Discontinuous Structures in DBS and PSG

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Abstract

In linguistics, grammatical constructions with semantically connected word forms are called *discontinuous* if the word forms are not adjacent. For example, in (i) Peter looked the number up, the semantically related looked ... up are separated by the_number, and in (ii) Yesterday Mary danced the semantically related Yesterday ... danced are separated by Mary.

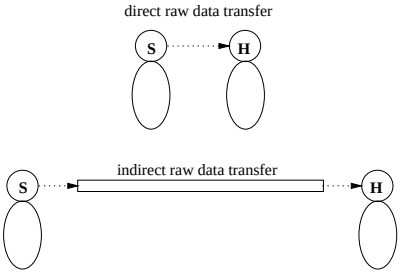
This paper explores why example (i) poses a descriptive problem for PSG (Phrase Structure Grammar), but not for DBS (Database Semantics), and why example (ii) poses a descriptive problem for DBS, but not for PSG. Then the PSG and DBS proposals for solving their respective problem are compared.

keywords: constituent structure, time-linear derivation, semantic relations

1 The Time-Linear Structure of Natural Language

Many syntactic-semantic content structures in human cognition are hierarchical, but the transfer of content in language communication is strictly linear. In the medium of speech, this holds for direct language communication, such as talking face to face, and for indirect language communication, such as talking on the phone:

1.1 COMPARING FACE-TO-FACE WITH ON THE PHONE TALKING



The cognitive aspects are located inside the agents' heads, with **S** for speaker, **H** for hearer, and the arrow heads indicating direction. Transfer operates the same regardless of whether communication is face to face (direct raw data transfer) or talking on the phone (indirect raw data transfer). It is therefore not appropriate to build linguistic semiotics on information theory, as has been proposed by Eco[1] (1975).

All that is required of an artificial or natural transfer channel is the transmission of data without distortion (Shannon and Weaver 1948). However, though the transfer channel is not the place for reconstructing cognition, it poses a crucial structural requirement for language communication: the signs must be in a strictly linear order (canonized by de Saussure ([1916]1972) as his *second principe*). This is because humans can neither produce nor interpret several words, phrases, sentences, or texts

[1]Eco's most basic prototype of communication is a buoy "telling" an engineer the water level of a lake; the engineer's partner of discourse is mother nature. Grice's (1957) "bus bell model" and Dretsky's (1981) "doorbell model" have another human ringing the bell (CLaTR 2.2.4).

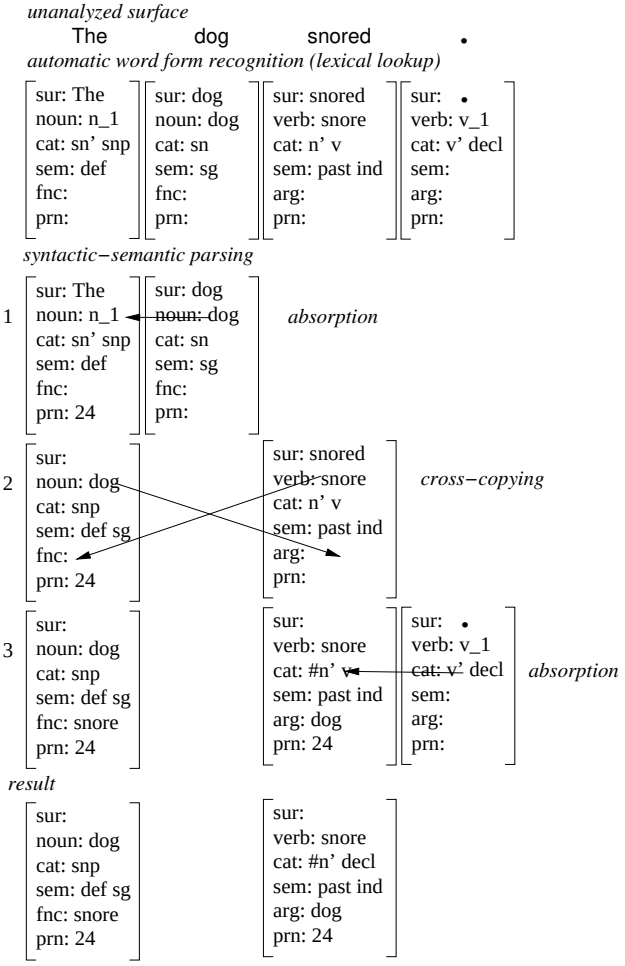
simultaneously. Cognitive structures may be as hierarchical as needed as long as language contents can be coded in time-linear order fit for the transfer channel.[2]

In DBS, a content is a set (order-free) of proplets connected by address. Proplets are non-recursive feature structures with ordered attributes. As the basic units of a content, proplets serve as the computational data structure. Language vs. nonlanguage contents differ in the presence vs. absence of language-dependent surfaces.

The speak mode takes a content as input and produces a surface sequence as output by traversing the input content along the address-coded semantic relations between proplets. The hear mode takes a surface sequence as input and produces an output content by concatenating proplets by address into a set. Because the speak and the hear mode take different kinds of input and output, they can never use the same algorithm.

