Outline of DBS

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Abstract

Database Semantics (DBS) models the cycle of natural language communication as a transition from the hear to the think to the speak and back to the hear mode (turn taking). In contradistinction to the sign-based substitution-driven approaches of truth-conditional semantics and phrase structure grammar, DBS is agent-based and data-driven. The goal is an efficient computational theory of natural language communication suitable for a talking autonomous robot.

Instead of denoting truth values, propositions are *content* in DBS (1–3). Content is built from the classical semantic kinds of referent, property, and relation, which are concatenated by the classical semantic relations of structure, i.e., functor-argument and coordination. To enable reference as an agent-internal cognitive process, language and nonlanguage contents use the same computational data structure and operation kinds, and differ mostly in the presence vs. absence of language-dependent surface values.

DBS consists of (i) an interface component for recognizing raw (i.e., cognition-external) data as input and producing raw data as output (action); (ii) an on-board database for storing and retrieving content provided by recognition, inferencing, and action; (iii) a now front as the arena for processing current content; (iv) an on-board orientation system (OBOS); and (v) an operations component for (a) content activation and inferencing in the think mode, (b) surface-content mapping in the hear mode, and (c) content-surface mapping in the speak mode.

keywords: data structure, data base schema, algorithm, pattern matching, turn taking, type-token, grounding, sensory and processing media and modalities, incremental transfer of content in communication using raw data

1 Building Content in the Agent's Hear Mode

DBS defines a content in terms of concepts like square (7.1) or blue (7.3) connected with the classical semantic relations of structure, i.e. subject/predicate, object\predicate, modifier|modified, and conjunct−conjunct. The concepts are supplied by the agent's memory and defined as types. In recognition, they are activated by matching raw data provided by the interface component, resulting in tokens.[1] In action, a type is adapted to a purpose as a token and realized as raw data (7.2, 7.4).

For concatenation, concepts are embedded as core values into nonrecursive feature structures with ordered attributes, called proplets. Proplets serve as the computational data structure of DBS. The semantic relations between proplets are established by address, making proplets order-free for purposes of storage and retrieval in the agent's content-addressable on-board database. Consider the following example of a content:

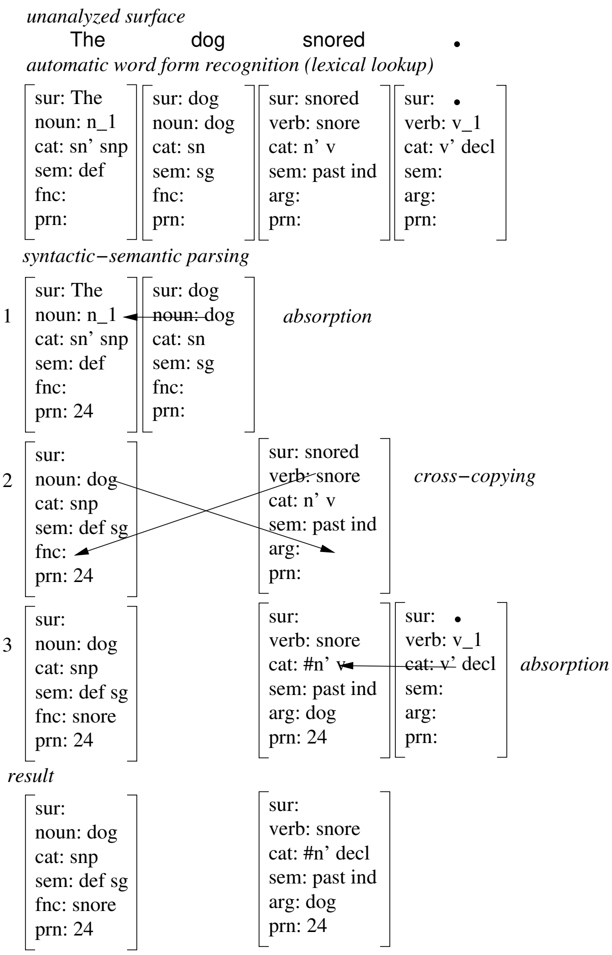
[1] The type-token terminology was introduced by C. S. Peirce (CP 4:537). It goes back to Aristotle's distinction between the *necessary* and the *accidental.*

