots} \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{noun: apple} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: buy} \\ \ldots \\ \text{prn: 32}\end{bmatrix}$$

Up to this point, the hearer has no indication of a subject gapping being attached to the initial proposition, just as the speaker, outside the laboratory set-up, is free to complete the sentence by adding interpunctuation [7] or by adding an open number of gapped items.

The next proplet provided by automatic word form recognition is *peel*. SBJ×PRD can not apply because the fnc slot of the shared subject *bob* is already occupied by the value buy. Therefore, we define the operation $\underline{\text{SBJ}^s \times \text{PRD}}$, with the superscript ^{s} indicating the subject as the shared item.

[7] In an isolated linguistic example, the start of a hear mode derivation requires two proplets from automatic word form recognition, e.g. *bob* (sentence start) and *buy* (next word) in 5.2.4. In a text or dialog, in contrast, all non-initial sentences have a preceding sentence start and therefore require only one proplet from automatic word form recognition, i.e. the next word, for the derivation to continue.

Also, in a text or dialog, the interpunctuation and the item intervening between interpunctuation and the verb of the next sentence, e.g. the subject, are (i) cross-copied and (ii) the verb of the next sentence is absorbed into the interpunctuation. In this way, a systematic discontinuity is bridged without suspension (Sect. 2.1).

5.2.7 CROSS-COPYING *bob* AND *peel* WITH SBJ^s×PRD (line 4)

SBJ^s×PRD (h8)

pattern level

$$\begin{bmatrix}\text{noun: } \alpha\\ \text{cat: NP}\\ \text{fnc: } \underline{\text{X}}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: } \beta\\ \text{cat: NP' Y v}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{noun: } \alpha\\ \text{cat: NP}\\ \text{fnc: } \underline{\text{X}}\ \beta\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: } \beta\\ \text{cat: \#NP}'\text{ Y v}\\ \text{arg: } \alpha\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.2.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: bob}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc: buy}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 32}\end{bmatrix}\quad\begin{bmatrix}\text{sur: peeled}\\ \text{verb: peel}\\ \text{cat: n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur: bob}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc: buy}\\ \quad\text{peel}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 32}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{verb: peel}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x]}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 32}\end{bmatrix}$$

SBJ^s×PRD cross-copies the core value of the shared subject into the first (subject) arg slot of the next, here 2nd, predicate and adds the core value of the 2nd predicate to the fnc slot of the shared subject. The variable $\underline{\text{X}}$ (1.6.5, 2) in the feature [fnc: $\underline{\text{X}}$] is used to buffer the presence of one or more values, here buy. Every time SBJ^s×PRD applies, the gap list of the shared subject's fnc slot is extended by another verb.[8]

With the first application of SBJ^s×PRD, the time-linear hear mode derivation has interpreted Bob bought an apple, ∅ peeled. The beginning of the object, i.e. the determiner a(n), is added with standard PRD×OBJ:

5.2.8 CROSS-COPYING *peel* AND *a(n)* WITH PRD×OBJ (line 5)

PRD×OBJ (h28)

pattern level

$$\begin{bmatrix}\text{verb: } \beta\\ \text{cat: } \underline{\text{\#X}}'\text{ N}'\text{ Y } \gamma\\ \text{arg: Z}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: } \alpha\\ \text{cat: CN}'\text{ NP}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{verb: } \beta\\ \text{cat: } \underline{\text{\#X}}'\text{ \#N}'\text{ Y } \gamma\\ \text{arg: Z } \alpha\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: } \alpha\\ \text{cat: CN}'\text{ NP}\\ \text{fnc: } \beta\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.3.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: peel}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x]}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 32}\end{bmatrix}\quad\begin{bmatrix}\text{sur: a(n)}\\ \text{noun: n\_2}\\ \text{cat: sn}'\text{ snp}\\ \text{sem: indef sg}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{verb: peel}\\ \text{cat: \#n}'\text{ \#a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x] n\_2}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 32}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{noun: n\_2}\\ \text{cat: sn}'\text{ snp}\\ \text{sem: indef sg}\\ \text{fnc: peel}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 32}\end{bmatrix}$$

[8] The formatting of the gap list in the noun proplet of the output, here writing the fnc value of *peel* underneath rather than beside the fnc value of *buy*, is left to the procedural side of the software.

The first gapped item is completed by adding *pear* with standard DET∪CN:

5.2.9 ABSORBING *pear* INTO *a(n)* WITH DET∪CN (line 6)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\ \text{NP}\\ \text{sem: Y}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{sem: Y Z}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.2.4.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: n\_2}\\ \text{cat: sn}'\ \text{snp}\\ \text{sem: indef sg}\\ \text{fnc: peel}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 32}\end{bmatrix}\begin{bmatrix}\text{sur: pear}\\ \text{noun: pear}\\ \text{cat: sn}\\ \text{sem: sg}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:}\\ \text{noun: pear}\\ \text{cat: snp}\\ \text{sem: indef sg}\\ \text{fnc: peel}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 32}\end{bmatrix}$$

The derivation has now interpreted Bob bought an apple, ∅ peeled a pear.

With the completion of the first gapped item, the second may begin. Theoretically, adding gapped items may go on indefinitely. Here, however, automatic word form recognition provides the coordinating conjunction and, which announces the arrival of the final gapped item in the chain.

Because *and* intervenes between the shared subject *bob* and *eat* as the predicate of the last gapped item, a direct[9] relation between *Bob* and *eat* is prevented. Technically, there are two possibilities: (i) cross-copying between the shared subject *bob* and *and* followed by the absorption of *eat* into *and*, or (ii) a suspension of *and* followed by a compensation consisting of (a) the absorption of *and* into the initial sem slot of *eat* and (b) cross-copying between the gap list of the shared subject *bob* and the initial arg slot of *eat*. Linguistically, the option of absorption, when possible, is preferred because it (i) saves a supernumerary derivation step, (ii) realizes the methodological principle that the semantic relations of the DBS hear mode must be established at the absolutely earliest, and (iii) provides the function word and with a pivotal role in the combinatorics of the construction.

Accordingly, the shared subject *bob* and the conjunction are cross-copied by writing the core value [person x] into the initial arg slot of verbal *and* (3.6.3) and the core value v_1 of *and* into the gap list of the shared subject:

[9] Unlike the relation between *Bob* and *peel*.

5.2.10 CROSS-COPYING *bob* AND *and* WITH $\mathbf{SBJ^s \times PRD^{and}}$(LINE 7)

$\mathbf{SBJ^s \times PRD^{and}}$ (h14)

pattern level

$$\begin{bmatrix}\text{noun: } \alpha \\ \text{fnc: } \underline{\text{X}} \\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{verb: } \beta \\ \text{arg:} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{fnc: } \underline{\text{X}}\ \beta \\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{verb: } \beta \\ \text{arg: } \alpha \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.2.
$\beta \in$ {and, or}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: bob} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: buy} \\ \quad\quad \text{peel} \\ \\ \text{mdr} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32}\end{bmatrix} \begin{bmatrix}\text{sur: and} \\ \text{verb: v\_1} \\ \text{cat:} \\ \text{sem: } \textit{and} \\ \text{arg:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur: bob} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: buy} \\ \quad\quad \text{peel} \\ \quad\quad \text{v\_1} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32}\end{bmatrix} \begin{bmatrix}\text{sur: and} \\ \text{verb: v\_1} \\ \text{cat:} \\ \text{sem: } \textit{and} \\ \text{arg: [person x]} \\ \text{mdr} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32}\end{bmatrix}$$

The trigger pattern of $\mathsf{SBJ^s \times PRD^{and}}$ takes the verbal shell of lexical *and* as input because subject gapping iterates predicates.

Next, simultaneous substitution replaces all occurrences of v_1 with eat:

5.2.11 ABSORBING *eat* INTO VERBAL *and* WITH $\mathbf{PRD^{and} \cup PRD}$ (line 8)

$\mathsf{PRD^{and} \cup PRD}$ (h24)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n \\ \text{cat:} \\ \text{sem: } \textit{and} \\ \text{arg: } \beta \\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{verb: } \alpha \\ \text{cat: } \beta\ \text{X} \\ \text{sem: Y} \\ \text{arg:} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \alpha \\ \text{cat: \#}\beta\ \text{X} \\ \text{sem: } \textit{and}\ \text{Y} \\ \text{arg:}\beta \\ \text{prn: K}\end{bmatrix}$$

$\beta \in$ {and, or}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: v\_1} \\ \text{cat:} \\ \text{sem: } \textit{and} \\ \text{arg: [person x]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32}\end{bmatrix} \begin{bmatrix}\text{sur: ate} \\ \text{verb: eat} \\ \text{cat: n}'\ \text{a}'\ \text{v} \\ \text{sem: ind past} \\ \text{arg:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: \#n}'\ \text{a}'\ \text{v} \\ \text{sem: } \textit{and}\ \text{ind past} \\ \text{arg: [person x]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32}\end{bmatrix}$$

At this point, the derivation has reached Bob bought an apple, $\emptyset$ peeled a pear, and $\emptyset$ ate.

It remains to provide the transitive verb *eat* with a grammatical object. Automatic word form recognition begins with providing the determiner a(n):

5.2.12 CROSS-COPYING *eat* AND *a(n)* WITH PRD×OBJ (line 9)

PRD×OBJ (h28)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \underline{\#X'}\ N'\ Y\ \gamma \\ \text{arg: } Z \\ \text{prn: } K\end{bmatrix} \quad \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: } CN'\ NP \\ \text{fnc:} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \underline{\#X'}\ \#N'\ Y\ \gamma \\ \text{arg: } Z\ \alpha \\ \text{prn: } K\end{bmatrix} \quad \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: } CN'\ NP \\ \text{fnc: } \beta \\ \text{prn: } K\end{bmatrix}$$

Agreement conditions as in 2.3.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: } \#n'\ a'\ v \\ \text{sem: } \textit{and} \text{ ind past} \\ \text{arg: [person x]} \\ \ldots \\ \text{prn: 32}\end{bmatrix} \quad \begin{bmatrix}\text{sur: a(n)} \\ \text{noun: n\_3} \\ \text{cat: } sn'\ snp \\ \text{sem: indef sg} \\ \text{fnc:} \\ \ldots \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: } \#n'\ \#a'\ v \\ \text{sem: } \textit{and} \text{ ind past} \\ \text{arg: [person x] n\_3} \\ \ldots \\ \text{prn: 32}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{noun: n\_3} \\ \text{cat: } sn'\ snp \\ \text{sem: indef sg} \\ \text{fnc: eat} \\ \ldots \\ \text{prn: 32}\end{bmatrix}$$

The object of *eat* is completed with DET∪CN adding peach:

5.2.13 ABSORBING *peach* INTO *a(n)* WITH DET∪CN (line 10)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n \\ \text{cat: } CN'\ NP \\ \text{sem: } Y \\ \text{prn: } K\end{bmatrix} \quad \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: CN} \\ \text{sem: } Z \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: NP} \\ \text{sem: } Y\ Z \\ \text{prn: } K\end{bmatrix}$$

Agreement conditions as in 2.2.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: n\_3} \\ \text{cat: } sn'\ snp \\ \text{sem: indef sg} \\ \text{fnc: eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32}\end{bmatrix} \quad \begin{bmatrix}\text{sur: peach} \\ \text{noun: peach} \\ \text{cat: sn} \\ \text{sem: sg} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{noun: peach} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: eat} \\ \ldots \\ \text{prn: 32}\end{bmatrix}$$

The final step of the hear mode derivation is adding the period with S∪IP to supply the syntactic mood value. However, the present example contains several verb proplets of equal rank, i.e. *buy, peel,* and *eat*. Which of them should store the syntactic mood value?

At first glance, one might be inclined to use the initial predicate for representing the proposition and as such the place for storing the syntactic mood value. However, the choice does not depend on the hear mode alone. Because the speak mode navigation traverses *bob buy apple* ∅ *peel pear and* ∅ *eat peach* and has to add the period before moving on to the next proposition, a return to the first predicate *buy* to retrieve the syntactic mood value would be needlessly laborious. Therefore, DBS uses the unique verb proplet with *and*[10] as the ini-

[10] The communicative function of the *and*, which is obligatory in gapping constructions, is to announce the final gapped item.

tial value of the sem slot, i.e. the last verb, here *eat*, for storing the syntactic mood value in the cat slot and as the extrapropositional exit.[11]

As an isolated linguistic example, the current hear mode derivation is completed by absorbing the interpunctuation into the final verb proplet *eat* with S∪IP:

5.2.14 Absorbing • into *eat* with S∪IP (line 11)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ VT} \\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{verb: V\_}n \\ \text{cat: VT}' \text{ SM} \\ \text{fnc:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ SM} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: } \#n' \ \#a' \text{ v} \\ \text{sem: ind past} \\ \text{arg: [person x] apple} \\ \ldots \\ \text{prn: 32}\end{bmatrix} \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: v\_2} \\ \text{cat: v}' \text{ decl} \\ \text{sem:} \\ \text{arg:} \\ \ldots \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: } \#n' \ \#a' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x] apple} \\ \ldots \\ \text{prn: 32}\end{bmatrix}$$

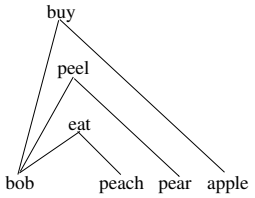
This completes the hear mode derivation of a subject gapping.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

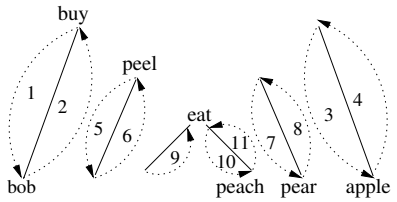
5.2.15 **<to-do 4>**

Graph analysis underlying production of 5.2.2

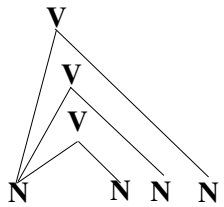
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



[11] Apart from the computational consideration, storing the syntactic mood value in the last predicate of the subject gapping construction is supported linguistically by the rhetorical interrogative variant Bob bought an apple, peeled a pear, and ate a peach???, in which the rising intonation corresponds to a syntactic mood marker in *eat*, and not in *buy*.

(iv) surface realization

1	2	3	4	1	6	7	8	5	9	10	11
Bob	bought	an_apple			peeled	a_pear			and_ate	a_peach	.
V/N^i	N^s/V	V\N	N\V	V/N^s	N^s/V	V\N	N\V	V/N^s	$N^s\backslash V$	V\N	N\V

The different tilts of the three N/V and N\V lines are solely for visual separation in the graph. The gaps appear as the empty traversals of the arcs 4, 1, and 8, 5. The navigation ends with arc 11. The upward arc 9 does not have a downward counterpart. The arc numbering is breadth-first (Sect. 1.4). The number of operations is even.

In accordance with the Continuity Condition (NLC 3.6.5), the DBS.Think-Speak navigation along the semantic relations between proplets is continuous. This is possible by leaving the control of the gaps in the surface to the lexicalization rules. For example, in the case of subject gapping, lexnoun realizes the surface of the shared noun if, and only if, its initial fnc value is not yet #-marked (compare 5.2.17 with 5.2.21 and 5.2.25).

That not every traversal of a proplet results in the realization of a surface is by no means limited to gapping, but may occur in all constructions of natural language. This is shown by 3.1.12, 3.2.12, 3.3.10, 3.4.10, 3.5.11, and many more, such as the following example:

5.2.16 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *buy* to *bob*	Bob	5.2.17
arc 2:	N↗V	from *bob* to *buy*	bought	5.2.18
arc 3:	V↘N	from *buy* to *apple*	an_apple	5.2.19
arc 7:	N↖V	from *apple* to *buy*		5.2.20
arc 1:	V/N^s	from *buy* to *bob*		5.2.21
arc 6:	N^s↗V	from *bob* to *peel*	peeled	5.2.22
arc 7:	V↘N	from *peel* to *pear*	a_pear	5.2.23
arc 8:	N↖V	from *pear* to *peel*		5.2.24
arc 5:	V/N^s	from *peel* to *bob*		5.2.25
arc 9:	N^s↗V	from *bob* to *eat*	and_ate	5.2.26
arc 10:	V↘N	from *eat* to *peach*	a_peach	5.2.27
arc 11:	N↖V	from *peach* to *eat*	.	5.2.28

Subject gapping visits the shared subject repeatedly (5.2.15, arcs 1,1, and 5) for retrieving the next item on the gap list as the continuation value.

The complete sequence of explicit navigation operations begins with V↙N:

5.2.17 **<to-do 6>**

NAVIGATING WITH $V_{\swarrow}N$ FROM *buy* TO *bob* (arc 1)

$V_{\swarrow}N$ (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Z} \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: buy} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{v} \\ \text{sem: ind past} \\ \text{arg: [person x] apple} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix} \quad \begin{bmatrix} \text{sur: Bob} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: buy} \\ \quad\quad \text{peel} \\ \quad\quad \text{eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix}$$

The result of the instruction shows up in the goal proplet of 5.2.18.

Next the navigation returns to the verb proplet to get the continuation value of the grammatical object, to be used in 5.2.19. The operation is standard $N_{\nearrow}V$:

5.2.18 NAVIGATING WITH $N_{\nearrow}V$ FROM *bob* BACK TO *buy* (arc 2)

$N_{\nearrow}V$ (s2)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: } \beta\ \text{W} \\ \text{prn: K} \end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur: bob} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: buy} \\ \quad\quad \text{peel} \\ \quad\quad \text{eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix} \quad \begin{bmatrix} \text{sur: bought} \\ \text{verb: buy} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{v} \\ \text{sem: ind past} \\ \text{arg: \#[person x] apple} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix}$$

The feature [fnc: α Y] of the first operation pattern ignores the gap list in the input proplet *bob*. Lexverb realizes the predicate surface bought based on the core value buy, the initial cat value n′, and the sem values ind past. The result of the instruction will show up in the output of 5.2.19.

The second arg value apple of *buy* provides the goal proplet for $V_{\searrow}N$:

5.2.19 NAVIGATING WITH V⧵N FROM *buy* TO *apple* (arc 3)

V⧵N (s3)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ v} \\ \text{sem: ind past} \\ \text{arg: \#[person x] apple} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32}\end{bmatrix} \quad \begin{bmatrix}\text{sur: an\_apple} \\ \text{noun: apple} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32}\end{bmatrix}$$

The initial sentence is completed by returning to the verb with standard N⧹V.

5.2.20 NAVIGATING WITH N⧹V FROM *apple* TO *buy* (arc 4)

N⧹V (s4)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{mdr: } \ddot{\text{Z}} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: apple} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ v} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#apple} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32}\end{bmatrix}$$

At this point, the initial proposition Bob bought an apple is completed in the think mode and lexverb could have realized a period. However, the content 5.2.16 contains several untraversed proplets with the intrapropositional prn value 32, still waiting to be traversed.[12]

To proceed, the navigation uses arc 1 to return to the shared subject and finds the first unmarked fnc value, here *peel*, in its gap list as the continuation value.

[12] For the gapping interpretation 5.2.2, a comma would be appropriate. However, in its current state, DBS handles only clausal interpunctuation.

5.2.21 NAVIGATING WITH V↙N^{s} FROM *buy* TO *bob* (arc 1)

V↙N^{s} (s25)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \#\beta\ \#\text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \underline{\#\text{Y}}\ \alpha\ \text{Z} \\ \text{prn: K} \end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: buy} \\ \text{cat: } \#\text{n}'\ \#\text{a}'\ \text{v} \\ \text{sem: ind past} \\ \text{arg: } \#[\text{person x}]\ \#\text{apple} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix} \quad \begin{bmatrix} \text{sur: bob} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: \#buy} \\ \quad\ \text{peel} \\ \quad\ \text{eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix}$$

The feature [arg: #β #X] in the input proplet pattern ensures that the initial proposition has been completely traversed (5.2.18–5.2.20). The feature [fnc: #$\underline{\text{Y}}$ α Z] in the goal proplet pattern ensures that at least one item of the gap list has been canceled. Because the initial value on the gap list, i.e. *buy*, is already #-marked, no subject surface is produced by lexnoun.

The speak mode derivation has now reached Bob bought an apple $\emptyset$, with $\emptyset$ indicating the first subject gap. The next item on the gap list, i.e. *peel*, is accessed with the operation N^{s}↗V:[13]

5.2.22 NAVIGATING WITH N^{s}↗V FROM *bob* TO *peel* (arc 6)

N^{s}↗V (s26)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: \#X } \alpha \text{ Y} \\ \text{mdr: Z} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: } \beta\ \text{W} \\ \text{prn: K} \end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur: bob} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: \#buy} \\ \quad\ \text{peel} \\ \quad\ \text{eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix} \quad \begin{bmatrix} \text{sur: peeled} \\ \text{verb: peel} \\ \text{cat: } \#\text{n}'\ \#\text{a}'\ \text{v} \\ \text{sem: ind past} \\ \text{arg: } \#[\text{person x}]\ \text{pear} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix}$$

Lexverb produces the surface peeled based on the #-marking of the first (subject) arg value, the core value peel, and the values ind past of the sem slot. The instruction #-marks peel on the gap list (showing up in 5.2.25).

Using the unmarked continuation value pear of *peel*, the standard V↘N operation navigates to the object of the gapped item.

5.2.23 NAVIGATING WITH V↘N FROM *peel* TO *pear* (arc 7)

V↘N (s3)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: peel} \\ \text{cat: \#n}' \text{ \#a}' \text{ v} \\ \text{sem: ind past} \\ \text{arg: \#[person x] pear} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix} \quad \begin{bmatrix} \text{sur: a\_pear} \\ \text{noun: pear} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#peel} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix}$$

Using the values pear and indef sg, lexnoun realizes a_pear.

Next, standard N↖V returns to the predicate of the current gapped item:

5.2.24 NAVIGATING WITH N↖V FROM *pear* TO *peel* (arc 8)

N↖V (s4)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{mdr: } \ddot{Z} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta \text{ Y} \\ \text{prn: K} \end{bmatrix}$$

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{noun: pear} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#peel} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix} \quad \begin{bmatrix} \text{sur:} \\ \text{verb: peel} \\ \text{cat: \#n}' \text{ \#a}' \text{ v} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#pear} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix}$$

The transition is empty because the second arg value of *peel* is #-marked.

The speak mode derivation has now produced Bob bought an apple ∅ peeled a pear and has returned to *peel*. Using the initial (subject) value of the feature [arg: #[person x], #pear], V↙N[s] moves back to the shared subject:

[13] As in SBJ[s]×PRD (5.2.7), the [s] in N[s]↗V indicates the shared subject, though here in the speak mode.

5.2.25 NAVIGATING WITH V↙N^{s} FROM *peel* TO *bob* (arc 5)

V↙N^{s} (s25)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \#\beta\ \#\text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \underline{\#\text{Y}}\ \alpha\ \text{Z} \\ \text{prn: K} \end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: peel} \\ \text{cat: } \#\text{n}'\ \#\text{a}'\ \text{v} \\ \text{sem: ind past} \\ \text{arg: } \#[\text{person x}]\ \#\text{pear} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix} \quad \begin{bmatrix} \text{sur: bob} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: \#buy} \\ \quad\quad \text{\#peel} \\ \quad\quad \text{eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix}$$

Next, N^{s}↗V proceeds to the predicate of the new (and final) gapped item, here *eat*:

5.2.26 NAVIGATING WITH N^{s}↗V FROM *bob* TO *eat* (arc 9)

N^{s}↗V (s26)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: \#X } \alpha \text{ Y} \\ \text{mdr: Z} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: } \beta\ \text{W} \\ \text{prn: K} \end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur: bob} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: \#buy} \\ \quad\quad \text{\#peel} \\ \quad\quad \text{eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix} \quad \begin{bmatrix} \text{sur: and\_ate} \\ \text{verb: eat} \\ \text{cat: } \#\text{n}'\ \#\text{a}'\ \text{decl} \\ \text{sem: } \textit{and}\text{ ind past} \\ \text{arg: } \#[\text{person x}]\ \text{peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix}$$

Lexverb uses the #-marking of the first arg value [person x], the core value eat, and the sem values *and* ind past to realize the surface and_ate. The instruction #-marks the last item on the gap list.

Similar to 5.2.19 and 5.2.23, V↘N uses the unmarked continuation value in the arg slot of *eat* to navigate to *peach*:

5.2.27 NAVIGATING WITH V↘N FROM *eat* TO *peach* (arc 10)

V↘N (s3)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: eat} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: } \textit{and} \text{ ind past} \\ \text{arg: \#[person x] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix} \quad \begin{bmatrix} \text{sur: a\_peach} \\ \text{noun: peach} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix}$$

The operation traversing the relation between the predicate and the grammatical object of the gapped item is independent of the shared subject, like 5.2.23.

The speak mode derivation concludes with a return to the final verb to realize the period.

5.2.28 NAVIGATING WITH N↖\V FROM *peach* TO *eat* (arc 11)

N↖\V (s4)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{mdr: } \ddot{\text{Z}} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta \text{ Y} \\ \text{prn: K} \end{bmatrix}$$

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{noun: apple} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix} \quad \begin{bmatrix} \text{sur: } \bullet \\ \text{verb: eat} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: } \textit{and} \text{ ind past} \\ \text{arg: \#[person x] \#apple} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 32} \end{bmatrix}$$

In the speak mode, ending with arc 11 saves a lengthy return to the initial verb *buy* (5.2.16).

Extending DBS.19 to an example class with subject gapping required the definition of the hear mode operation $\text{SBJ}^{\text{s}} \times \text{PRD}^{and}$ (h14), and of the speak mode operations $\text{V}\swarrow\text{N}^{\text{s}}$ (s25) and $\text{N}^{\text{s}}\nearrow\text{V}$ (s26). The hear and the speak mode derivation used 12 operation applications each.

5.2.29 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

	1		2		3		4		5		6		7
Bob	×	bought	×	an	∪	apple	×	peeled	×	a	∪	pear	×

	8		9		10		11	
and	∪	ate	×	a	∪	peach	∪	•

speak mode:

1		2		3		4	1	6	
$V_{\swarrow}/N$	Bob	$N^{s}_{\nearrow}\backslash V$	bought	$V_{\searrow}\backslash N$	an_apple	$N_{\nwarrow}\backslash V$	$V_{\swarrow}/N^{s}$	$N^{s}_{\nearrow}\backslash V$	peeled

7		8	5		9		10		11	
$V_{\searrow}\backslash N$	a_pear	$N_{\nwarrow}\backslash V$	$V_{\swarrow}/N^{s}$	and	$N^{s}_{\nearrow}\backslash V$	ate	$V_{\searrow}\backslash N$	a_peach	$N_{\nwarrow}\backslash V$	•

The numbering of the speak mode operations corresponds to the arc traversal numbers in 5.2.16. Arc 1 is traversed twice.

5.3 DBS.21: Predicate Gapping

The pretheoretical characterization of predicate gapping in 5.2.1 may be instantiated formally as the following content:

5.3.1 **<to-do 1>**

Bob **bought** an apple, Jim Ø a pear, and Bill Ø a peach**.**

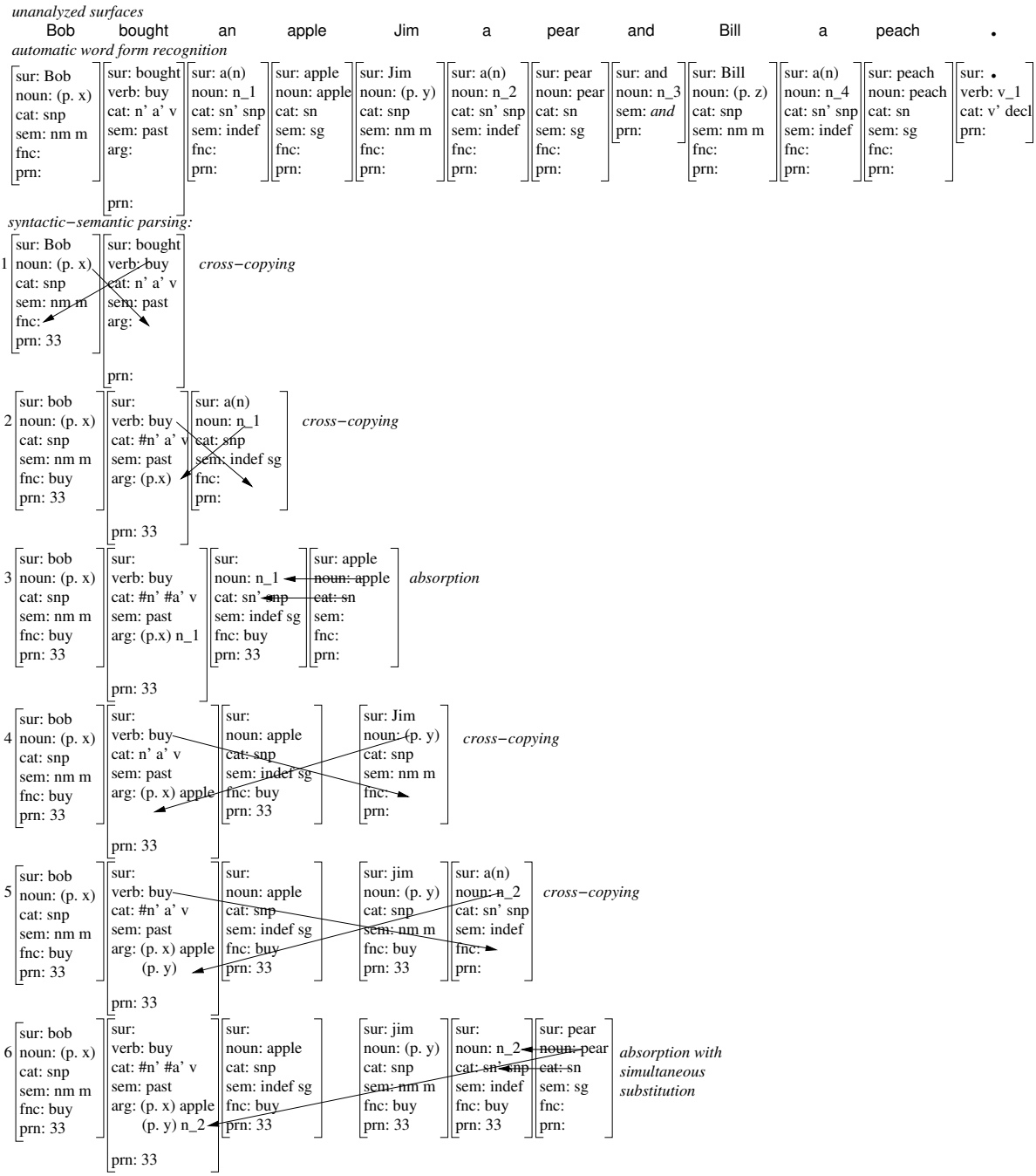
sur: bob	sur:	sur:	sur: jim	sur:	sur: bill	sur:
noun: [p. x]	verb: buy	noun: apple	noun: [p. y]	noun: pear	noun: [p. z]	noun: peach
cat: snp	cat: #n′ #a′ decl	cat: snp	cat: snp	cat: snp	cat: snp	cat: snp
sem: nm m	sem: ind past	sem: indef sg	sem: nm m	sem: indef sg	sem: *and* nm m	sem: indef sg
fnc: buy	arg: [p. x] apple	fnc: buy	fnc: buy	fnc: buy	fnc: buy	fnc: buy
mdr:	[p. y] pear	mdr:	mdr:	mdr:	mdr:	mdr:
nc:	[p. z] peach	nc:	nc:	nc:	nc:	nc:
pc:	mdr:	pc:	pc:	pc:	pc:	pc:
prn: 33	nc:	prn: 33	prn: 33	prn: 33	prn: 33	prn: 33
	pc:					
	prn: 33					

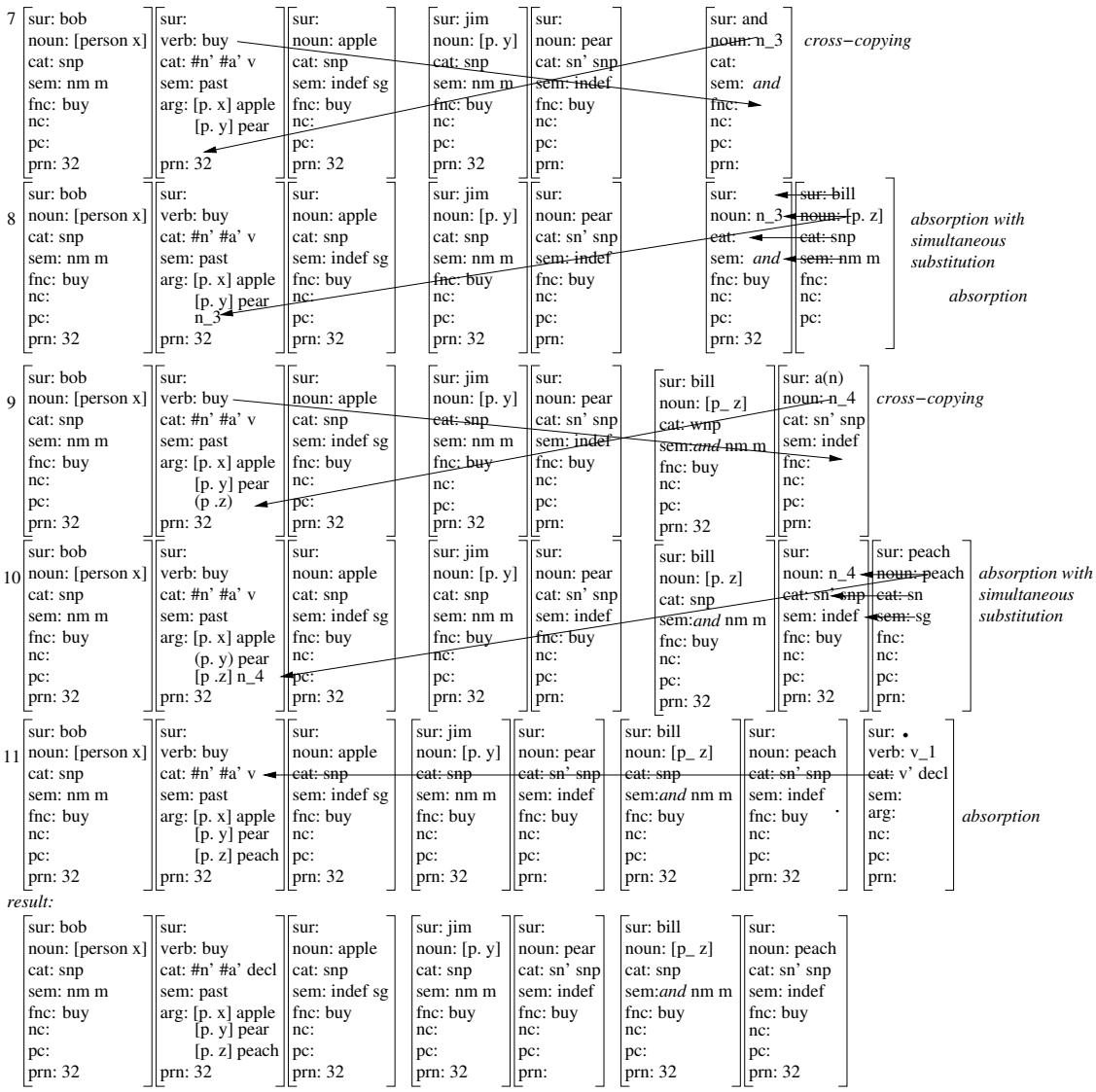
The shared item is *buy*. Its arg slot contains the gap list, here the subject-object pairs *bob apple, jim pear,* and *bill peach*. The conjunction *and* is used in its noun variant (3.6.3) and coded into the initial sem slot of *bill*. The subject and object proplets of the gapped items take buy as their shared fnc value.