Consider the hear mode taking the unanalyzed *surface* The dog snored. as input for the time-linear surface compositional derivation producing the output *content*:

1.2 DERIVING CONTENT FROM SURFACE IN HEAR MODE



[2]This requirement is not fulfilled by formal grammars which compute possible substitutions, such as PSG and CG. For this reason, Chomsky emphasizes tirelessly (e.g., Chomsky 1965, p. 9) that Generative Grammar (nativism) models the innate structure of natural language (structuralism), and is "not intended" for a transfer of content in language communication ("autonomy of syntax", Chomsky 1982). It is somewhat

Automatic word form recognition of the hearer's interface component provides a sequence of four *lexical* proplets, unconnected with nonempty sur slots. The derivation provides the output, i.e., a content of two *nonlexical* proplets, connected with empty sur slots. The derivation order is (i) *time-linear* (left-associative[3]), shown by the stair-like addition of next word proplets, the analysis is (ii) *surface compositional* because each lexical item has a concrete sur value and there are no surfaces without a proplet analysis, and the activation and application of operations is (iii) *data-driven* by the lexical input proplets provided by automatic word form recognition.

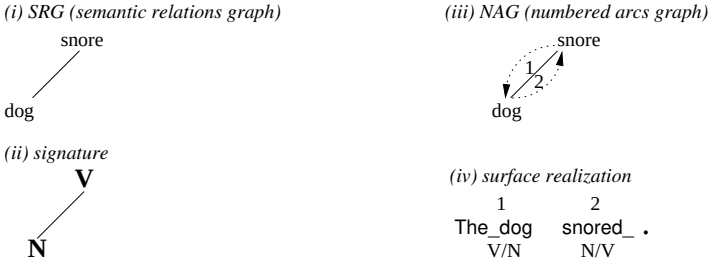
Defining a content as a set of proplets connected by address is essential for storage in and retrieval from the agent's on-board memory (content-addressable database). The following example illustrates the order-free coding of the subject/predicate relation:

1.3 ORDER-FREE PROPLETS CODING CONTENT OF The dog snored.

sur:	sur:
noun: **dog**	verb: **snore**
cat: def sg	cat: #n′ decl
sem:	sem: past ind
fnc: **snore**	arg: **dog**
mdr:	mdr:
nc:	nc:
pc:	pc:
prn: 24	prn:24

Computationally, semantic relations are established by cross-copying addresses. Intuitively, the semantic relations of a content are shown graphically in four views:

1.4 GRAPHICAL PRESENTATION OF SEMANTIC RELATIONS IN 1.4



The *(i) SRG* and the *(ii) signature* on the left show the static aspect of the hierarchical content structure. The *(iii) NAG (numbered arcs graph* and *(iv) surface realization* on the right show its dynamic traversal.

The arc numbers of the *NAG* are used for specifying (1) a think mode navigation and (2) a think-speak mode surface production as shown by the *surface realization*. The main traversal operations in the think mode are (1) predicate↙subject, (2) subject↗predicate, (3) predicate↘object, (4) object↖predicate, (5) noun↓adnominal, (6) adnominal↑noun, (7) verb↓adverbial, (8) adverbial↑verb, (9) noun→noun, (10) noun←noun, (11) adnominal→adnominal, (12) adnominal←adnominal, and (13) verb→verb.

The *(iv) surface realization* shows language-dependent production. It is implemented as the speak mode riding piggy-back on the think mode navigation. The agent's memory provides the concepts of dog and snore as types (*declarative specification*). The

unlikely, however, that the innate structure of the natural language ability would do without a speak mode, a hear mode, and a transfer channel, especially in language acquisition.

[3] Aho and Ullman (1977), p. 47; FoCL 10.1.1.

agent's interface component adapts the surface types into tokens and realizes them as raw data (*operational implementation*).

2 Constituent Structure Paradox of PSG

DBS and PSG differ ontologically in that DBS is agent-based data-driven, while PSG is sign-based substitution-driven. The derivations of PSG generate different language expressions from the same node, called S for sentence or start. The number of possible tree structures for a given surface grows exponentially with the length of the surface. Assuming binary branching, there are two PSG trees for a three-word sentence:

2.1 PSG TREES FOR THREE-WORD UNAMBIGUOUS SURFACE

From a formal point of view, both trees are equally well-formed.

However, because more than one tree for an unambiguous surface does not make sense linguistically, there must be an intuitive principle for choosing the "good" one. In chomskyan linguistics, this is the principle of Constituent Structure:[4]

2.2 DEFINITION[5] OF CONSTITUENT STRUCTURE

1. Words or constituents which belong together semantically must be dominated directly and exhaustively by a node.

2. The lines of a Constituent Structure may not cross (*nontangling condition*).

Assuming that knows and John (predicate-object) belong closer together semantically than Julia and knows (subject-predicate), the tree on the left in 2.1 satisfies 2.2 and is therefore considered linguistically correct, while the tree on the right is not. Yet it has been known at least since 1953 (Bar-Hillel 1964, p. 102) that there are certain natural language constructions with "discontinuous elements" which violate the definition of Constituent Structure.[6]

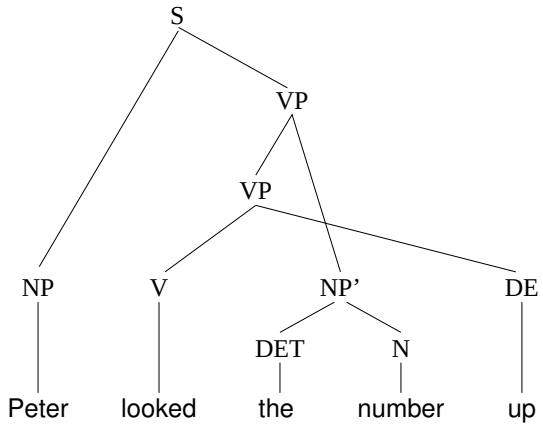
Known as the Constitutent Structure Paradox (FoCL 8.5), the problem may be illustrated with discontinuous look__up in the following attempts to analyze Peter looked the number up as a Constituent Structure:

[4]Compared to the writings of Aristotle, Constituent Structure is quite recent. It evolved from the *immediate constituent analysis* of L. Bloomfield (1887–1949). His student Z. Harris (1909–1992) turned the constituent analyses into substitution and movement tests. Harris's student N. Chomsky turned the methodologically motivated tests into generative rules, called transformations and proffered as innate.

