Language and Nonlanguage Cognition

Roland Hausser
Universität Erlangen-Nürnberg (em.)

Abstract

A basic distinction in agent-based data-driven DBS is between language and nonlanguage cognition. Language action and recognition transfer content between agents by means of raw data. Nonlanguage recognition and action map between content and raw data inside the focus agent. Action precedes recognition in language cognition, while recognition - including the output of inferencing - precedes action in nonlanguage cognition.

Action adapts concept types to a purpose, resulting in concept tokens. In language action, the focus agent (speaker) produces language-dependent surfaces for another agent (hearer), while nonlanguage action produces nonlanguage intentions for the focus agent. In either case, the input is a content and the output raw data.

Recognition applies concept types to raw data, resulting in concept tokens. In language recognition, the focus agent (hearer) takes raw language-data (surfaces) produced by another agent (speaker) as input, while nonlanguage recognition applies to raw nonlanguage-data of the focus agent. In either case, the input is raw data and the output a content.

By using place holder values for the concepts in language cognition, language and nonlanguage cognition are independent but interacting. As long as an independent procedural implementation of place holder values works properly, it supports the methodological requirement of input-output equivalence between the natural prototype and its reconstruction as a DBS robot.

keywords: data structure, semantic relations of structure, language and nonlanguage content, computational pattern matching, type-token relation, speak mode, hear mode, on-board database, interface component, surface composition

1 Building Blocks and Relations of DBS Cognition

Nonlanguage and language cognition use the same elementary building blocks and the same semantic relations connecting them into content:

1.1 Elementary building blocks

The elementary building blocks of DBS cognition are *proplets*, defined as nonrecursive feature structures with ordered attributes.

The relations connecting proplets into content are the classic semantic relations of structure (as opposed to the semantic relations of the lexicon):

1.2 Elementary semantic relations

1. subject/predicate
2. object\predicate
3. modifier|modified
4. conjunct−conjunct

2 Example of a Content

In contradistinction to propositions denoting truth values, propositions *are content* in DBS. A content is defined as a set of proplets, connected by the semantic relations of structure, coded by address. Consider the following example:

2.1 CONTENT OF Lucy found a big blue square . AS PROPLET SET

sur: lucy	sur:	sur:	sur:	sur:
noun: (person x)	**verb: find**	adj: **big**	adj: **blue**	**noun: square**
cat: snp	cat: n′ a′ decl	cat: adn	cat: adnv	cat: sn
sem: nm f	sem: ind past	sem: pad	sem: pad	sem: sg
fnc: find	**arg: (person x) square**	mdd: **square**	mdd:	**fnc: find**
mdr:	mdr:	mdr:	mdr:	mdr: **big**
nc:	nc:	nc: **blue**	nc:	nc:
pc:	pc:	pc:	pc: **big**	pc:
prn: 14	prn: 14	prn: 14	prn: 14	prn: 14

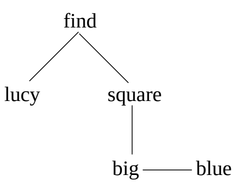
The subject/predicate relation is coded between (i) the core feature [noun: (person x)] of *lucy* and the continuation feature [arg: (person x) square] of *find* and (ii) the core feature [verb: find] of *find* and the continuation feature [fnc: find] of *lucy*. Similarly, the object\predicate relation is coded between (i) the core feature [noun: square] of *square* and the continuation feature [arg: (person x) square] of *find* and (ii) the core feature of [verb: find] of *find* and the continuation feature [fnc: find] of *square* (bidirectional).

3 Content as Input to the Speak Mode

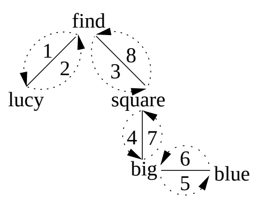
The speak mode takes a content like 2.1 as (i, ii) input, (iii) activates it with a time-linear navigation along the semantic relations of structure, and (iv) results in a language-dependent surface as output, realized as raw data in a medium of choice:

3.1 SEMANTIC RELATIONS UNDERLYING SPEAK MODE DERIVATION

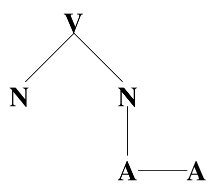
(i) SRG (semantic relations graph)



(iii) NAG (numbered arcs graph)