As a first conceptual orientation consider the derivation graph:

5.3.2 <to-do 2>

GRAPHICAL HEAR MODE DERIVATION OF THE CONTENT 5.3.1





One direction of the relation between the shared predicate *buy* and the gapped items is copying the core values of *jim pear* as the second item and the core values of *bill apple* as the third item into the gap list of *buy*. The other direction is copying the core value of *buy* into the fnc slot of the gapped items, i.e. the noun proplets *jim, pear* (lines 4–6) and *bill peach* (lines 8–10). Like subject gapping (Sect. 5.2), predicate gapping starts with a complete proposition. Also, predicate gapping requires a transitive predicate.

The complete sequence of explicit hear mode operation applications begins with SBJ×PRD:

5.3.3 **<to-do 3>**

CROSS-COPYING Bob AND buy WITH SBJ×PRD (line 1)

SBJ×PRD (h1)

pattern level

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP}'\text{ X v}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ X v}\\ \text{arg: }\alpha\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.2.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: Bob}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc:}\\ \ldots\\ \text{prn: 33}\end{bmatrix}\quad\begin{bmatrix}\text{sur: bought}\\ \text{verb: buy}\\ \text{cat: n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \ldots\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur: bob}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc: buy}\\ \ldots\\ \text{prn: 33}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{verb: buy}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x]}\\ \ldots\\ \text{prn: 33}\end{bmatrix}$$

5.3.4 CROSS-COPYING *buy* AND *a(n)* WITH PRD×OBJ (line 2)

PRD×OBJ (h28)

pattern level

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\text{\#X}'}\text{ N}'\text{ Y }\gamma\\ \text{arg: Z}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\text{ NP}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\text{\#X}'}\text{ \#N}'\text{ Y }\gamma\\ \text{arg: Z }\alpha\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\text{ NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 4.5.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: buy}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x]}\\ \ldots\\ \text{prn: 33}\end{bmatrix}\begin{bmatrix}\text{sur: a(n)}\\ \text{noun: n\_1}\\ \text{cat: sn}'\text{ snp}\\ \text{sem: indef sg}\\ \text{fnc:}\\ \ldots\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{verb: buy}\\ \text{cat: \#n}'\text{ \#a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x] n\_1}\\ \ldots\\ \text{prn: 33}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{noun: n\_1}\\ \text{cat: sn}'\text{ snp}\\ \text{sem: indef sg}\\ \text{fnc: buy}\\ \ldots\\ \text{prn: 33}\end{bmatrix}$$

The grammatical object is completed by absorbing the common noun:

5.3.5 ABSORBING *apple* INTO *a(n)* WITH DET∪CN (line 3)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\text{ NP}\\ \text{sem: Y}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{sem: Y Z}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.2.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: n\_1}\\ \text{cat: sn}'\text{ snp}\\ \text{sem: indef sg}\\ \text{fnc: buy}\\ \ldots\\ \text{prn: 33}\end{bmatrix}\begin{bmatrix}\text{sur: apple}\\ \text{noun: apple}\\ \text{cat: sn}\\ \text{sem: sg}\\ \text{fnc:}\\ \ldots\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{noun: apple}\\ \text{cat: snp}\\ \text{sem: indef sg}\\ \text{fnc: buy}\\ \ldots\\ \text{prn: 33}\end{bmatrix}$$

Next automatic word form recognition provides the hearer with the first gapped item, which consists of the subject *jim*, the gap marker $\emptyset$,and the object

pear.[14] Semantically, a gapped item is related to the shared item, which may precede (subject and predicate gapping), or follow (object gapping). Technically, the shared item is the location for storing the gap list.

In 5.3.2 the addition of *jim* in line 4 turns *buy* from a simple predicate into a shared item. This is marked in the following operations by using PRD^{p}, with the diacritic ^{p} for **p**redicate.

5.3.6 Cross-copying *buy* and *jim* with PRD^{p}×SBJ (line 4)

PRD^{p}×SBJ (h44)

pattern level

$$\begin{bmatrix}\text{verb: } \beta\\ \text{cat: \#NP}'\ \text{\#X v}\\ \text{arg: } \underline{\text{Y}}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: } \alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{verb: } \beta\\ \text{cat: \#NP}'\ \text{X v}\\ \text{arg: } \underline{\text{Y}}\ \alpha\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: } \alpha\\ \text{cat: NP}\\ \text{fnc: } \beta\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.2.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: buy}\\ \text{cat: \#n}'\ \text{\#a}'\ \text{v}\\ \text{sem: ind past}\\ \text{arg: [person x] apple}\\ \ldots\\ \text{prn: 33}\end{bmatrix}\quad\begin{bmatrix}\text{sur: Jim}\\ \text{noun: [person y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc:}\\ \ldots\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{verb: buy}\\ \text{cat: \#n}'\ \text{a}'\ \text{v}\\ \text{sem: ind past}\\ \text{arg: [person x] (apple)}\\ \quad\text{[person y]}\\ \ldots\\ \text{prn: 33}\end{bmatrix}\quad\begin{bmatrix}\text{sur: jim}\\ \text{noun: [person y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc: buy}\\ \ldots\\ \text{prn: 33}\end{bmatrix}$$

The #-cancellation of the object valency position in the cat attribute of the shared item *buy* is removed in the output, enabling standard PRD×OBJ (h28) to apply in 5.3.7. The variable $\underline{\text{Y}}$ in the arg slot of the shared predicate ensures that it is non-empty (1.6.5, 2).

The next item provided is the beginning of the first gapped item's object:

5.3.7 Cross-copying *buy* and *a(n)* with PRD^{p}×OBJ (line 5)

PRD^{p}×OBJ (h38)

pattern level

$$\begin{bmatrix}\text{verb: } \beta\\ \text{cat: } \underline{\text{\#X}'}\ \text{N}'\ \text{Y}\ \gamma\\ \text{arg: Z}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: } \alpha\\ \text{cat: CN}'\ \text{NP}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{verb: } \beta\\ \text{cat: } \underline{\text{\#X}'}\ \text{\#N}'\ \text{Y}\ \gamma\\ \text{arg: Z}\ \alpha\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: } \alpha\\ \text{cat: CN}'\ \text{NP}\\ \text{fnc: } \beta\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 4.5.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: buy}\\ \text{cat: \#n}'\ \text{a}'\ \text{v}\\ \text{sem: ind past}\\ \text{arg: [person x] apple}\\ \quad\text{[person y]}\\ \ldots\\ \text{prn: 33}\end{bmatrix}\quad\begin{bmatrix}\text{sur: a(n)}\\ \text{noun: n\_2}\\ \text{cat: sn}'\ \text{snp}\\ \text{sem: indef sg}\\ \text{fnc:}\\ \ldots\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{verb: buy}\\ \text{cat: \#n}'\ \text{\#a}'\ \text{v}\\ \text{sem: ind past}\\ \text{arg: [person x] apple}\\ \quad\text{[person y] n\_2}\\ \ldots\\ \text{prn: 33}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{noun: n\_2}\\ \text{cat: sn}'\ \text{snp}\\ \text{sem: indef sg}\\ \text{fnc: buy}\\ \ldots\\ \text{prn: 33}\end{bmatrix}$$

[14] The comma between the gapped items is ignored at the cost of a minimal -global syntactic ambiguity (FoCL 11.3.6).

The time-linear hear mode derivation has now interpreted Bob bought an apple, Jim ∅ a.

The variable n_2 is replaced with the value pear by the absorption operation DET∪CN. Simultaneous substitution applies also to the variable in the gap list of *buy* (5.3.2, line 6):

5.3.8 ABSORBING *pear* INTO *a(n)* WITH DET∪CN (line 6)

DET∪CN (h47)

pattern level

noun: N_*n*	noun: α		noun: α
cat: CN′ NP	cat: CN	⇒	cat: NP
sem: Y	sem: Z		sem: Y Z
prn: K	prn:		prn: K

Agreement conditions as in 2.2.4.

⇑ ⇓

content level

sur:	sur: pear	sur:
noun: n_2	noun: pear	noun: pear
cat: sn′ snp	cat: sn	cat: snp
sem: indef	sem: sg	sem: indef sg
fnc: buy	fnc:	fnc: buy
mdr:	mdr:	mdr:
nc:	nc:	nc:
pc:	pc:	pc:
prn: 33	prn:	prn: 33

With the completion of the first gapped item, the second begins. Theoretically, adding gapped items may go on indefinitely. Here, however, automatic word form recognition provides a coordinating conjunction, added with the cross-copying operation PRD^{p}×SBJ^{and} (as the counterpart to 5.2.10):

5.3.9 CROSS-COPYING *buy* AND *and* WITH PRD^{p}×SBJ^{and} (line 6)

PRD^{p}×SBJ^{and} (h45)

pattern level

verb: α	noun: N_*n*		verb: α	noun: N_*n*
sem: X	sem: β		sem: X	sem: β
arg: Y	fnc:	⇒	arg: Y N_*n*	fnc: α
prn: K	prn:		prn: K	prn: K

$\beta \in$ {and, or}

⇑ ⇓

content level

sur:	sur: and	sur:	sur:
verb: buy	noun: n_3	verb: buy	noun: n_3
cat: #n′ #a′ v	cat:	cat: #n′ #a′ v	cat:
sem: ind past	sem: *and*	sem: ind past	sem: *and*
arg: [p. x] apple	fnc:	arg: [p. x] apple	fnc: buy
[p. y] pear	mdr:	[p. y] pear	mdr:
	nc:	n_3	nc:
mdr:	pc:	mdr:	pc:
nc:	prn:	nc:	prn: 33
pc:		pc:	
prn: 33		prn: 33	

Next the attached conjunction absorbs the final gapped item's subject:

5.3.10 ABSORBING *Bill* INTO *and* WITH SBJ^{and}∪SBJ (line 8)

SBJ^{and}∪SBJ (h50)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{sem: }\beta\\ \text{fnc: }\gamma\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{sem: X}\\ \text{prn:}\end{bmatrix}\;\Rightarrow\;\begin{bmatrix}\text{noun: }\alpha\\ \text{sem: }\beta\text{ X}\\ \text{fnc: }\gamma\\ \text{prn:}\end{bmatrix}$$

$\beta \in$ {and, or}

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: n\_3}\\ \text{cat:}\\ \text{sem: }\textit{and}\\ \text{fnc: buy}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 33}\end{bmatrix}\Uparrow\begin{bmatrix}\text{sur: Bill}\\ \text{noun: [person z]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\qquad\Downarrow\begin{bmatrix}\text{sur: bill}\\ \text{noun: [person z]}\\ \text{cat: snp}\\ \text{sem: }\textit{and}\text{ nm m}\\ \text{fnc: buy}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 33}\end{bmatrix}$$

The simultaneous substitution covers also the occurrence of n_3 in buy (cf. line 8 in 5.3.2). The lexical entry of the conjunction uses the English surface, here *and*, to specify its kind. As the initial value of the sem attribute, it is (i) a significant contribution to the content and (ii) needed for realization in the speak mode (5.3.24).

The grammatical object of the final gapped item is added with applications of the operations PRD^{p}×OBJ and DET∪CN:

5.3.11 CROSS-COPYING *buy* AND *a(n)* WITH PRD^{p}×OBJ (line 9)

PRD^{p}×OBJ (h38)

pattern level

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\#\text{X}'}\text{ N}'\text{ Y v}\\ \text{arg: Z}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\text{ NP}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\;\Rightarrow\;\begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\#\text{X}'}\text{ \#N}'\text{ Y v}\\ \text{arg: Z }\alpha\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\text{ NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 4.5.4.

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: buy}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x] apple}\\ \quad\text{[person y] pear}\\ \quad\text{[person z]}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 33}\end{bmatrix}\Uparrow\begin{bmatrix}\text{sur: a(n)}\\ \text{noun: n\_3}\\ \text{cat: sn}'\text{ snp}\\ \text{sem: indef sg}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\qquad\begin{bmatrix}\text{sur:}\\ \text{verb: buy}\\ \text{cat: \#n}'\text{ \#a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x] apple}\\ \quad\text{[person y] pear}\\ \quad\text{[person z] n\_3}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 33}\end{bmatrix}\Downarrow\begin{bmatrix}\text{sur:}\\ \text{noun: n\_3}\\ \text{cat: sn}'\text{ snp}\\ \text{sem: indef sg}\\ \text{fnc: buy}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 33}\end{bmatrix}$$

The final gapped item is completed by DET∪CN absorbing the next word proplet *peach*:

5.3.12 ABSORBING *peach* INTO *a(n)* WITH DET∪CN (line 10)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\ \text{NP}\\ \text{sem: Y}\\ \text{prn: K}\end{bmatrix}\ \begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix}\ \Rightarrow\ \begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{sem: Y Z}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.2.4.

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: n\_3}\\ \text{cat: sn}'\ \text{snp}\\ \text{sem: indef sg}\\ \text{fnc: buy}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 33}\end{bmatrix}\ \Uparrow\ \begin{bmatrix}\text{sur: peach}\\ \text{noun: peach}\\ \text{cat: sn}\\ \text{sem: sg}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\ \Downarrow\ \begin{bmatrix}\text{sur:}\\ \text{noun: peach}\\ \text{cat: snp}\\ \text{sem: indef sg}\\ \text{fnc: buy}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 33}\end{bmatrix}$$

The simultaneous substitution triggered by DET∪CN also replaces n_3 in the second slot of the third item in the gap list in the shared predicate with the value peach (5.3.2, line 10).bbbb

For adding the period, the first input pattern of S∪IP finds only a single predicate at the now front (in contradistinction to 5.2.6 and 5.4.14).

5.3.13 ABSORBING • INTO *buy* WITH S∪IP (LINE 11)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#X}'\ \text{VT}\\ \text{prn: K}\end{bmatrix}\ \begin{bmatrix}\text{verb: V\_}n\\ \text{cat: VT}'\ \text{SM}\end{bmatrix}\ \Rightarrow\ \begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#X}'\ \text{SM}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

content level

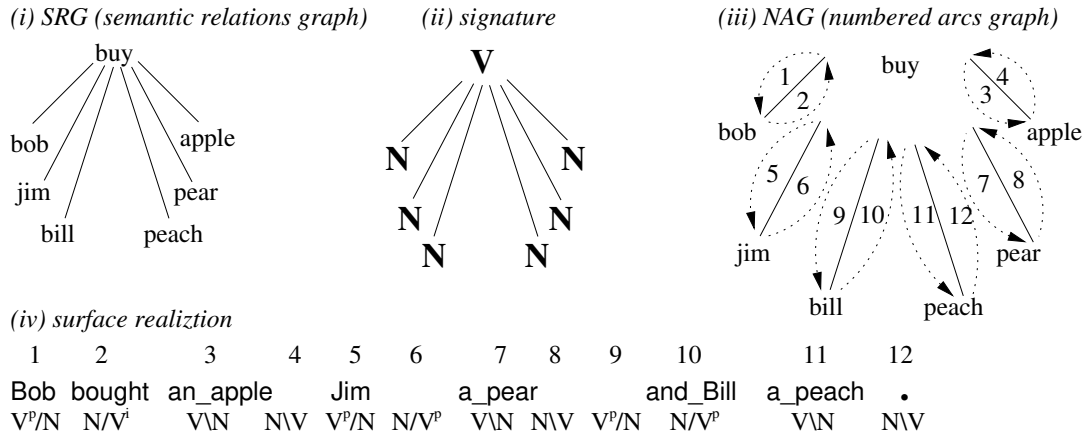
$$\begin{bmatrix}\text{sur:}\\ \text{verb: buy}\\ \text{cat: \#n}'\ \text{\#a}'\ \text{v}\\ \text{sem: ind past}\\ \text{arg: [person x] apple}\\ \quad\text{[person y] pear}\\ \quad\text{[person z] peach}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 33}\end{bmatrix}\ \Uparrow\ \begin{bmatrix}\text{sur: }\bullet\\ \text{verb: v\_1}\\ \text{cat: v}'\ \text{decl}\\ \text{sem:}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\ \Downarrow\ \begin{bmatrix}\text{sur:}\\ \text{verb: eat}\\ \text{cat: \#n}'\ \text{\#a}'\ \text{decl}\\ \text{sem: ind past}\\ \text{arg: [person x] apple}\\ \quad\text{[person y] pear}\\ \quad\text{[person z] peach}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 33}\end{bmatrix}$$

The cat value decl of the period determines the sentential mood in the shared predicate proplet *buy*. The hear mode derivation of a predicate gapping construction is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

5.3.14 **<to-do 4>**

GRAPH ANALYSIS UNDERLYING PRODUCTION OF 5.3.1



The shared predicate relates to the subject and object of its initial sentence (arcs 1–4) and of its two gapped items (arcs 5–8 and 9–12). As in subject gapping (5.2.15) and object gapping (5.4.15), the arc numbering is breadth-first: it follows the initial sentence and the gapped items from the outside in, completing each level before going to the next one down (Sect. 1.4).

Word form production is summarized as the following list of speak mode operations:

5.3.15 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	$V_{\swarrow}N$	from *buy* to *bob*	Bob	5.3.16
arc 2:	$N_{\nearrow}V$	from *bob* to *buy*	bought	5.3.17
arc 3:	$V\searrow N$	from *buy* to *apple*	an_apple	5.3.18
arc 4:	$N\nwarrow V$	from *apple* to *buy*		5.3.19
arc 5:	$V^p_{\swarrow}N$	from *buy* to *jim*	Jim	5.3.20
arc 6:	$N_{\nearrow}V^p$	from *jim* to *buy*		5.3.21
arc 7:	$V\searrow N$	from *buy* to *pear*	a_pear	5.3.22
arc 8:	$N\nwarrow V$	from *pear* to *buy*		5.3.23
arc 9:	$V^p_{\swarrow}N$	from *buy* to *bill*	and_Bill	5.3.24
arc 10:	$N_{\nearrow}V^p$	from *bill* to *buy*		5.3.25
arc 11:	$V\searrow N$	from *buy* to *peach*	a_peach	5.3.26
arc 12:	$N\nwarrow V$	from *peach* to *buy*	•	5.3.27

As in subject gapping, there is a complete initial sentence which is oblivious to the following predicate gappings.

The complete sequence of explicit navigation operations begins with $V_{\swarrow}N$:

5.3.16 **<to-do 6>**

NAVIGATING WITH V↙N FROM *buy* TO *bob* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x] apple} \\ \quad\quad \text{[person y] pear} \\ \quad\quad \text{[person z] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33} \end{bmatrix} \quad \begin{bmatrix} \text{sur: Bob} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33} \end{bmatrix}$$

The operation applies to the initial arg value, regardless of whether the verb is intransitive, transitive, or contains a gap list. These diverse non-initial values are buffered by the variable X. The goal value is [person x]. The transition realizes Bob from the goal proplet

The navigation returns with standard N↗V to the verb and realizes bought from the goal proplet:

5.3.17 NAVIGATING WITH N↗V FROM *bob* BACK TO *buy* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{Y} \\ \text{prn: K} \end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur: bob} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33} \end{bmatrix} \quad \begin{bmatrix} \text{sur: bought} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] apple} \\ \quad\quad \text{[person y] pear} \\ \quad\quad \text{[person z] peach} \\ \ldots \\ \text{prn: 33} \end{bmatrix}$$

Next the grammatical object, i.e. *apple*, of the initial clause containing the shared predicate has to be realized:

5.3.18 NAVIGATING WITH V↘N FROM *buy* TO *apple* (arc 3)

V↘N (s3)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \underset{\cdot\cdot}{\alpha} \\ \text{prn: } \ddot{\text{K}}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] apple} \\ \quad\quad\text{[person y] pear} \\ \quad\quad\text{[person z] peach} \\ \ldots \\ \text{prn: 33}\end{bmatrix} \quad \begin{bmatrix}\text{sur: an\_apple} \\ \text{noun: apple} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33}\end{bmatrix}$$

The variables #X and Y in the feature [arg: #X β Y], originally introduced for accommodating oblique arguments (e.g. 2.3.10), serve here to accommodate the grammatical objects in the gap list cost-free.

The initial sentence is completed by returning to the verb with N↖\V.

5.3.19 NAVIGATING WITH N↖\V FROM *apple* TO *buy* (arc 4)

N↖\V (s4)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \underset{\cdot\cdot}{\alpha} \\ \text{mdr: } \ddot{\text{Z}} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: apple} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#apple} \\ \quad\quad\text{[person y] pear} \\ \quad\quad\text{[person z] peach} \\ \ldots \\ \text{prn: 33}\end{bmatrix}$$

The navigation has now traversed Bob bought an apple and #-marked the two arguments in the shared predicate's first gap list line.

The next step is to navigate from the shared predicate *buy* to the first unmarked item in the gap list, i.e. to the subject *jim* in the second line, using the new operation $V^p\underset{\swarrow}{/}N$[15]:

[15] The grammatical functions of the operations $N^s\nearrow V$ (s26, subject gapping), $V^p\swarrow/N$ (s27, predicate gapping), and $N^o\nwarrow\backslash V$ (s30, object gapping) are similar insofar as they manage the repeated transitions from the shared item to the first unmarked item on the gap list.

5.3.20 NAVIGATING WITH $\mathsf{V^p}\swarrow\mathsf{N}$ FROM *buy* TO *jim* (arc 5)

$\mathbf{V^p}\swarrow\mathbf{N}$ (s27)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#apple} \\ \quad\text{[person y] pear} \\ \quad\text{[person z] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33}\end{bmatrix} \quad \begin{bmatrix}\text{sur: Jim} \\ \text{noun: [person y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: \#buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33}\end{bmatrix}$$

To find the next unmarked item, i.e. the gapped item's grammatical object, in the predicate's current gap list, the navigation must return from the gapped item's subject to the shared predicate, using $\mathsf{N}\nearrow\mathsf{V^p}$:

5.3.21 NAVIGATING WITH $\mathsf{N}\nearrow\mathsf{V^p}$ FROM *jim* BACK TO *buy* (arc 6)

$\mathbf{N}\nearrow\mathbf{V^p}$ (s28)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: jim} \\ \text{noun: [person y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: \#buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#apple} \\ \quad\text{\#[person y] pear} \\ \quad\text{[person z] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33}\end{bmatrix}$$

The navigation has now traversed Bob bought an apple, Jim $\emptyset$, and is currently at the shared predicate. Using the first unmarked item in its current gap list, here pear, it continues to the object of the gapped item:

5.3.22 NAVIGATING WITH V↘N FROM *buy* TO *pear* (arc 7)

V↘N (s3)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#apple} \\ \quad \text{\#[person y] pear} \\ \quad \text{[person z] peach} \\ \ldots \\ \text{prn: 33} \end{bmatrix} \quad \begin{bmatrix} \text{sur: a\_pear} \\ \text{noun: pear} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33} \end{bmatrix}$$

Using the sem values indef sg and the core value pear, lexnoun realizes the surface a_pear.

The navigation returns from *pear* to the shared predicate with N↖V to find the next unmarked item in the current gap list, here [person z]:

5.3.23 NAVIGATING WITH N↖V FROM *pear* TO *buy* (arc 8)

N↖V (s4)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{mdr: } \ddot{Z} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta \text{ Y} \\ \text{prn: K} \end{bmatrix}$$

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{noun: pear} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33} \end{bmatrix} \quad \begin{bmatrix} \text{sur:} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#apple} \\ \quad \text{\#[person y] \#pear} \\ \quad \text{[person z] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33} \end{bmatrix}$$

The item pear in the gap list was #-marked as the result of the instruction in V↘N (5.3.21). Lexverb($\hat{\alpha}$) produces no surface.

As the first unmarked item in the predicate's current gap list, [person z] is the continuation value for V^{p}↙N:

5.3.24 NAVIGATING WITH $V^p\swarrow N$ FROM *buy* TO *bill* (arc 9)

$\mathbf{V^p\swarrow N}$ (s27)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#apple} \\ \quad\text{\#[person y] \#pear} \\ \quad\text{[person z] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33}\end{bmatrix} \quad \begin{bmatrix}\text{sur: and\_Bill} \\ \text{noun: [person z]} \\ \text{cat: snp} \\ \text{sem: } \textit{and} \text{ nm m} \\ \text{fnc: \#buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33}\end{bmatrix}$$

Lexnoun($\hat{\alpha}$) uses the name marker bill in the sur slot of *bill* and the initial sem value *and* to realize the surface and_Bill.

To find the object of the last gapped item, $N\nearrow V^p$ returns to the shared predicate for a look at its current gap list:

5.3.25 NAVIGATING WITH $N\nearrow V^p$ FROM *bill* BACK TO *buy* (arc 10)

$\mathbf{N\nearrow V^p}$ (s28)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: [person z]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: \#buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#apple} \\ \quad\text{\#[person y] \#pear} \\ \quad\text{\#[person z] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33}\end{bmatrix}$$

As in 5.3.20, lexverb does not realize any surface because the second arg value apple of *buy* is #-marked (5.3.18).

Using the last unmarked value in the current gap list, $V\searrow N$ applies as follows:

5.3.26 NAVIGATING WITH $\mathsf{V}\searrow\mathsf{N}$ FROM *buy* TO *peach* (arc 11)

V↘N (s3)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \underset{\cdot\cdot}{\alpha} \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#apple} \\ \quad\text{\#[person y] \#pear} \\ \quad\text{\#[person z] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33}\end{bmatrix} \quad \begin{bmatrix}\text{sur: a\_peach} \\ \text{noun: peach} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33}\end{bmatrix}$$

It remains to return to the shared predicate to realize the period and to reach a location potentially suitable for navigating along an extrapropositional coordination to a next proposition (1.4.4):

5.3.27 NAVIGATING WITH $\mathsf{N}\nwarrow\mathsf{V}$ FROM *peach* TO *buy* (arc 12)

N↖V (s4)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \underset{\cdot\cdot}{\alpha} \\ \text{mdr: } \underset{\cdot\cdot}{\text{Z}} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: peach} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33}\end{bmatrix} \quad \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#apple} \\ \quad\text{\#[person y] \#pear} \\ \quad\text{\#[person z] \#peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 33}\end{bmatrix}$$

Extending DBS.20 to an example class with predicate gapping required the definition of the hear mode operation $\mathsf{PRD}^{\mathsf{p}}\times\mathsf{SBJ}$ (h44) and of the speak mode operations $\mathsf{V}^{\mathsf{p}}\swarrow\mathsf{N}$, (s27) and $\mathsf{N}\nearrow\mathsf{V}^{\mathsf{p}}$ (s28). The hear and the speak mode derivation used 12 operation applications each.

5.3.28 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

	1		2		3		4		5		6		7
Bob	×	bought	×	an	∪	apple	×	Jim	×	a	∪	pear	×

	8		9		10		11	
and	∪	Bill	×	a	∪	peach	∪	•

speak mode:

1		2		3		4		5		6	
V⤵N	Bob	N⤴V	bought	V⤷N	an_apple	N⤹V	V^p⤵N	Jim	N⤴V^p		

7		8		9		10		11		12	
V⤷N	a_pear_and	N⤹V	V^p⤵N	Bill	N⤴V^p	V⤷N	a_peach	N⤹V	•		

The breadth-first numbering of the speak mode operations corresponds to the arc traversal numbers of the NAG in 5.3.14.

5.4 DBS.22: Object Gapping

If filler and slot are adjacent in the hear mode, for example, subject⤴predicate (filler-slot) and predicate⤷object (slot-filler) in 2.3.6, order does not make a difference. However, in a slot-filler discontinuity (a) the slot defines the kind of compatible filler, (b) the relation is initiated, and (c) the hearer can simply wait until the filler arrives and plops into the slot. In a filler-slot discontinuity, in contrast, there may be many kinds of slot which is why no relation can be initiated;[16] instead the hearer must wait until automatic word form recognition provides the slot, enabling a filler-slot combination in one fell-swoop.