[5]Provided by Prof. Ivan Sag, personal communication, Stanford 1984-86.

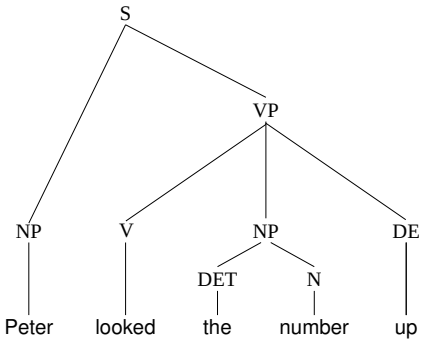
[6] Bloomfield's (1933, p. 210) analysis of gentle/man/ly argues for constituent structure. Along the same lines, we could take Latin te video (I see you) and use the morphological (inflectional) coding of the subject role and the syntactic coding of the object role as an argument against the Structuralists' sweeping assumption that the object belongs semantically more closely to the verb than the subject.

2.3 VIOLATING THE SECOND CONDITION OF 2.1



Here the semantically related expressions looked and up are dominated directly and exhaustively by a node, satisfying the first condition of 2.1. The analysis violates the second condition, however, because the lines cross.[7]

2.4 VIOLATING THE FIRST CONDITION OF 2.1



Here the lines of the tree do not cross, satisfying the second condition, but the semantically related expressions looked – up, or rather the nodes V and DE dominating them, are not *exhaustively* dominated by a node. Instead, the node directly dominating V and DE also dominates the NP the_ number.

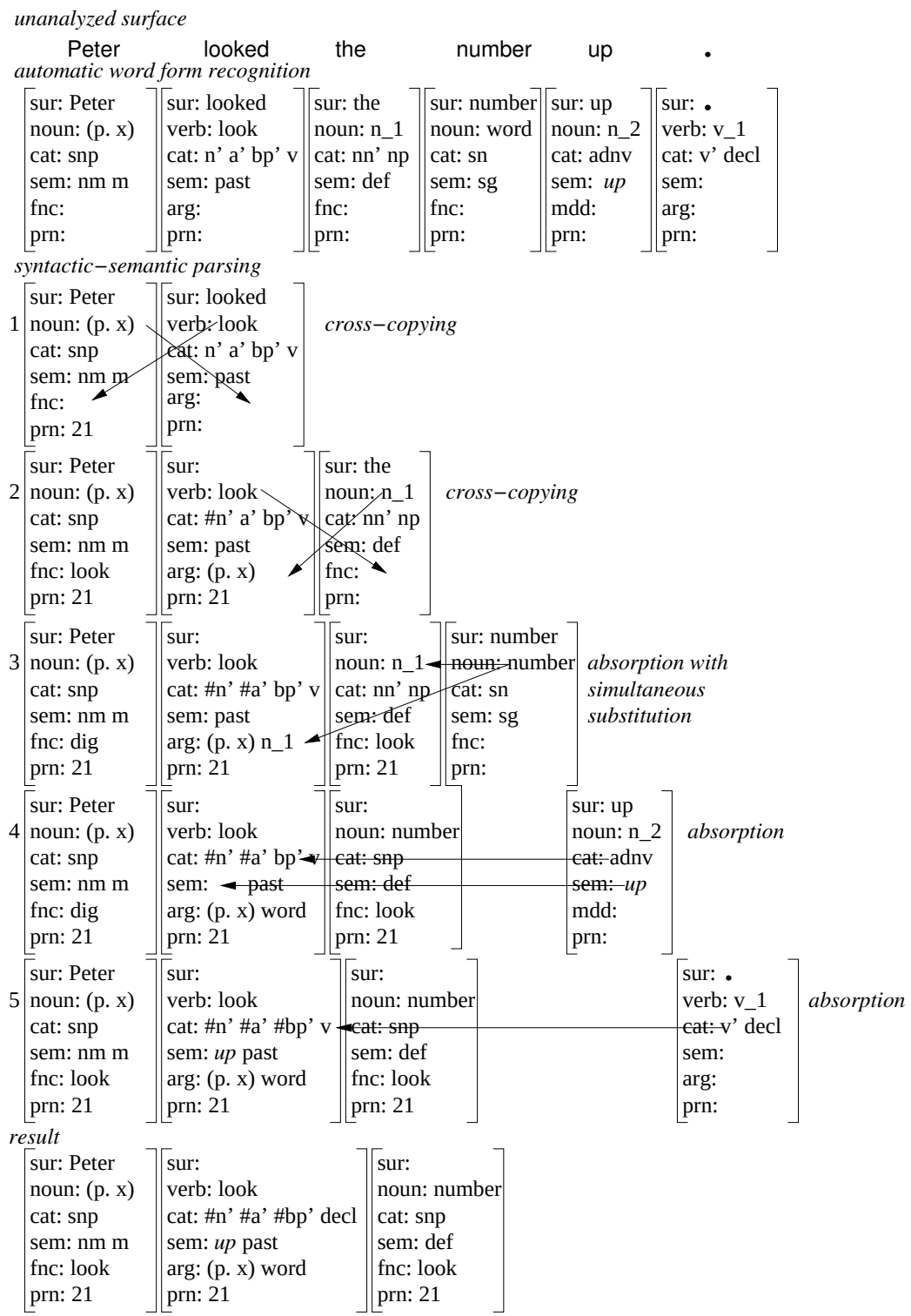
In summary, the output of the context-free base in transformational grammar must satisfy Constituent Structure but presumably[8] can not accommodate some natural surfaces. The output of the transformation component must satisfy the natural surfaces, but sometimes violates Constituent Structure. Worst of all, the introduction of transformations raises the computational complexity degree from polynomial (n^3) of context-free PSG to undecidable (Peters&Ritchie 1973).