1.1 THE 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

The proplets implement the subject/predicate relation by using the noun value **dog** of the first proplet as the arg value of the second, and the verb value **snore** as the fnc value of the first (bidirectional pointering). The order-free proplets of a content are stored and retrieved according to the alphabetical sequence of their core values, yet are connected by the address of their continuation values, here (snore 24) and (dog 24). In the hear mode, the content 1.1 results from the following derivation:

1.2 SURFACE COMPOSITIONAL TIME-LINEAR DERIVATION



The operations for concatenation in the hear mode, and activation and inferencing in the think-speak mode consist of (i) an antecedent, (ii) a connective, and (iii) a consequent. Defined as proplet patterns, operations are data-driven in that they are activated by matching content proplets.[2]

The hear mode uses three kinds of operations, each characterized by a connective: (1) × for cross-copying, (2) ∪ for absorption, and (3) ∼ for suspension. Cross-copying encodes the semantic relations such as SBJ×PRED (line 2). Absorption combines a function word with a content word such as DET∪CN (line 1) or another function word as in PREP∪DET. Suspension such as ADV∼NOM (TExer 3.1.3) applies if no semantic relation exists for connecting the next word with the content processed so far, as in Perhaps ∼ Fido (slept).

Consider the hear mode operation SBJ×PRED as it applies in line 2 of 1.2:

1.3 HEAR MODE APPLYING SBJ×PRED APPLYING (CROSS-COPYING)

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

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

$$\textit{content level}\quad \begin{bmatrix}\text{sur:}\\ \text{noun: }\textbf{dog}\\ \text{cat: def sg}\\ \text{sem:}\\ \text{fnc:}\\ \dots\\ \text{prn: 24}\end{bmatrix} \begin{bmatrix}\text{sur:}\\ \text{verb: }\textbf{snore}\\ \text{cat: n}'\text{ decl}\\ \text{sem: past ind}\\ \text{arg:}\\ \dots\\ \text{prn:}\end{bmatrix} \quad \begin{bmatrix}\text{sur:}\\ \text{noun: }\textbf{dog}\\ \text{cat: def sg}\\ \text{sem:}\\ \text{fnc: }\textbf{snore}\\ \dots\\ \text{prn: 24}\end{bmatrix} \begin{bmatrix}\text{sur:}\\ \text{verb: }\textbf{snore}\\ \text{cat: \#n}'\text{ decl}\\ \text{sem: past ind}\\ \text{arg: }\textbf{dog}\\ \dots\\ \text{prn:24}\end{bmatrix}$$

The second input proplet to a hear mode operation is the 'next word' provided by automatic word form recognition, here *snore*. By matching the second input pattern at the pattern level (⇑), the operation is triggered to look for a content proplet matching its first input pattern (⇕) at the now front (2.3). By binding α to dog and β to snore, the consequent produces the output as content proplets (⇓).

2 Storage and Retrieval of Content in the On-Board Memory

Contents derived in the hear mode and activated in the think-speak mode (3) have in common that they are defined as sets of self-contained proplets, concatenated by proplet-internal address. As sets, the proplets of a content are order-free, which is essential for their storage in and retrieval from the agent's A-memory (formerly called word bank). The database schema of A-memory is defined as follows:

2.1 TWO-DIMENSIONAL DATABASE SCHEMA OF A-MEMORY

- *horizontal token line*
  Horizontally, proplets with the same core value are stored in the same token line in the time-linear order of their arrival.
- *vertical column of token lines*
  Vertically, token lines are in the alphabetical order induced by the letter sequence of their core value.

[2]While the hear mode takes word form surfaces as input, the input to the think mode is content. Think mode operations are used with and without a surface realization, depending on whether the language-dependent lexicalization rules in the sur slots of the output pattern are turned on or off.