Yet in filler-slot constellations, the shared item, i.e. the filler, may be used for absorbing and storing the gapped items as they accumulate during the derivation in the form of a gap list; in slot-filler constellations, in contrast, the accumulating gap list must be temporarily stored in a derivation-external *cache*, *buffer*, or *storage variable*[17] until the shared object arrives, finally available for incorporating the complete gap list in one fell swoop.

In English filler-slot constellations, the intervening items must often be bridged by a suspension. Consider the following examples:

[16] The situation resembles finding an unmarked key in a big house.

[17] Technicalities aside, the constructs of a cache, a buffer, and a storage variable are roughly equivalent. Storage variables were introduced in computer science in the late 1950s (ALGOL). In linguistics, storage variables were used in Montague grammar (Cooper 1983). The DBS analysis of object gapping in the hear mode (Sect. 5.4) uses a cache at the now front for the derivation-external storage of the gap list.

5.4.1 Suspension in filler-slot discontinuities

1. Clausal subject[18] precedes main clause.
   That Fido found a bone surprised Mary.
2. Adverbial precedes predicate (Sect. 3.1)
   Perhaps Fido ... is sleeping...
3. Clausal modifier precedes main clause (Sect. 3.5)
   When Fido barked Mary laughed.
4. Long distance dependency (Sect. 5.5)
   Who(m) did John say that Bill believes that Mary loves?

In many slot-filler constructions, the intervening word forms may be bridged by *absorption*:

5.4.2 Absorption in slot-filler discontinuities

1. Period precedes subject in extrapropositional coordination (Sect. 2.1):
   Mary sleeps. Fido snores.
2. Verb precedes bare preposition (Sect. 4.3)
   Fido dug the bone up.
3. Clausal object (Sect. 2.6
   Mary heard that Fido barked.
4. Main clause precedes clausal modifier (3.5.3)
   Mary laughed when Fido barked.
5. Repeating object clauses (Sect. 5.6)
   Mary saw the man who loves the woman who fed Fido.

In gapping constructions, however, the relation between the order of filler and slot, and the use of suspension vs. absorption seems to be in reverse as compared to 5.4.1 and 5.4.2:

5.4.3 Absorption vs. suspension in gapping

1. Subject gapping (Sect. 5.2)
   Bob bought an apple, peeled a pear, and ate a peach.
   Exception because filler-slot is without suspension
2. Predicate gapping (Sect. 5.3)
   Bob bought an apple, Jim a pair, and Bill a peach.
   Exception because filler-slot is without suspension
3. Object gapping (Sect. 5.4)
   Bill bought, Jim peeled, and Bill ate a peach.
   Exception because slot-filler is with suspension

Object gapping is special in that it requires not only suspension, but also a derivation-external cache until the filler (as the standard location of the gap list) arrives.

These procedural aspects are not reflected in the content:

[18] In That Fido barked amused Mary, the V/V relation between adjacent *bark* and *amuse* does not constitute a suspension because the verb is intransitive. It is similar in the V|A relation of Mary danced yesterday, with intransitive *dance*.

5.4.4 **<to-do 1>**

Bob bought ∅, Jim peeled ∅, and Bill ate **a peach.**

sur: bob	sur:	sur: jim	sur:
noun: [person x]	verb: buy	noun: [person y]	verb: peel
cat: snp	cat: #n′ #a′ v	cat: snp	cat: #n′ #a′ v
sem: nm m	sem: ind past	sem: nm m	sem: ind past
fnc: buy	arg: [person x] peach	fnc: peel	arg: [person y] peach
...	...	...	...
prn: 34	prn: 34	prn: 34	prn: 34

sur: bill	sur:	sur:
noun: [person z]	verb: eat	noun: peach
cat: snp	cat: #n′ #a′ decl	cat: snp
sem: nm m	sem: *and* ind past	sem: indef sg
fnc: eat	arg: [person z] peach	fnc: [p. x] buy
mdr:	mdr:	[p. y] peel
nc:	nc:	[p. z] eat
pc:	pc:	...
prn: 34	prn: 34	prn: 34

The three verb proplets all take the core value peach of the shared object as their non-initial arg value.

As a first conceptual orientation consider the derivation graph:

5.4.5 **<to-do 2>**

GRAPHICAL HEAR MODE DERIVATION OF THE CONTENT 5.4.4

unanalyzed surfaces

Bob bought Jim peeled and Bill ate a peach .

automatic word form recognition

sur: Bob	sur: bought	sur: Jim	sur: peeled	sur: and	sur: Bill	sur: ate	sur: a(n)	sur: peach	sur: .
noun: [p. x]	verb: buy	noun: [p. y]	verb: peel	noun: n_1	noun: [p. z]	verb: eat	noun: n_2	noun: peach	verb: v_1
cat: snp	cat: n' a' v	cat: snp	cat: n' a' v	cat:	cat: snp	cat: n' a' v	cat: sn' snp	cat: sn	cat: v' decl
sem: nm m	sem: past	sem: nm m	sem: past	sem: *and*	sem: nm m	sem: past	sem: indef	sem: sg	prn:
fnc:	arg:	fnc:	arg:	arg:	fnc:	arg:	fnc:	fnc:	
prn:	prn:	prn:	prn:	prn:	prn:	prn:	prn:	prn:	

syntactic−semantic parsing:

1 | sur: Bob | sur: bought |
|---|---|
| noun: [p. x] | verb: buy |
| cat: snp | cat: n' a' v |
| sem: nm m | sem: past |
| fnc: | arg: |
| prn: 34 | prn: |

cross−copying

2 | sur: bob | sur: | sur: Jim |
|---|---|---|
| noun: [p. x] | verb: buy | noun: (p. y) |
| cat: snp | cat: #n' a' v | cat: snp |
| sem: nm m | sem: past | sem: nm m |
| fnc: buy | arg: [p. x] | fnc: |
| prn: 34 | prn: 34 | prn: |

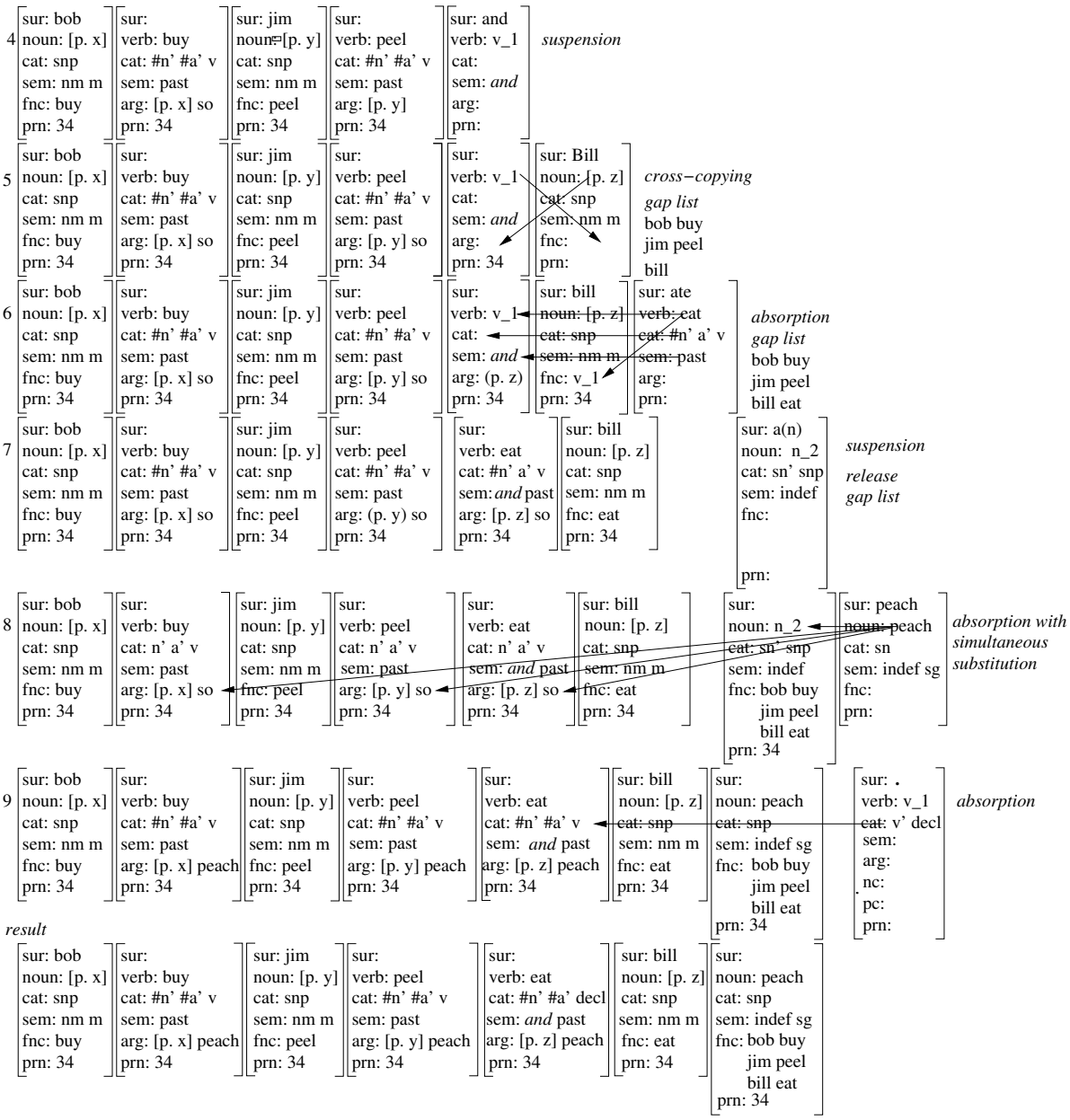
suspension

gap list:
bob buy
jim

3 | sur: bob | sur: | sur: jim | sur: peeled |
|---|---|---|---|
| noun: [p. x] | verb: buy | noun: [p. y] | verb: peel |
| cat: snp | cat: #n' #a' v | cat: snp | cat: n' a' v |
| sem: nm m | sem: past | sem: nm m | sem: past |
| fnc: buy | arg: [p. x] so | fnc: | arg: |
| prn: 34 | prn: 34 | prn: 34 | prn: |

cross−copying

gap list:
bob buy
jim peel



Lines 2, 3 and 5, 6 write to the derivation-external gap list, which is cached at the now front. Lines 3, 5, and 7 also write the substitution variable so (shared object) into the second (i.e. object) arg slot of *buy*, *peel*, and *eat*.

Line 7 moves the content of the gap list, now complete, from the cache into the fnc slot of the determiner of the shared object (*release gap list*). In line 8, all occurrences of so (shared object) are replaced with peach. In line 9, the content is completed by adding the syntactic mood value decl to the cat slot

of the final verb (in analogy to subject gapping, 5.2.3).

The complete sequence of explicit hear mode operation applications begins with SBJ×PRD:

5.4.6 **<to-do 3>**

CROSS-COPYING *bob* AND *buy* WITH SBJ×PRD (line 1)

SBJ×PRD (h1)

pattern c level

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP}'\text{ X v}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ X v}\\ \text{arg: }\alpha\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.2.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: Bob}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc:}\\ \ldots\\ \text{prn: 34}\end{bmatrix}\begin{bmatrix}\text{sur: bought}\\ \text{verb: buy}\\ \text{cat: n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \ldots\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur: bob}\\ \text{noun: [person x]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc: buy}\\ \ldots\\ \text{prn: 34}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: buy}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x]}\\ \ldots\\ \text{prn: 34}\end{bmatrix}$$

The next proplet is *jim*. One possible interpretation is as the grammatical object (as in a slave society). The other is suspending *jim* in order to combine it with the following predicate *peel* of a gapped item. The first reading is eliminated when *peel* arrives (-global ambiguity, FoCL 11.3.6):

For the gapping interpretation, we define the operation PRD°×SBJ, with the superscript ° indicating its role in an **o**bject-gapping construction. It adds *jim* to *bob buy* in a derivation-external gap list (caching).

5.4.7 SUSPENSION ADDING *jim* WITH PRD° ∼SBJ (line 2)

PRD° ∼SBJ (h52)

pattern level

$$\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#X}'\text{ N}'\text{ v}\\ \text{arg: Y}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\beta\\ \text{prn: K}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#X}'\text{ \#N}'\text{ v}\\ \text{arg: Y so}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\beta\\ \text{prn: K}\end{bmatrix}$$

extend gap list in cache

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: buy}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x]}\\ \ldots\\ \text{prn: 34}\end{bmatrix}\begin{bmatrix}\text{sur: Jim}\\ \text{noun: [person y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc:}\\ \ldots\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{verb: buy}\\ \text{cat: \#n}'\text{ \#a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person x] so}\\ \ldots\\ \text{prn: 34}\end{bmatrix}\begin{bmatrix}\text{sur: jim}\\ \text{noun: [person y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc:}\\ \ldots\\ \ldots\\ \text{prn: 34}\end{bmatrix}$$

initial gap list:
bob buy
jim

Used here initially, the operation writes *bob buy* as the first line to an external (cached) gap list and adds current *jim* in the second line. The operation introduces the substitution variable so (for shared object) into the second arg slot

of all output verbs in the sequence. The shared object, here *peach*, replaces the instances of so by simultaneous substitution when it arrives (5.4.5, line 8).

The next word provided by automatic word form recognition is *peel*. It triggers SBJ×PRD° to continue the from the subject *jim* to the predicate:bbbbbb

5.4.8 CROSS-COPYING *jim* AND *peeled* WITH SBJ×PRD° (line 3)

SBJ×PRD° (h9)

pattern level

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP}'\text{ X v}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ X v}\\ \text{arg: }\alpha\text{ so}\\ \text{prn: K}\end{bmatrix}$$

extend gap list in cache

Agreement conditions as in 2.1.2.

content level

$$\begin{bmatrix}\text{sur: jim}\\ \text{noun: [person y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc:}\\ \ldots\\ \text{prn: 34}\end{bmatrix}\Uparrow\begin{bmatrix}\text{sur: peeled}\\ \text{verb: peel}\\ \text{cat: n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \ldots\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur: jim}\\ \text{noun: [person y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc: peel}\\ \ldots\\ \text{prn: 34}\end{bmatrix}\Downarrow\begin{bmatrix}\text{sur:}\\ \text{verb: peel}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person y] so}\\ \ldots\\ \text{prn: 34}\end{bmatrix}$$

gap list:
bob buy
jim peel

This operation application bcompletes the second line of the cached gap list.

The hear mode derivation has now processed the input Bob bought ∅ Jim peeled, with *peel* added at the end of the current gap list. The next word *and* announces the final gapped item; *peel* and *and* are suspended until ate arrives (5.4.11) to be absorbed into *and*:

5.4.9 SUSPENDING *peel* AND *and* WITH **PRD° ∼PRD^{and}** (LINE 4)

PRD° ∼PRD^{and} (h27)

pattern level

$$\begin{bmatrix}\text{verb: }\alpha\\ \text{arg: X}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\textit{and}\ \beta\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{verb: }\alpha\\ \text{arg: X so}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\textit{and}\ \beta\\ \text{prn: K}\end{bmatrix}$$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: peel}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person y] so}\\ \ldots\\ \text{prn: 34}\end{bmatrix}\Uparrow\begin{bmatrix}\text{sur: and}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: }\textit{and}\\ \text{arg:}\\ \ldots\\ \text{prn:}\end{bmatrix}\quad\begin{bmatrix}\text{sur:}\\ \text{verb: peel}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg: [person y] so}\\ \ldots\\ \text{prn: 34}\end{bmatrix}\Downarrow\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: }\textit{and}\\ \text{arg:}\\ \ldots\\ \text{prn: 34}\end{bmatrix}$$

By first suspending peel and *and*, and then cross-copying *and* and *bill*, the subject is already taken care of in the arg slot of verbal *and* (3.6.3) when the core value *eat* is absorbed by simultaneous substitution of v_1 into the verb slot of *and* (5.4.11).

5.4.10 CROSS-COPYING *and* AND *Bill* WITH PRD^{and}×SBJ (line 5)

PRD^{and}×SBJ (46)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\beta\\ \text{arg:}\\ \text{prn: K}\end{bmatrix}\ \begin{bmatrix}\text{noun: }\alpha\\ \text{sem: X}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\beta\\ \text{arg: }\alpha\text{ so}\\ \text{prn: K}\end{bmatrix}\ \begin{bmatrix}\text{noun: }\alpha\\ \text{sem: }\beta\text{ X}\\ \text{fnc: V\_}n\\ \text{prn:}\end{bmatrix}$$

extend gap list in cache

$\beta \in$ {and, or}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: }\textit{and}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 34}\end{bmatrix}\ \begin{bmatrix}\text{sur: Bill}\\ \text{noun: [person z]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad \begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: }\textit{and}\\ \text{arg: [person z] so}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 34}\end{bmatrix}\ \begin{bmatrix}\text{sur: bill}\\ \text{noun: [person z]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc: v\_1}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 34}\end{bmatrix}$$

gap list:
bob buy
jim peel
bill

This operation cross-copies the predicate shell with the subject and provides special instructions. Next, the verbal variant of *and* absorbs *eat*:

5.4.11 ABSORBING *eat* INTO *and* WITH PRD^{and}∪PRD^{o} (line 6)

PRD^{and}∪PRD^{o} (h25)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\beta\\ \text{arg:}\\ \text{prn: K}\end{bmatrix}\ \begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#X}'\text{ N}'\text{ v}\\ \text{arg: Y}\\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#X}'\text{ \#N}'\text{ v}\\ \text{arg: Y so}\\ \text{prn: K}\end{bmatrix}$$

extend gap list in cache

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: }\textit{and}\\ \text{arg: [person z]}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 34}\end{bmatrix}\ \begin{bmatrix}\text{sur:}\\ \text{verb: eat}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad \begin{bmatrix}\text{sur:}\\ \text{verb: eat}\\ \text{cat: \#n}'\text{ \#a}'\text{ v}\\ \text{sem: }\textit{and}\text{ ind past}\\ \text{arg: [person z] so}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 34}\end{bmatrix}$$

final gap list:
bob buy
jim peel
bill eat

The output pattern puts the place holder so into the second arg slot of the predicate, the valency position a′ is #-marked, and *eat* is added to the gap list.

The hear mode derivation has now processed the input Bob bought ∅ Jim peeled ∅ and Bill ate. It remains to complete the construction-final proposition, which is the only complete proposition in a object gapping construction. The first step is combining the newly added predicate with the incoming determiner of the shared object, using PRD×OBJ°

5.4.12 CROSS-COPYING *eat* AND *a(n)* WITH PRD×OBJ° (line 7)

PRD×OBJ° (h39)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \underline{\#X'}\ \text{N}'\ \text{Y}\ \gamma \\ \text{arg: Z so} \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: CN}'\ \text{NP} \\ \text{fnc:} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \underline{\#X'}\ \#\text{N}'\ \text{Y}\ \gamma \\ \text{arg: Z } \alpha \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{noun: so} \\ \text{cat: CN}'\ \text{NP} \\ \text{fnc: } \emptyset\ \beta \\ \text{prn: K}\end{bmatrix}$$

clear cache into ∅ slot of so.

Agreement conditions as in 2.3.4.

$$\Uparrow \qquad\qquad\qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: \#n}'\ \text{a}'\ \text{v} \\ \text{sem: } \textit{and}\text{ ind past} \\ \text{arg: [person z] so} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix} \begin{bmatrix}\text{sur: a(n)} \\ \text{noun: n\_3} \\ \text{cat: sn}'\ \text{snp} \\ \text{sem: indef sg} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{v} \\ \text{sem: } \textit{and}\text{ ind past} \\ \text{arg: [person z] so} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix} \begin{bmatrix}\text{sur:} \\ \text{noun: so} \\ \text{cat: sn}'\ \text{snp} \\ \text{sem: indef sg} \\ \text{fnc: bob buy} \\ \quad\text{jim peel} \\ \quad\text{bill eat} \\ \ldots \\ \text{prn: 34}\end{bmatrix}$$

The operation differs from PRD×OBJ in that it (i) requires so in the arg slot of the first input pattern, (ii) replaces α in the second output pattern with so, and (iii) moves the gap list from the derivation-external cache into the fnc slot of *so*.

Absorbing *peach* into the determiner completes the shared object:

5.4.13 ABSORBING *peach* INTO *a(n)* WITH DET∪CN (line 8)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n \\ \text{cat: CN}'\ \text{NP} \\ \text{sem: Y} \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: CN} \\ \text{sem: Z} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: NP} \\ \text{sem: Y Z} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.2.4.

$$\Uparrow \qquad\qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: so} \\ \text{cat: sn}'\ \text{snp} \\ \text{sem: indef sg} \\ \text{fnc: bob buy} \\ \quad\text{jim peel} \\ \quad\text{bill eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix} \begin{bmatrix}\text{sur: peach} \\ \text{noun: peach} \\ \text{cat: sn} \\ \text{sem: sg} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{noun: peach} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: bob buy} \\ \quad\text{jim peel} \\ \quad\text{bill eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix}$$

The operation replaces so in the first input proplet with peach. Because standard DET∪CN has simultaneous substitution, the so place holder variable in the second (object) arg slot of all the verbs in the example are replaced with the value peach as well.

The final step of this hear mode derivation is adding the period with S∪IP.

5.4.14 ABSORBING • INTO *buy* WITH S∪IP (LINE 9)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ VT} \\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{verb: V\_}n \\ \text{cat: VT}' \text{ SM}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ SM} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: } \#n' \ \#a' \text{ v} \\ \text{sem: ind past} \\ \text{arg: [person x] peach} \\ \ldots \\ \text{prn: 34}\end{bmatrix} \quad \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: v\_1} \\ \text{cat: v}' \text{ decl} \\ \text{sem:} \\ \text{arg:} \\ \ldots \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: } \#n' \ \#a' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x] peach} \\ \ldots \\ \text{prn: 34}\end{bmatrix}$$

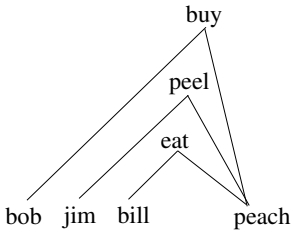
The hear mode derivation of an object gapping construction is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

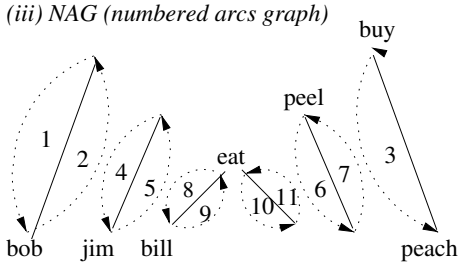
5.4.15 **<to-do 4>**

GRAPH ANALYSIS UNDERLYING PRODUCTION OF 5.4.4

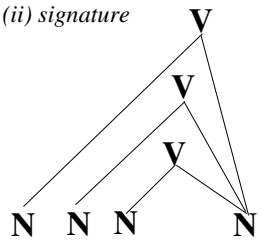
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

1	2	3	7	4	5	6	11	8	9	10	11
Bob	bought			Jim	peeled			and_Bill	ate	a_peach	•
V/N	N/V	V\N^o	N^o\V	V/N	N/V	V\N^o	N^o\V	V/N	N/V	V\N^f	N^f\V

The shared object is clearly shown.[19] Just as the graph 5.2.16 for subject gapping is missing a downward arc opposite arc 9, the current graph for object gapping is missing an upward arc opposite arc 3 (1.4.6).

Word form production is summarized as the following list of speak mode operations:

[19] The different tilts of the three V/N and the three V\N lines are solely for visual separation in the graph.

5.4.16 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *buy* to *bob*	Bob	5.4.17
arc 2:	N↗V	from *bob* to *buy*	bought	5.4.18
arc 3:	V↘N°	from *buy* to *peach*		5.4.19
arc 7:	N°↖V	from *peach* to *peel*		5.4.20
arc 4:	V↙N	from *peel* to *jim*	Jim	5.4.21
arc 5:	N↗V	from *jim* to *peel*	peeled	5.4.22
arc 6:	V↘N°	from *peel* to *peach*		5.4.23
arc 11:	N°↖V	from *peach* to *eat*		5.4.24
arc 8:	V↙N	from *eat* to *bill*	and_Bill	5.4.25
arc 9:	N↗V	from *bill* to *eat*	ate	5.4.26
arc 10:	V↘N	from *eat* to *peach*	a_peach	5.4.27
arc 11:	N↖V	from *peach* to *eat*	.	5.4.28

The operation names V↘N° and N°↖V characterize the N as the shared grammatical **o**bject. The traversals take the shortest route, i.e. from *peach* via *peel* to Jim and from the shared object *peach* via *eat* to Bill, which is why arc 3 has no upward counterpart.

The complete sequence of explicit navigation operations begins with V↙N:

5.4.17 **<to-do 6>**

NAVIGATING WITH V↙N FROM *buy* TO *bob* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34} \end{bmatrix} \quad \begin{bmatrix} \text{sur: Bob} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34} \end{bmatrix}$$

Because neither the input nor the output proplet is a shared item (no gap list) standard V↙N may be used .

Next, N↗V travels from *bob* back to *buy* and realizes bought:

5.4.18 NAVIGATING WITH N↗V FROM *bob* BACK TO *buy* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: buy} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: bought} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix}$$

At this point, it is open whether Bob bought will be continued into a complete sentence or with a gapped item.

To get to the beginning of the second gapped item, i.e. Jim, the navigation first moves to the shared object to get the second item on the gap list, i.e. peel, as a means to find the second subject. This is based on the operation V↘N°:

5.4.19 NAVIGATING WITH V↘N° FROM *buy* TO *peach* (arc 3)

V↘N° (s29)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: \#Y } \alpha \text{ Z} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: buy} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{noun: peach} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: buy} \\ \quad\quad \text{peel} \\ \quad\quad \text{eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix}$$

The result of the instruction shows up in the fnc slot of the start proplet in 5.4.20. An unmarked prefinal value on the gap list prevents lexnoun from realizing the surface a_peach of the shared object. Thus the traversal to the object noun is empty, but provides the next unmarked item on the gap list of *peach*, here *peel*.

The traversal from the shared object to *peel* is based on $\mathsf{N^{o}}\nwarrow\backslash\mathsf{V}$.

5.4.20 Navigating with $\mathsf{N^{o}}\nwarrow\backslash\mathsf{V}$ from *peach* to *peel* (arc 7)

N°↖\V (s30)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: \#X } \alpha \text{ Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: } \beta \text{ W} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: peach} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#buy} \\ \quad\quad \text{peel} \\ \quad\quad \text{eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: peel} \\ \text{cat: \#n}' \text{ \#a}' \text{ v} \\ \text{sem: ind past} \\ \text{arg: [person y] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix}$$

At this point, the navigation has realized Bob bought $\emptyset$ and traversed the proplets *buy, bob, buy, peach, peel*.

Standard $\mathsf{V}\swarrow\mathsf{N}$ provides the traversal from *peel* to the subject *jim* of the second gapped item. Analogous to 5.4.17, the surface Jim is realized:

5.4.21 Navigating with $\mathsf{V}\swarrow\mathsf{N}$ from *peel* to *jim* (arc 4)

V↙N (s1)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: } \beta \text{ X} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: peel} \\ \text{cat: \#n}' \text{ \#a}' \text{ v} \\ \text{sem: ind past} \\ \text{arg: [person y] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix} \quad \begin{bmatrix}\text{sur: Jim} \\ \text{noun: [person y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: peel} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix}$$

The following return to *peel* with standard $\mathsf{N}\nearrow\mathsf{V}$ realizes the surface of the second gapped item's predicate:

5.4.22 NAVIGATING WITH N↗V FROM *jim* TO *peel* (arc 5)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{Y} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: jim} \\ \text{noun: [person y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: peel} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix} \quad \begin{bmatrix}\text{sur: peeled} \\ \text{verb: peel} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{v} \\ \text{sem: ind past} \\ \text{arg: \#[person y] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix}$$

The navigation has now traversed *buy, bob, buy, peach, peel, jim, peel* and realized the surfaces Bob bought ∅ Jim peeled.

To get to the beginning of the final sentence, i.e. the subject Bill, the navigation first returns to the shared object to get the third predicate on the gap list as a means to access the third subject. This is based on another application of V↘N° (5.4.19):

5.4.23 NAVIGATING WITH V↘N° FROM *peel* TO *peach* (arc 6)

V↘N° (s29)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: \#Y } \alpha\ \text{Z} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: peel} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{v} \\ \text{sem: ind past} \\ \text{arg: \#[person y] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{noun: peach} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#buy} \\ \quad\quad \text{peel} \\ \quad\quad \text{eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix}$$

As in 5.4.19, the instruction applies to a value in the goal proplet: it #-marks the second item on the gap list. The result is shown in the fnc slot of the start proplet when the operation N°↖V reapplies (5.4.20) next:

5.4.24 NAVIGATING WITH $N^{o}\nwarrow V$ FROM *peach* TO *eat* (arc 11)

$N^{o}\nwarrow V$ (s30)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: \#X } \alpha \text{ Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: } \beta \text{ W} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: peach} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#buy} \\ \quad\quad \text{\#peel} \\ \quad\quad \text{eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix} \quad \begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: \#n}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{and} \text{ ind past} \\ \text{arg: [person z] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix}$$

The feature [fnc: #X α Y] of the start pattern binds the values *#buy #peel* to #X, the value eat to α, and the value NIL to Y. The re-occurrence of α in the goal pattern enables access to the predicate *eat* of the final sentence.

From there, the navigation moves with $V\swarrow N$ to the subject and realizes and_Bill with lexnoun:

5.4.25 NAVIGATING WITH $V\swarrow N$ FROM *eat* TO *bill* (arc 8)

$V\swarrow N$ (s1)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: } \beta \text{ X} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: \#n}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{and} \text{ ind past} \\ \text{arg: [person z] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix} \quad \begin{bmatrix}\text{sur: and\_Bill} \\ \text{noun: [person z]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix}$$

Lexnoun uses the initial *and* value in the sem and the name marker in the sur slot of the goal proplet for realizing and_Bill.

From the subject *bill* of the construction-final proposition, the navigation returns with standard $N\nearrow V$ to the predicate and realizes ate:

5.4.26 NAVIGATING WITH N↗V FROM *bill* TO *eat* (arc 9)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: bill} \\ \text{noun: [person z]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: ate} \\ \text{verb: eat} \\ \text{cat: \#n}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{and} \text{ ind past} \\ \text{arg: \#[person z] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix}$$

Using the second arg value peach of *eat* as the continuation value, the navigation proceeds with V↘N to the shared object.

5.4.27 NAVIGATING WITH V↘N FROM *eat* TO *peach* (arc 10)

V↘N (s38)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: \#Y } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β,
#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: eat} \\ \text{cat: \#n}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{and} \text{ ind past} \\ \text{arg: \#[person z] peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: a\_peach} \\ \text{noun: peach} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#buy} \\ \quad\ \text{\#peel} \\ \quad\ \text{eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix}$$

instructions show up in the following operation application. With all items but one on the gap list #-marked, lexnoun realizes the shared object a_peach.

Using the last fnc value eat, now #-marked, of the shared object *peach* as the continuation value, the navigation proceeds with $\text{N}^{\&}$↖V to the last predicate to realize the period. $\text{N}^{\&}$↖V differs from N°↖V (s30) because it requires all items on the gap list to be #-marked.