In DBS, the example shown in 2.3 and 2.4 for PSG derives without any problem in the strictly time-linear, surface-compositional, data-driven manner of the hear mode:

[7] DPSG (Discontinuous Phrase Structure Grammar, Bunt et al. 1987) argues for accepting crossing lines in Phrase Structure Trees (quasi three-dimensional). It was preceded by pleas for using only context-free phrase structure by Harman (1963), McCawley (1982a), Gazdar et al. (1985), and others.

[8] Perhaps surprisingly, there exists a context-free PSG analysis for Peter looked the number up which satisfies 2.2. It is shown in 5.1 on the left, opposite the tree for Yesterday Mary danced.

2.5 DISCONTINUOUS STRUCTURE DERIVATION IN DBS HEAR MODE

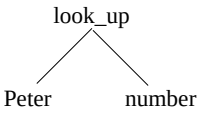


The semantic relations in the resulting content are shown by the following graph anal-

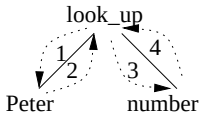
ysis. The surface realization of the speak mode is English:

2.6 Graphical presentation of the semantic relations in 2.5

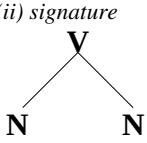
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

1	2	3	4
peter	looked	the_number	up_.
V/N	N/V	V\N	N\V

The content derived in 2.5 codes the discontinuous element *up* as the initial sem value of the *look* proplet in line 4. In the *(iv) surface realization*, up_. is realized from the finite verb (goal proplet of arc 4 in the *(iii) NAG*).

3 Suspension in DBS

The reason why Peter looked the number up violates Constituent Structure but Yesterday Mary danced does not may be shown by comparing their respective context-free PSG derivations, driven by the possible substitutions of rewrite rules:

3.1 CONTEXT-FREE PSGS FOR DISCONTINUOUS STRUCTURES

Peter looked the number up

S → NP VP
VP → VP NP
VP → V NP DE
NP → N
NP → DET N
N → Peter
V → looked
DET→ the
N → number
DE → up

Yesterday Mary danced

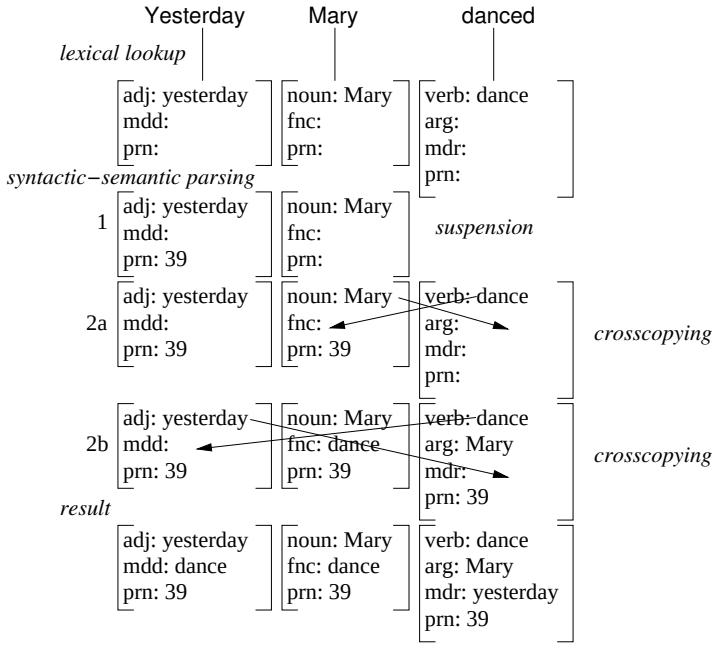
S → ADV VP
VP → NP V
NP → N
ADV→ yesterday
N → Mary
V → danced

The left PSG for 2.4 violates the requirement of *exhaustive* dominance with the rule VP→V NP DE.[9] The PSG on the right, in contrast, generates Yesterday Mary danced without any problem: first the ADV is placed in initial position by S→ADV VP; then VP→NP V places the subject noun after the ADV and before the V.