The arrival order of the member proplets is reflected by (a) the position in their token line and by (b) their prn value. The *(i) member proplets* are followed by a free slot as part of the column called the *(ii) now front*, and by the *(iii) owner*:[3]

2.2 A-MEMORY BEFORE INCREMENTAL STORAGE OF LEXICAL 1.1

	(i) member proplets		*(ii) now front*	*(iii) owner*
...	[sur: noun: dog ... prn: 3]	[sur: noun: dog ... prn: 6]		dog
...	[sur: noun: snore ... prn: 5]	[sur: noun: snore ... prn: 7]		snore

The owners equal the core values in their token line and are used for access in storage and retrieval. Proplets provided by current recognition, by A-memory, or by inferencing are stored at the now front in the token line corresponding to their core value:

2.3 STORAGE OF 1.1 AT THE NOW FRONT OF A-MEMORY

	(i) member proplets		*(ii) now front*	*(iii) owner*
...	[sur: noun: dog ... prn: 3]	[sur: noun: dog ... prn: 6]	[sur: chien noun: dog ... prn: 14]	dog
...	[sur: noun: snore ... prn: 5]	[sur: noun: snore ... prn: 7]	[sur: ronfler noun: snore ... prn: 14]	snore

Once a content has been assembled as a proposition, the now front is cleared by moving it and the owners to the right into fresh memory space (loom-like clearance,3). This leaves the proplets of the current content behind in what is becoming their permanent storage location as member proplets never to be changed, like sediment.

2.4 A-MEMORY AFTER NOW FRONT CLEARANCE

	(i) member proplets			*(ii) now front*	*(iii) owner*
...	[sur: noun: dog ... prn: 3]	[sur: noun: dog ... prn: 6]	[sur: noun: dog ... prn: 14]		dog
...	[sur: noun: snore ... prn: 5]	[sur: noun: snore ... prn: 7]	[sur: noun: snore ... prn: 14]		snore

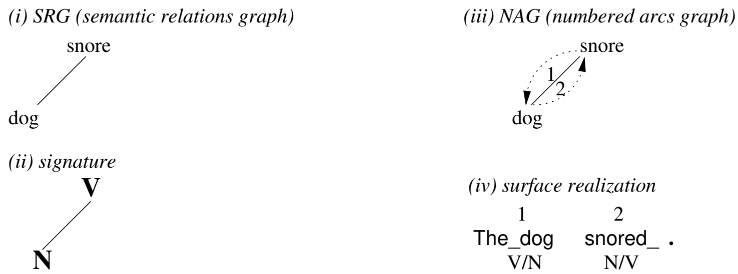
[3]The terminology of member proplets and owner values is reminiscent of the member and owner records in a classic network database (Elmasri and Navathe 1989[1]–2017[7]), which inspired the content-addressable database schema of the A-memory in DBS.

Current now front clearance is triggered when its proplets have ceased to be candidates for additional processing, i.e., when an elementary proposition is completed (formally indicated by the automatic incrementation of the prn value for the next proposition). Exceptions arise in *extrapropositional* (i) coordination and (ii) functor-argument. In these two cases, the verb of the completed proposition remains at the now front for cross-copying with the verb of the next proposition until the extrapropositional relation has been established in the strictly time-linear derivation order of DBS.

3 Speak Mode Riding Piggyback on the Think Mode

The speak mode counterpart to the hear mode derivation 1.2 is a graphical characterization of the semantic relations of structure, here only N/V for subject/predicate:

3.1 SEMANTIC RELATIONS GRAPH UNDERLYING THE CONTENT 1.1



The static aspects of the semantic relations of structure are shown on the left: the *(i) SRG* is based on the core values of the content and the *(ii) signature* on the core attributes. The dynamic aspects of a think-speak mode activation are shown on the right: the arc numbers of the *(iii) NAG* are used for specifying a time-linear think mode navigation along the semantic relations between proplets. The *(iv) surface realization* shows the language-dependent production as the speak mode riding piggy-back on the think mode navigation.

The think mode uses the following kinds of traversal operations: (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) verb→verb, (12) verb←verb, (13) adnominal→adnominal, and (14) adnominal←adnominal.