5.4.28 NAVIGATING WITH N↖\V FROM *peach* TO *buy* (arc 11)

N↖\V (s4)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: \#X \#}\alpha \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#W \#}\beta \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: peach} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#buy} \\ \quad\quad\text{\#peel} \\ \quad\quad\text{\#eat} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix} \quad \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: eat} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: } \textit{and} \text{ ind past} \\ \text{arg: \#[person z] \#peach} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 34}\end{bmatrix}$$

With all continuation values in the *eat* proplet #-marked, lexverb realizes the period, using the cat value decl.

Extending DBS.21 to an example class with object gapping required the definition of two hear mode operations, PRD°×SBJ (h45) and PRD°×OBJ (h38), and the two speak mode operations V↘N° (s29), and N°↖\V (s30). The hear mode derivation used nine operation applications and the speak mode 11.

5.4.29 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

1		2		3		4		5		6		7		8		9	
Bob	×	bought	∼	Jim	×	peeled	∼	and	×	Bill	∪	ate	×	a	∪	peach	∪	•

speak mode:

1		2		3		7		4		5	
V↙N	Bob	N↗V	bought	V↘N°		N°↖\V		V↙N	Jim	N↗V	peeled

6		11		8		9		10		11		
V↘N°	and	N°↖\V		V↙N	Bill	N↗V	ate	V↘N$^{\&}$	a_peach	N$^{\&}$↖\V		•

The numbering of the speak mode operations corresponds to the arc traversal numbers of the NAG in 5.4.15. As in subject gapping (5.2.28), there is one multiple traversal, here of arc 11.

5.5 DBS.23: Long-Distance Dependency

The linguistic terms *long-distance dependency* or *unbounded dependency* refer to grammatical constructions in which there is no fixed limit on the surface distance between gap(s) and filler(s).[20] Examples are subject (Sect. 5.2), predicate (Sect. 5.3), and object gapping (Sect. 5.4), but also repeating object clause interrogatives (ROCIs). Consider the following comparison:

Object gapping:
(i) Bob bought ∅, Jim peeled ∅, . . . , and Bill ate **an_apple**.

Repeating object clause interrogative (ROCI):
(ii) **Who(m)** does John say that Bill believes . . . that Mary loves ∅?

(i) and (ii) have in common that there is an unlimited iteration between filler and gap, indicated by the dots . . . (here for unbounded iteration). They differ in that in (i) the gaps (range items) precede a single filler (domain item), but in (ii) a single filler in initial position precedes a single gap in final position.

The unbounded dependency in (ii) has the form of an unbounded *suspension*, here between initial Who(m) and the transitive verb form loves in final position. The dependency is a semantic N\V (object\predicate) relation. Because the length of the suspension is only determined at the end of the input sentence, the time-linear surface compositional hear mode derivation is subject to the following structure of syntactic[21] ambiguity (NLC 7.6.5):

5.5.1 Ambiguity structure of an unbounded suspension

```
A  Whom   does  John   love?
    1 ——— 1 ——— 1 ——— 1
B        does  John   say    that   Bill   loves?
          2 ——— 2 ——— 2 ——— 1 ——— 1 ——— 1
C                            that   Bill   believes  that   Mary   loves?
                              3 ——— 3 ——— 3 ——— 1 ——— 1 ——— 1
D                                                 that   Mary   claims  that  Suzy  loves?
                                                   4 ——— 4 ——— 4 ——— 1 ——— 1 ——— 1
```

Who(m) requires a two-place (transitive) or three-place (ditransitive) verb because it is oblique, as shown by the optional morphological marking for grammatical object.[22]

In line A, who(m) is the object of an elementary proposition with a transitive verb which does not take a clausal object. Thus all proplets in line A share the

[20] In this sense, DET ADN* N constructions constitute an unbounded dependency as well: DET is the gap and the ADN* (* for Kleene Star) coordination is the unbounded iteration separating the gap and the noun filler.

[21] For the distinction between syntactic, semantic, and pragmatic ambiguity see FoCL Sects. 11.3, 12.5.

[22] The declarative variant John said that Bill believes that Mary loves Tom. has the same semantic relations of structure except that the object is final Tom rather than initial who(m) (NLC Sect. 7.6).

prn value 1. In line B, in contrast, the matrix verb takes a clausal object which who(m) belongs to. Thus, does John say X has the prn value 2, whereby X is Bill loves who(m) with the prn value 1. The construction in line B terminates because the verb *love* does not take a clausal object.

Line C branches off line B because the first object clause uses a verb which takes a second object clause as its oblique argument. Thus, does John say X continues to have the prn value 2, but the new object clause Bill believes Y has the new prn value 3, whereby Y is that Mary loves who(m) with the prn value 1. The construction terminates in branch C.

Line D branches off C because the second object clause uses a verb which takes a third object clause as its argument. Thus, does John say X continues to have the prn value 2, Bill believes Y continues to have the prn value 3, but the new object clause that Mary claims Z has the prn value 4, whereby Z is that Suzy loves who(m) with the prn value 1.

Even though an unbounded suspension (i) may be continued indefinitely and (ii) causes a systematic syntactic ambiguity, it does not increase the computational complexity of natural language (FoCL Sect. 11.5). This is because one of the two branches always terminates when the next ambiguity begins. In other words, there is no +global ambiguity in 5.5.3, in the same sense as there is no +global ambiguity in the famed 'garden path' sentence (FoCL 11.3.6).

The following example shows the content of an unbounded dependency:

5.5.2 **<to-do 1>**

Who(m) did John say that Bill believes that Mary loves?

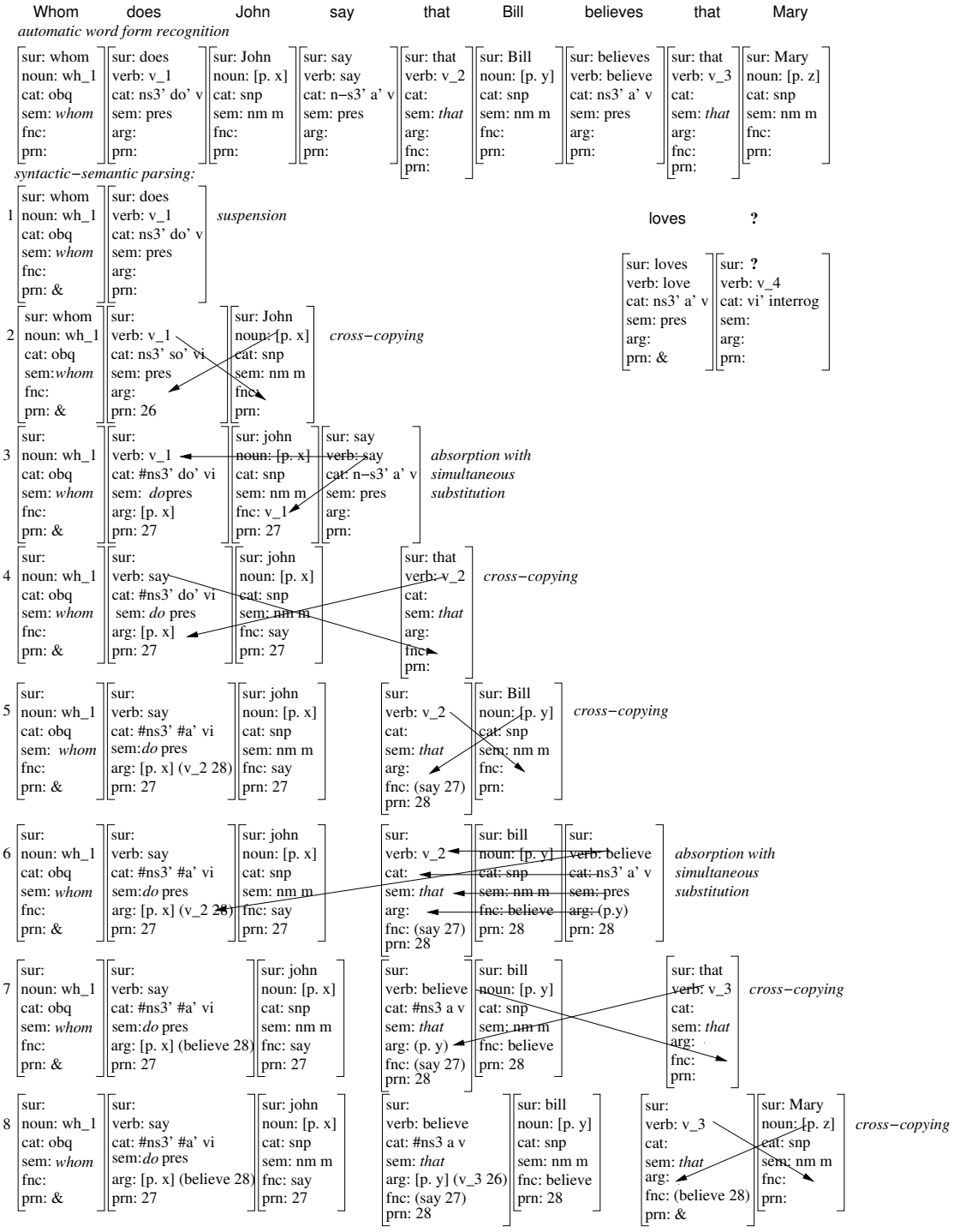
sur:	sur:	sur: john	sur:
noun: wh_1	verb: say	noun: [person x]	verb: believe
cat: obq	cat: #ns3′ #a′ interrog	cat: snp	cat: #ns3′ #a′ v
sem: *who(m)*	sem: *do* past	sem: nm m	sem: *that* pres
fnc:	arg: [person x] (believe 28)	fnc: say	arg: [person y] (love &)
mdr:	mdr:	mdr:	fnc: (say 27)
nc:	nc:	nc:	mdr:
pc:	pc:	pc:	nc:
prn: &	prn: 27	prn: 27	pc:
			prn: 28

sur: bill	sur:	sur: mary
noun: [person y]	verb: love	noun: [person z]
cat: snp	cat: #ns3′ #a′ v	cat: snp
sem: nm m	sem: *that* pres	sem: nm f
fnc: believe	arg: [person z] (wh_1 &)	fnc: love
mdr	fnc: (believe 28)	mdr:
nc:	mdr:	nc:
pc:	nc:	pc:
prn: 28	pc:	prn: &
	prn: &	

As a first conceptual orientation consider the derivation graph:

5.5.3 <to-do 2>

GRAPHICAL HEAR MODE DERIVATION OF THE CONTENT 5.5.1



9a	sur: noun: wh_1 cat: obq sem: *whom* fnc: love prn: &	sur: verb: say cat: #ns3' #a' vi sem:*do* pres arg: [p. x] (believe 28) prn: 27	sur: john noun: [p. x] cat: snp sem: nm m fnc: say prn: 27	sur: verb: believe cat: #n−s3 #a v sem: *that* arg: [p. y] (v_3 26) fnc: say prn: 28	sur: bill noun: [p. y] cat: snp sem: nm m fnc: believe prn: 28	sur: verb: v_3 cat: sem: *that* arg: fnc: (believe 28)	sur: mary ~~noun: [p. z]~~ ~~cat: snp~~ ~~sem: nm m~~ ~~fnc: love~~ prn: &	sur: ~~verb: love~~ ~~cat: #ns3' #a' v~~ ~~sem: pres~~ ~~arg:~~ (p. z) wh_1 prn: &	*absorption with simultaneous substitution*
9b	sur: noun: wh_1 cat: obq sem: *whom* fnc: prn: &	sur: verb: say ~~cat: #ns3' #a' vi~~ sem:*do* pres ~~arg: [p. x]~~ (believe 28) prn: 27	sur: john noun: [p. x] cat: snp ~~sem: nm m~~ fnc: say prn: 27	sur: verb: believe ~~cat: #n−3 #a v~~ ~~sem: *that*~~ arg: [p. y] (love 26) fnc: say prn: 27	sur: bill noun: [p. y] cat: snp sem: nm m fnc: believe prn: 28	sur: ~~verb~~: love cat: #ns3 #a v sem: *that* pres ~~arg: [p. z]~~ fnc: (believe 28) prn: &	sur: mary noun: [p. z] cat: snp sem: nm m fnc: love prn: &		*cross−copying*
10	sur: noun: wh_1 cat: obq sem: *whom* fnc: love prn: &	sur: verb: say cat: #ns3' #a' vi sem:*do* pres arg: [p. x] (believe 28) prn: 27	sur: john noun: [p. x] ~~cat: snp~~ sem: nm m fnc: say prn: 27	sur: verb: believe ~~cat: #n−s3 #a v~~ sem: *that* arg: [p. y] (love 26) fnc: say prn: 28	sur: bill noun: [p. y] ~~cat: snp~~ sem: nm m fnc: believe prn: 28	sur: verb: love ~~cat: #ns3 #a v~~ sem: *that* pres arg: [p. z] wh_1 fnc: (believe 28) prn: &	sur: mary noun: [p. z] ~~cat: snp~~ sem: nm m fnc: love prn: &	sur: **?** verb: v_4 cat: vi' interrog prn:	*absorption*

result of syntactic−semantic parsing:

sur: noun: wh_1 cat: obq sem: *whom* fnc: love prn: &	sur: verb: say cat: #ns3' #a' interrog sem:*do* pres arg: [p. x] (believe 28) prn: 27	sur: john noun: [p. x] cat: snp sem: nm m fnc: say prn: 27	sur: verb: believe cat: #n−3 #a v sem: *that* arg: [p. y] (love 26) fnc: say prn: 27	sur: bill noun: [p. y] cat: snp sem: nm m fnc: believe prn: 28	sur: verb: love cat: #ns3 #a v sem: *that* pres arg: [p. z] wh_1 fnc: (believe 28) prn: &	sur: mary noun: (p. z) cat: snp sem: nm m fnc: love prn: &

The initial suspension between *who(m)* and *do* in line 1 is compensated by the additional operation application in line 9b. The number of object sentences between initial *who(m)* and the final incomplete clause is open, as shown, for example, by does John say that Bill believes that Suzy claims that John hopes that Bob regrets that Jim remembered that Laura suspects...?[23] Thus, the prn value assigned to Whom ... Mary loves is unrelated to the prn numbers of intervening clauses. This is expressed by assigning a constant, here &, as the prn value to Whom ... Mary loves. This constant exempts *whom* from the usual now front clearance of extrapropositional proplets such that it is still available for concatenation when the incomplete final clause arrives.

The following sequence of operations is 'deterministic' in the sense of classic computational complexity theory (FoCL Sect. 12.1). Accordingly, each derivation step will show only those operation applications which lead to the intended result; branches which are caused by the ambiguity structure 5.5.1 but turn out to be dead ends are omitted.

The first operation to apply in the hear mode derivation of the content 5.5.2 is WH∼DO. It is a suspension because the first two words are unrelated semantically and belong to different propositions. The operation requires the first word to be a WH in the oblique case and the next word to be a form of

[23] Though it is unlikely that this example may be found outside a linguistic example, i.e. in a "real" text, and may therefore be derided as an instance of "armchair linguistics," it is well-suited to make an empirical point regarding the grammatical phenomenon of unboundedness in natural language.

the auxiliary *do*.[24] It assigns suitable prn values in the output and changes the final category segment v to vi, enforcing a question mark in line 10 of 5.5.3.

The complete sequence of explicit hear mode operation applications begins with WH∼AUX:

5.5.4 **<to-do 3>**

SUSPENDING *Who(m)* AND *do* WITH WH∼AUX (line 1)

WH∼DO (h26)

pattern level

noun: WH	verb: V_*n*		noun: WH	verb: V_*n*
cat: obq	cat: NOM′ DO′ v	⇒	cat: obq	cat:NOM′ DO′ vi
prn: &	prn:		prn: &	prn: K

⇑ ⇓

content level

sur: Who(m)	sur: does		sur:	sur:
noun: wh_1	verb: v_1		noun: wh_1	verb: v_1
cat: obq	cat: ns3′ do′ v		cat: obq	cat: ns3′ do′ vi
sem: *who(m)*	sem: *do* pres		sem: *who(m)*	sem: *do* pres
fnc:	arg:		fnc:	arg:
mdr:	mdr:		mdr:	mdr:
nc:	nc:		nc:	nc:
pc:	pc:		pc:	pc:
prn: &	prn:		prn: &	prn: 27

Next, the finite auxiliary and the subject of the top clause are combined with the operation AUX×SBJ:

5.5.5 CROSS-COPYING *do* AND *john* WITH AUX×SBJ (line 2)

AUX×SBJ (h30)

pattern level

verb: V_*n*	noun: α		verb: V_*n*	noun: α
cat: NOM′ AUX′ vi	cat: NOM	⇒	cat: #NOM′ AUX′ vi	cat: NOM
arg:	fnc:		arg: α	fnc: V_*n*
prn: K	prn:		prn: K	prn: K

⇑ ⇓

content level

sur:	sur: John		sur:	sur: john
verb: v_1	noun: [person x]		verb: v_1	noun: [person x]
cat: ns3′ do′ vi	cat: snp		cat: #ns3′ do′ vi	cat: snp
sem: *do* pres	sem: nm m		sem: *do* pres	sem: nm m
arg:	fnc:		arg: [person x]	fnc: v_1
mdr:	mdr:		mdr:	mdr:
nc:	nc:		nc:	nc:
pc:	pc:		pc:	pc:
prn: 27	prn:		prn: 27	prn: 27

Compared to SBJ×PRD (h1), the order of the noun and verb patterns is inverted in AUX×SBJ,[25] but the agreement conditions and the canceling of

[24] These highly specific requirements make the example an instance of Fillmore's *construction theory* (Fillmore and Kay 1996).

[25] This operation has multiple applications, as in What has John done?, Why did John leave?, Where are they?, etc. In Transformational Grammar the phenomenon is called "aux-inversion."

the subject valency position are the same. The derivation has now interpreted Who(m) does John.

When automatic word form recognition provides say, the following operation AUX∪NFV combines the finite auxiliary does and the non-finite (bare infinitive) main verb as part of the current proposition with the prn value 27:

5.5.6 Absorbing *say* into *do* with AUX∪NFV (line 3)

AUX∪NFV (h16)

pattern level

verb: V_*n*	verb: α		verb: α
cat: #W′ AUX′ VT	cat: Y AUX	⇒	cat: #W′ Y VT
sem: X	sem: Z		sem: X Z
prn: K	prn:		prn: K

AUX ϵ {be, hv, do}. VT ϵ {v, vi}.

⇑ ⇓

content level

sur:	sur: say	sur:
verb: v_1	verb: say	verb: say
cat: #ns3′ do′ vi	cat: n-s3′ a′ v	cat: #ns3′ a′vi
sem: ind pres	sem: ind pres	sem: ind pres
arg: [person x]	arg:	arg: [person x]
...	...	...
prn: 27	prn:	prn: 27

For the English infinitive, here say, DBS uses the unmarked present tense form of the main verb matching the pattern [cat: n-s3′ X v][26] (CLaTR Sects. 15.4–15.6). The result of the absorption uses the nominative valency of the finite auxiliary.

The iteration of object sentences begins in line 4 of 5.5.3 with the arrival of the conjunction that, represented by its core value *v_2*. This derivation step corresponds to line 2 in 2.6.2 and is based on the same operation (2.6.4):

5.5.7 Cross-copying *say* and *that* with PRD×PRD^{obl} (line 4)

PRD×PRD^{obl} (h6)

pattern level

verb: β	verb: V_*n*		verb: β	verb: V_*n*
cat: #NP′ a′ V	sem: *that*	⇒	cat: #NP′ #a′ V	sem: *that*
arg: Y	fnc:		arg: Y (V_*n* K+1)	fnc: (β K)
prn: K	prn:		prn: K	prn: K+1

Agreement conditions as in 2.6.4.

⇑ ⇓

content level

sur:	sur: that	sur:	sur:
verb: say	verb: v_2	verb: say	verb: v_2
cat: #ns3′ a′ vi	cat:	cat: #ns3′ #a′ vi	cat:
sem: pres	sem: *that*	sem: pres	sem: *that*
arg: [person x]	arg:	arg: [person x] (v_2)	arg:
mdr:	fnc:	mdr:	fnc: (say 27)
nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:
prn: 27	prn:	prn: 27	prn: 28

[26] Across languages, the form of the verbal paradigm used for the infinitive varies: German uses the first/third person plural for the infinitive, e.g. gehen, Latin uses a separate form, e.g. andare, etc.

The *that* proplet has (i) the core attribute verb, (ii) the continuation attribute arg for the subclause, (iii) the fnc attribute for the connection to the higher clause, and (iv) specifies the kind of conjunction by storing its English surface in the initial sem slot. The operation connects *say* and the (beginning of the) first object clause by copying the core value v_2 into the second arg slot of *say* and say into the fnc slot of *that*.

The surface-compositional time-linear processing of the input has now reached Who(m) does John say that. The next step 5.5.8 is analogous to 2.6.5:

5.5.8 Cross-copying *that* and *bill* with PRD^{obl}×SBJ (line 5)

PRD^{obl}×SBJ (h31)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\textit{that}\\ \text{arg:}\\ \text{prn: K}\end{bmatrix}\ \begin{bmatrix}\text{noun: }\beta\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\ \Rightarrow\ \begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\textit{that}\\ \text{arg: }\beta\\ \text{prn: K}\end{bmatrix}\ \begin{bmatrix}\text{noun: }\beta\\ \text{fnc: V\_}n\\ \text{prn: K}\end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_2}\\ \text{cat:}\\ \text{sem: }\textit{that}\\ \text{arg:}\\ \text{fnc: (say 27)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 28}\end{bmatrix}\ \begin{bmatrix}\text{sur: Bill}\\ \text{noun: [person y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\ \begin{bmatrix}\text{sur:}\\ \text{verb: v\_2}\\ \text{cat:}\\ \text{sem: }\textit{that}\\ \text{arg: [person y]}\\ \text{fnc: (say 27)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 28}\end{bmatrix}\ \begin{bmatrix}\text{sur: bill}\\ \text{noun: [person y]}\\ \text{cat: snp}\\ \text{sem: nm m}\\ \text{fnc: v\_2}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 28}\end{bmatrix}$$

The cross-copying writes v_2 of *that* into the fnc slot of *bill* and [person y] of *bill* into the arg slot of *that*.

Next, the subclause verb believe triggers its absorption into the subordinating conjunction *that* with PRD^{that}∪PRD.

5.5.9 Absorbing *believe* into *that* with **PRD^{obl}∪PRD** (line 6)

PRD^{obl}∪PRD (h19)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\textit{that}\\ \text{arg }\alpha\\ \text{fnc: }(\delta\text{ K-1})\\ \text{prn: K}\end{bmatrix}\ \begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP}'\text{ X v}\\ \text{sem: Y}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\ \Rightarrow\ \begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ X v}\\ \text{sem: }\textit{that}\text{ Y}\\ \text{arg: }\alpha\\ \text{fnc: }(\delta\text{ K-1})\\ \text{prn: K}\end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_2}\\ \text{cat:}\\ \text{sem: }\textit{that}\\ \text{arg: [person y]}\\ \text{fnc: (say 27)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 28}\end{bmatrix}\ \begin{bmatrix}\text{sur: believes}\\ \text{verb: believe}\\ \text{cat: ns3}'\text{ a}'\text{ v}\\ \text{sem: pres}\\ \text{arg:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\ \begin{bmatrix}\text{sur:}\\ \text{verb: believe}\\ \text{cat: \#ns3}'\text{ a}'\text{v}\\ \text{sem: }\textit{that}\text{ pres}\\ \text{arg: [person y]}\\ \text{fnc: (say 27)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 28}\end{bmatrix}$$

Simultaneous substitution replaces all occurrences of v_2 with the value believe. Fusing the *that* and the *believe* proplet results in a *that* proplet which is enriched with the relevant values of the next word, resulting in the predicate of the subclause.

Having processed Who(m) does John say that Bill believes, the derivation could either (i) add another object sentence with a clausal object or (ii) be completed by adding a question mark (as in line B of 5.5.3). However, because the next word is another that proplet, a third object clause is entered.

The operations applying in the following lines 7–9a resemble the operations of the previous lines 4–6 (cycle repetition), except that they realize the possibility of being final by assigning the prn value & of initial Who(m):

5.5.10 Cross-copying *believe* and *that* with PRD×PRD$^{\&}$ (line 7)

PRD×PRD$^{\&}$ (h11)

pattern level

$$\begin{bmatrix}\text{verb: } \beta\\ \text{cat: \#NP}'\ \text{a}'\ \text{V}\\ \text{arg: Y}\\ \text{prn: K}\end{bmatrix}\ \begin{bmatrix}\text{verb: V\_}n\\ \text{sem: } \textit{that}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta\\ \text{cat: \#NP}'\ \text{\#a}'\ \text{V}\\ \text{arg: Y V\_}n\\ \text{prn: K}\end{bmatrix}\ \begin{bmatrix}\text{verb: V\_}n\\ \text{sem: } \textit{that}\\ \text{fnc: } (\beta\ \text{K})\\ \text{prn: \&}\end{bmatrix}$$

Agreement conditions as in 2.6.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: believe}\\ \text{cat: \#ns3}'\ \text{a}'\ \text{v}\\ \text{sem: } \textit{that}\ \text{pres}\\ \text{arg: [person y]}\\ \text{fnc: (say 27)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 28}\end{bmatrix}\ \begin{bmatrix}\text{sur: that}\\ \text{verb: v\_3}\\ \text{cat:}\\ \text{sem: } \textit{that}\\ \text{arg:}\\ \text{fnc:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\quad \begin{bmatrix}\text{sur:}\\ \text{verb: believe}\\ \text{cat: \#ns3}'\ \text{a}'\ \text{v}\\ \text{sem: } \textit{that}\ \text{pres}\\ \text{arg: [person y] v\_3}\\ \text{fnc: (say 27)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 28}\end{bmatrix}\ \begin{bmatrix}\text{sur:}\\ \text{verb: v\_3}\\ \text{cat:}\\ \text{sem: } \textit{that}\\ \text{arg:}\\ \text{fnc: (believe 28)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: \&}\end{bmatrix}$$

The next word proplet *mary* is added with PRD$^{\&}$×SBJ:

5.5.11 Cross-copying *that* and *mary* with PRD$^{\&}$×SBJ (line 8)

PRD$^{\&}$×SBJ (h40)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: } \textit{that}\\ \text{arg:}\\ \text{prn: \&}\end{bmatrix}\ \begin{bmatrix}\text{noun: } \beta\\ \text{fnc:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: V\_}n\\ \text{sem: } \textit{that}\\ \text{arg: } \beta\\ \text{prn: \&}\end{bmatrix}\ \begin{bmatrix}\text{noun: } \alpha\\ \text{fnc: V\_}n\\ \text{prn: \&}\end{bmatrix}$$

Agreement conditions as in 2.5.3.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_3}\\ \text{cat:}\\ \text{sem: } \textit{that}\\ \text{arg:}\\ \text{fnc: (believe 28)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: \&}\end{bmatrix}\ \begin{bmatrix}\text{sur: Mary}\\ \text{noun: [person z]}\\ \text{cat: snp}\\ \text{sem: nm f}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\ \begin{bmatrix}\text{sur:}\\ \text{verb: v\_3}\\ \text{cat:}\\ \text{sem: } \textit{that}\\ \text{arg: [person z]}\\ \text{fnc: (believe 28)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: \&}\end{bmatrix}\ \begin{bmatrix}\text{sur: mary}\\ \text{noun: [person z]}\\ \text{cat: snp}\\ \text{sem: nm f}\\ \text{fnc: v\_3}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: \&}\end{bmatrix}$$

Cross-copying between *that* and *mary* provides the [person z] value to the first arg slot of *that* and the v_3 value of *that* to the fnc slot of *mary*. Parallel to being in the middle of the initial (=final) clause Who(m) . . . Mary loves there is the alternative of being in another iteration, e.g. that Mary claims that..., represented by applying $\mathsf{PRD}^{\mathsf{obj}} \times \mathsf{SBJ}$ in parallel to $\mathsf{PRD}^{\&} \times \mathsf{SBJ}$.

The two possibilities are mutually exclusive. Which of them survives is decided by the next word love not taking a clausal object:

5.5.12 Absorbing *loves* into *that* with $\mathbf{PRD}^{\&} \cup \mathbf{PRD}$ (line 9a)

$\mathbf{PRD}^{\&} \cup \mathbf{PRD}$ (h21)

pattern level

$$\begin{bmatrix} \text{verb: V\_}n \\ \text{sem: } \gamma \\ \text{arg } \alpha \\ \text{fnc: } (\beta \text{ K-1}) \\ \text{prn: \&} \end{bmatrix} \begin{bmatrix} \text{verb: } \beta \\ \text{cat: NP}' \text{ X v} \\ \text{sem: Y} \\ \text{arg:} \\ \text{prn:} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{verb: } \beta \\ \text{cat: \#NP}' \text{ X v} \\ \text{sem: Y} \\ \text{arg: } \alpha \\ \text{fnc: } (\beta \text{ K-1}) \\ \text{prn: \&} \end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: v\_3} \\ \text{cat:} \\ \text{sem: } \textit{that} \\ \text{arg: [person z]} \\ \text{fnc: (believe 28)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: \&} \end{bmatrix} \begin{bmatrix} \text{sur: loves} \\ \text{verb: love} \\ \text{cat: ns3}' \text{ a}' \text{ v} \\ \text{sem: ind pres} \\ \text{arg:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:} \end{bmatrix} \begin{bmatrix} \text{sur:} \\ \text{verb: love} \\ \text{cat: \#ns3}' \text{ a}'\text{v} \\ \text{sem: } \textit{that} \text{ ind pres} \\ \text{arg: [person z]} \\ \text{fnc: (believe 28)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: \&} \end{bmatrix}$$

To complete the compensation of the suspension 5.5.4 it remains to explicitly code the relation between Who(m) and loves (5.5.3, line 9b):

5.5.13 Cross-cop. betw. initial *Who(m)* and final *loves* (line 9b)

$\mathbf{WH} \times \mathbf{PRD}^{\&}$ (h10)

pattern level

$$\begin{bmatrix} \text{noun: WH} \\ \text{cat: obq} \\ \text{fnc:} \\ \text{prn: \&} \end{bmatrix} \begin{bmatrix} \text{verb: } \alpha \\ \text{cat: \#X NP v} \\ \text{arg: Y} \\ \text{prn: \&} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{noun: WH} \\ \text{cat: obq} \\ \text{fnc: } \alpha \\ \text{prn: \&} \end{bmatrix} \begin{bmatrix} \text{verb: } \alpha \\ \text{cat: \#X \#NP vi} \\ \text{arg: Y WH} \\ \text{prn: \&} \end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur: Who(m)} \\ \text{noun: wh\_1} \\ \text{cat: obq} \\ \text{sem: } \textit{who(m)} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: \&} \end{bmatrix} \begin{bmatrix} \text{sur:} \\ \text{verb: love} \\ \text{cat: \#ns3}' \text{ a}' \text{ v} \\ \text{sem: ind pres} \\ \text{arg: [person z]} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: \&} \end{bmatrix} \begin{bmatrix} \text{sur:} \\ \text{noun: wh\_1} \\ \text{cat: obq} \\ \text{sem: } \textit{who(m)} \\ \text{fnc: love} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: \&} \end{bmatrix} \begin{bmatrix} \text{sur:} \\ \text{verb: love} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ vi} \\ \text{sem: ind pres} \\ \text{arg: [person z] wh\_1} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: \&} \end{bmatrix}$$

Being a suspension compensation, the operation is exceptional in that the input to the second input pattern is not provided lexically by automatic word form

recognition, but by the now front, as indicated by the non-empty prn slot. The operation has also been tried in lines 3 and 6 in 5.5.3, but the branch (5.5.1) was terminated by subsequent input (-global ambiguity, FoCL 11.3.6):

The isolated linguistic example uses S∪IP to add the interpunctuation. Because WH∼AUX (5.5.4) changed v to vi, the interpunctuation sign must be **?**.