The apparent problem of DBS with Yesterday Mary danced, in contrast, results from the time-linear derivation order. It creates a temporary situation in which the modifier yesterday can not be connected because the modified danced has not yet arrived. The solution is a *suspension* until danced becomes available:

[9]Perhaps surprisingly, there exists a context-free PSG analysis for Peter looked the number up which satisfies 2.2. For comparison, it is shown in 5.1 on the left, opposite the tree for Yesterday Mary danced.

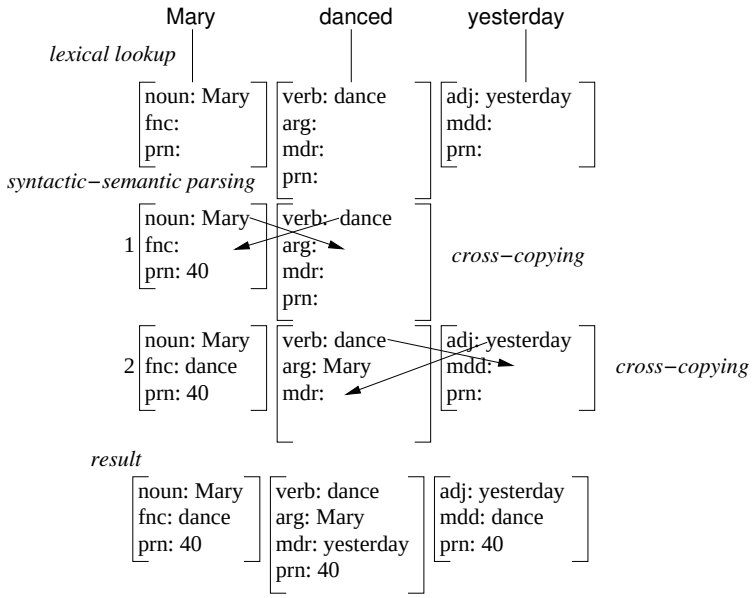
3.2 HEAR MODE DERIVATION OF Yesterday Mary danced.



Because operations are data-driven in DBS, instances of suspension are compensated automatically, without any need for additional software (convergence in science).

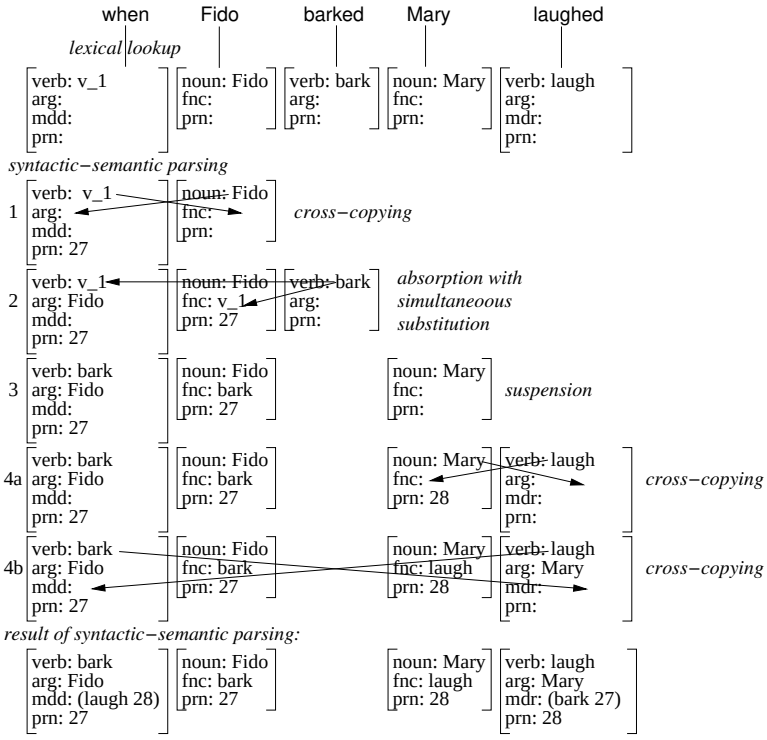
The phenomenon is asymmetric in that neither suspension nor absorption is required by the semantically equivalent word order Mary danced+yesterday (adjacency).

3.3 HEAR MODE DERIVATION OF Mary danced yesterday.



Suspension at the elementary level scales up directly to the phrasal and clausal levels. At the clausal level, the relation is extrapropositional:

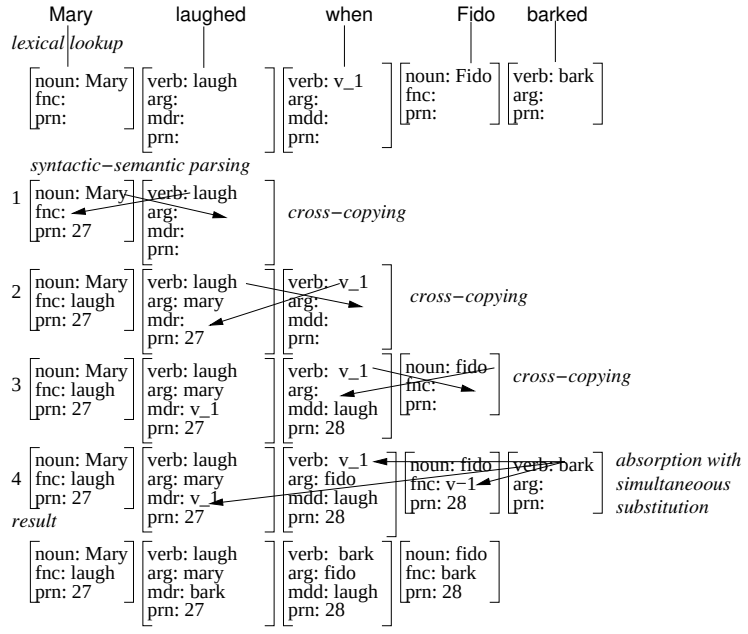
3.4 INTERPRETATION OF When Fido barked Mary laughed



The suspension occurs in line 3 and is compensated in lines 4a and 4b.