The think mode operations driving the traversal of the NAG in 3.1 are V↙N and N↗V, and apply as follows (shown with English surface production):

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

	V↙N		
pattern level	[verb: α arg: β X prn: K]	⇒	[sur: lexnoun($\hat{\beta}$) noun: β fnc: α prn: K]
	⇑		⇓
content level	[sur: verb: snore cat: #n′ decl sem: past ind arg: dog . . . prn: 14]		[sur: The_dog noun: dog cat: snp sem: sg m fnc: snore . . . prn: 14]

3.3 NAVIGATING WITH N↗V FROM *dog* BACK TO *snore* (arc 2)

N↗V

pattern level

[noun: β fnc: α mdr: Z prn: K]	⇒	[sur: lexverb($\hat{\alpha}$) verb: α arg: #β Y prn: K]

Z is NIL, or elementary and #-marked

⇑ ⇓

content level

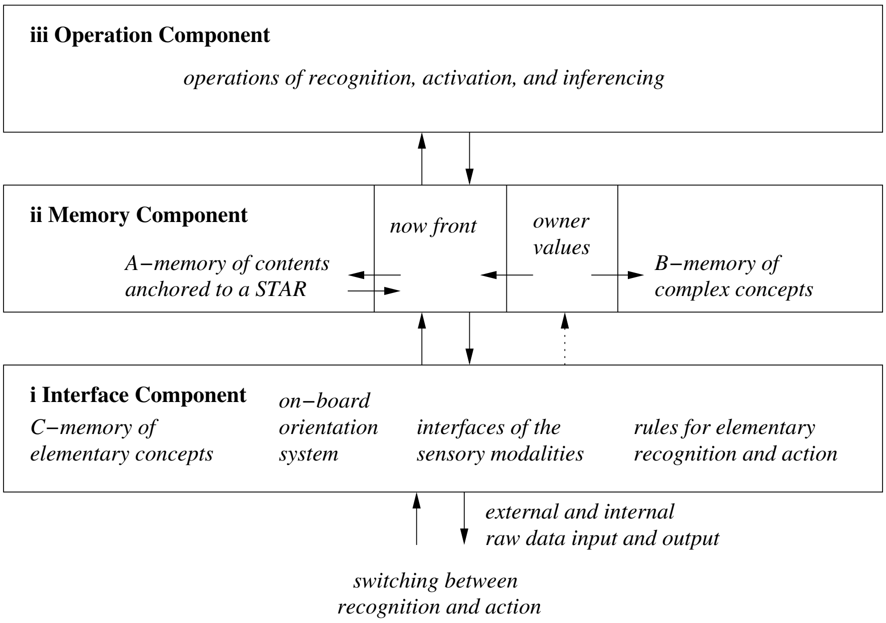
[sur noun: dog cat: snp sem: sg m fnc: snore . . . prn: 14]	[sur: snored_. verb: snore cat: #n′ decl sem: past ind arg: #dog . . . prn: 14]

If the lexnoun rules in the sur slot of the output patterns are switched on (as assumed in the surface realization of 3.1), they generate a language-dependent surface using relevant values of the output proplet.

4 Component Structure of DBS Cognition

The component structure of DBS cognition may be summarized as the following graph:

4.1 TWO-DIMENSIONAL LAYOUT OF DBS COGNITION COMPONENTS



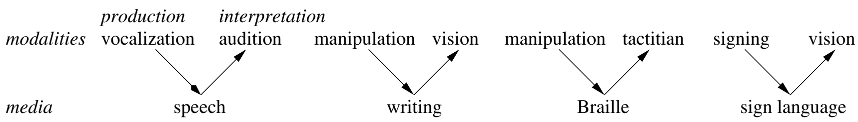
Cognitive content is processed at the now front. It gets proplets (a) from the interface component (aided by the owners) and (b) from A-memory. For processing, the now front provides proplets as input to (iii) the operations, which either replace the input with their output or add their output to the input. As the now front is cleared in regular intervals by moving into fresh memory space (2), the processed proplets are left behind in A-memory like sediment. Processing may also result in blueprints for action, which may be copied to the interface component for realization as raw data (subjunctive transfer, CLaTR 5.6).

5 Sensory Media, Processing Media, and their Modalities

A talking autonomous robot and its human prototype use different processing media, mockingly called hardware vs. wetware. Consequently, adequate modeling is limited to *functional equivalence*. A classic example of independence from the processing medium is the basic operations of arithmetic: 3+4 equals 7 no matter whether the calculation is performed by (i) a human,[4] (ii) a mechanical calculator, or (iii) a computer.