5.5.14 ABSORBING **?** INTO *say* WITH S∪IP (line 10)

S∪IP (h18)

pattern level

verb: β	verb: V_n		verb: β
cat: #X′ VT	cat: VT′ SM	⇒	cat: #X′ SM
prn: K			prn: K

Agreement conditions as in 2.1.4.

⇑ ⇓

content level

sur:	sur: **?**	sur:
verb: say	verb: v_3	verb: say
cat: #ns3′ #a′ vi	cat: vi′ interrog	cat: #ns3′ #a′ interrog
sem: pres	sem:	sem: pres
arg: [person x] (believe 28)	arg:	arg: [person x] (believe 28)
mdr:	mdr:	mdr:
nc:	nc:	nc:
pc:	pc:	pc:
prn: 27	prn:	prn: 27

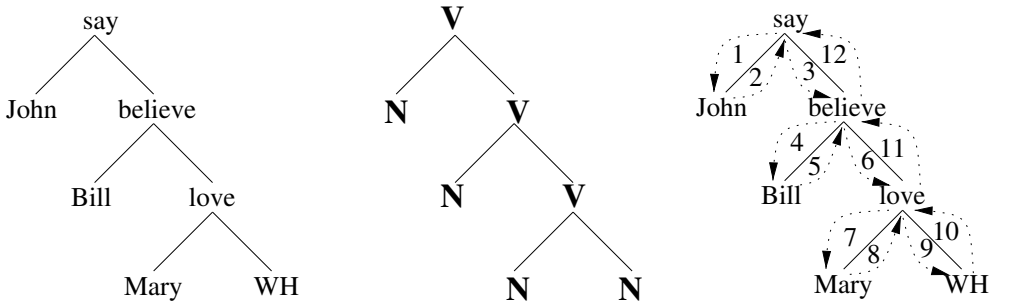
In the output, the sur value **?** is deleted and the final cat value is interrog. The hear mode derivation of a long distance dependency is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

5.5.15 **<to-do 4>**

GRAPH ANALYSIS UNDERLYING PRODUCTION OF 5.5.1

(i) SRG (semantic relations graph) *(ii) signature* *(iii) NAG (numbered arcs graph)*



(iv) surface realization

3	6	9	10	11	12	1	2	3	4	5	6	7	8	11	12
		Whom			does	John	say	that	Bill	believes	that	Mary	loves		**?**
V\V	V\V	V\N	N\V	V\V	V\V	V/N	N/V	V\V	V/N	N/V	V\V	V/N	N/V	V\V	V\V

Grammatically, cycles like the arcs 3, 4, 5 or 6, 7, 8 may be repeated without limit, whereby the content and the arc numbers of each iteration are new. The cycles represented by the arcs 9-10 and 7-8, in contrast, occur only once, the first as the end of the beginning, the second as the beginning of the end of the unbounded repetition.

Word form production is summarized as the following list of speak mode operations:

5.5.16 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 3:	V↘V	from *say* to *believe*		5.5.17
arc 6:	V↘V&	from *believe* to *love*		5.5.18
arc 9:	V↘WH	from *love* to *wh*	Who(m)	5.5.19
arc 10:	WH↖V	from *wh* to *love*		5.5.20
arc 11:	V&↖V	from *love* to *believe*		5.5.21
arc 12:	V↖V	from *believe* to *say*	does	5.5.22
arc 1:	V↙N	from *say* to *john*	John	5.5.23
arc 2:	N↗V	from *john* to *say*	say	5.5.24
arc 3:	V↘V	from *say* to *believe*	that	5.5.25
arc 4:	V↙N	from *believe* to *bill*	Bill	5.5.26
arc 5:	N↗V	from *bill* to *believe*	believes	5.5.27
arc 6:	V↘V&	from *believe* to *love*	that	5.5.28
arc 7:	V↙N	from *love* to *mary*	Mary	5.5.29
arc 8:	N↗V	from *mary* to *love*	loves	5.5.30
arc 11:	V&↖V	from *love* to *believe*		5.5.31
arc 12:	V↖V	from *believe* to *say*	**?**	5.5.32

As shown by the NAG in 5.5.15, the navigation for realizing the first word Who(m) must travel from the top verb *say* all the way down to the last object clause–which has the special prn value & (5.5.4).

The complete sequence of explicit navigation operations begins with V↘V:

5.5.17 **<to-do 6>**

NAVIGATING WITH V↘V FROM *say* TO *believe* (arc 3)

V↘V (s7)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: X } (\beta \text{ K+1}) \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{sem: } \textit{that} \\ \text{fnc: } (\alpha \text{ K}) \\ \text{prn: K+1} \end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: say} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ interrog} \\ \text{sem: pres} \\ \text{arg: [person x] (believe 28)} \\ \ldots \\ \text{prn: 27} \end{bmatrix} \qquad \begin{bmatrix} \text{sur:} \\ \text{verb: believe} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{that} \text{ pres} \\ \text{arg: [person y] (love \&)} \\ \text{fnc: (say 27)} \\ \ldots \\ \text{prn: 28} \end{bmatrix}$$

In an unbounded repetition with an initial *wh*-interrogative and n object clauses, there are n-2 extrapropositional V\V applications like 5.5.17, followed by V\V$^{\&}$, followed by intrapropositional V\WH. Because the present example has only three object clauses (i.e. the minimum for showing a repetition), V\V applies only once, i.e. it stops the iteration and the final object clause is entered directly with V\V$^{\&}$:

5.5.18 NAVIGATING WITH V\V$^{\&}$ FROM *believe* TO *love* (arc 6)

V\V$^{\&}$ (s38)

pattern level

verb: α	sur: lexverb($\hat{\gamma}$)
arg: X (β &)	verb: β
prn: K	fnc: (α K)
	prn: &

$\Rightarrow$

content level

sur:	sur:
verb: believe	verb: love
cat: #ns3′ #a′ v	cat: #ns3′ #a′ v
sem: *that* pres	sem: *that* pres
arg: [person y] (love &)	arg: [person z] wh_1
fnc: (say 27)	fnc: (believe 28)
mdr:	mdr:
nc:	nc:
pc:	pc:
prn: 28	prn: &

The second arg value wh of the goal proplet *love* serves as the continuation value for the speak mode operation V\WH (which performs a similar function as V\N in 2.3.10).

5.5.19 NAVIGATING WITH V\WH FROM *love* TO *wh* (arc 9)

V\WH (s31)

pattern level

verb: α	sur: lexnoun($\hat{\gamma}$)
sem: *that* X	noun: WH_*n*
arg: X WH_*n*	fnc: α
prn: &	prn: &

$\Rightarrow$ #-mark WH_*n* in the proplet α.

content level

sur:	sur: Who(m)
verb: love	noun: wh_1
cat: #ns3′ #a′ v	cat: obq
sem: *that* pres	sem:
arg: [person z] wh_1	fnc: love
fnc: (believe 28)	mdr:
mdr:	nc:
nc:	pc:
pc:	prn: &
prn: &	

Lexnoun uses the & marker of the prn value, the core value wh, and the cat value obq to realize the surface Who(m).

The next word to be realized is does. For this the navigation has to return empty to the top verb *say* to retrieve the initial sem value *do*. The first step on the route back is from *wh* to *love* with the operation WH↖V via arc 10:

5.5.20 Navigating with WH↖V from *wh* back to *love* (arc 10)

WH↖V& (s32)

pattern level

$$\begin{bmatrix} \text{noun: WH\_}n \\ \text{fnc: } \alpha \\ \text{prn: \&} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{verb: } \alpha \\ \text{sem: } \textit{that}\ \text{X} \\ \text{arg: \{ X \#WH\_}n\text{\}} \\ \text{prn: \&} \end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{noun: wh\_1} \\ \text{cat: obq} \\ \text{sem:} \\ \text{fnc: love} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: \&} \end{bmatrix} \qquad \begin{bmatrix} \text{sur:} \\ \text{verb: love} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{that}\ \text{pres} \\ \text{arg: [person z] \#wh\_1} \\ \text{fnc: (believe 28)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: \&} \end{bmatrix}$$

The next step on the empty return to the top verb *say* is from *love* to *believe* via arc 11, based on V&↖V (2.6.15).

5.5.21 Navigating with V&↖V from *love* back to *believe* (arc 11)

V&↖V (s34)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{sem: } \textit{that}\ \text{Z} \\ \text{fnc: } (\beta\ \text{K}) \\ \text{prn: \&} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{arg: Y } (\alpha\ \&) \\ \text{prn: K} \end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: love} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{that}\ \text{pres} \\ \text{arg: [person z] \#wh\_1} \\ \text{fnc: (believe 28)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: \&} \end{bmatrix} \qquad \begin{bmatrix} \text{sur:} \\ \text{verb: believe} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{that}\ \text{pres} \\ \text{arg: [person y] (love \&)} \\ \text{fnc: (say 27)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 28} \end{bmatrix}$$

Lexverb realizes the surface believes from the core, the initial cat, and the second sem value; the preceding surfaces that and Bill were already realized on the way down from the goal proplets of arcs 3 and 4.

Arc 12 is traversed with another application of V↖V. The lexicalization rule lexverb in the sur slot of the goal pattern realizes the surface does from the cat value #ns3′ and the sem values *do* ind pres of the goal proplet *say*.

5.5.22 NAVIGATING WITH V↖V FROM *believe* BACK TO *say* (arc 12)

V↖V (s8)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{sem: } \textit{that}\ \text{Z} \\ \text{fnc: } (\beta\ \underline{\text{K}}) \\ \text{prn: \&} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{arg: Y } (\alpha\ \text{L}) \\ \text{prn: K} \end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: believe} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{that}\ \text{ind pres} \\ \text{arg: [person y] (love \&)} \\ \text{fnc: (say 27)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 28} \end{bmatrix} \qquad \begin{bmatrix} \text{sur: does} \\ \text{verb: say} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ interrog} \\ \text{sem: } \textit{do}\ \text{ind pres} \\ \text{arg: [person x] (believe 28)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 27} \end{bmatrix}$$

The dotted underline (1.6.5, 3) of [fnc: (β K)] allows matching constants with (e.g. 2.6.15, 5.5.31, 5.5.32) or without (e.g. 5.5.21, 5.5.22) a #-marking.

Using the operations for clausal object constructions (Sect. 2.6), the next navigation steps follow arcs 1–8 through the NAG (5.5.15), realizing remaining John say that Bill believes that Mary loves. The first step is an application of standard V↙N:

5.5.23 NAVIGATING WITH V↙N FROM *say* TO *john* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: say} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ interrog} \\ \text{sem: } \textit{do}\ \text{pres} \\ \text{arg: [person x] (believe 28)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 27} \end{bmatrix} \qquad \begin{bmatrix} \text{sur: John} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: say} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 27} \end{bmatrix}$$

Using the marker in the sur slot of a name, here john, lexnoun realizes the surface John, temporarily covering the name marker until the name surface is passed to the agent's interface component for word form realization, revealing the name marker again.

Next, the navigation returns to the top verb *say* using the operation N↗V.

5.5.24 NAVIGATING WITH N↗V FROM *john* BACK TO *say* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: john} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: say} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 27}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: say} \\ \text{verb: say} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ interrog} \\ \text{sem: } \textit{do} \text{ pres} \\ \text{arg: \#[person x] (believe 28)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 27}\end{bmatrix}$$

Lexverb uses the core value say and the sem value *do* for realizing the surface in the goal proplet. The result of the instruction shows up in the goal proplet of 5.5.25.

The traversal of arc 3 accesses the verb of the first object sentence with V↘V:

5.5.25 NAVIGATING WITH V↘V FROM *say* TO *believe* (arc 3)

V↘V (s7)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: X } (\beta\ \text{K+1}) \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{sem: } \textit{that}\ \text{Z} \\ \text{fnc: } (\alpha\ \text{K}) \\ \text{prn: K+1}\end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: say} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ interrog} \\ \text{sem: } \textit{do} \text{ pres} \\ \text{arg: \#[person x] (believe 28)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 27}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: that} \\ \text{verb: believe} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{that} \text{ pres} \\ \text{arg: [person y] (love \&)} \\ \text{fnc: \#(say 27)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 28}\end{bmatrix}$$

Lexverb uses the initial sem value of the goal proplet *believe* to realize the subordinating conjunction that (function word precipitation; see 5.5.9 for the corresponding function word absorption in the hear mode).

The next navigation step resembles the usual beginning of a declarative sentence: by going from the verb to the first argument, V↙N realizes the subject, here Bill.

5.5.26 NAVIGATING WITH $\mathbf{V}\swarrow\mathbf{N}$ FROM *believe* TO *bill* (arc 4)

$\mathbf{V}\swarrow\mathbf{N}$ (s1)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: believe} \\ \text{cat: \#ns3}'\ \text{\#a}'\ \text{v} \\ \text{sem: } \textit{that}\ \text{pres} \\ \text{arg: [person y] (love \&)} \\ \text{fnc: \#(say 27)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 28}\end{bmatrix} \quad \begin{bmatrix}\text{sur: Bill} \\ \text{noun: [person y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: believe} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 28}\end{bmatrix}$$

The result of the instruction shows up in the goal proplet of 5.5.27

The object sentence continues like a declarative sentence: by returning from the subject to the predicate, $\mathsf{N}\nearrow\mathsf{V}$ realizes the finite verb.

5.5.27 NAVIGATING WITH $\mathbf{N}\nearrow\mathbf{V}$ FROM *bill* BACK TO *believe* (arc 5)

$\mathbf{N}\nearrow\mathbf{V}$ (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: bill} \\ \text{noun: [person y]} \\ \text{cat: snp} \\ \text{sem: nm m} \\ \text{fnc: believe} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 28}\end{bmatrix} \quad \begin{bmatrix}\text{sur: believes} \\ \text{verb: believe} \\ \text{cat: \#ns3}'\ \text{\#a}'\ \text{v} \\ \text{sem: } \textit{that}\ \text{pres} \\ \text{arg: \#[person y] (love \&)} \\ \text{fnc: \#(say 27)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 28}\end{bmatrix}$$

The second arg slot of the verb proplet *believe* provides the value for continuing to the grammatical object, which happens to be another object clause, represented by the address of its predicate, i.e. (love &). The &-marking of its prn value, provided by the hear mode derivation (5.5.4, 5.5.11), marks *love* as representing (i) the final clause of the repeating object clause construction and (ii) as the functor taking the initial who(m) as its grammatical object. The result of the instruction shows up in the goal proplet of 5.5.28.

The first step of entering the final subclause (re)uses (5.5.18) the operation $\mathsf{V}\searrow\mathsf{V}^{\&}$:

5.5.28 NAVIGATING WITH V\↘V& FROM *believe* TO *love* (arc 6)

V\↘V& (s33)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: X } (\beta\ \&) \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\gamma}) \\ \text{verb: } \beta \\ \text{fnc: } (\alpha\ \text{K}) \\ \text{prn: \&}\end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: believe} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{that} \text{ pres} \\ \text{arg: \#[person y] (love \&)} \\ \text{fnc: \#(say 27)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 28}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: that} \\ \text{verb: love} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{that} \text{ pres} \\ \text{arg: [person z] \#wh\_1} \\ \text{fnc: \#(believe 28)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: \&}\end{bmatrix}$$

The second arg value wh in the goal proplet was #-marked by the instruction of V\↘WH in 5.5.19.

At this point, the navigation through the content 5.5.1 has realized Who(m) does John say that Bill believes that. The following two navigation steps resemble the application of V↙N in 5.5.26 and of N↗V in 5.5.27 in that they are like the beginning of a declarative sentence. The fact that they apply in an object clause, and moreover in the final clause of an object clause repetition, is not noticed by these operations:

5.5.29 NAVIGATING WITH **V↙N** FROM *love* TO *[person z]* (arc 7)

V↙N (s1)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: love} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{that} \text{ pres} \\ \text{arg: [person z] \#wh\_1} \\ \text{fnc: \#(believe 28)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: \&}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: Mary} \\ \text{noun: [person z]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: love} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: \&}\end{bmatrix}$$

Using the marker in the sur slot of a name proplet, here mary, lexnoun realizes the surface Mary, temporarily covering the name marker until the name surface is passed to the agent's interface component for word form realization. The result of the instruction shows up in the arg slot of the goal proplet of 5.5.30.

5.5.30 NAVIGATING WITH **N↗V** FROM *mary* BACK TO *love* (arc 8)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\text{ X} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur: mary} \\ \text{noun: [person z]} \\ \text{cat: snp} \\ \text{sem: nm f} \\ \text{fnc: love} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: \&}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: loves} \\ \text{verb: love} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{that} \text{ pres} \\ \text{arg: \#[person z] \#wh\_1} \\ \text{fnc: \#(believe 28)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: \&}\end{bmatrix}$$

With the second arg value wh of *love* already #-marked (5.5.19) there is no other option than taking the short route via arcs 11 and 12 back to the top verb to realize the question mark and end up in a position suitable for a possible navigation to a next proposition (1.4.5). These steps are performed by two consecutive applications of V&↖V:

5.5.31 NAVIGATING WITH V&↖V FROM *love* TO *believe* (arc 11)

V&↖V (s34)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{sem: } \textit{that} \text{ Z} \\ \text{fnc: } (\beta \text{ K}) \\ \text{prn: \&}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{arg: Y } (\alpha \text{ \&}) \\ \text{prn: K}\end{bmatrix}$$

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: love} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{that} \text{ pres} \\ \text{arg: \#[person z] \#wh\_1} \\ \text{fnc: \#(believe 28)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: \&}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{verb: believe} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{that} \text{ pres} \\ \text{arg: \#[person y] (love \&)} \\ \text{fnc: \#(say 27)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 28}\end{bmatrix}$$

Similar to 5.5.21 and 5.5.22, the different prn ????variables L and K match the values & and 28 in the current as well as the values 28 and 27 in the following application. In all four V↖V applications, the relation coded by the fnc value of the input and the verb value of the output is sufficient for proper matching, i.e. it doesn't rely or insist on consecutive prn values *à la* K and K+1.

5.5.32 NAVIGATING WITH V↖V FROM *believe* TO *say* (arc 12)

V↖V (s8)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{sem: } \textit{that}\ \text{Z} \\ \text{fnc: } (\beta\ \text{K}) \\ \text{prn: L} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{arg: Y } (\alpha\ \text{L}) \\ \text{prn: K} \end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: believe} \\ \text{cat: \#ns3}' \ \text{\#a}' \ \text{v} \\ \text{sem: } \textit{that}\ \text{pres} \\ \text{arg: \#[person y] (love \&)} \\ \text{fnc: \#(say 27)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 28} \end{bmatrix} \qquad \begin{bmatrix} \text{sur: ?} \\ \text{verb: say} \\ \text{cat: \#ns3}' \ \text{\#a}' \ \text{interrog} \\ \text{sem: } \textit{do}\ \text{pres} \\ \text{arg: \#[person x] (believe 28)} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 27} \end{bmatrix}$$

Lexverb uses the cat value interrog of *say* to realize the question mark.

Extending DBS.22 to an example class with repeating object clauses required the three hear mode operations WH∼DO (h26), AUX×SBJ (h26), and PRD×PRD$^{\&}$(h12), and the three speak mode operations V↘WH (s31), WH↖V (s32), and V↘V$^{\&}$ (s38). The hear mode derivation used 11 operation applications and the speak mode used 17.

5.5.33 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

	1		2		3		4		5		6
Who(m)	∼	does	×	John	∪	say	×	that	×	Bill	∪

	7		8		9a	9b		10	
believes	×	that	×	Mary	∪	×	loves	∪	**?**

speak mode:

3	6	9		10	11	12		1	
V↘V	V↘V$^{\&}$	V↘WH	Who(m)	WH↖V	V↖V	V↖V	does	V↙/N	John

2	3	4	5		6		7	
N↖V	say	V↘V	that	V↙/N	Bill	N↗V	believes	V↘V$^{\&}$	that	V↙/N	Mary

8	11	12	10
N↗V	loves	V↖V	V↖V	**?**

Unlike the gapping constructions, the arc numbering of the NAG is not breadth-first, but depth-first. There are four multiple traversals, namely 3, 6, 11, and 12.

5.6 DBS.24: Repeating Adnominal Clauses

A repeating object clause interrogative (Sect. 5.5) and repeating adnominal clauses are alike in that they are (i) extrapropositional and (ii) iterate next-lower clauses:

(i) Repeating object clause interrogative

Who(m) did John say that Bill believes . . . that Mary loves?

(ii) Repeating adnominal clause

Mary saw the man who loves the woman . . . who fed Fido.

They differ in that (a) has a long distance relation, which is absent in (b) (including extraposition[27]). Also, each adnominal clause has a gap, e.g. the conjunction who (subject gap) or who(m) (object gap), whereas repeating object clause constructions have only one gap at the end which is filled by a single oblique interrogative pronoun in initial position.

Consider a surface with two iterating adnominal clauses and its content:

5.6.1 **<to-do 1>**

Mary saw the man who loves the woman who fed Fido.

sur: mary	sur:	sur:	sur:	sur:
noun: [person x]	verb: see	noun: man	verb: love	noun: woman
cat: snp	cat: #n′ #a′ decl	cat: snp	cat: #ns3′ #a′ v	cat: snp
sem: nm f	sem: ind past	sem: def sg	sem: *who* pres	sem: def sg
fnc: see	arg: [person x] man	fnc: see	arg: ∅ woman	fnc: love
mdr:	mdr:	mdr: (love 30)	mdd: (man 29)	mdr: (feed 31)
prn: 29	prn: 29	prn: 29	prn: 30	prn: 30

sur:	sur: fido
verb: feed	noun: [dog y]
cat: #n′ #a v	cat: snp
sem: *who* ind past	sem: nm
arg: ∅ [dog y]	fnc: feed
mdd: (woman 30)	mdr:
prn: 31	prn: 31

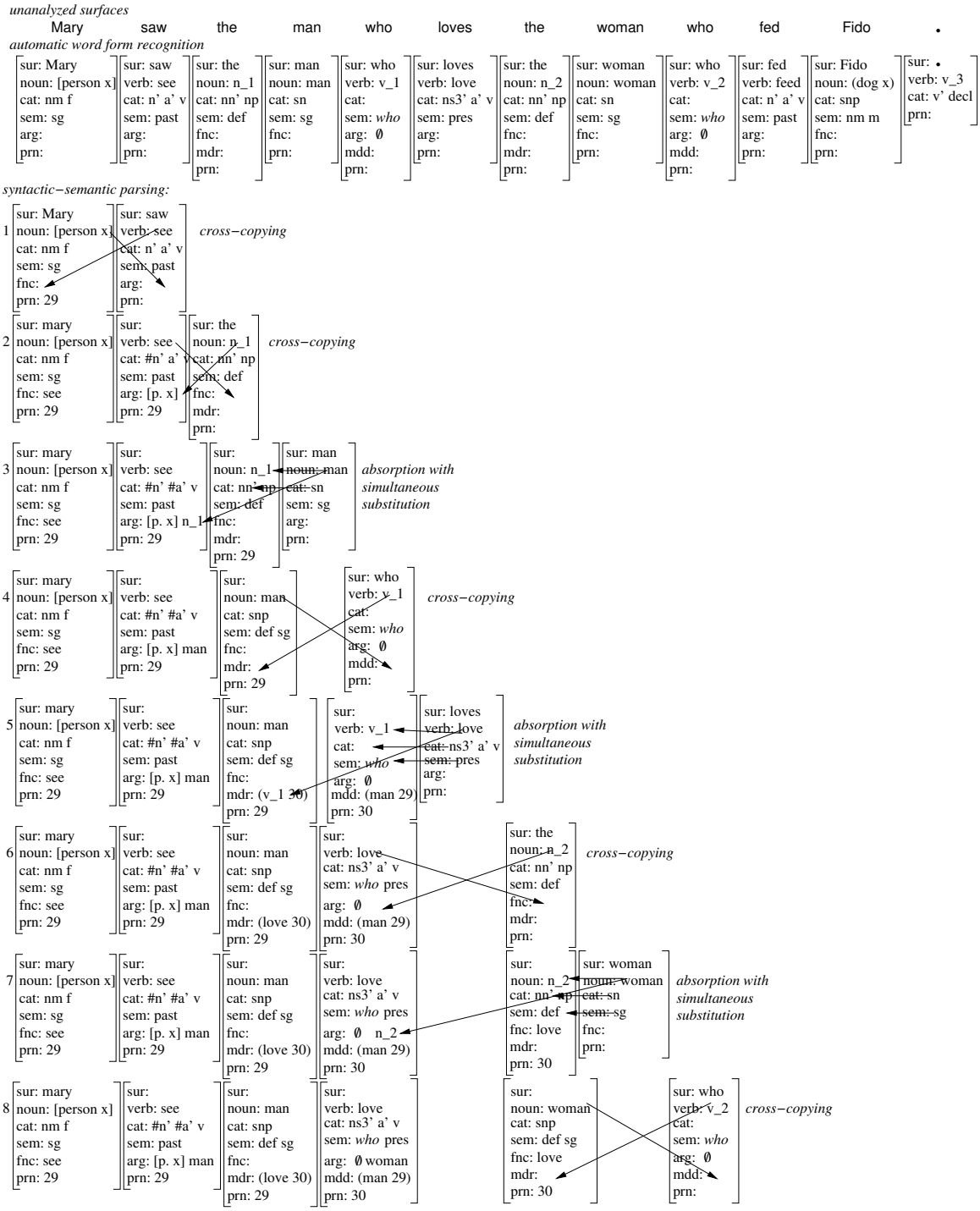
Similar to the examples with a single adnominal clause in Sects. 3.3 (subject gap) and 3.4 (object gap), the extrapropositional mdr|mdd relation between man and (who) loves... is coded by the features [mdr: (love 30)] in the *man* proplet and [mdd: (man 29)] in the *love* proplet, and similarly between the *woman* and the *feed* proplet. The two occurrences of the subordinating adnominal conjunction who (aka relative pronoun) have absorbed the predicate of their subclause and show a gap, represented as ∅, in their first arg slot (subject). The implicit filler is shown in the mdd slot directly underneath.

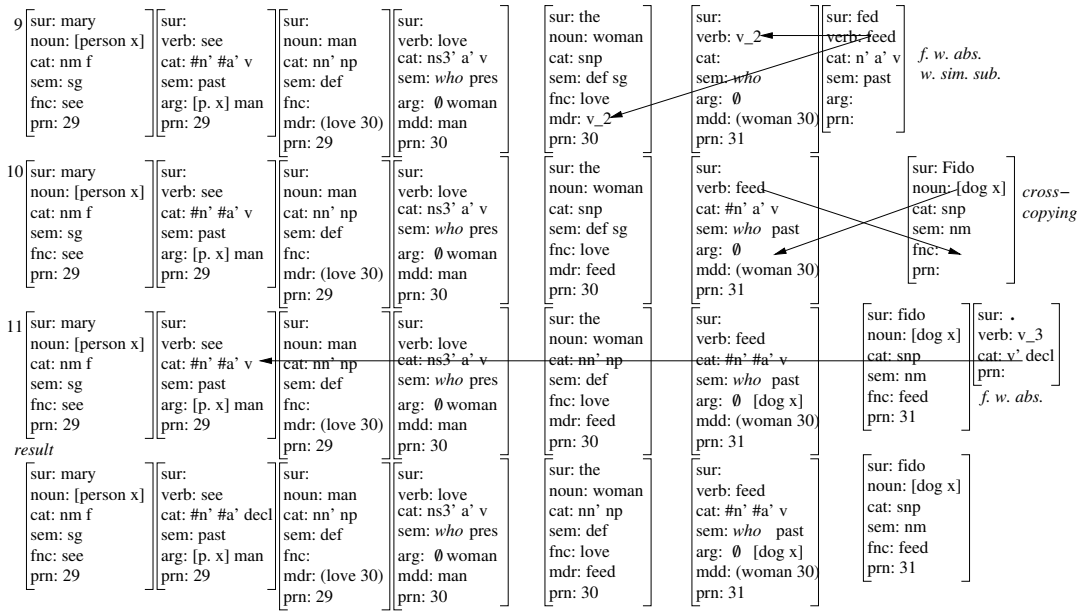
As a first conceptual orientation consider the derivation graph:

[27] For example, in Someone left a message who we don't know, the extraposed adnominal modifier who we don't know of Someone follows directly at the end of the main clause.

5.6.2 <to-do 2>

GRAPHICAL HEAR MODE DERIVATION OF THE CONTENT 5.6.1





The initial sentence Mary saw the man is completed in line 3 (except for the interpunctuation). The modified noun man in line 4 is is extended with the beginning of a clausal adnominal by adding the subordinating connective who, serving as the gap. In line 5, the two occurrences of v_1 (i.e. the core value of who) are replaced by the core value of love (absorption of a content word into a function word using simultaneous substitution). Lines 6 and 7 complete the clausal adnominal, resulting in Mary saw the man who loves the woman. In line 8, the addition of a second who extends woman with the beginning of another clausal adnominal with a subject gap, namely who fed Fido.

The repeated addition of adnominal subclauses has no grammatical limit. For illustration, however, a minimal example with only one iteration, i.e. 5.6.1, may suffice. Also, with each additional iteration, examples get increasingly contrived pragmatically, regardless of their syntactic-semantic well-formedness.

The first input surface Mary is interpreted as a proplet by automatic word form recognition and stored at the now front. The second surface, i.e. saw, is interpreted as well and serves as the trigger proplet. It activates an operation, here familiar SBJ×PRD (h1), by matching its second input pattern. The activated operation looks at the now front for a proplet matching its first input pattern.

The complete sequence of explicit hear mode operation applications begins with SBJ×PRD:

5.6.3 **<to-do 3>**

CROSS-COPYING *mary* AND *see* WITH SBJ×PRD (line 1)

SBJ×PRD (h1)

pattern level

noun: α	verb: β		noun: α	verb: β
cat: NP	cat: NP′ X v	⇒	cat: NP	cat: #NP′ X v
fnc:	arg:		fnc: β	arg: α
prn:K	prn:		prn: K	prn: K

Agreement conditions as in 2.1.2.

⇑ ⇓

content level

sur: Mary	sur: saw		sur: mary	sur:
noun: [person x]	verb: see		noun: [person x]	verb: see
cat: snp	cat: n′ a′ v		cat: snp	cat: #n′ a′ v
sem: nm f	sem: ind past		sem: nm f	sem: ind past
fnc:	arg:		fnc: see	arg: [person x]
mdr:	mdr:		mdr:	mdr:
nc:	nc:		nc:	nc:
pc:	pc:		pc:	pc:
prn: 29	prn:		prn: 29	prn: 29

Next, the automatic word recognition of the agent's interface component takes the raw data of the third surface the as input and renders a determiner proplet as output. Grammatically, the functions here as the beginning of a phrasal object. As the trigger proplet, it activates the operation PRD×OBJ by matching its second input pattern. The activated operation looks at the now front for a proplet matching its first input pattern. Finding *see*, it applies as follows:

5.6.4 CROSS-COPYING *see* AND *the* WITH PRD×OBJ (line 2)

PRD×OBJ (h28)

pattern level

verb: β	noun: α		verb: β	noun: α
cat: #X′ N′ Y v	cat: CN′ NP	⇒	cat: #X′ #N′ Y v	cat: CN′ NP
arg: Z	fnc:		arg: Z α	fnc: β
prn: K	prn:		prn: K	prn: K

Agreement conditions as in 2.3.4.