If the modifier clause follows the main clause, there is no suspension, just as in 3.3:

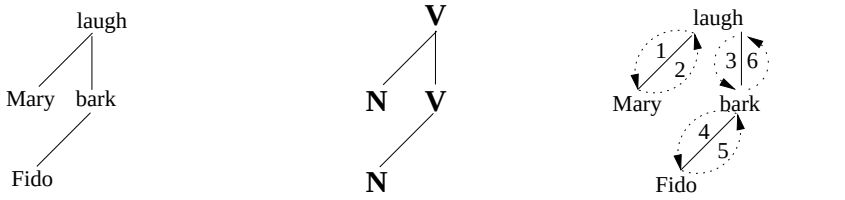
3.5 INTERPRETATION OF Mary laughed when Fido barked



Consider the semantic relations graph which underlies both surfaces:

3.6 GRAPHICAL PRESENTATION OF RELATIONS IN 3.4 AND 3.5

(i) SRG (semantic relations graph) *(ii) signature* *(iii) NAG (numbered arcs graph)*



(iv) surface realization

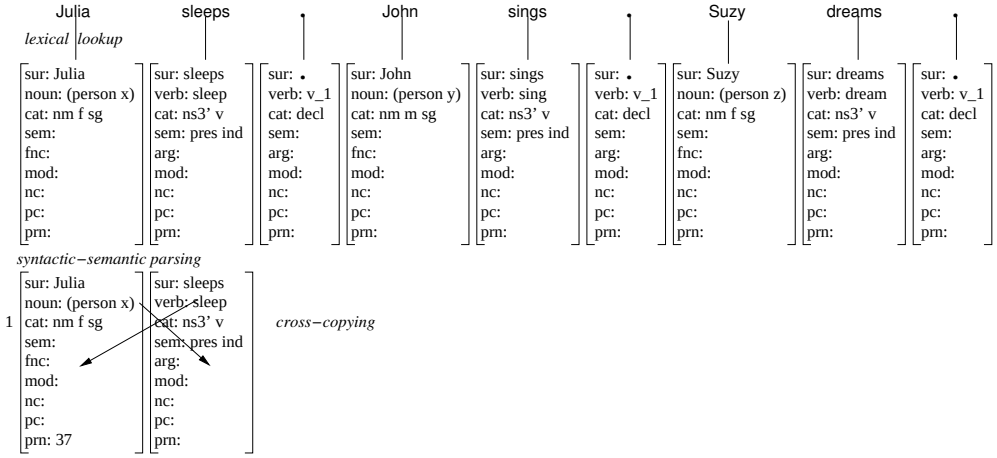
	3	4	5	6	1	2	
(a)	When	Fido	barked		Mary	laughed	.
	V|V	V/N	N/V	V|V	V/N	N/V	
	1	2	3	4	5	6	
(b)	Mary	laughed	when	Fido	barked	.	
	V/N	N/V	V|V	V/N	N/V	V|V	