In addition to the processing media there are the sensory media. In natural language communication, there exist four, each of which has two sensory modalities.[5] For example, if the speaker chooses the medium of speech, the only sensory modality for production is vocalization (↘), which leaves the hearer no other option than using the sensory modality of audition (↗). This asymmetry of modalities holds also for the other sensory media of natural language, namely writing, Braille, and sign language:

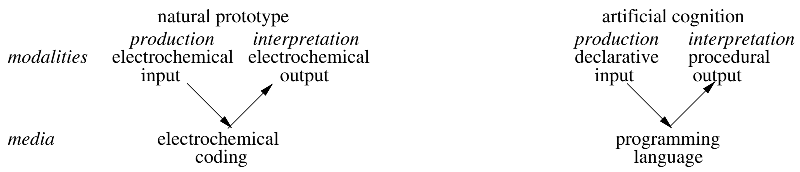
5.1 Sensory media and their modalities in communication



In terms of human evolution, the primary sensory medium is speech.

While the sensory media must be the same in the natural prototype and the artificial counterpart, as required by functional equivalence, the processing media are fundamentally different between the two. For the natural prototype, neurology suggests an electrochemical processing medium, though much is still unknown.[6] In artificial DBS cognition, in contrast, the processing medium is a programming language; its processing modalities are (i) the declarative specification of commands for interpretation by the computer and (ii) their procedural execution by the computer's electronic operations.

5.2 Processing media and their processing modalities



Utilizing a programming language as the processing medium of an artificial agent requires an interface component capable of efficiently mediating between raw data and an alphanumeric representation in recognition and action.

6 Reference as a Purely Cognitive Process

Sign-based philosophy defines reference as a relation between language (referring part) and the world (referred-to part). Reimer and Michaelson (2014) extend the referring

[4]The operations of arithmetic as they are processed by the human brain are described by Menon (2011).

[5]In the literature, the term modality has a multitude of uses, such as the temperature (Dodt and Zotterman 1952), the logical (Barcan Marcus 1961), and the epistemic (Kiefer 2018) modalities.

[6]For an early overview see Benson (1994).

part from language to “representational tokens,” which include cave paintings, pantomime, photographs, videos, etc. DBS continues in this direction by generalizing the referring part to content *per se*, i.e., without the need for any cognition-external counterpart (6.3, [-surface, -external]).

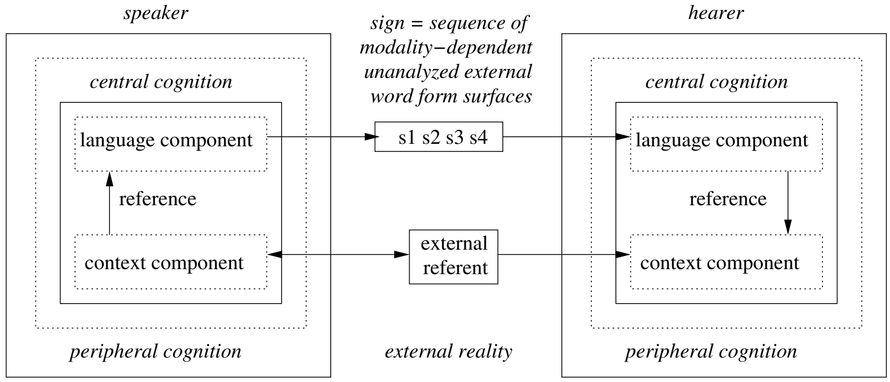
At the same time, agent-based DBS confines reference to nouns (CC 1.5.3, 12.3.3) and distinguishes (1) between referring nouns with and without external surfaces and (2) between referred-to nouns with and without external[7] counterparts. The two distinctions are characterized by the binary features [±surface] and [±external], whereby [+external] reference is called *immediate*, while [−external] reference is called *mediated* (FoCL 4.3.1).

For example, identifying “the man with the brown coat” (Quine 1960) with someone seen before, or identifying an unusual building with an earlier language content, e.g., something read in a guide book or heard about, is [−surface +external]. Talking about Aristotle or J.S. Bach, in contrast, is [+surface −external].