⇑ ⇓

content level

sur:	sur: the		sur:	sur:
verb: see	noun: n_1		verb: see	noun: n_1
cat: #n′ a′ v	cat: nn′ np		cat: #n′ #a′ v	cat: nn′ np
sem: ind past	sem: def		sem: ind past	sem: def
arg: [person x]	fnc:		arg: [person x] n_1	fnc: see
mdr:	mdr:		mdr:	mdr:
nc:	nc:		nc:	nc:
pc:	pc:		pc:	pc:
prn: 29	prn:		prn: 29	prn: 29

The fourth surface man is interpreted by automatic word form recognition as a proplet which matches the second input pattern of DET∪CN:

5.6.5 ABSORBING *man* INTO *the* WITH DET∪CN (line 3)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\text{ NP}\\ \text{sem: Y}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{sem: Y Z}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.2.4.

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: n\_1}\\ \text{cat: nn}'\text{ np}\\ \text{sem: def}\\ \text{fnc: see}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 29}\end{bmatrix} \Uparrow \begin{bmatrix}\text{sur: man}\\ \text{noun: man}\\ \text{cat: sn}\\ \text{sem: sg}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \qquad \Downarrow \begin{bmatrix}\text{sur:}\\ \text{noun: man}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc: see}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 29}\end{bmatrix}$$

The operation fuses the *man* and the determiner proplets into one (function word absorption), and stores the result at the now front.

At this point, the hear mode derivation has interpreted the proposition Mary saw the man with the prn value 29, consisting of three order-free proplets. Next automatic word form recognition provides the proplet *who*, which matches the second input pattern of the operation CN×sub^{who} (3.3.4):

5.6.6 CROSS-COPYING *man* AND *who* WITH **CN×PRD**^{which} (line 4)

CN×PRD^{which} (h12)

pattern level

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{mdr:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: }\beta\\ \text{arg: }\emptyset\\ \text{mdd:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{mdr: (V\_n K+1)}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: }\beta\\ \text{arg: }\emptyset\\ \text{mdd: }(\alpha\text{ K})\\ \text{prn: K+1}\end{bmatrix}$$

$\beta \in$ {who, which}.

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: man}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc: see}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 29}\end{bmatrix} \Uparrow \begin{bmatrix}\text{sur: who}\\ \text{verb: v\_1}\\ \text{cat:}\\ \text{sem: }who\\ \text{arg: }\emptyset\\ \text{mdd:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \qquad \Downarrow \begin{bmatrix}\text{sur:}\\ \text{noun: man}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc: see}\\ \text{mdr: v\_1}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 29}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: v\_1}\\ \text{cat: \{ns3}'\text{, n}'\text{\}}\\ \text{sem: }who\\ \text{arg: }\emptyset\\ \text{mdd: (man 29)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 30}\end{bmatrix}$$

CN×PRD^{which} increments the prn value of the subordinating conjunction who as the beginning of an adnominal modifier clause. The lexical entry uses the English surface as the first value of the sem attribute to specify the kind of conjunction. The core value v_1 is cross-copied into the mdr slot of *man* and

(man 29) into the mdd slot of *who*. At this point the grammatical role of *who* as possible subject vs. object is still undecided.

The issue is decided by PRD^{who}∪PRD (3.3.5), which absorbs the verb *love* of the first adnominal clause into the subordinating conjunction:

5.6.7 Absorbing *love* into *who* with PRD^{who}∪PRD (line 5)

PRD^{who}∪PRD (h22)

pattern level

verb: V_*n*	verb: β		verb: β
cat:	cat: NP X v		cat: #NP X v
sem: α	sem: Y	⇒	sem: α Y
arg: $\emptyset$	arg:		arg: $\emptyset$
mdd: (γ K-1)	prn:		mdd: (γ K-1)
prn: K			prn: K

$\alpha \in$ {who, which}

⇑ ⇓

content level

sur:	sur: loves	sur:
verb: v_1	verb: love	verb: love
cat: {ns3′, n′}	cat: ns3′ a′ v	cat: #ns3′ a′ v
sem: *who*	sem: pres	sem: *who* pres
arg: $\emptyset$	arg:	arg: $\emptyset$
mdd: (man 29)	mdd:	mdd: (man 29)
nc:	nc:	nc:
pc:	pc:	pc:
prn: 30	prn:	prn: 30

Simultaneous substitution replaces v_1 with love not only in the conjunction (shown), but also in the mdr slot of *man* (not shown, see line 5 of 5.6.2).

The hear mode derivation has now interpreted Mary saw the man who loves. The adnominal clause with the prn value 30 is continued by adding the grammatical object the woman to the transitive verb *love*, beginning with the determiner.

5.6.8 Cross-copying *loves* and *the* with PRD×OBJ (line 6)

PRD×OBJ (h28)

pattern level

verb: β	noun: α		verb: β	noun: α
cat: #X′ NP′ Y v	cat: CN′ NP		cat: #X′ #NP′ Y v	cat: CN′ NP
arg: Z	fnc:	⇒	arg: Z α	fnc: β
prn: K	prn:		prn: K	prn: K

Agreement conditions as in 4.5.4.

⇑ ⇓

content level

sur:	sur: the	sur:	sur:
verb: love	noun: n_2	verb: love	noun: n_2
cat: #ns3′ a′ v	cat: nn′ np	cat: #ns3′ #a′ v	cat: nn′ np
sem: *who* pres	sem: def	sem: *who* pres	sem: def
arg: $\emptyset$	fnc:	arg: $\emptyset$ n_2	fnc: love
mdd: (man 29)	mdr:	mdd: (man 29)	mdr:
nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:
prn: 30	prn:	prn: 30	prn: 30

The valency positions of *love* are shown as [arg: ∅ n_2].

Next, the place-holder variable n_2 is replaced with the constant value woman by simultaneous substitution:

5.6.9 ABSORBING *woman* INTO *the* WITH DET∪CN (line 7)

DET∪CN (h47)

pattern level

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\text{ NP}\\ \text{sem: Y}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{sem: Y Z}\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.2.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: n\_2}\\ \text{cat: nn}'\text{ np}\\ \text{sem: def}\\ \text{fnc: love}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 30}\end{bmatrix}\begin{bmatrix}\text{sur: woman}\\ \text{noun: woman}\\ \text{cat: sn}\\ \text{sem: sg}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\qquad\begin{bmatrix}\text{sur:}\\ \text{noun: woman}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc: love}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 30}\end{bmatrix}$$

With the completion of the first adnominal subclause modifying the grammatical object *man* in the main clause, the grammatical object *woman* may itself be extended with a second adnominal clause (first repetition), beginning with the subordinating conjunction (similar to 5.6.6):

5.6.10 CROSS-COPYING *woman* AND *who* WITH CN×PRD^{which} (line 8)

CN×PRD^{which} (h12)

pattern level

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{mdr:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: }\beta\\ \text{arg: }\emptyset\\ \text{mdd:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{mdr: (V\_n K+1)}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: }\beta\\ \text{arg: }\emptyset\\ \text{mdd: }(\alpha\text{ K})\\ \text{prn: K+1}\end{bmatrix}$$

$\beta \in$ {who, which}.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{noun: woman}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc: see}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 30}\end{bmatrix}\begin{bmatrix}\text{sur: who}\\ \text{verb: v\_2}\\ \text{cat:}\\ \text{sem: }who\\ \text{arg: }\emptyset\\ \text{mdd:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\qquad\begin{bmatrix}\text{sur:}\\ \text{noun: woman}\\ \text{cat: snp}\\ \text{sem: def sg}\\ \text{fnc: see}\\ \text{mdr: (v\_2)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 30}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: v\_2}\\ \text{cat: \{ns3}', \text{n}'\}\\ \text{sem: }who\\ \text{arg: }\emptyset\\ \text{mdd: (woman 30)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 31}\end{bmatrix}$$

In the output, the ∅ marker it switched to subject position. Using the pattern [prn: K+1], the operation has incremented the prn value of the latest subordinating conjunction to 31. At this point, the hear mode derivation has interpreted Mary saw the man who loves the woman who.

The derivation continues intrapropositionally with PRD^{who}∪PRD, which absorbs the verb of the adnominal subclause (similar to 3.3.5 and 5.6.7):

5.6.11 ABSORBING *fed* INTO *who* WITH PRD^{who}∪PRD (line 9)

PRD^{who}∪PRD (h22)

pattern level

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: }\alpha\\ \text{arg: }\emptyset\\ \text{mdd: }(\gamma\text{ K-1})\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP X v}\\ \text{sem: Y}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP X v}\\ \text{sem: }\alpha\text{ Y}\\ \text{arg: }\emptyset\\ \text{mdd: }(\gamma\text{ K-1})\\ \text{prn: K}\end{bmatrix}$$

$\alpha \in$ {who, which}

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: v\_2}\\ \text{cat: \{ns3}',\text{ n}'\}\\ \text{sem: }\textit{who}\\ \text{arg: }\emptyset\\ \text{mdd: (woman 30)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 31}\end{bmatrix}\begin{bmatrix}\text{sur: fed}\\ \text{verb: feed}\\ \text{cat: n}'\text{ a}'\text{ v}\\ \text{sem: ind past}\\ \text{arg:}\\ \text{mdd:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: feed}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: }\textit{who}\text{ ind past}\\ \text{arg: }\emptyset\\ \text{mdd: (woman 30)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 31}\end{bmatrix}$$

At this point, the derivation has interpreted Mary saw the man who loves the woman who fed. The implicit subject of the adnominal subclause is the mdd value (woman 30) directly underneath the feature [arg: ∅] in the output.

To complete the second adnominal subclause, standard PRD×OBJ applies and combines *feed* and *fido*:

5.6.12 CROSS-COPYING *fed* AND *fido* WITH PRD×OBJ (line 10)

PRD×OBJ (h28)

pattern level

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\text{\#X}'}\text{ NP}'\text{ Y v}\\ \text{arg: Z}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\text{ NP}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\text{\#X}'}\text{ \#NP}'\text{ Y v}\\ \text{arg: Z }\alpha\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\text{ NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.3.4.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix}\text{sur:}\\ \text{verb: feed}\\ \text{cat: \#n}'\text{ a}'\text{ v}\\ \text{sem: }\textit{who}\text{ ind past}\\ \text{arg: }\emptyset\\ \text{mdd: (woman 30)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 31}\end{bmatrix}\begin{bmatrix}\text{sur: Fido}\\ \text{noun: [dog y]}\\ \text{cat: snp}\\ \text{sem: nm}\\ \text{fnc:}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\begin{bmatrix}\text{sur:}\\ \text{verb: feed}\\ \text{cat: \#n}'\text{ \#a}'\text{ v}\\ \text{sem: }\textit{who}\text{ ind past}\\ \text{arg: }\emptyset\text{ [dog y]}\\ \text{mdd: (woman 30)}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 31}\end{bmatrix}\begin{bmatrix}\text{sur: fido}\\ \text{noun: [dog y]}\\ \text{cat: snp}\\ \text{sem: nm}\\ \text{fnc: feed}\\ \text{mdr:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: 31}\end{bmatrix}$$

Given that the current adnominal clause is not expanded further by another adnominal clause modifying the object, we could have used an intransitive verb, as in who smiled, instead of transitive who fed Fido.

Because the present hear mode derivation is an isolated linguistic example, it uses S∪IP for interpunctuation:

5.6.13 ABSORBING • INTO *see* WITH S∪IP (line 11)

S∪IP (h18)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ VT} \\ \text{prn: K}\end{bmatrix} \quad \begin{bmatrix}\text{verb: V\_}n \\ \text{cat: VT}' \text{ SM}\end{bmatrix} \quad \Rightarrow \quad \begin{bmatrix}\text{verb: } \beta \\ \text{cat: } \#X' \text{ SM} \\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.4.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: see} \\ \text{cat: } \#n' \ \#a' \text{ v} \\ \text{sem: ind past} \\ \text{arg: [person x] man} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 29}\end{bmatrix} \quad \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: v\_1} \\ \text{cat: v}' \text{ decl} \\ \text{sem:} \\ \text{arg:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur: } \bullet \\ \text{verb: see} \\ \text{cat: } \#n' \ \#a' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x] man} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 29}\end{bmatrix}$$

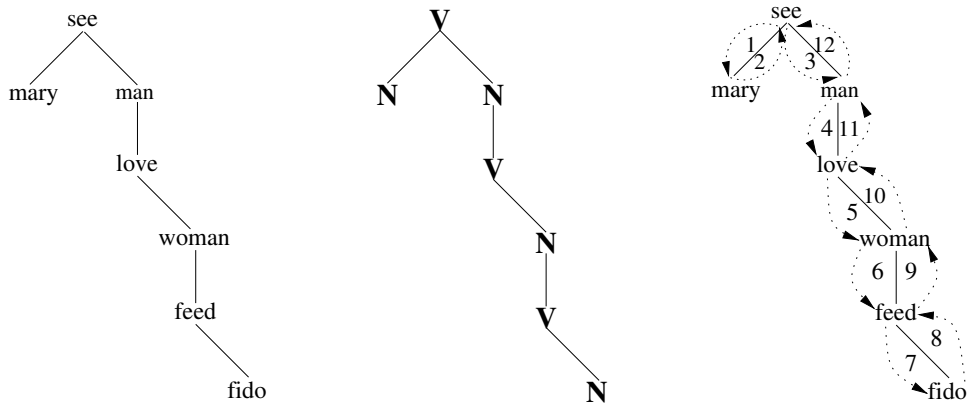
The hear mode derivation of repeating adnominal clauses is now complete.

The DBS analysis of the think-speak mode begins with the graphical analysis of the semantic relations of structure:

5.6.14 **<to-do 4>**

GRAPH ANALYSIS UNDERLYING REPEATING ADNOMINAL CLAUSES

(i) SRG (semantic relations graph) *(ii) signature* *(iii) NAG (numbered arcs graph)*



(iv) surface realization (English, subject gaps)

1	2	3	4	5	6	7	8	9	10	11	12
Mary	saw	the_man	who_loves	the_woman	who_fed	Fido					•
V/N	N/V	V\N	N|V	V\N	N|V	V\N	N\V	V|N	N\V	V|N	N\V

Compared to the clausal_object\predicate relation in 5.5.15, the present example uses a clausal_modifier|noun relation. The love|man relation shows love as a modifier of man, whereby the modified, i.e. the object *man* of *see*, serves as the implicit subject of love, and similarly for the feed|woman relation (NLC 7.3.1). The consecutive traversal numbers in the *(iv) surface realization*) rely on a depth first arc numbering.

Word form production is summarized as follows:

5.6.15 **<to-do 5>**

SEQUENCE OF OPERATION NAMES AND SURFACE REALIZATIONS

arc 1:	V↙N	from *see* to *mary*	Mary	5.6.16
arc 2:	N↗V	from *mary* to *see*	saw	5.6.17
arc 3:	V↘N	from *see* to *man*	the_man	5.6.18
arc 4:	N↓V	from *man* to *love*	who_loves	5.6.19
arc 5:	V↘N	from *love* to *woman*	the_woman	5.6.20
arc 6:	N↓V	from *woman* to *feed*	who_fed	5.6.21
arc 7:	V↘N	from *feed* to *fido*	Fido	5.6.22
arc 8:	N↖V	from *fido* to *feed*		5.6.23
arc 9:	V↑N	from *feed* to *woman*		5.6.24
arc 10:	N↖V	from *woman* to *love*		5.6.25
arc 11:	V↑N	from *love* to *man*		5.6.26
arc 12:	N↖V	from *man* to *see*	.	5.6.27

The complete sequence of explicit navigation operations begins with V↙N:

5.6.16 **<to-do 6>**

NAVIGATING WITH V↙N FROM *see* TO *mary* (arc 1)

V↙N (s1)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: see} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: [person x] man} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 29} \end{bmatrix} \quad \begin{bmatrix} \text{sur: Mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: see} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 29} \end{bmatrix}$$

5.6.17 NAVIGATING WITH N↗V FROM *mary* BACK TO *see* (arc 2)

N↗V (s2)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K}\end{bmatrix}$$

#-mark α in the fnc slot of proplet β.

Z is NIL, or elementary and #-marked.

⇑ ⇓

content level

$$\begin{bmatrix}\text{sur: mary} \\ \text{noun: [person x]} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: see} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 29}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: saw} \\ \text{verb: see} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] man} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 29}\end{bmatrix}$$

5.6.18 NAVIGATING WITH V↘N FROM *see* TO *man* (arc 3)

V↘N (s3)

pattern level

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta\ \text{Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

#-mark β in the arg slot of proplet α.

⇑ ⇓

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: see} \\ \text{cat: \#n}'\ \text{\#a}'\ \text{decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] man} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 29}\end{bmatrix} \qquad \begin{bmatrix}\text{sur: the\_man} \\ \text{noun: man} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#see} \\ \text{mdr: (love 30)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 29}\end{bmatrix}$$

At this point, it is open whether the initial proposition Mary saw the man is completed by an interpunctuation sign or continued with, for example, an adverbial like in the garden, a clausal modifier like when she came home, or an adnominal clause.

The next transition moves from the modified noun *man* to the verb loves with N↓V (3.3.12) and realizes the surface who loves:

5.6.19 NAVIGATING WITH N↓V FROM *man* TO *love* (arc 4)

N↓V (s15)

pattern level

$$\begin{bmatrix}\text{noun: } \alpha \\ \text{mdr: } (\beta\ \text{K+1}) \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{mdd: } (\alpha\ \text{K}) \\ \text{prn: K+1}\end{bmatrix}$$

#-mark β in the mdr slot of proplet α.

⇑ ⇓

content level

sur:	sur: who_loves
noun: man	verb: love
cat: snp	cat: #ns3′ #a′ v
sem: indef sg	sem: *who* pres
fnc: #see	arg: ∅ woman
mdr: (love 30)	mdd: (man 29)
nc:	nc:
pc:	pc:
prn: 29	prn: 30

Lexverb realizes who_loves based the feature [sem: *who* pres], the core value love, the cat value #ns3′, and the initial arg value ∅ of the goal proplet.

The traversal of the first adnominal subclause is completed as follows:

5.6.20 Navigating with V↘N from *love* to *woman* (arc 5)

pattern level

V↘N (s3)

verb: α	sur: lexnoun($\hat{\beta}$)
arg: #X β Y	noun: β
prn: K	fnc: α
	prn: K

⇒ #-mark β in the arg slot of proplet α.

content level

sur:	sur: the_woman
verb: love	noun: woman
cat: #ns3′ #a′ decl	cat: snp
sem: pres	sem: def sg f
arg: ∅ woman	fnc: love
mdr:	mdr: (feed 31)
nc:	nc:
pc:	pc:
prn: 30	prn: 30

The speak mode derivation has now traversed the proplets *mary, see, man, love, woman*, and realized Mary saw the man who loves the woman.

The derivation continues with N↓V, first applied in 5.6.19 and now repeated, to navigate to the proplet *feed*. Lexverb realizes the surface who_fed based on the sem values *who* past, and the core value of *feed*:

5.6.21 Navigating with N↓V from *woman* to *feed* (arc 6)

pattern level

N↓V (s15)

noun: α	sur: lexverb($\hat{\beta}$)
mdr: (β K+1)	verb: β
prn: K	mdd: (α K)
	prn: K+1

⇒ #-mark β in the mdr slot of proplet α.

content level

sur:	sur: who_fed
noun: woman	verb: feed
cat: snp	cat: #n′ #a′ v
sem: indef sg	sem: *who* ind past
fnc: love	arg: ∅ [dog y]
mdr: (feed 31)	mdd: (woman 30)
nc:	nc:
pc:	pc:
prn: 30	prn: 31

The traversal of the second adnominal subclause is completed with an application of intrapropositional V↘N, similar to 5.6.18 and 5.6.20:

5.6.22 NAVIGATING WITH V↘N FROM *feed* TO *fido* (arc 7)

V↘N (s3)

pattern level

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: \#X } \beta \text{ Y} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{prn: } \ddot{\text{K}} \end{bmatrix}$$

#-mark β in the arg slot of proplet α.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur:} \\ \text{verb: feed} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: } \emptyset \text{ [dog y]} \\ \text{mdr: (woman 30)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 31} \end{bmatrix} \quad \begin{bmatrix} \text{sur: Fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: def sg f} \\ \text{fnc: feed} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 31} \end{bmatrix}$$

Using the marker in the sur slot of a name proplet, here fido, lexnoun realizes the surface Fido, momentarily covering the name marker until the name surface has been passed to the agent's interface component for word form realization.

It remains to return to the top predicate *see* to realize the punctuation mark and to reach a location potentially suitable for navigating along a coordination relation to a next proposition (if the nc slot provides an extrapropositional value). This return, which is empty except for the last step, is illustrated graphically in 5.6.14 and performed by standard applications of N↖V (arc 8), V↑N (arc 9), N↖V (arc 10), V↑N (arc 11), and N↖V (arc 12).

5.6.23 NAVIGATING WITH N↖V FROM *fido* BACK TO *feed* (arc 8)

N↖V (s4)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: } \ddot{\alpha} \\ \text{mdr: } \ddot{\text{Z}} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta \text{ Y} \\ \text{prn: K} \end{bmatrix}$$

Z is #-marked or NIL.

$\Uparrow$ $\Downarrow$

content level

$$\begin{bmatrix} \text{sur: fido} \\ \text{noun: [dog y]} \\ \text{cat: snp} \\ \text{sem: def sg} \\ \text{fnc: feed} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 31} \end{bmatrix} \quad \begin{bmatrix} \text{sur:} \\ \text{verb: feed} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: } \emptyset \text{ \#[dog y]} \\ \text{mdr: (woman 30)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 31} \end{bmatrix}$$

5.6.24 NAVIGATING WITH V↑N FROM *feed* BACK TO *woman* (arc 9)

V↑N (s16)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{mdd: } (\alpha\ \text{K}) \\ \text{prn: K+1}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{mdr: } (\beta\ \text{K+1}) \\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: feed} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: } \emptyset \text{ \#[dog y]} \\ \text{mdr: (woman 30)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 31}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{noun: woman} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: love} \\ \text{mdr: \#(feed 31)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 30}\end{bmatrix}$$

5.6.25 NAVIGATING WITH N↖V FROM *woman* BACK TO *love* (arc 10)

N↖V (s4)

pattern level

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{mdr: } \ddot{\text{Z}} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta\text{ Y} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL.

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{noun: woman} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: feed} \\ \text{mdr: \#(love 30)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 30}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{verb: love} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{who} \text{ pres} \\ \text{arg: } \emptyset \text{ \#woman} \\ \text{mdd: (man 29)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 30}\end{bmatrix}$$

5.6.26 NAVIGATING WITH V↑N FROM *love* BACK TO *man* (arc 11)

V↑N (s16)

pattern level

$$\begin{bmatrix}\text{verb: } \beta \\ \text{mdd: } (\alpha\ \text{K}) \\ \text{prn: K+1}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{mdr: } (\beta\ \text{K+1}) \\ \text{prn: K}\end{bmatrix}$$

$$\Uparrow \qquad\qquad \Downarrow$$

content level

$$\begin{bmatrix}\text{sur:} \\ \text{verb: love} \\ \text{cat: \#ns3}' \text{ \#a}' \text{ v} \\ \text{sem: } \textit{who} \text{ pres} \\ \text{arg: } \emptyset \text{ \#woman} \\ \text{mdd: (man 29)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 30}\end{bmatrix} \qquad \begin{bmatrix}\text{sur:} \\ \text{noun: man} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#see} \\ \text{mdr: \#(love 30)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 29}\end{bmatrix}$$

5.6.27 NAVIGATING WITH N↖\V FROM *man* BACK TO *see* (arc 12)

N↖\V (s4)

pattern level

$$\begin{bmatrix} \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{mdr: } \ddot{Z} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta\text{ Y} \\ \text{prn: K} \end{bmatrix}$$

Z is #-marked or NIL.

⇑ ⇓

content level

$$\begin{bmatrix} \text{sur:} \\ \text{noun: man} \\ \text{cat: snp} \\ \text{sem: indef sg} \\ \text{fnc: \#see} \\ \text{mdr: \#(love 30)} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 29} \end{bmatrix} \quad \begin{bmatrix} \text{sur: } \bullet \\ \text{verb: see} \\ \text{cat: \#n}' \text{ \#a}' \text{ decl} \\ \text{sem: ind past} \\ \text{arg: \#[person x] \#man} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn: 29} \end{bmatrix}$$

The goal proplet *see* is recognized by lexverb as the top predicate because its cat slot concludes with a mood marker and its arg slot contains no ∅ value, in contradistinction to the other predicates *love* and *feed*.

Extending DBS.23 to an example class with repeating adnominal clauses did not require the definition of any additional operations. The hear mode derivation used 11 operation applications and the speak mode used 12.

5.6.28 **<to-do 7>**

COMPARING HEAR AND SPEAK MODE SURFACE SEGMENTATION

hear mode:

	1		2		3		4		5		6		7
Mary	×	saw	×	the	×	man	∪	who	×	loves	∪	the	×

	8		9		10		11	
woman	∪	who	×	fed	×	Fido	∪	•

speak mode:

1		2		3		4		5	
V↙N	Mary	N↗V	saw	V↘N	the_man	N↓V	who_loves	V↘N	the _woman

6		7		8	9	10	11	12	
N↓V	who_fed	V↘N	Fido	N↖V	V↑N	N↖V	V↑N	V↖N	•

As shown also by the surface realization in 5.6.14, the arc numbers of the speak mode operations are consecutive. Unlike the gapping constructions, the arc numbering of the NAG is not breadth first, but depth first as in most other constructions. There are no multiple traversals.

6. Summary of the Formal System

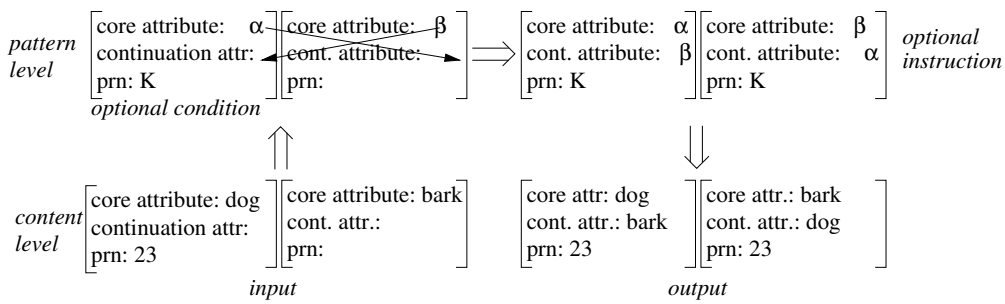
This chapter summarizes the hear and the speak mode operations which resulted from analyzing the 24 constructions in Chaps. 2–5. Sect. 6.1 reviews the three basic formats of the hear mode operations as abstract schemata. Sect. 6.2 explores how the operations should be ordered. Sect. 6.3 presents the 56 operations of DBS.Hear. Sect. 6.4 reviews the four basic formats of the speak mode operations as abstract schemata and explains the principles of their order. Sect. 6.5 presents the 38 operations of DBS.Speak. Sect. 6.6 shows the low computational complexity of the DBS.Hear and DBS.Speak grammars.

6.1 Three Operation Formats in the Hear Mode

A DBS hear mode operation consists of two input patterns and one or two output patterns. The name of a hear mode operation, e.g. PRD×OBJ (2.3.4), specifies the input with two input patterns, here PRD for predicate and OBJ for grammatical object, and an intervening connective, here ×, which determines how the output is constructed from the input. There are only three kinds of time-linear hear mode combination in DBS, characterized by their connectives (i) × (cross-copying), (ii), ∪ (absorption), and (iii) ∼ (suspension).

Computationally, cross-copying establishes a semantic relation between two proplets by copying the core value of one into a continuation slot of the other:

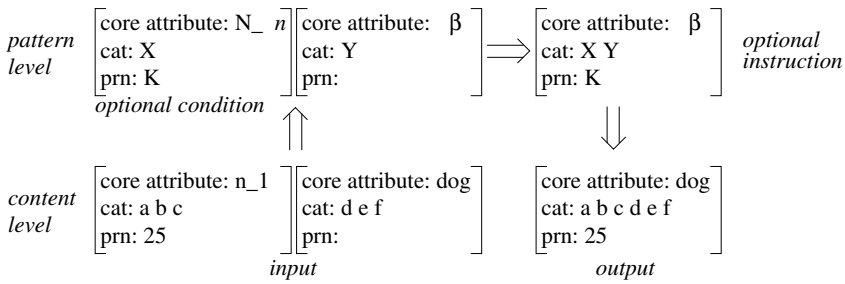
6.1.1 Schematic application of a cross-copying operation (×)



By binding the values dog and bark to the variables α and β, respectively, in the input patterns, the output patterns copy them into the respective continuation slots, establishing the semantic relation of structure at the content level.

An absorption operation (∪) consists of two input and one output pattern:

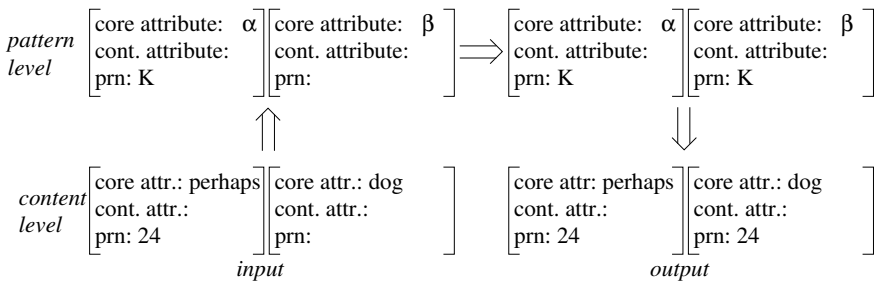
6.1.2 Schematic application of an absorption operation (∪)



Absorption combines a function proplet and a content proplet into one. For example, DET∪CN in 3.2.6 absorbs the content proplet *bone* into the function proplet *n_1* representing the determiner the, while S∪IP in 2.1.3 absorbs the function proplet period into the content proplet *sleep*. If a substitution variable to be replaced by an absorption operation occurs more than once at the current now front, e.g. n_2 in 2.4.2 line 6, all its instances are automatically replaced (simultaneous substitution).

A suspension operation (∼) resembles cross-copying insofar as it has two input and two output patterns. Also, it assigns a prn value to the second input proplet (next word). It differs in that it does not define a semantic relation between the input proplets; instead, establishing the semantic relation is postponed (suspended) until the required item is provided by automatic word form recognition in the time-linear input sequence (suspension compensation).

6.1.3 Schematic application of a suspension operation (∼)



For example, in 3.1.2 (line 1), Perhaps and Fido cannot be connected because there is no semantic relation between them. They must wait (suspension) at the now front until the hear mode operations SBJ×PRD (3.1.4) and

ADV×FV (3.1.5) are simultaneously activated by the arrival of a shared trigger proplet (data driven), here is. SBJ×PRD connects Fido and is (line 2a), and ADV×FV connects Perhaps and is (line 2b).

The sole location in which the operations of the DBS hear, think, and speak mode apply to input and store output is the now front of the agent's memory. In the hear mode, the trigger activating a certain operation is the current next word matching its second input pattern. An activated hear mode operation applies successfully if, and only if, it finds a proplet matching its first input pattern at the now front, whereby the input is replaced by the output. The content resulting from successful hear, think, and speak mode operations is cleared from the now front in regular intervals by moving the now front into fresh memory space, leaving current content behind to join the sediment of the database, never to be changed (loom-like now front clearance).

Linguistically, the grammatical role of input and output patterns in the hear mode is indicated by using the following terms in the operation names:

6.1.4 Proplet kinds specified by DBS.Hear operation names

1. ADN = adnominal, adj proplet
2. ADV = adverb, adj proplet
3. AUX = auxiliary, verb proplet
4. BP = bare preposition, adv proplet
5. CN = common noun, concept proplet
6. CNJ = coordinating conjunction, noun, verb, or adj proplet
7. DET = determiner, noun proplet
8. DO = do, auxiliary, verb proplet
9. FV = finite verb, verb proplet
10. INF = infinitive, verb proplet
11. IP = interpunctuation, verb proplet
12. N = noun, noun proplet
13. NFV = nonfinite verb, verb proplet
14. NOM = nominative, noun proplet
15. NP = noun phrase, noun proplet
16. OBJ = grammatical object, noun proplet
17. PRD = predicate, verb proplet
18. PREP = preposition, noun proplet
19. SBJ = subject, noun proplet
20. WH = wh-proplet, interrogative noun proplet

A proplet is called a noun proplet if its core attribute is noun, and correspondingly for verb and adj proplets.