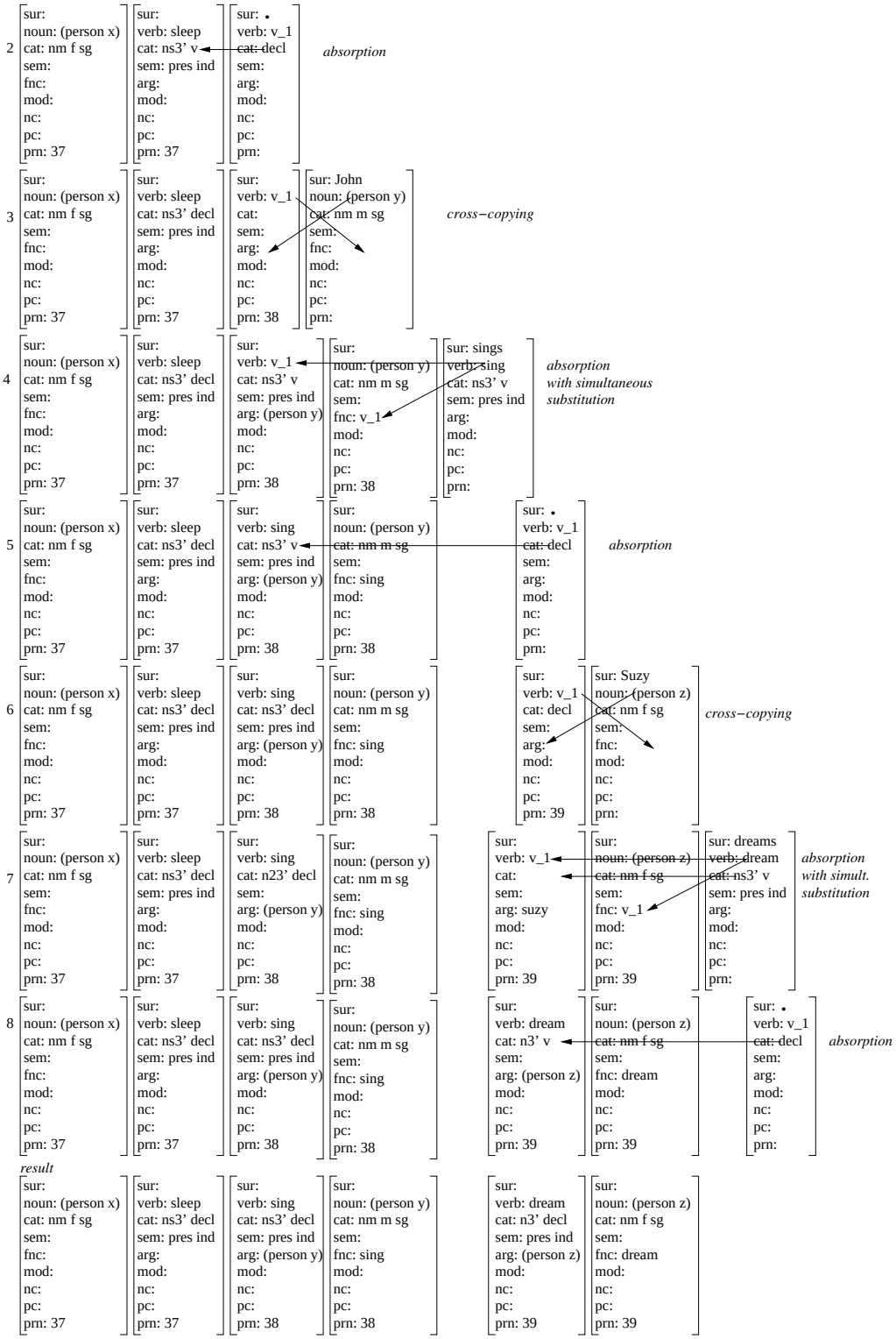
The suspension at the elementary level 3.2 and its variant 3.4 at the clausal level of grammatical complexity show that there are natural surface orders in which suspension cannot be avoided. Regarding the linear complexity of LAG/DBS, ambiguities induced by suspension are benign because they are not recursive (TCS'92).

It seems that discontinuous filler-slot constructions require a suspension (4.1), whereas discontinuous slot-filler constructions make do with an absorption (i.e., without ambiguity, 4.2). An example is extrapropositional coordination, as in a text. The relation between two adjacent sentences holds between the top verb of sentence n (into which the interpunctuation has been absorbed) and the top verb of sentence n+1. In a sequence of English declaratives, for example, the verb of sentence n+1 is usually preceded by the subject or an adverbial, creating the discontinuity.

The pivot of the absorption transition from the verb of sentence n to the verb of sentence n+1 is the interpunctuation (function word). This is shown by the following hear mode derivation of Julia sleeps. John sings. Suzy dreams.:

3.7 ABSORPTIONS IN EXTRAPROPOSITIONAL COORDINATION





Despite two extrapropositional transitions with intervening subjects (lines 3 and 6), there are no suspensions and consequently no compensations. Instead, the full stop

proplets in lines 2 and 5 simultaneously (i) supply the verbal mood decl to the verb of proposition n, i.e., the one the full-stop belongs to, and (ii) cross-copy with the subject of proposition n+1 if there is one. However, if there is no subsequent proposition, a variant of the interpunct operation (TExer 2.1.5–2.1.19) discards the interpunctuation proplet once its verbal mood value has been utilized (line 8).

4 Discontinuity with and without Suspension in DBS

The domain-range structure of a semantic relation may be viewed as a filler-slot constellation, with the domain providing the filler (also called the argument, actant, or complement) and the range (also called functor, codomain, or valency[10] carrier) providing the slot. In (i) subject/predicate, the subject is the filler and the predicate provides the slot, in (ii) object\predicate, the predicate provides the slot and the object is the filler, in (iii) modifier|modified, the modifier is the filler and the modified provides the slot, and in (iv) coordination, the slot-filler relation between conjuncts is bidirectional.[11]

If filler and slot provider are adjacent in the hear mode, i.e., if there are no intervening items, order does not make a difference. However, if there are intervening items and the slot provider precedes, then (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 place. If the filler precedes, in contrast, there may be many kinds of slot providers which is why no relation can be initiated; instead the hearer must wait until automatic word form recognition provides the slot, finally enabling an on the spot filler-slot combination.

In English filler-slot constellations, intervening items must be bridged by a suspension. Consider the following examples:

4.1 Suspension in 'Filler precedes slot' discontinuities

1. Clausal subject precedes main clause.
   That Fido found a bone surprised Mary.[12]
2. Adverbial precedes predicate (3.2)
   Yesterday Mary danced.
3. Clausal modifier precedes main clause (3.4)
   When Fido barked Mary laughed.
4. Subject gapping (TExer 5.2)
   Bob bought an apple, peeled a pear, and ate a peach.
5. Predicate gapping (TExer 5.3)
   Bob bought an apple, Jim a pair, and Bill a peach.
6. Long distance dependency (TExer 5.5)
   Who(m) did John say that Bill believes that Mary loves?

The grammatical role of the function words that, when, who, and and is shown in detail in the explicit hear mode derivations referred to.

Discontinuous 'slot provider precedes filler' constructions, in contrast, do not require a suspension. Instead, an *absorption* suffices:

[10] L. Tesnière (1959).

[11] The explicit specification of the semantic relations of structure by means of the connectives /, \, |, and – is more concise than the "belong semantically together" intuition of nativism.