The [±surface] and [±external] distinctions are not available in truth-conditional semantics and generative grammar because their sign-based ontology does not distinguish (i) between cognition-external reality and cognition-internal processing, and between (ii) recognition and action, including the hear- and the speak-mode. Also, there is no onboard interface component with sensors and activators, no memory (content-addressable database) with an on-board orbientation system, and no algorithm for moment-by-moment monitoring. In short, sign-based substition-driven systems exclude by definition the components of a von Neumann machine (vNm, von Neumann 1945) and are therefore unsuitable in principle for designing and building a talking robot in particular and for AI in general.

Let us go systematically through the four kinds of generalized DBS reference, beginning with the [+surface +external] constellation between speaker and hearer:

6.1 Immediate reference in language communication

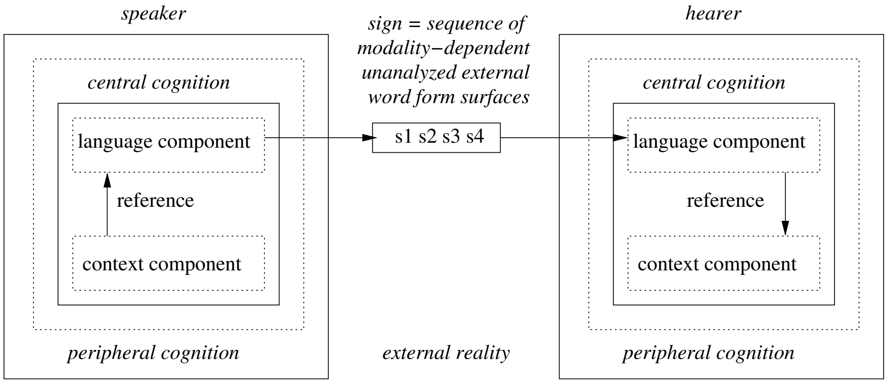


Agent-externally, language surfaces (shown here as s1 s2 s3 s4) are modality-specific unanalyzed external signs (raw data) which are passed from the speaker to the hearer and have neither meaning nor any grammatical properties, but may be measured by the natural sciences.

The corresponding [+surface −external] constellation between the speaker and the hearer is as follows:

[7]Newell and Simon (1972) call the agent’s external surroundings the *task environment*.

6.2 MEDIATED REFERENCE IN LANGUAGE COMMUNICATION



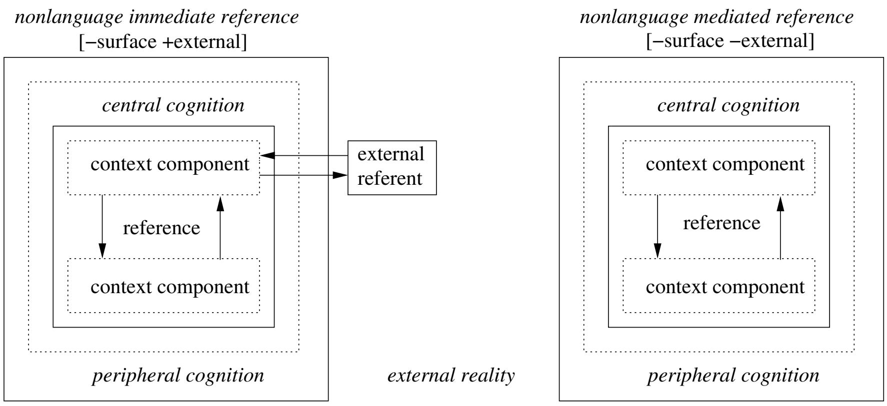
The reference relation begins with content in the memory of the speaker and ends as content in the memory of the hearer. The mechanisms of assigning surfaces to content in the speak mode and content to surfaces in the hear mode are the same in immediate and mediated language reference.

The graphs 6.1 and 6.2 show the speaker on the left, the sign in left-to-right writing order in the middle, and the hearer on the right. This is a possible constellation which is in concord with the naive assumption that time passes with the sun from left to right (→) on the Northern Hemisphere. Yet it appears that the first surface s1 leaves the speaker last and the last surface s4 arrives at the hearer first, which would be functionally incorrect.