To indicate special grammatical conditions, some of the terms are further distinguished by the following diacritics:

6.1.5 Main diacritics used by DBS.Hear operation patterns

1. ^{obl} = obligatory
2. ^{opt} = optional
3. ^{s} = shared item in subject
4. ^{p} = shared item in predicate gapping
5. ^{o} = object gapping
6. $^{\&}$ = final object clause in WH long distance construction
7. ^{that} = obligatory subject or object clause
8. ^{which} = optional adnominal subclause
9. ^{who} = optional adnominal subject clause
10. $^{who(m)}$ = optional adnominal object clause
11. ^{and} = obligatory prefinal coordinating conjunction

In addition, DBS operations may have *conditions* and *instructions* (6.1.1).

The most basic distinction between the operations of a DBS grammar is between those of the hear and the speak mode. Hear mode operations have two input proplets while speak mode operations have only one. Also, the operations in the two classes use different kinds of connectives, take different kinds of input, and produce different kinds of output.

Within the hear mode, the second distinction between operations is the core attribute of their trigger proplet, i.e. whether the core attribute of the second input pattern is a noun, a verb, or an adv. This distinction results in the three *trigger classes* of DBS hear mode operations.

Within the trigger classes, a third distinction between operations is between their connective, i.e. whether the connective is $\times$, $\cup$, or $\sim$. This distinction results in the three time three *connective classes*, i.e. (a) $\times$noun, $\times$verb, $\times$adj, (b) $\cup$noun, $\cup$verb, $\cup$adj, and (c) $\sim$noun, $\sim$verb, $\sim$adj.

Within the connective classes, a fourth distinction is between operations with and without a diacritic in their name, formally the $\pm$diacritic distinction. Accordingly we call the class of operations with a diacritic in their name + (plus) and those without - (minus). This results in a total of 3·3·2=18 hear mode distinctions, written as $\times$noun+, $\times$noun-, etc., in the following containment hierarchy:

1 class of hear mode operations $\supset$ 3 trigger classes $\supset$ 9 connective classes $\supset$ 18 diacr. classes

For grammar development, the containment hierarchy has the empirical consequence that operations in different trigger and/or connective sets can not be combined, i.e. generalized into one. The only candidates for linguistic generalization are within the two diacritic classes in the same connective class.

6.2 Ordering the Hear Mode Operations of DBS

The 56 operations parsing the 24 constructions of the example set in Sect. 1.6 are presented in the following order:

6.2.1 Operation ordering of DBS.Hear

H.1	trigger class: verb	1-27
H.1.1	connective class: $\times$	1-13
H.1.1.1	diacritic class: $-$	1-4
H.1.1.2	diacritic class: $+$	5-13
H.1.2	connective class: $\cup$	16-26
H.1.2.1	diacritic class $-$:	16-18
H.1.2.2	diacritic class $+$:	20-25
H.1.3	connective class: $\sim$	26-27
H.1.3.1	diacritic class: $-$	26
H.1.3.2	diacritic class: $+$	27
H.2.	trigger class: noun	28-54
H.2.1	connective class: $\times$	28-33
H.2.1.1	diacritic class: $-$	28-30
H.2.1.2	diacritic class: $+$	31-33
H.2.2	connective class: $\cup$	47-50
H.2.2.1	diacritic class: $-$	47-49
H.2.2.2	diacritic class: $+$	50
H.2.3	connective class: $\sim$	51-54
H.2.3.1	diacritic class: $-$	51
H.2.3.2	diacritic class: $+$	52-54
H.3.	trigger class: adj	55-57
H.3.1	connective class: $\times$	55-57
H.3.1.1	diacritic class: $-$	55-57
H.3.1.2	diacritic class: $+$	not instantiated
H.3.2	connective class: $\cup$	not instantiated
H.3.2.1	diacritic class: $-$	
H.3.2.2	diacritic class: $+$	
H.3.3	connective class: $\sim$	not instantiated
H.3.3.1	diacritic class: $-$	
H.3.3.2	diacritic class: $+$	

The number(s) at the end of each line refer to the hear mode operation numbers in the following section.

6.3 Definition of DBS.Hear

This section presents the DBS.Hear grammar for the test list in Sect. 1.6. The grammar analyzes the linguistic as well as the computational aspects of each

example, based on a declarative specification format which is readable by humans but also has a straightforward translation into a general purpose programming language like Lisp, C, Java, or Perl.

The operations are ordered in accordance with the diacritic classes in 6.2.1. Operations in a +diacritic class follow the order of 6.1.5. Operations in different trigger classes can not be listed in the same class even if they may be considered linguistically related, e.g. SBJ×PRD (1) and PRD×OBJ (28). The same holds for operations in different connective classes, e.g. $\mathsf{PRD}^{\mathsf{opt}}\times\mathsf{PRD}$ (7) and $\mathsf{PRD}^{\mathsf{opt}}\cup\mathsf{PRD}$ (20).

Each operation is presented as an entry which consists of (i) a consecutive item number, (ii) the operation name, (iii) the list of applications in the sample set 1.6.1, and (iv) the declarative specification of the operation.

6.3.1 Listing the operations of DBS.Hear

H.1.1.1 trigger: verb
connective: ×
diacritic: –

1. Continuing from noun in subject position (SBJ) to verb (PRD):
   SBJ×PRD
   (1.1.4, 2.1.3, 2.1.7, 2.1.2, 2.2.5, 2.3.3, 2.4.5, 2.6.3, 3.1.4, 3.2.4, 3.3.7, 3.4.7, 3.5.7, 3.6.7, 4.1.3, 4.2.4, 4.3.3, 4.4.5, 4.5.3, 4.6.3, 5.2.4, 5.3.3, 5.4.6, 5.6.3)
   $$\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP}'\text{ Y v}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ Y v}\\ \text{arg: }\alpha\\ \text{prn: K}\end{bmatrix}$$

2. Adding interpunctuation to a sentence in a text:
   S×IP
   (2.1.8)
   $$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#X}'\text{ VT}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: V\_}n\\ \text{cat: VT}'\text{ SM}\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#X}'\text{ SM}\\ \text{nc: (V\_}n\text{ K+1)}\\ \text{pc:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{nc:}\\ \text{pc: (}\beta\text{ K)}\\ \text{prn: K+1}\end{bmatrix}$$

3. Continuing from interpunctuation to next subject
   IP×SBJ
   (2.1.9)
   $$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat: VT}'\text{ SM}\\ \text{arg:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: V\_}n\\ \text{cat: VT}'\text{ SM}\\ \text{arg: }\alpha\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc: V\_}n\\ \text{prn:K}\end{bmatrix}$$

4. Continuing from elementary adverbial (ADV) to finite verb (FV):
   ADV×FV
   (3.1.5)

$$\begin{bmatrix}\text{adj: } \alpha \\ \text{cat: ADV} \\ \text{mdd:} \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: } \gamma \\ \text{mdr: X} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{adj: } \alpha \\ \text{cat: ADV} \\ \text{mdd: } \gamma \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: } \gamma \\ \text{mdr: X } \alpha \\ \text{prn: K}\end{bmatrix}$$

ADV ϵ {adv, adnv}

H.1.1.2 trigger: verb
connective: $\times$
diacritic: $+$

5. Continuing from clausal subject (PRD^{obl}) to verb (PRD):
PRD$^{\text{obl}}\times$PRD
(2.5.5)

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{cat: \#X}' \text{ v} \\ \text{sem: } \textit{that} \text{ Y} \\ \text{fnc:} \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: } \beta \\ \text{cat: NP' Y v} \\ \text{arg:} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \alpha \\ \text{cat: \#X}' \text{ v} \\ \text{sem: } \textit{that} \text{ Y} \\ \text{fnc: } (\beta \text{ K+1}) \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: } \beta \\ \text{cat: \#NP' Y v} \\ \text{arg: } (\alpha \text{ K}) \\ \text{prn: K+1}\end{bmatrix}$$

6. Continuing from verb (PRD) to clausal object (PRD^{obl}):
PRD$\times$PRD^{obl}
(2.6.4, 5.5.7)

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: \#NP}' \text{ a}' \text{ V} \\ \text{arg: } \gamma \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: V\_}n \\ \text{sem: } \alpha \\ \text{fnc:} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta \\ \text{cat: \#NP}' \text{ \#a}' \text{ v} \\ \text{arg: } \gamma \text{ (V\_}n \text{ K+1)} \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: V\_}n \\ \text{m: } \alpha \\ \text{fnc: } (\beta \text{ K}) \\ \text{prn: K+1}\end{bmatrix}$$

7. Continuing from optional clausal modifier (PRD^{opt}) to verb (PRD):
PRD$^{\text{opt}}\times$PRD
(3.5.8)

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{mdd:} \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: } \beta \\ \text{mdr:} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \alpha \\ \text{mdd: } (\beta \text{ K+1}) \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: } \beta \\ \text{mdr: } (\alpha \text{ K}) \\ \text{prn: K+1}\end{bmatrix}$$

8. Continuing from shared subject (SBJ^{s}) to predicate (PRD) of gapped item:
SBJ$^{\text{s}}\times$PRD
(5.2.7)

$$\begin{bmatrix}\text{noun: } \alpha \\ \text{sem: X} \\ \text{fnc: Y} \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: V\_}n \\ \text{sem: } \beta \\ \text{arg:} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{sem: X} \\ \text{fnc: Y V\_}n \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: V\_}n \\ \text{sem: } \beta \\ \text{arg: } \alpha \\ \text{prn: K}\end{bmatrix}$$

β ϵ {and, or}

9. Continuing from subject (SBJ) of gapped item to predicate in object gapping (PRD^{o}):
(5.4.8)
SBJ$\times$PRD^{o}

$$\begin{bmatrix}\text{noun: } \alpha \\ \text{cat: NP} \\ \text{fnc:} \\ \text{prn:K}\end{bmatrix} \begin{bmatrix}\text{verb: } \beta \\ \text{cat: NP}' \text{ X v} \\ \text{arg:} \\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{cat: NP} \\ \text{fnc: } \beta \\ \text{prn: K}\end{bmatrix} \begin{bmatrix}\text{verb: } \beta \\ \text{cat: \#NP}' \text{ X v} \\ \text{arg: } \alpha \text{ so} \\ \text{prn: K}\end{bmatrix} \quad \textit{extend gap list in cache}$$

10. Continuing from initial WH to final verb (PRD^{f}):
WH$\times$PRD$^{\&}$
(5.5.13)

$$\begin{bmatrix}\text{noun: WH}\\ \text{cat: obq}\\ \text{fnc:}\\ \text{prn: \&}\end{bmatrix}\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#X NP v}\\ \text{arg: Y}\\ \text{prn: \&}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: WH}\\ \text{cat: obq}\\ \text{fnc: }\alpha\\ \text{prn: \&}\end{bmatrix}\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#X \#NP vi}\\ \text{arg: Y WH}\\ \text{prn: \&}\end{bmatrix}$$

11. Continuing from object clause iteration (PRD) to final(=initial) *that*-clause (PRD$^{\&}$):
PRD$\times$**PRD**$^{\&}$
(5.5.10)

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#X}'\text{ N}'\text{ v}\\ \text{arg: Y}\\ \text{fnc:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\textit{that}\\ \text{arg:}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#X}'\text{ \#N}'\text{ v}\\ \text{arg: Y V\_}n\\ \text{fnc:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\textit{that}\\ \text{arg:}\\ \text{fnc: }(\beta\text{ K})\\ \text{prn: \&}\end{bmatrix}$$

12. Continuing from head noun (CN) to adnominal clause (PRD^{which}):
CN$\times$**PRD**^{which}
(3.3.4, 3.4.4, 5.6.6, 5.6.10)

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{mdr:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: }\beta\\ \text{arg: }\emptyset\\ \text{mdd:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: }\alpha\\ \text{cat:}\\ \text{mdr: (V\_n K+1)}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: V\_}n\\ \text{cat: \{NP}'\text{\}}\\ \text{sem: }\beta\\ \text{arg: }\emptyset\\ \text{mdd: }(\alpha\text{ K})\\ \text{prn: K+1}\end{bmatrix}$$

$\beta\ \epsilon$ {which, who}

13. Continuing from verb (PRD) to try infinitive (INF^{try}):
PRD$\times$**INF**^{try}
(4.4.6)

$$\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#NOM}'\text{ a}'\text{ v}\\ \text{arg: }\beta\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: v\_1}\\ \text{cat: inf}\\ \text{fnc:}\\ \text{arg: }\emptyset\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#NOM}'\text{ \#a}'\text{ v}\\ \text{arg: }\beta\text{ v\_1}\\ \text{prn:}\end{bmatrix}\begin{bmatrix}\text{verb: v\_1}\\ \text{cat: inf}\\ \text{fnc: }\alpha\\ \text{arg:}\emptyset\\ \text{prn: K}\end{bmatrix}$$

14. Continuing from shared subject SBJ^{s} to prefinal conjunction PRD^{and}:
SBJ$^{s}\times$**PRD**^{and}
(5.2.10)

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{fnc: }\underline{\text{X}}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: }\alpha\\ \text{fnc: }\underline{\text{X}}\,\beta\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{arg: }\alpha\\ \text{prn: K}\end{bmatrix}$$

H.1.2.1 trigger: verb
connective: $\cup$
diacritic: $-$

15. Absorbing next predicate into IP
IP$\cup$**PRD**
(2.1.10)

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat: VT}'\text{ SM}\\ \text{sem:}\\ \text{arg: Z}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: NP X VT}\\ \text{sem: Y}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#NP X SM}\\ \text{sem: Y}\\ \text{arg: Z}\\ \text{prn: K}\end{bmatrix}$$

16. Fusing finite auxiliary (AUX) and nonfinite verb (NFV):
AUX∪NFV
(2.2.6, 2.2.7, 3.1.7, 5.5.6)
$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat: \#W}'\ \text{AUX}'\ \text{VT}\\ \text{sem: X}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: Y AUX}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#W}'\ \text{\#AUX}'\ \text{Y VT}\\ \text{sem: X Z}\\ \text{prn: K}\end{bmatrix}$$
AUX ϵ {be, hv, do}. VT ϵ {v, vi}.

17. Fusing infinitive (INF) and nonfinite verb (NFV):
INF∪NFV
(4.4.7)
$$\begin{bmatrix}\text{verb: v\_1}\\ \text{cat: inf}\\ \text{arg: }\beta\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: NP}'\ \text{X v}\\ \text{arg:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: X inf}\\ \text{arg: }\beta\\ \text{prn: K}\end{bmatrix}$$

18. Fusing sentence (S) without successor and interpunctuation sign (IP):
S∪IP
(2.1.4, 2.2.8, 2.3.5, 2.4.9, 2.5.7, 2.6.7, 3.1.10, 3.2.10, 3.3.8, 3.4.8, 3.5.9, 3.6.9, 4.1.9, 4.2.7, 4.3.7, 4.4.8, 4.5.6, 4.6.5, 5.2.14, 5.3.13, 5.4.14, 5.5.14, 5.6.13)
$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#X}'\ \text{VT}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: V\_}n\\ \text{cat: VT}'\ \text{SM}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#X}'\ \text{SM}\\ \text{prn: K}\end{bmatrix}$$

H.1.2.2 trigger: verb
connective: ∪
diacritic: +

19. Fusing subordinating conjunction (PRD^{obl}) subclause verb (PRD):
PRD^{obl}∪PRD
(2.5.4, 2.6.6, 5.5.9)
$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: }\textit{that}\\ \text{arg: }\beta\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP' X v}\\ \text{sem: }\gamma\\ \text{arg:}\\ \text{prn: K}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP' X v}\\ \text{sem: }\textit{that}\text{ Y}\\ \text{arg: }\beta\\ \text{prn: K}\end{bmatrix}$$
γ ϵ {that, what, when, where, how, why}

20. Fusing optional subordinating conjunction (PRD^{opt}) and lower verb (PRD):
PRD^{opt}∪PRD
(3.5.5)
$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: }\gamma\\ \text{arg: }\beta\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP' X v}\\ \text{sem: }\gamma\\ \text{arg:}\\ \text{prn: K}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP' X v}\\ \text{sem: }\gamma\text{ Y}\\ \text{arg: }\beta\\ \text{prn: K}\end{bmatrix}$$
γ ϵ {what, when, where, how, why}

21. Fusing final *that* ($\text{PRD}^{\&}$) and verb (PRD):
$\text{PRD}^{\&}$∪PRD

(5.5.12)

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: } \textit{that}\\ \text{arg } \alpha\\ \text{fnc: } (\beta \text{ K-1})\\ \text{prn: K\&}\end{bmatrix}\begin{bmatrix}\text{verb: } \beta\\ \text{cat: NP}' \text{ X v}\\ \text{sem: Y}\\ \text{arg:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta\\ \text{cat: \#NP}' \text{ X v}\\ \text{sem: sem: } \textit{that} \text{ Y}\\ \text{arg: } \alpha\\ \text{fnc: } (\beta \text{ K-1})\\ \text{prn: K\&}\end{bmatrix}$$

22. Fusing optional subordinating conjunction (PRD^{who}) and predicate (PRD):
PRD$^{who}\cup$**PRD**
(3.3.5, 5.6.7, 5.6.11)

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: } \alpha\\ \text{arg: } \emptyset\\ \text{mdd: } (\gamma \text{ K-1})\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: } \beta\\ \text{cat: NP X v}\\ \text{sem: Y}\\ \text{arg:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta\\ \text{cat: \#NP X v}\\ \text{sem: } \alpha \text{ Y}\\ \text{arg: } \emptyset\\ \text{mdd: } (\gamma \text{ K-1})\\ \text{prn: K}\end{bmatrix}$$

$\alpha \in$ {who, which}

23. Fusing optional subordinating conjunction (PRD$^{who(m)}$) and predicate (PRD):
PRD$^{who(m)}\cup$**PRD**
(3.4.6)

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: } \alpha\\ \text{arg: } \beta \quad \emptyset\\ \text{mdd: } (\gamma \text{ K-1})\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: } \delta\\ \text{cat: NP X v}\\ \text{sem: Y}\\ \text{arg:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \delta\\ \text{cat: NP X v}\\ \text{sem: } \alpha \text{ Y}\\ \text{arg: } \beta \quad \emptyset\\ \text{mdd: } (\gamma \text{ K-1})\\ \text{prn: K}\end{bmatrix}$$

$\alpha \in$ {who, who(m), which}

24. Fusing obligatory coordinating conjunction (PRD^{and}) and predicate (PRD):
PRD$^{and}\cup$**PRD**
(5.2.11)

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: } \alpha\\ \text{arg: } \emptyset\\ \text{mdd: } (\gamma \text{ K-1})\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: } \beta\\ \text{cat: NP X v}\\ \text{sem: Y}\\ \text{arg:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \beta\\ \text{cat: NP X v}\\ \text{sem: } \alpha \text{ Y}\\ \text{arg: } \emptyset\\ \text{mdd: } (\gamma \text{ K-1})\\ \text{prn: K}\end{bmatrix}$$

$\alpha \in$ {who, which}

25. Fusing coordinating conjunction and final predicate in object gapping:
PRD$^{and}\cup$**PRD**$^{\circ}$
(5.4.11)

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: } \beta\\ \text{arg:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: } \alpha\\ \text{cat: \#X}' \text{ N}' \text{ v}\\ \text{arg: Y}\\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \alpha\\ \text{cat: \#X}' \text{ \#N}' \text{ v}\\ \text{arg: Y so}\\ \text{prn: K}\end{bmatrix} \quad \textit{extend gap list in cache}$$

H.1.3.1 trigger: verb
connective: $\sim$
diacritic: $-$

26. Suspending initial Who(m) (WH) and adjacent auxiliary (DO):
WH$\sim$DO
(5.5.4)

$$\begin{bmatrix}\text{noun: WH}\\ \text{cat: obq}\\ \text{prn: \&}\end{bmatrix}\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: NOM}'\ \text{DO}'\ \text{v}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: V\_}n\\ \text{cat: obq}\\ \text{prn: \&}\end{bmatrix}\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: NOM}'\ \text{DO}'\ \text{vi}\\ \text{prn: K}\end{bmatrix}$$

H.1.3.2 trigger: verb
connective: $\sim$
diacritic: $+$

27. Suspending verb of prefinal object gap (PRD°) and conjunction (PRD^{and}):
PRD° $\sim$PRD^{and}
(5.4.9)

$$\begin{bmatrix}\text{verb: }\alpha\\ \text{arg: X}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\textit{and}\ \beta\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: }\alpha\\ \text{arg: X so}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\textit{and}\ \beta\\ \text{prn: K}\end{bmatrix}$$

H.2.1.1 trigger: noun
connective: $\times$
diacritic: $-$

28. Continuing from verb (PRD) to non-clausal object (OBJ):
PRD$\times$OBJ
(2.3.4, 2.4.6, 2.5.6, 3.2.5, 3.3.6, 4.1.4, 4.2.5, 4.3.4, 4.5.4, 4.5.7, 5.2.5, 5.2.8, 5.3.4, 5.6.4, 5.6.8, 5.6.12)

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\#\text{X}'}\ \text{N}'\ \text{Y}\ \gamma\\ \text{arg: Z}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\ \text{NP}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\#\text{X}'}\ \#\text{N}'\ \text{Y}\ \gamma\\ \text{arg: Z }\alpha\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\ \text{NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}$$

29. Continuing from Non-initial nominal conjunct (N) to successor (N):
N$\times$N
not instantiated, requires at least four conjuncts

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{nc:}\\ \text{pc: }\gamma\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: }\alpha\\ \text{nc: }\beta\\ \text{pc: }\gamma\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{nc:}\\ \text{pc: }\alpha\\ \text{prn: K}\end{bmatrix}$$

The sem slot of α may not contain a conjunction.

30. Continuing from auxiliary (AUX) to subject (SBJ):
AUX$\times$SBJ

(5.5.5)

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat: NOM}'\ \text{AUX}'\ \text{vi}\\ \text{arg:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NOM}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: V\_}n\\ \text{cat: \#NOM}'\ \text{AUX}'\ \text{vi}\\ \text{arg: }\alpha\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NOM}\\ \text{fnc: V\_}n\\ \text{prn: K}\end{bmatrix}$$

H.2.1.2 trigger: noun
connective: $\times$
diacritic: $+$

31. Continuing from (PRD^{obl}) to subclause subject (SBJ):
PRD$^{\text{obl}}\times$SBJ
(2.5.3, 2.6.5, 5.5.8)

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\textit{that}\\ \text{arg:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\textit{that}\\ \text{arg: }\beta\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{fnc: : V\_}n\\ \text{prn: K}\end{bmatrix}$$

32. Continuing from verb (PRD) to obligatory non-clausal modifier (MOD^{obl}):
PRD$\times$PREP^{obl}
(4.1.6)

$$\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#X mdr}'\ \text{Y}\\ \text{mdr:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{mdd:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#X \#mdr}'\ \text{Y}\\ \text{mdr: N\_}n\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{mdd: }\alpha\\ \text{prn: K}\end{bmatrix}$$

33. Continuing from verb (PRD) to obligatory phrasal modifier (PREP^{obl}):
PRD$\times$PREP^{obl}
(4.1.6)

$$\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#X mdr}'\ \text{v}\\ \text{mdr:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{mdd:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#X \#mdr}'\ \text{v}\\ \text{mdr: N\_}n\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{mdd: }\alpha\\ \text{prn: K}\end{bmatrix}$$

34. Continuing from noun (N) to optional prepositional phrase (PREP^{opt}):
N$\times$PREP^{opt}
(5.1.3, 5.1.6, 5.1.9)

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{mdr:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{mdd:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: }\alpha\\ \text{mdr: N\_}n\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{mdd: }\alpha\\ \text{prn: K}\end{bmatrix}$$

35. Continuing from verb (PRD) to optional phrasal modifier (PREP^{opt}):
PRD$\times$PREP^{opt}
(3.2.7)

$$\begin{bmatrix}\text{verb: }\alpha\\ \text{mdr:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{mdd:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\alpha\\ \text{mdr: N\_}n\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{mdd: }\alpha\\ \text{prn: K}\end{bmatrix}$$

36. Continuing from an optional conjunction (PRD^{opt}) to a lower subject (SBJ):
PRD$^{\text{opt}}\times$SBJ
(3.5.4)

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\alpha\\ \text{arg:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\alpha\\ \text{arg: }\beta\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{fnc: : V\_}n\\ \text{prn: K}\end{bmatrix}$$

37. Continuing from predicate (PRD) to shared object (OBJ$^{\mathbf{o}}$) in object gapping:
PRD×OBJ°
(5.4.12)

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\#X'}\text{ N}'\text{ Y }\gamma\\ \text{arg: Z so}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\text{ NP}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\#X'}\text{ \#N}'\text{ Y }\gamma\\ \text{arg: Z }\alpha\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: so}\\ \text{cat: CN}'\text{ NP}\\ \text{fnc: }\emptyset\ \beta\\ \text{prn: K}\end{bmatrix}$$

38. Continuing from a shared predicate (PRD^{p}) to its object (OBJ):
PRD^{p}×OBJ
(5.3.7, 5.3.11)

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\#X'}\text{ N}'\text{ Y }\gamma\\ \text{arg: Z}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\text{ NP}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\#X'}\text{ \#N}'\text{ Y }\gamma\\ \text{arg: Z }\alpha\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\text{ NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}$$

39. Continuing from a last predicate (PRD) to the shared object (OBJ$^{\mathbf{s}}$):
PRD×OBJ°
(5.4.12)

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\#X'}\text{ N}'\text{ Y }\gamma\\ \text{arg: Z so}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\text{ NP}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\beta\\ \text{cat: }\underline{\#X'}\text{ \#N}'\text{ Y }\gamma\\ \text{arg: Z }\alpha\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: so}\\ \text{cat: CN}'\text{ NP}\\ \text{fnc: }\beta\\ \text{Prn: K}\end{bmatrix}$$

Clear cache into fnc slot of so. Replace all occurrences of `n_c` to α by simultaneous substitution.

40. Continuing from final iteration (PRD$^{\&}$) to subject (SBJ):
PRD$^{\&}$×SBJ
(5.5.11)

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\textit{that}\\ \text{arg:}\\ \text{prn: \&}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\textit{that}\\ \text{arg: }\beta\\ \text{prn: \&}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{fnc: V\_}n\\ \text{prn: \&}\end{bmatrix}$$

41. Continuing from initial nominal conjunct (N_1) to next conjunct (N):
N_1×N
(3.6.4)

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{nc:}\\ \text{pc:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{fnc:}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: K}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: }\alpha\\ \text{nc: }\beta\\ \text{pc:}\\ \text{prn: K@}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{fnc:}\\ \text{nc:}\\ \text{pc: }\alpha\\ \text{prn: K}\end{bmatrix}$$

42. Continuing from prefinal conjunct (N) to coordinating conjunction (CNJ^{N}):
N×CNJ^{N}
(3.6.5)

$$\begin{bmatrix}\text{noun: }\alpha\\ \text{sem: X}\\ \text{nc:}\\ \text{pc:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: N\_}n\\ \text{sem: }\beta\\ \text{nc:}\\ \text{pc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: }\alpha\\ \text{sem: X}\\ \text{nc: N\_}n\\ \text{pc:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: N\_}n\\ \text{sem: }\beta\\ \text{nc:}\\ \text{pc: }\alpha\\ \text{prn: K}\end{bmatrix}$$

$\beta \in$ {and, or}

43. Continuing from adnominal object conjunction (PRD$^{who(m)}$) and subject (SBJ):
PRD$^{who(m)}$×SBJ
(3.4.5)

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\alpha\\ \text{arg: }\emptyset\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\beta\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\alpha\\ \text{arg: }\beta\ \ \emptyset\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\beta\\ \text{fnc: V\_}n\\ \text{prn: K}\end{bmatrix}$$

$\alpha \in$ {who, who(m), which}

44. Continuing from shared predicate (PRD^{p}) to next subject (SBJ)
PRD^{p}×SBJ
(5.3.6)

pattern level

$$\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ \#X v}\\ \text{arg: }\underline{\text{Y}}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP}'\text{ X v}\\ \text{arg: }\underline{\text{Y}}\ \alpha\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{fnc: }\beta\\ \text{prn: K}\end{bmatrix}$$

Agreement conditions as in 2.1.2.

45. Continuing from shared predicate (PRD^{p}) to prefinal conjunction (SBJ^{and})
PRD^{p}×SBJ^{and}
(5.3.9)

$$\begin{bmatrix}\text{verb: }\alpha\\ \text{sem: X}\\ \text{arg: }\underline{\text{Y}}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: N\_}n\\ \text{sem: }\beta\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{verb: }\alpha\\ \text{sem: X}\\ \text{arg: }\underline{\text{Y}}\text{ N\_}n\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: N\_}n\\ \text{sem: }\beta\\ \text{fnc: }\alpha\\ \text{prn: K}\end{bmatrix}$$

46. Continuing from verbal conjunction (PRD^{and}) and subject (SBJ):
PRD^{and}×SBJ
(5.4.10)

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\beta\\ \text{arg:}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{sem: X}\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{verb: V\_}n\\ \text{sem: }\beta\\ \text{arg: }\alpha\text{ so}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{sem: }\beta\text{ X}\\ \text{fnc: V\_}n\\ \text{prn:}\end{bmatrix}$$

extend gap list in cache

H.2.2.1 trigger: noun
connective: ∪
diacritic: –

47. Fusing determiner (DET) and concept, name, or indexical noun (CN):
DET∪CN
(2.2.4, 2.4.4, 2.4.8, 3.2.6, 3.2.9, 3.3.3, 3.4.3, 4.1.5, 4.1.8, 4.2.3, 4.3.5, 4.5.5, 5.1.5, 5.1.8, 5.1.11, 5.2.6, 5.2.9, 5.2.14, 5.3.5, 5.3.8, 5.3.12, 5.4.13, 5.6.5, 5.6.9)

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\text{ NP}\\ \text{sem: Y}\\ \text{prn: K}\end{bmatrix}\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix}\quad\Rightarrow\quad\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: NP}\\ \text{sem: Y Z}\\ \text{prn: K}\end{bmatrix}$$

Delete any ea+ marker.