(ii) signature



(iv) surface realization

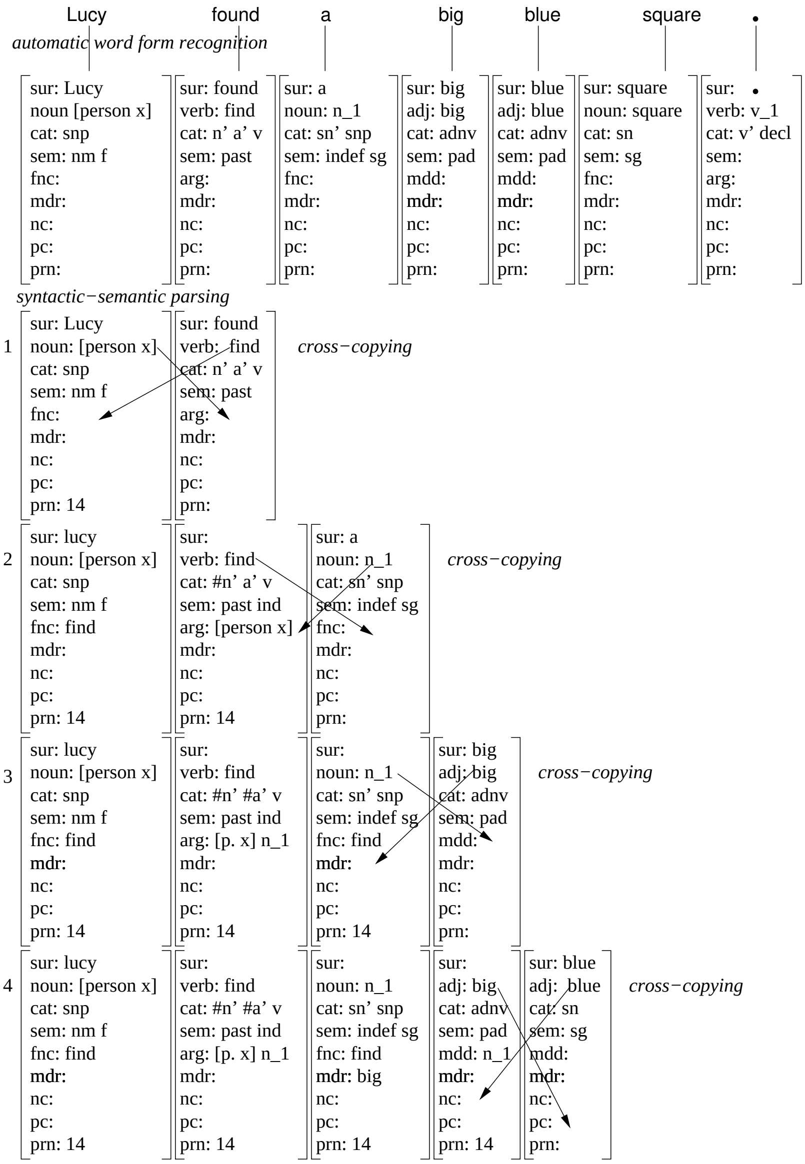
1	2	3	4	5	6	7	8
Lucy	found	a	big	blue		square	.
V/N	N/V	V\N	N|A	A−A	A−A	A|N	N|V

A kind of line has the same interpretation in all four representations. For example, the / line is the subject/predicate relation no matter whether it is long, as in the graphs (i), (ii), (iii), or short and of a somewhat different angle (for better formatting in print) in (iv) the surface realization.

4 Content as Output of the Hear Mode

The speaker's output is the hearer's input. The hearer reconstructs the speaker's input content 2.1 by means of a time-linear surface compositional derivation:

4.1 TIME-LINEAR SURFACE-COMPOSITIONAL HEAR MODE DERIVATION



5	sur: lucy noun: (person x) cat: snp sem: nm f fnc: find mdr: nc: pc: prn: 14	sur: verb: find cat: #n' #a' v sem: past ind arg: (p. x) n_1 mdr: nc: pc: prn: 14	sur: noun: n_1 cat: sn' snp sem: indef sg fnc: find mdr: big nc: pc: prn: 14	sur: adj: big cat: adnv sem: pad mdd: n_1 mdr: nc: blue pc: prn: 14	sur: adj: blue cat: adnv sem: pad mdd: mdr: nc: pc: big prn: 14	sur: square noun: square cat: sn sem: sg fnc: mdr: nc: pc: prn:	*absorption with simultaneous substitution*
6	sur: lucy noun: (person x) cat: snp sem: nm f fnc: find mdr: nc: pc: prn: 14	sur: verb: find cat: #n' #a' v sem: past ind arg: (p. x) square mdr: nc: pc: prn: 14	sur: noun: square cat: sn' snp sem: indef sg fnc: find mdr: big nc: pc: prn: 14	sur: adj: big cat: adnv sem: pad mdd: square mdr: nc: blue pc: prn: 14	sur: adj: blue cat: adnv sem: pad mdd: mdr: nc: pc: big prn: 14	sur: . verb: v_1 cat: v' decl sem: arg: mdr: nc: pc: prn:	*absorption*