It is a pseudo-problem, however, which vanishes if each surface is transmitted individually and placed to the right of its predecessor, i.e., (((s1 s2) s3) s4). This *left-associative*[8] departure and arrival structure allows incremental surface by surface processing, provided the derivation order is based on computing possible continuations, as in Left-Associative Grammar (TCS).

Nonlanguage reference differs from language reference in that it is [−surface]. Thereby nonlanguage immediate reference is [−surface +external] while nonlanguage mediated reference is [−surface −external]:

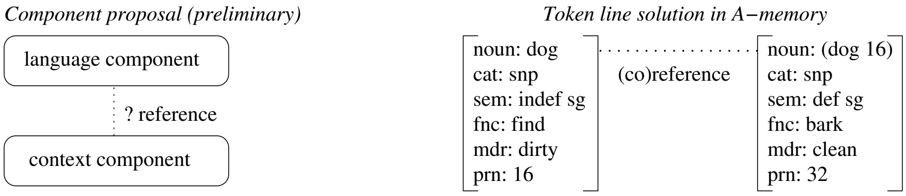
6.3 Nonlanguage immediate vs. mediated reference



The referring content in the [−surface +external] constellation is a current nonlanguage recognition, as when recognizing a person on the street. In the [−surface −external] constellation of nonlanguage mediated reference, in contrast, the referring content is activated without an external trigger, for example, by reasoning. In both, the referred-to content is resonating (CC 3.2, 3.3) in memory.

Computationally, the conceptual view of reference as a vertical interaction between two separate components in 6.1–6.3 is implemented as a horizontal relation between two proplets in the same token line:

6.4 COMPARING THE NAIVE AND THE COMPUTATIONAL SOLUTION

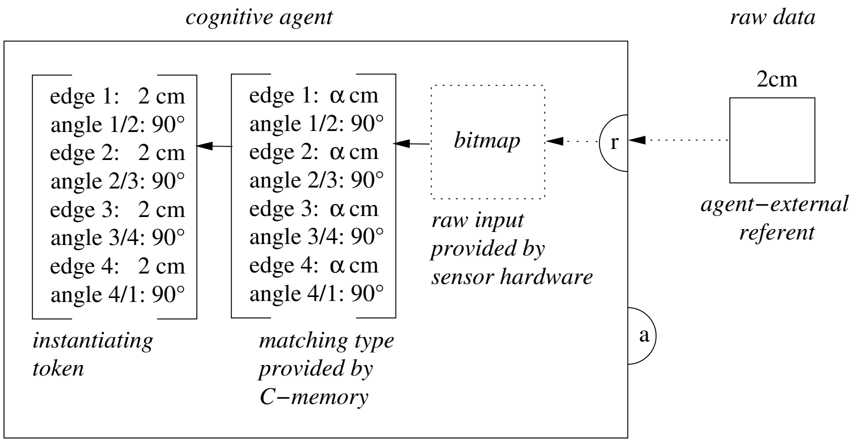


Because the semantic kind of referent is limited to the syntactic kind of noun, (co)reference is restricted to nominal concepts, indexicals, and names (CC 6.4.1, 6.4.4–6.4.6). The core value of the referring noun (shadow, copy) at the now front is always an address. The core value of the referred-to noun (referent, original) is never an address. The fnc and mdr values are free (identity in change, CC 6.4.7).

7 Grounding

The semantics of DBS is grounded (Barsalou et al. 2003, Steels 2008, Spranger et al. 2010). In recognition, concept types (supplied by the agent's memory) are matched with raw data (provided by sensors of the agent's interface component):