48. Fusing preposition (PREP) and elementary or phrasal noun (NP):
PREP∪NP
(3.2.8, 4.1.7, 5.1.4, 5.1.7, 5.1.10)

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{sem: X}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\text{ NP}\\ \text{sem: Z}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: }\alpha\\ \text{cat: CN}'\text{ NP}\\ \text{sem: X Z}\\ \text{prn: K}\end{bmatrix}$$

49. Fusing verb (PRD) and bare preposition (BP, separable prefix):
PRD∪BP
(4.3.6)

$$\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#X }\beta'\text{ v}\\ \text{sem: Y}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: adnv}\\ \text{sem: }\beta\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#X \#}\beta'\text{ v}\\ \text{sem: }\beta\text{ Y}\\ \text{prn: K}\end{bmatrix}$$

H.2.2.2 trigger: noun
connective: $\cup$
diacritic: $+$

50. Fusing coordinating conjunction (CNJ) and last noun conjunct (N):
SBJ^{and}**∪SBJ**
(3.6.6, 5.3.10)

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{sem: }\beta\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{sem: X}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: }\alpha\\ \text{sem: }\beta\text{ X}\\ \text{prn:}\end{bmatrix}$$

$\beta\ \epsilon$ {and, or}

H.2.3.1 trigger: noun
connective: $\sim$
diacritic: $-$

51. Suspending initial adverb (ADV) and adjacent subject (SBJ)
ADV∼SBJ
(3.1.3)

$$\begin{bmatrix}\text{adj: }\alpha\\ \text{cat: adv}\\ \text{mdd:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{fnc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{adj: }\alpha\\ \text{cat: adv}\\ \text{mdd:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{fnc:}\\ {}^{\text{N}}\ \text{prn: K}\end{bmatrix}$$

H.2.3.2 trigger: noun
connective: $\sim$
diacritic: $+$

52. Suspending next subject (SBJ) and current verb in object gapping (PRD°):
PRD° ∼SBJ
(5.4.7)

$$\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#X}'\text{ N}'\text{ v}\\ \text{arg: Y}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{prn: K}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#X}'\text{ \#N}'\text{ v}\\ \text{arg: Y so}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\beta\\ \text{prn: K}\end{bmatrix}\quad\begin{matrix}\text{extend gap list}\\ \text{in cache}\end{matrix}$$

53. Fusing modifier connective **PRD**^{opt}**∪PRD** and subclause predicate (PRD)
PRD^{opt}**∪PRD**

(3.5.5)

$$\begin{bmatrix}\text{verb: V\_}n\\ \text{cat:}\\ \text{sem: }\gamma\\ \text{arg: }\beta\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{verb: }\beta\\ \text{cat: NP' X v}\\ \text{sem: }\gamma\\ \text{arg:}\\ \text{prn: K}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\beta\\ \text{cat: \#NP' X v}\\ \text{sem: }\gamma\text{ Y}\\ \text{arg: }\beta\\ \text{prn: K}\end{bmatrix}$$

54. Suspending optional modifier clause (PRD^{opt}) and higher subject (SBJ):
$\text{PRD}^{\text{opt}}\sim$SBJ
(3.5.6)

$$\begin{bmatrix}\text{verb: }\beta\\ \text{sem: }\gamma\text{ Z}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\beta\\ \text{sem: }\gamma\text{ Z}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{noun: }\alpha\\ \text{prn: K+1}\end{bmatrix}$$

$\alpha\ \epsilon$ {when, where, how, why}, NP ϵ {snp, pnp, s1, s3, p1, sp2, p3}.

H.3.1.1 trigger: adj
connective: $\times$
diacritic: $-$

55. Continuing from determiner (DET) to initial elem. adnominal modifier (ADN):
DET$\times$ADN
(2.2.3, 2.4.3, 2.4.7)

$$\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\text{ NP}\\ \text{mdr:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{adj: }\alpha\\ \text{cat: ADN}\\ \text{mdd:}\\ \text{nc:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{noun: N\_}n\\ \text{cat: CN}'\text{ NP}\\ \text{mdr: }\alpha\\ \text{prn:K}\end{bmatrix}\begin{bmatrix}\text{adj: }\alpha\\ \text{cat: ADN}\\ \text{mdd: N\_}n\\ \text{nc: ea+}\\ \text{prn: K}\end{bmatrix}$$

56. Continuing from finite verb (FV) to optional postverbal adverb (ADV):
FV$\times$ADV
(3.1.6, 3.1.8, 3.1.9, 3.6.8)

$$\begin{bmatrix}\text{verb: }\gamma\\ \text{mdr: X}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{adj: }\alpha\\ \text{cat: ADV}\\ \text{mdd:}\\ \text{prn:}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\gamma\\ \text{mdr: X ! }\alpha\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{adj: }\alpha\\ \text{cat: ADV}\\ \text{mdd: }\gamma\\ \text{prn: K}\end{bmatrix}$$

ADV ϵ {adv, adnv}

57. Verb (PRD) takes a modifier (ADN) as obligatory mdr value:
PRD$\times$ADN
(4.2.6, 4.6.4)

$$\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#X }\gamma'\text{ Y}\\ \text{mdr:}\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{adj: }\beta\\ \text{cat: ADN}\\ \text{mdd:}\\ \text{prn: K}\end{bmatrix}\Rightarrow\begin{bmatrix}\text{verb: }\alpha\\ \text{cat: \#X \#}\gamma'\text{ Y}\\ \text{mdr: }\beta\\ \text{prn: K}\end{bmatrix}\begin{bmatrix}\text{adj: }\beta\\ \text{cat: ADN}\\ \text{mdd: }\alpha\\ \text{prn: K}\end{bmatrix}$$

$\gamma\ \epsilon$ {mdr$'$, be$'$}, ADN ϵ {adn, adnv}.

Parsing the sample set 1.6.1 required a total of 154 applications of the 56 operations, i.e. an average of 2.75 applications per hear mode operation. Linguistically, this application average results from a highly distinctive sample set and will increase if the grammar is applied to a sample set with realistic proportions of high frequency common use constructions. Computationally, string search (Knuth et al. 1977) in combination with content-addressable storage

and retrieval based on letter sequences is efficient. It depends on the length of the search term but is independent of the number of operations.

6.4 Four Operation Formats in the Speak Mode

The DBS hear mode is driven by incoming raw data recognized by the agent's interface component as language surfaces and results in content stored in memory. The DBS think mode is driven by autonomous navigation along the semantic relations of structure which connect the proplets of content. The DBS speak mode is a think mode[1] with additional language-dependent lexicalization rules, embedded into the sur slot of goal patterns (e.g. 3.3.11).

The lexicalization rules take the core, the cat and the sem values of their proplet as input and produce zero, one, or more language-dependent surfaces which are passed to the agent's interface component for realization as outgoing raw data. The following definitions of DBS speak mode operations, however, concentrate on the think mode navigation aspect, leaving the language-dependent lexicalization aspect to informal remarks in Chaps. 2–5.[2]

The most basic semantic distinction within the think-speak operations is between the *functor-argument* and the *coordination* relations. The functor argument relation further divides into (i) subject/predicate, (ii) object\predicate, and (iii) modifier|modified, while coordination is the single (iv) conjunct−conjunct relation.

For activation by navigation, these four relations have two alternative directions each, indicated by arrow heads added to the relation lines. Also, each relation has a nonclausal (intrapropositional) and clausal (extrapropositional) variant. For example the subject/predicate relation has the variants (i) V↙/N and (ii) N↗V (nonclausal), and (iii) V↙/V and (iv) V↗V (clausal).

In more detail, the nonclausal V↙/N variant of the subject/predicate relation may be shown schematically as follows:

[1] In line with the DBS laboratory set-up, the think mode operations used here are limited to the selective activation of content derived by DBS.Hear. For the inferencing aspect of the think mode see CC.

[2] For explicitly defined lexicalization rules see NLC Sects. 12.4–12.6.

6.4.1 SCHEMATIC APPLICATION OF A V↙N OPERATION (NONCLAUSAL)

pattern level	verb: α arg: β X prn: K *condition*	⟹	noun: β fnc: α prn: K	*instruction*
	⇑		⇓	
content level	verb: eat arg: dog bone prn: 23 *input*		noun: dog fnc: eat prn: 23 *output*	

The feature [arg: β X] of the input pattern picks the initial arg value, i.e. the subject, as its goal proplet for the continuation.

The clausal counterpart V↙V may be shown schematically as follows:

6.4.2 SCHEMATIC APPLICATION OF A V↙V OPERATION (CLAUSAL)

pattern level	verb: α arg: (β K) prn: K+1 *condition*	⟹	verb: β fnc: (α K+1) prn: K	*instruction*
	⇑		⇓	
content level	verb: amuse arg: (bark 23) prn: 24 *input*		verb: bark fnc: (amuse 24) prn: 23 *output*	

For the formal definition of V↙V see 2.5.10, and for the complete content of That Fido barked amused Mary. see 2.5.1.

Next let us turn to the object\predicate relation. Its four variants are (i) V↘N and (ii) N↖V (nonclausal), and (iii) V↘V and (iv) V↖V (clausal). In more detail, the nonclausal V↘N variant of the object\predicate relation may be shown schematically as follows:

6.4.3 SCHEMATIC APPLICATION OF A V↘N OPERATION (NONCLAUSAL)

pattern level	verb: α arg: #X β Y prn: K *condition*	⟹	noun: β fnc: #α prn: K	*instruction*
	⇑		⇓	
content level	verb: eat arg: #dog bone prn: 24 *input*		noun: bone fnc: #eat prn: 24 *output*	

The feature [arg: #X β Y] of the input pattern picks a noninitial arg value, i.e. the object, as its goal proplet for the continuation. For the explicit definition of the clausal V↘V counterpart see 2.6.12, and 2.6.1 for the complete content of Mary heard that Fido barked.

The modifier|modified relation splits into the adnominal|noun and the adverbial|verb relation, each of which has four variants. For example, the four variants of the adnominal|noun relation are (i) N↓A and (ii) A↑N (nonclausal), and (iii) V↓V and (iv) V↑V (clausal). In more detail, the clausal N↓A variant of the adnominal|noun relation may be shown schematically as follows:

6.4.4 Schematic application of an N↓A operation

pattern level	noun: β mdr: α prn: K *condition*	⟹	adj: α mdd: β prn: K	*instruction*
	⇑		⇓	
content level	noun: dog mdr: big prn: 25 *input*		adj: big mdd: dog prn: 25 *output*	

The [mdd: β] pattern of the modifier α together with the prn value specify the address of the modified. For the explicit definition of the clausal V↓V counterpart see 3.5.12, and for the complete content of When Fido barked Mary laughed. see 3.5.1.

Finally, the conjunct−conjunct relation splits into (a) N−N, (b) V−V, (c) A−A (nonclausal), and (d) V−V (clausal), of which (a) and (c) have two variants each while (b) and (d) together constitute the three variants (i) V→V and (ii) V←V (nonclausal), and (iii) V→V (clausal). The fourth variant of clausal V←V is absent because extrapropositional coordination is unidirectional. The nonclausal and clausal variant of V→V differ in that the prn value of the latter is incremented.

In more detail, the N→N variant may be shown schematically as follows:

6.4.5 Schematic N→N application (nonclausal)

pattern level	noun: α nc: β prn: K *condition*	⟹	noun: β pc: α prn: K	*instruction*
	⇑		⇓	
content level	noun: table nc: chair prn: 26 *input*		noun: chair pc: table prn: 26 *output*	

The [nc: β] pattern of the current conjunct α together with the prn value specify the address of the next conjunct. For the clausal counterpart see NLC Sect. 9.1, and for the complete content of Julia slept. John sang. Suzy dreamt. see Sect. 9.2.

Like the operations of the DBS hear mode (6.1.4), the operations of the DBS think-speak mode use terms which specify the grammatical roles, though only five instead of 20:

6.4.6 Proplet kinds specified by DBS.Speak operation names

1. V = verb proplet
2. N = noun proplet
3. A = adj proplet
4. INF = verb proplet
5. WH = noun proplet

Similar to DBS.Hear (6.1.5), DBS.Speak operations use diacritics, here to differentiate particular traversals:

6.4.7 Main diacritics used in names of DBS.Speak operations

1. ^{s} = shared item is subject
2. ^{p} = shared item is predicate
3. ^{o} = shared item is object
4. $^{\&}$ = items of a long-distance relation

Based on diacritics, the number of speak mode operations is increased from 24 to a total of 38 (Sect. 6.5).

Remains the question of how to order the think-speak mode operations for selective activation in a meaningful way. The answer is decided by the kind of input taken by two kinds of operation: the input to the hear mode is a unidirectional sequence of word forms provided by the agent's interface component; the input to the think-speak mode, in contrast, is content provided by the agent's memory or by inferencing.

The think-speak mode operations are bidirectional in that a semantic relation of structure in a content is usually traversed in both directions.[3] It is therefore an obvious possibility to order the think-speak operations into pairs of opposite direction. For example, $V_{\swarrow}N$ (downward, 6.4.1) and $N_{\nearrow}V$ (upward, 6.4.2) use the same relation and the same patterns for V and N (1.2.1); they differ only in the direction of traversing the semantic relation N/V, as indicated by the arrow heads and the start proplet in initial position.

The set of opposite direction pairs is ordered further according to the pair nodes, e.g. $N_{\swarrow}/V$ vs. $V_{\swarrow}/V$, going systematically through the four connectives. Finally, these sets are divided into pairs without and with diacritics.

[3] The exception is the unidirectional traversal of conjunct–conjunct relations (1.4.4). Also, subject (1.4.5, 1.4.7, 5.2.16) and object (1.4.6, 5.4.15) gapping each have only one unidirectional arc.

6.5 Definition of DBS.Speak

Similar to the DBS.Hear grammar presented in Sect. 6.3, the entries of the following DBS.Speak grammar each consist of (i) a consecutive item number, (ii) the operation name, (iii) the list of applications in the production of the sample set 1.6.1, and (iv) the definition of the operation. The ordering is as described in the preceding section. The speak mode operations differ from the hear mode operation in section 6.3 in their connectives and their input and output consisting of a single pattern.

6.5.1 Listing the operations of DBS.Speak

1. **V↙N**
   (1.2.4, 2.1.6, 2.2.11, 2.3.8, 2.4.12, 2.5.11, 2.6.10, 2.6.13, 3.1.15, 3.2.10, 3.2.13, 3.3.11, 3.4.11, 3.4.14, 3.5.13, 3.5.16, 3.6.12, 4.1.12, 4.2.10, 4.3.10, 4.4.11, 4.5.9, 4.6.8, 5.1.14, 5.2.17, 5.3.16, 5.4.17, 5.4.21, 5.4.25, 5.5.23, 5.5.26, 5.5.29, 5.6.16)
   $$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$
2. **N↗V**
   (1.2.5, 2.1.7, 2.2.14, 2.3.9, 2.4.15, 2.5.12, 2.6.11, 2.6.14, 3.1.16, 3.2.14, 3.4.16, 3.5.14, 3.5.17, 3.6.17, 4.1.13, 4.2.11, 4.3.11, 4.4.12, 4.5.10, 4.6.9, 5.1.15, 5.3.17, 5.4.18, 5.4.22, 5.4.26, 5.5.24, 5.5.27, 5.5.30, 5.6.17)
   $$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha\ \text{Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#}\beta\ \text{X} \\ \text{prn: K}\end{bmatrix}$$
3. **V↘N**
   (2.3.10, 2.4.16, 2.5.14, 3.2.15, 3.4.13, 4.1.14, 4.2.12, 4.3.12, 4.5.11, 5.1.16, 5.2.19, 5.2.23, 5.2.27, 5.3.18, 5.3.22, 5.3.26, 3.4.13, , 5.6.18, 5.6.20, 5.6.22)
   $$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta\ \text{Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$
4. **N↖V**
   (2.3.11, 2.4.19, 2.5.15, 3.2.16, 3.3.14, 3.3.16, 3.4.14, 4.1.15, 4.2.13, 4.3.13, 4.5.12, 5.1.23, 5.2.20, 5.2.25, 5.2.28, 5.3.19, 5.3.23, 5.3.27, 3.4.14, 5.2.28, 5.4.28, 5.6.23, 5.6.25, 5.6.27)
   $$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta\ \text{Y} \\ \text{prn: K}\end{bmatrix}$$
   Z is #-marked or NIL
5. **V↙V**
   (2.5.10)
   $$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: } (\beta\ \text{K})\ \text{X} \\ \text{prn: K+1}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{sem: } \textit{that}\ \text{Z} \\ \text{fnc: } (\alpha\ \text{K+1}) \\ \text{prn: K}\end{bmatrix}$$

6. **V↗V**
(2.5.13)

$$, \begin{bmatrix} \text{verb: } \beta \\ \text{sem: } \textit{that}\ \text{Z} \\ \text{arg: \#X} \\ \text{fnc: } (\alpha\ \text{K+1}) \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: } (\beta\ \text{K})\ \text{X} \\ \text{prn: K+1} \end{bmatrix}$$

7. **V↘V**
(2.6.12, 5.5.17, 5.5.25)

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{arg: X } (\beta\ \text{K+1}) \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{sem: } \textit{that}\ \text{Z} \\ \text{fnc: } (\alpha\ \text{K}) \\ \text{prn: K+1} \end{bmatrix}$$

8. **V↖V**
(2.6.15, 5.5.22, 5.5.32)

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{sem: } \textit{that}\ \text{Z} \\ \text{fnc: } (\beta\ \text{K}) \\ \text{prn: K+1} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{arg: Y } (\alpha\ \text{K+1}) \\ \text{prn: K} \end{bmatrix}$$

9. **V↓A**
(3.1.13, 3.1.17, 3.1.19, 3.1.21, 3.6.18, 4.2.14, 4.6.10)

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{mdr: \#X } \beta\ \text{Y} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexadj}(\hat{\beta}) \\ \text{adj: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K} \end{bmatrix}$$

10. **A↑V**
(3.1.14, 3.1.18, 3.1.20, 3.1.22, 3.6.19, 4.2.15, 4.6.11)

$$\begin{bmatrix} \text{adj: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{mdr: X } \beta\ \text{Y} \\ \text{prn: K} \end{bmatrix}$$

11. **N↓A**
(2.2.12, 2.4.13, 2.4.17)

$$\begin{bmatrix} \text{noun: } \beta \\ \text{mdr: } \gamma \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexadj}(\hat{\gamma}) \\ \text{adj: } \gamma \\ \text{mdd: } \beta \\ \text{prn: K} \end{bmatrix}$$

12. **A↑N**
(2.2.13, 2.4.14, 2.4.18)

$$\begin{bmatrix} \text{adj: } \gamma \\ \text{mdd: } \beta \\ \text{nc: Z} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{mdr: \#}\gamma \\ \text{prn: K} \end{bmatrix}$$

Z is NIL or elementary and #-marked

13. **V↓N**
(3.2.17, 4.1.16)

$$\begin{bmatrix} \text{verb: } \alpha \\ \text{mdr: X } \beta\ \text{Y} \\ \text{prn: K} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K} \end{bmatrix}$$

14. **N↑V**
(3.2.18, 3.3.12, 4.1.17)

$$\begin{bmatrix}\text{noun: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{mdr: X } \beta \text{ Y} \\ \text{prn: K}\end{bmatrix}$$

15. **N↓V**
(3.3.12, 3.4.12, 5.6.19, 5.6.21)

$$\begin{bmatrix}\text{noun: } \alpha \\ \text{mdr: } (\beta \text{ K+1}) \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{mdd: } (\alpha \text{ K}) \\ \text{prn: K+1}\end{bmatrix}$$

16. **V↑N**
(3.3.15, 3.4.15, 5.6.24, 5.6.26)

$$\begin{bmatrix}\text{verb: } \beta \\ \text{mdd: } \#(\alpha \text{ K}) \\ \text{prn: K+1}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{noun: } \alpha \\ \text{mdr: } \#(\beta \text{ K+1}) \\ \text{prn: K}\end{bmatrix}$$

17. **V↓V**
(3.5.12)

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{mdr: X } \beta \text{ Y} \\ \text{prn: K+1}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix}$$

18. **V↑V**
(3.5.15)

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{mdd: X } \#\beta \text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{mdr: } \alpha \\ \text{prn: K+1}\end{bmatrix}$$

19. **V→V**
(2.1.16)

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{nc: } \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{pc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

20. **V←V**
(not instantiated)

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{pc: } \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{nc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

21. **N↓N**
(5.1.17, 5.1.18, 5.1.19)

$$\begin{bmatrix}\text{noun: } \alpha \\ \text{mdr: } \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexadj}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{mdd: } \alpha \\ \text{prn: K}\end{bmatrix}$$

22. **N↑N**
(5.1.20, 5.1.21, 5.1.22)

$$\begin{bmatrix}\text{noun: } \alpha \\ \text{mdd: } \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexadj}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{mdr: } \alpha \\ \text{prn: K}\end{bmatrix}$$

23. **N→N**
(3.6.13, 3.6.14)

$$\begin{bmatrix}\text{noun: } \alpha \\ \text{nc: } \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{sem: CNJ X} \\ \text{pc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

24. **N←N**
(3.6.15, 3.6.16)

$$\begin{bmatrix}\text{noun: } \beta \\ \text{pc: } \alpha \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \alpha \\ \text{nc: } \beta \\ \text{prn: K}\end{bmatrix}$$

25. $\mathbf{V}\swarrow\mathbf{N}^{s}$
(5.2.21, 5.2.25)

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#}\beta\text{ \#X} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \underline{\text{\#Y}}\ \alpha\ \text{Z} \\ \text{prn: K}\end{bmatrix}$$

26. $\mathbf{N}^{s}\nearrow\mathbf{V}$
(5.2.22, 5.2.26)

$$\begin{bmatrix}\text{noun: } \beta\text{ fnc: \#X } \alpha\text{ Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: } \beta\text{ W} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL

27. $\mathbf{V}^{p}\swarrow\mathbf{N}$
(5.3.16, 5.3.20, 5.3.24)

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta\text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{prn: K}\end{bmatrix}$$

28. $\mathbf{N}\nearrow\mathbf{V}^{p}$
(5.3.21, 5.3.25, 5.3.28)

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: } \alpha \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: \#X \#}\beta\text{ Y} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL

29. $\mathbf{V}\searrow\mathbf{N}^{o}$
(5.4.19, 5.4.23)

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#X } \beta\text{ Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\beta}) \\ \text{noun: } \beta \\ \text{fnc: \#Y } \alpha\text{ Z} \\ \text{prn: K}\end{bmatrix}$$

30. $\mathbf{N}^{o}\nwarrow\mathbf{V}$
(5.4.20, 5.4.24)

$$\begin{bmatrix}\text{noun: } \beta \\ \text{fnc: \#X } \alpha\text{ Y} \\ \text{mdr: Z} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: } \beta\text{ W} \\ \text{prn: K}\end{bmatrix}$$

Z is #-marked or NIL

31. **V\WH**
(5.5.19)

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{sem: } \textit{that}\ \text{X} \\ \text{arg: X WH\_}n \\ \text{prn: \&}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexnoun}(\hat{\gamma}) \\ \text{noun: WH\_}n \\ \text{fnc: } \alpha \\ \text{prn: \&}\end{bmatrix}$$

32. **WH↖V&**
(5.5.20)

$$\begin{bmatrix}\text{noun: WH\_}n \\ \text{fnc: } \alpha \\ \text{prn: \&}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{verb: } \alpha \\ \text{sem: } \textit{that}\ \text{X} \\ \text{arg: \{ X \#WH\_}n\text{\}} \\ \text{prn: \&}\end{bmatrix}$$

33. **V\V&**
(5.5.28)

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: X } (\beta\ \&) \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\gamma}) \\ \text{verb: } \beta \\ \text{fnc: } (\alpha\ \text{K}) \\ \text{prn: \&}\end{bmatrix}$$

34. **V&↖V**
(5.5.21, 5.5.31)

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{sem: } \textit{that}\ \text{Z} \\ \text{fnc: } (\beta\ \text{K}) \\ \text{prn: \&}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{arg: Y } (\alpha\ \&) \\ \text{prn: K}\end{bmatrix}$$

35. **V→V**
(2.1.16)

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{nc: } \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\beta}) \\ \text{verb: } \beta \\ \text{prn: K+1}\end{bmatrix}$$

36. **V\INF**^{try}
(4.4.13)

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: \#}\gamma\ \beta \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \beta \\ \text{cat: \#X inf} \\ \text{fnc: \#}\alpha \\ \text{arg: \#}\gamma\ \text{Y} \\ \text{prn: K}\end{bmatrix}$$

37. **INF↖V**
(4.4.14)

$$\begin{bmatrix}\text{verb: } \beta \\ \text{cat: \#X v} \\ \text{sem: } \textit{to}\text{\#X} \\ \text{arg: } \emptyset\ \text{\#Y} \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\alpha}) \\ \text{verb: } \alpha \\ \text{arg: } \beta\ \text{X} \\ \text{prn: K}\end{bmatrix}$$

38. **V\V&**
(5.4.27, 5.5.18, 5.5.28)

$$\begin{bmatrix}\text{verb: } \alpha \\ \text{arg: X } (\beta\ \&) \\ \text{prn: K}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{sur: lexverb}(\hat{\gamma}) \\ \text{verb: } \beta \\ \text{arg: Y WH\_}n \\ \text{fnc: } (\alpha\ \text{K}) \\ \text{prn: \&}\end{bmatrix}$$

Of the 38 DBS.Speak operations, 32 are bidirectional, such as $\mathsf{V}\swarrow\mathsf{N}$ (2.1.6) and $\mathsf{N}\nearrow\mathsf{V}$ (2.1.7). The exceptions are $\mathsf{V}\rightarrow\mathsf{V}$ (35), $\mathsf{V}\searrow\mathsf{INF}^{try}$ (36), and $\mathsf{V}\searrow\mathsf{V}^{\&}$ (38). Clausal $\mathsf{V}\rightarrow\mathsf{V}$ is unidirectional (NLC 9.1.2, 12.1.1, CLaTR 7.5.12 ff., Sect. 9.4), while the other two use standard $\mathsf{V}\nwarrow\mathsf{V}$ (8) for the return to the higher verb.

The production of the 24 examples required 183 application of 36 operations (not counting two which were not instantiated), resulting in an application average per operation of 5.08. The higher average compared to the hear mode originates in the lex rules which may produce several word form surfaces in one transition.

6.6 Computational Complexity

The computational complexity analysis of DBS began at a time, in which the transition from a sign- to an agent-based ontology had not yet taken place. To compensate for the absence of an agent-based interface component, memory, and now front, the number of rule applications in a time-linear derivation step of Left-Associative Grammar was restricted by a finite-state transition network which connected each rule with a package of legal successor rules.

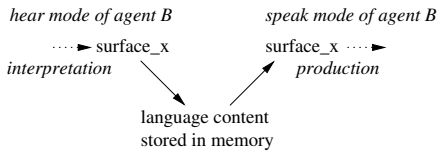
In such a system the only source of computational complexity is recursive ambiguity (FoCL Sect. 11.3). Accordingly, formal languages with a high degree of complexity in the PSG hierarchy[4] of formal languages, but without recursive ambiguity, parse in linear time in LA-grammar. Examples are $\mathsf{a}^k\mathsf{b}^k$ and $\mathsf{a}^k\mathsf{b}^k\mathsf{c}^m\mathsf{d}^m \cup \mathsf{a}^k\mathsf{b}^m\mathsf{c}^m\mathsf{d}^k$, which are polynomial ($n^3$) in PSG, but linear (C1) in LAG. as well as many languages which are exponential in PSG (context-sensitive), but linear (C1) in LAG, such as $\mathsf{a}^k\mathsf{b}^k\mathsf{c}^k$, $\mathsf{a}^k\mathsf{b}^k\mathsf{c}^k\mathsf{d}^k\mathsf{e}^k$, $\{\mathsf{a}^k\mathsf{b}^k\mathsf{c}^k\}^*$, L_{square}, L^k_{hast}, a^{2^i}, $\mathsf{a}^k\mathsf{b}^m\mathsf{c}^{k\cdot m}$, and $\mathsf{a}^{i!}$, whereby the last one is not even an index language. The LA-grammar hierarchy is the first, and so far the only, complexity hierarchy alternative to the PSG hierarchy (TCS).

When the ontology changed from substitution-driven sign-based NEWCAT'86 to data-driven agent-based DBS, the complexity results of the LA-algorithm were carried over to the hear mode of DBS. The complexity-theoretic counterpart for the speak mode is the continuity condition (NLC 3.6.5).

To separate the linguistic and the computational aspects of surface production from such autonomous control issues as the *what to say* and the *how to say it* (NLC 3.5.2), the speak mode uses the laboratory set-up (Sect. 1.5).

[4] Also known as the Chomsky hierarchy of the regular, context-free, context-sensitive, and recursively enumerable language classes.

6.6.1 Functional flow within the DBS laboratory set-up



The laboratory set-up stores the content derived in the hear mode in the system's database and uses it as input to the speak mode. The surface produced by the speak mode must equal the surface analyzed in the hear mode.

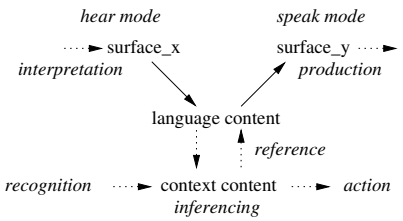
Outside the laboratory set-up, an isolated algorithm for selectively activating content by navigation may be complex. This is because more than one goal proplet may be accessible from a given proplet (multiple continuations), making the number of parallel traversals through a given content potentially exponential. However, while the hear mode is controlled by the incoming data, the think mode action underlying the speak mode is controlled by the agent.

More specifically, while an agent in the hear mode must understand what is being said before being able to evaluate it, a speaker can evaluate the options of what to say and how to say it before acting on them. This does not require a complete consideration of each alternative provided by the content in the agent's memory. Instead, alternatives which appear to be unattractive in the agent's current situation may be disregarded from the start. How many options are considered and how far their consequences are being pursued is determined by the agent's computational resources available at the moment. Whether or not the choice taken was in fact optimal is decided by the outcome.

The overall goal of behavior in DBS is survival and reproduction, in line with Darwin (1859). In an individual agent, the goal is realized as the innate drive to maintain a state of balance vis à vis a constantly changing external and internal environment. The purpose of maintaining or regaining balance includes human desires for acceptance, love, belonging, freedom, and fun, which may be subsumed under the balance principle by treating them as part of the agent's internal environment, like hunger.

When the DBS laboratory set-up is replaced by the balance principle, it serves as the agent's general behavior control which provides the speak mode with the *what to say* and *how to say it*:

6.6.2 Functional flow outside the DBS laboratory set-up



Computationally, a well-functioning combination of language and non-language cognition is ensured by their using the same data structure, the same database schema, the same time-linear algorithm based on the same method of matching between the pattern and the content level, and the same recognition and action concepts for type-token matching with raw data (grounding).

List of Examples

The following test list is intended as a quick overview.[5] For a more detailed linguistic description of the examples and the systematic reasons behind their choice and ordering see Sect. 1.6.

2.1.1 Mary slept. Fido snored.
2.2.1 The old dog had been sleeping.
2.3.1 I saw you.
2.4.1 The big dog saw a small bird.
2.5.1 That Fido barked amused Mary.
2.6.1 Mary heard that Fido barked.

3.1.1 *Perhaps* Fido is *still* sleeping *there now*.
3.2.2 Fido ate the bone on the table (adverbial)
3.3.1 The dog which saw Mary barked.
3.4.1 The dog which Mary saw barked.
3.5.1 When Fido barked Mary laughed.
3.6.1 Fido, Tucker, and Buster snored loudly.

4.1.1 Julia put the flowers on the table.
4.2.1 The letter made Mary happy.

[5] Online, the preceding three-digit numbers allow comfortable access via automatic cross-referencing (`\hyperref`).

4.3.1 Fido dug the bone up.
4.4.1 John tried to sing.
4.5.1 Julia is a doctor.
4.6.1 Fido is hungry.

5.1.1 Fido ate the bone on the table under the tree in the garden...
5.2.2 Bob bought an apple, # peeled a pear, ..., and # ate a peach.
5.3.1 Bob bought an apple, Jim # a pear, ..., and Bill # a peach.
5.4.4 Bob bought #, Jim peeled #, ..., and Bill ate a peach.
5.5.1 Who(m) does John say that Bill believes ... that Mary loves?
5.6.1 Mary saw the man who loves the woman ... who fed Fido.

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Name Index

Subject Index

This book presents a data-driven, agent-based approach to analyzing the hear and the speak mode of 24 linguistically informed English examples. The hear mode maps a time-linear input sequence of language-dependent surfaces into a content as output. The speak mode maps an input content into a time-linear sequence of language-dependent surfaces as output. Using the declarative specification format of DBS, the examples are systematically analyzed to the same degree of linguistic and computational detail.