result

sur: lucy noun: (person x) cat: snp sem: nm f fnc: find mdr: nc: pc: prn: 14	sur: verb: find cat: #n' #a' decl sem: past ind arg: (p. x) square mdr: nc: pc: prn: 14	sur: noun: square cat: sn' snp sem: indef sg fnc: find mdr: big nc: pc: prn: 14	sur: adj: big cat: adnv sem: pad mdd: square mdr: nc: blue pc: prn: 14	sur: adj: blue cat: adnv sem: pad mdd: mdr: nc: pc: big prn: 14

As required by the minimal standard for successful natural language communication, the output content of this hear mode derivation equals the content 2.1 used as input to the speak mode derivation 3.1 (iv).

The analysis of a DBS hear mode derivation is (a) *surface compositional* because each lexical item has a concrete sur value and there are no surfaces without a proplet analysis. The derivation order is (b) *time-linear*, as shown by the stair-like addition of a next word proplet. The application of operations is (c) *data-driven* by the incoming sequence of word form proplets provided by automatic word form recognition.

5 Nonlanguage Cognition Provides Definitions for Place Holder Values

A basic distinction in DBS grammar is between content and function words. Content words such as square, blue, and find use concept place holders as core and continuation values, while function words like (a) determiners, prepositions, and conjunctions use *substitution variables* and (b) pronouns use *pointers* at STAR values.

The following noun proplets have the same attributes, but differ in values:

5.1 Some lexical content word proplets: nouns

sur: square noun: *square* cat: sn sem: sg fnc: mdr: nc: pc: prn:	sur: squares noun: *square* cat: pn sem: pl fnc: mdr: nc: pc: prn:	sur: John noun: (person 10) cat: snp sem: sg m fnc: mdr: nc: pc: prn:	sur: Mary noun: (person 11) cat: snp sem: sg f fnc: mdr: nc: pc: prn:	sur: Gorch Fock noun: (bark 12) cat: snp sem: sg f fnc: mdr: nc: pc: prn:

The common noun proplets square and squares differ in grammatical number (cat slot), needed for agreement with the finite verb in the 3rd person singular indicative present. The name proplets John and Mary differ in grammatical gender, needed for coreference with the correct personal pronoun, e.g. he vs. she. The name proplet Gorch Fock illustrates the naming of inanimate objects like ships, mountains, and cities. Name proplets occur also in the plural[1], as in the Millers, which have the cat value pnp.

Function words with the same attributes as nouns are the determiners. They differ from content words in that their core value is a substitution variable, here n_1:

5.2 Some lexical function word proplets: determiners

sur: a(n)	sur: some	sur: all	sur: every	sur: the
noun: n_1	noun: n_1	noun: n_1	noun: n_1	noun: n_1
cat: sn′ snp	cat: nn′ np	cat: pn′ pnp	cat: sn′ snp	cat: nn′ np
sem: indef sg	sem: indef sel	sem: pl exh	sem: pl exh	sem: def
fnc:	fnc:	fnc:	fnc:	fnc:
...	...	...	...	...
prn:	prn:	prn:	prn:	prn:

For grammatical agreement, certain grammatical values of determiners equal those of common nouns, e.g. sg and pl. Additional grammatical values like def, indef, sn′, pn′, nn′, sel, and exh characterize grammatical properties needed for determiner∪noun combination by absorption (6.1).

6 Function Word Absorbs Content Word

The hear mode operation combining a determiner with a common noun takes two input proplets and produces one output proplet (function word absorption):

6.1 *The* absorbing *square* with DET∪CN

DET∪CN (h37)

pattern level				
	noun: N_*n*	noun: α	⇒	noun: α
	cat: X CN′ NP	cat: CN		cat: X NP
	sem: Y	sem: Z		sem: Y Z
	prn: K	prn:		prn: K

Agreement condition as in TExer 2.2.4

⇑ ⇓

content level			
	sur: The	sur: square	sur:
	noun: n_1	noun: square	noun: square
	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

[1] Pace Russell's (1905) "uniqueness condition" for"proper" names.

The input to the operation are the proplets *the* and *square*. The content word is absorbed into the function word by replacing the substitution variable n_1 with the place holder value square and adjusting the cat and sem values.