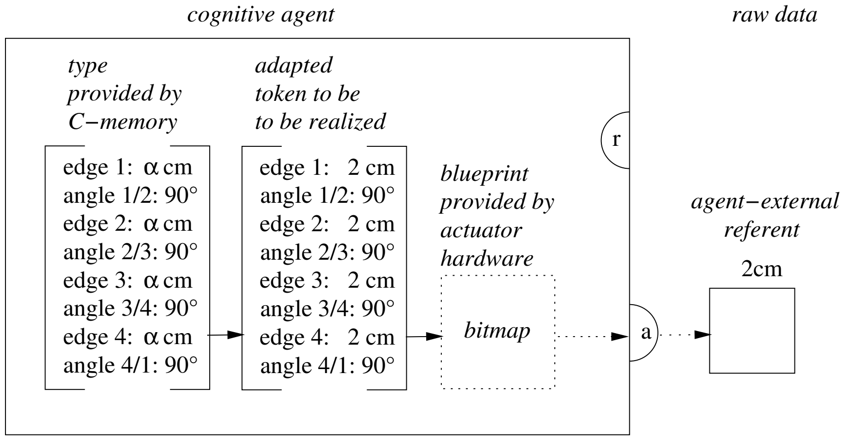
7.1 RECOGNITION OF square



The raw data are supplied by a sensor, here for vision, as input to the interface component. The raw data are matched by the type, resulting in a token.

In action, a type is adapted to a token for the purpose at hand and realized by the agent's actuators as raw data:

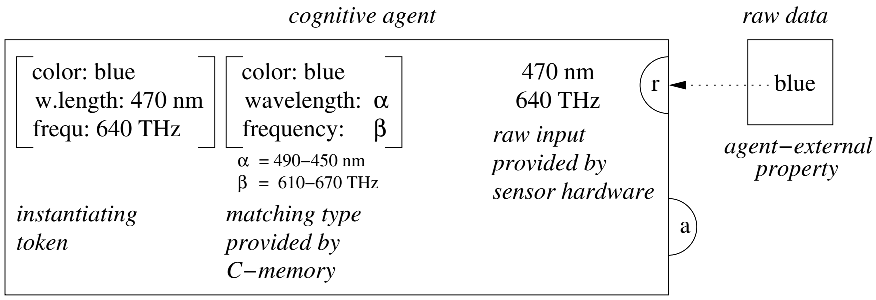
7.2 Action of realizing square



The token is used as a blueprint for action, (e.g., drawing a square).

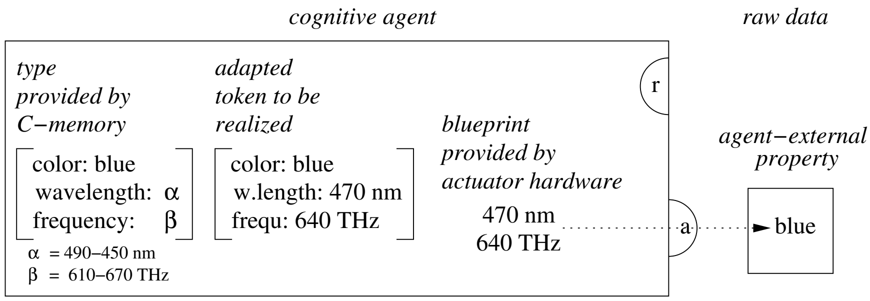
Next consider the recognition of a color, here blue:

7.3 Recognition of blue



An example of the corresponding action is turning on the color blue, as in a cuttlefish using its chromatophores:

7.4 Action of realizing blue



The concept type matches different shades of blue, whereby the variables α and β are instantiated as constants in the resulting token. Recognizing the color blue is a general mechanism which may be applied to all colors. It may be expanded to infrared and ultraviolet, and to varying intensity.[9]

Conclusion

Pattern matching based on the type-token relation applies to nonlanguage items (e.g., 7.1, 7.2, 7.3, 7.4) and language surfaces alike. For example, in the surfaces of spoken language the type generalizes over different pitch, timbre, dialect, and speaker-dependent pronunciation. In written language, the type generalizes over the size, color, and font of the letters. Computational type-token matching is more adequate descriptively than the nonbivalent (Rescher 1969; FoCL Chap. 20.5) and fuzzy (Zadeh 1965) logics for treating vagueness because type-token matching treats the phenomenon at the root (best candidate principle in pattern matching, FoCL 5.2) instead of tinkering with the truth tables of Propositional Calculus.

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[9]Complementary approaches from cognitive psychology are Prototype Theory (Rosch 1975) and Recognition by Components (RBC) based on geons (Biederman 1987).

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