[12] In That Fido barked amused Mary (TExer 2.5), the V/V relation between *bark* and *amuse* is not discontinuous because of there is no grammatical object and no suspension is needed. It is similar in the V|A relation of Mary danced yesterday (3.3).

4.2 NO SUSPENSION IN 'SLOT PRECEDES FILLER' DISCONTINUITIES

1. Verb precedes bare preposition (2.5)
   Peter looked the number up.
2. Main clause precedes clausal object (TExer 2.6)
   Mary heard that Fido barked.
3. Main clause precedes clausal modifier (3.5)
   Mary laughed when Fido barked.
4. Object gapping (TExer 5.4)
   Bill bought, Jim peeled, and Bill ate a peach.
5. Repeating object clauses (TExer 5.6)
   Mary saw the man who loves the woman who fed Fido.
6. Period precedes subject in extrapropositional coordination (3.7):
   Julia sleeps. John sings. Suzy dreams.

In English,'slot provider precedes filler' discontinuities use the additional function words who, whom, and . to (i) cross-copy with the intervening item and then to (ii) absorb and simultaneously substitute the filler.

In gapping constructions, the relation between the order of filler and slot provider, and the use of suspension vs. absorption is the reverse as compared to 4.1 and 4.2:

4.3 ABSORPTION VS. SUSPENSION IN GAPPING

1. Subject gapping (TExer 5.2)
   Bob bought an apple, peeled a pear, and ate a peach.
   Exception: filler-slot without suspension

2. Predicate gapping (TExer 5.3)
   Bob bought an apple, Jim a pair, and Bill a peach.
   Exception: filler-slot without suspension

3. Object gapping (TExer 5.4)
   Bill bought, Jim peeled, and Bill ate a peach.
   Exception: slot-filler with suspension

Object gapping is special in that it requires not only suspension, but also a derivation-external cache for storing the gap providers until the filler (as the standard location of the gap list) arrives.

5 Conclusion

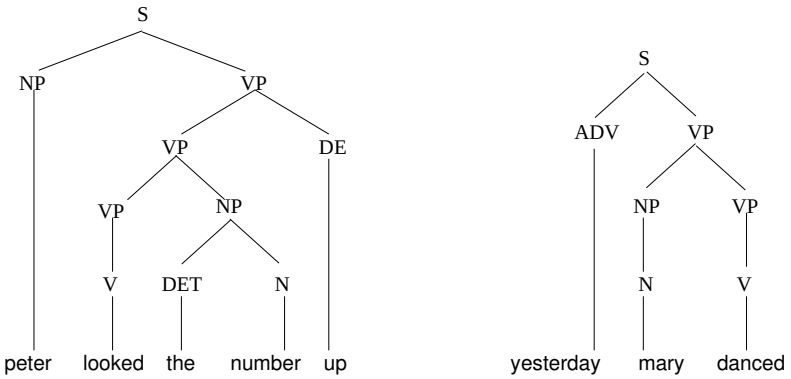
This paper started with an enigma. The examples

(i) Peter *looked* the number *up*. and

(ii) *Yesterday* Maria *danced.*

are both discontinuous. For context-free PSG, (i) poses a problem, solved by adding a movement component, while (ii) runs straight through. For DBS, (i) runs straight through, while (ii) poses a problem, solved by suspension and data-driven cross-copying (3.2). Let us conclude by showing what applying the PSG solution for example (ii) to example (i) in 3.1 would look like:

5.1 EXAMPLE 2.3 AS A PHRASE STRUCTURE SATISFYING 2.2



If the phrase structure on the right satisfies the Constituent Structure definition 2.2 then so does the one on the left: in both trees the lines do not cross; also the rules (a) VP $\rightarrow$ VP DE used on the left and (b) S $\rightarrow$ ADV VP used on the right are alike in that two nodes which "belong together semantically" are dominated directly and exhaustively by a single node.[13]

Today's PSG interprets "belonging together semantically" as the functor-argument relation of symbolic logic (first order predicate calculus). Thereby the question of whether the functor precedes or follows in the surface is treated as the language-dependent "problem of linearization." In data-driven DBS, in contrast, the functor-argument relation introduces a surface-compositional asymmetry, namely between a *slot-filler* and a *filler-slot* relation.

A slot provider looking for a filler is like trying a bag of old keys on a given piece of furniture, while a filler looking for a slot provider is like trying a given key on an open number of antiques. In English declaratives, the potential inefficiency of the filler-slot order in the subject/predicate constellation is effectively avoided by the post-nominative position (FoCL 18.3) of the finite verb, which provides adjacency.

Acknowledgement: Thanks to Professor Kiyong Lee for helpful comments.

[13] It is perhaps not unlikely that some of the linguists working with constituent structure at the time were secretly aware of the obvious possibility shown by the analysis on the left of 5.1. If so, what is so wrong with this phrase structure that adding a movement component was preferred even at the price of making the grammar algorithm undecidable?

First, being undecidable was fashionable in substitution-driven complexity analysis of the time, e.g., Post's (1946) Correspondence Problem. Second, discontinuities were not the main motivation for introducing a movement component; instead it was the assumption of a universal, innate context-free base in combination with a transformation component (nativism). Thus a discontinuity analysis exceeding the generative power of context-free PSGs came in handy as "empirical" support for the Standard Theory (ST, Chomsky 1965).

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