Thereby all instances of the substitution variable accumulated so far are replaced by the substitution value (simultaneous substitution, 4.1, line 5). It follows from the time-linear derivation order of natural language that once a substution variable has been replaced by a place holder, it cannot be used again (functional universal). However, subsequent reference to, e.g. the big, blue square, is enabled by an adnominal modifier clause, e.g. which ..., or a personal pronoun, e.g. it.

7 Type-Token Matching in Recognition and Action

The implementation of concepts like square or blue is language-independent work in cognitive psychology and robotics, while the construction of syntactic-semantic DBS grammars in the speak and the hear mode is language-dependent work in linguistics. Separating the empirical work on implementing language-independent concepts vs. language-dependent DBS grammars is made possible by the use of place holder values, which have abstract definitions based on natural science:

7.1 CONCEPT TYPE square AS DEFINED IN SCIENCE (GEOMETRY)

$$\begin{bmatrix}\text{edge 1: } \alpha \text{ cm}\\ \text{angle 1/2: } 90^o\\ \text{edge 2: } \alpha \text{ cm}\\ \text{angle 2/3: } 90^o\\ \text{edge 3: } \alpha \text{ cm}\\ \text{angle 3/4: } 90^o\\ \text{edge 4: } \alpha \text{ cm}\\ \text{angle 4/1: } 90^o\end{bmatrix}$$

The functioning of this nonlanguage recognition concept may be shown as follows:

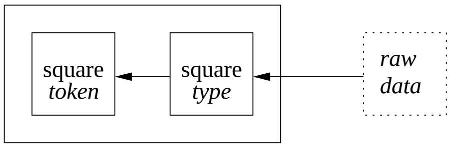
7.2 RECOGNITION: RAW DATA MATCHING TYPE RESULT IN TOKEN

$$\begin{array}{llcll}
\textit{concept type} & \begin{bmatrix}\text{edge 1: } \alpha \text{ cm}\\ \text{angle 1/2: } 90^o\\ \text{edge 2: } \alpha \text{ cm}\\ \text{angle 2/3: } 90^o\\ \text{edge 3: } \alpha \text{ cm}\\ \text{angle 3/4: } 90^o\\ \text{edge 4: } \alpha \text{ cm}\\ \text{angle 4/1: } 90^o\end{bmatrix} & \Rightarrow & \begin{bmatrix}\text{edge 1: 2 cm}\\ \text{angle 1/2: } 90^o\\ \text{edge 2: 2 cm}\\ \text{angle 2/3: } 90^o\\ \text{edge 3: 2 cm}\\ \text{angle 3/4: } 90^o\\ \text{edge 4: 2 cm}\\ \text{angle 4/1: } 90^o\end{bmatrix} & \textit{concept token}\\
 & \Uparrow \textit{ matching} & & & \\
\textit{raw data} & \begin{array}{l}\text{edge 1: 2 cm}\\ \text{angle 1/2: } 90^o\\ \text{edge 2: 2 cm}\\ \text{angle 2/3: } 90^o\\ \text{edge 3: 2 cm}\\ \text{angle 3/4: } 90^o\\ \text{edge 4: 2 cm}\\ \text{angle 4/1: } 90^o\end{array} & & &
\end{array}$$

The type defines the concept of a *square*. Replacing its variables with constants, here α with *2cm*, results in a concept token. The constants are measurements of raw input data provided by the agent's interface component.

More schematically, the agent's nonlanguage recognition of a square by means of type-token matching may be shown as follows:

7.3 USING A CONCEPT TYPE IN NONLANGUAGE RECOGNITION



The raw input data are provided by the agent's interface component. They are recognized as an instance of the two-dimensional shape square because there are four lines of equal length and the angle of their intersections is 90^{o}.

The action counterpart to 7.2 is the agent's cognition adapting a concept type into a concept token for a purpose:

7.4 ACTION: TYPE-TOKEN ADAPTATION RESULTS IN RAW DATA

$$\textit{concept type} \begin{bmatrix} \text{edge 1: } \alpha \text{ cm} \\ \text{angle 1/2: } 90^{o} \\ \text{edge 2: } \alpha \text{ cm} \\ \text{angle 2/3: } 90^{o} \\ \text{edge 3: } \alpha \text{ cm} \\ \text{angle 3/4: } 90^{o} \\ \text{edge 4: } \alpha \text{ cm} \\ \text{angle 4/1: } 90^{o} \end{bmatrix} \Rightarrow \begin{bmatrix} \text{edge 1: 2 cm} \\ \text{angle 1/2: } 90^{o} \\ \text{edge 2: 2 cm} \\ \text{angle 2/3: } 90^{o} \\ \text{edge 3: 2 cm} \\ \text{angle 3/4: } 90^{o} \\ \text{edge 4: 2 cm} \\ \text{angle 4/1: } 90^{o} \end{bmatrix} \textit{concept token}$$

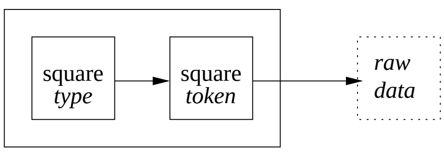
$$\Downarrow \textit{ matching}$$

$$\textit{raw data} \quad \begin{matrix} \text{edge 1: 2 cm} \\ \text{angle 1/2: } 90^{o} \\ \text{edge 2: 2 cm} \\ \text{angle 2/3: } 90^{o} \\ \text{edge 3: 2 cm} \\ \text{angle 3/4: } 90^{o} \\ \text{edge 4: 2 cm} \\ \text{angle 4/1: } 90^{o} \end{matrix}$$

Adapting the type to a purpose results in a token which is realized as raw data.

More schematically, the agent's nonlanguage action of drawing a square by means of a type-token adaptation may be shown as follows:

7.5 USING A CONCEPT TOKEN IN NONLANGUAGE ACTION



The definition of concept types, corresponding concept tokens, and raw data relies on the natural sciences, here geometry. Type-token matching in recognition and action is an instance of computational pattern matching in DBS (CC 1.6).

The concept *square* may be extended routinely to other two-dimensional geometric objects:

7.6 SIMILARITY AND DIFFERENCE BETWEEN CONCEPT SHAPE TYPES

place holder: equilateral triangle	place holder: rectangle	place holder: square
sensory modality: vision	sensory modality: vision	sensory modality: vision
semantic field: two-dim geom.	semantic field: two-dim geom.	semantic field: two-dim geom.
content kind: concept	content kind: concept	content kind: concept
shape: [edge 1: α cm	shape: [edge 1: α cm	shape: [edge 1: α cm
angle 1/2: 60^o	angle 1/2: 90^o	angle 1/2: 90^o
edge 2: α cm	edge 2: β cm	edge 2: α cm
angle 2/3: 60^o	angle 2/3: 90^o	angle 2/3: 90^o
edge 3: α cm	edge 3: α cm	edge 3: α cm
angle 3/4: 60^o	angle 3/4: 90^o	angle 3/4: 90^o
samples: a, b, c,...]	edge 4: β cm	edge 4: α cm
	angle 4/1: 90^o]	angle 4/1: 90^o]
samples: a, b, c,...	samples: a′, b′, c′,...	samples: a″, b″, c″,...

For retrieving the correct type, i.e. the one best matching the raw data at hand, the examples expand the concept analysis by embedding the geometric type shape into non-recursive feature structures with ordered attributes which specify the sensory modality, the semantic field, and whatever else is useful to aid retrieval of the type most suitable for matching the raw data.

The method of type-token matching in recognition and action illustrated above has been extended to the recognition and production of colors in CC 11.3.2, 11.3.4, and 11.3.5. In today's science, the work on OCR (optical character recognition) and ASR (automatic speech recognition) is largely based on statistics, but the method of type-token matching may be superimposed. In industrial applications, the electronic tongue (Winquist 2008) and the electronic nose (Persaud and George 1982) model the natural prototype using natural science. Integrating these modalities into the nonlanguage cognition of a DBS robot may provide many more place holder values with explicit operational counterparts.

8 Independence/Interaction of Language and Nonlanguage Cognition

On the one hand, the lines and angles of two-dimensional geometry have counterparts in neurology, such as the line, edge, and angle detectors in the optical cortex of the cat (Hubel and Wiesel 1962), and the iconic or sensory memories from which the internal image representations are built (Sperling 1960) and Neisser (1967). On the other hand, robotic vision (Wiriyathammabhum et al. 2016) applies the natural science of optics in ways which differ from the natural prototype (Pylyshyn 2009).

This is analogous to the difference between the natural flight of (i) birds, bats, and butterflies (flapping wings), and the artificial flight of (ii) air planes (fixed wings), and (iii) helicopters (rotors), all of which satisfy the laws of aerodynamics (CLaTR 1.1). The list goes on with differences in earth-bound locomotion (legs vs. wheels), and power supply (metabolism vs. electricity).

Input-output equivalence with the natural prototype is not in conflict with alternative (artificial) processing methods for the place holder values. As illustrated in 4.1, input-output equivalence affects macro-processing while alternative uses of the natural sciences affect micro-processing. This mutual independence/interaction between language and nonlanguage cognition is based on the largely language-independent place holder values in language cognition.

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