Concepts in Computational Cognition

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Abstract

The sign kinds of natural language are the *concepts*, the *indexicals,* and the *names*. Of these, only the concepts interact directly with the agent's cognition-external environment, whereas indexicals and names receive their interpretation indirectly from cognition-internal content.

The analysis of concepts has been based on the ten categories of Aristotle, the four categories of Kant, Wittgenstein's family resemblance, and the prototypes of cognitive psychology. Their computational implementation as the recognition and action of an artificial cognition is adequate if and only if they equal the natural counterpart.

In natural and technological concepts, the desired equivalence has solutions grounded in science.[1] The problem is the computational implementation of the cultural concepts in different belief systems and traditions. The technical details of content transfer from speaker to hearer by means of raw data (sound waves, formants, light waves, pixels) are explicated in Sect. 8.

keywords: Cultural concepts, prototype, satellite, data structure, communication

1 Concept-Based Interpretation of Indexicals and Names

In agent-based data-driven DBS (AIJ'92), the reliance of indexicals and names on concepts is based on the type-token distinction from philosophy (Peirce 1906, CP Vol.4, p. 375) which goes back to Aristotle's distinction between the necessary and the accidental (Metaphysics). Consider the DBS analysis of a nonlanguage clausal content type with an indexical (first person pronoun pro1) and a name (Fido):

1.1 NONLANGUAGE CONTENT OF I saw Fido. AS TYPE

sur:	sur:	sur: fido
noun: **pro1**	verb: **see**	noun: β
cat: s1	cat: #n #a decl	cat: snp
sem: sg	sem: ind past	sem: sg
fnc: **see**	arg: **pro1** β	fnc: **see**
mdr:	mdr:	mdr:
nc:	nc:	nc:
pc:	pc:	pc:
prn: K	prn: K	prn: K

This is a nonlanguage content because the first two sur slots are empty and the value of the third sur slot is a marker, here fido (needed for the speak mode of agent-based DBS). It is a type because it is not connected to a STAR (as provided by the agent's onboard orientation system (FoCL 5.3, Hausser 2021b)), and the core value of the name proplet and the prn values are variables, here β and K.

[1]For the grounding of concepts in computer science see Barsalou et al. (2003) and Steels (2008).

In DBS, the STAR of a language content specifies the value of Space (location of the speaker), Time (moment of utterance), Agent (speaker), and Recipient (hearer), plus 3rd (third person), and prn (proposition number). Based on a STAR and language-dependent sur values, the nonlanguage clausal content type 1.1 may be turned into the token of a clausal language content:

1.2 LANGUAGE CONTENT OF I saw Fido. AS TOKEN

sur: I	sur: saw	sur: Fido	S: backyard
noun: **pro1**	verb: **see**	noun: **[dog x]**	T: Monday
cat: snp	cat: #n #a decl	cat: sp2	A: Sylvester
sem: sg	sem: ind past	sem: sg	R: Speedy
fnc: **see**	arg: **pro1 [dog x]**	fnc: **see**	3rd:
mdr:	mdr:	mdr:	prn: 3
nc:	nc:	nc:	
pc:	pc:	pc:	
prn: 3	prn: 3	prn: 3	

This is a language content because the sur slots have surfaces as values, here English. It is a token because it is connected to an explicit STAR proplet by a shared prn value defined as a constant, here 3, and the name proplet has a named referent (CASM'17) as core value, here **[dog x]**, instead of a variable. According to the STAR, the sentence was uttered in the space S (backyard) at the time T (Monday) by the agent A (speaker Sylvester) directed at the recipient R (hearer Speedy).

1.2 illustrates the dependence of indexicals on concepts by **pro1** pointing at the A value of the STAR. It shows the dependence of names on concepts by the named referent **[dog x]** as the core value of Fido, which serves as the grammatical object (second arg value of **see**). The Space and Time values of the STAR instantiate Aristotle's and Kant's category of *quantity* in DBS.

2 Concepts grounded in Science

The type-token distinction applies not only to clausal, but also to phrasal and elementary content. In elementary concepts with a grounding in physics this is straightforward, such as the following concept of the color blue:

2.1 TYPE AND TOKEN OF THE COLOR CONCEPT blue

type	*token*
place holder: blue	place holder: blue
sensory modality: vision	sensory modality: vision
semantic field: color	semantic field: color
content kind: concept	content kind: concept
wavelength: 450–495nm	wavelength: 470nm
frequency: 670–610 THz	frequency: 637 THz
samples: a, b, c, ...	

In the type, the color is specified by intervals for wavelength and frequency. In the token, the intervals are replaced by constants which lie within the intervals.

This method of defining the color blue may be generalized to all colors:

2.2 SIMILARITY AND DIFFERENCE BETWEEN COLOR CONCEPT TYPES

place holder: red	place holder: green	place holder: blue
sensory modality: vision	sensory modality: vision	sensory modality: vision
semantic field: color	semantic field: color	semantic field: color
content kind: concept	content kind: concept	content kind: concept
wavelength: 700-635 nm	wavelength:495-570 nm	wavelength: 490-450 nm
frequency: 430-480 THz	frequency: 526-606 THz	frequency: 610-670 THz
samples: a, b, c, ...	samples: a', b', c', ...	samples: a'', b'', c'', ...

The three types differ in their wavelength and frequency intervals, and their place holder and samples values; they share the sensory modality, semantic field, and content kind values.

Another class of concepts grounded in science are the shapes of two-dimensional geometry, such as the concept type and token of square:

2.3 TYPE AND TOKEN OF THE CONCEPT square

type		*token*	
place holder: square		place holder: square	
sensory modality: vision		sensory modality: vision	
semantic field: two-dim geom.		semantic field: two-dim geom.	
content kind: concept		content kind: concept	
shape:	edge 1: α cm	shape:	edge 1: 2 cm
	angle 1/2: 90°		angle 1/2: 90°
	edge 2: α cm		edge 2: 2 cm
	angle 2/3: 90°		angle 2/3: 90°
	edge 3: α cm		edge 3: 2 cm
	angle 3/4: 90°		angle 3/4: 90°
	edge 4: α cm		edge 4: 2 cm
	angle 4/1: 90°		angle 4/1: 90°
samples: a, b, c,...			

The edge value of the type is the variable α which matches an infinite number of square tokens with different edge lengths, here 2cm in the token.

Just as the definition of the concept *blue* may be generalized routinely to other colors (2.2), the definition of the concept *square* may be generalized to other shapes in two-dimensional geometry, such as *equilateral triangle,* and *rectangle*:

2.4 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°		angle 1/2: 90°		angle 1/2: 90°
	edge 2: α cm		edge 2: β cm		edge 2: α cm
	angle 2/3: 60°		angle 2/3: 90°		angle 2/3: 90°
	edge 3: α cm		edge 3: α cm		edge 3: α cm
	angle 3/4: 60°		angle 3/4: 90°		angle 3/4: 90°
	samples: a, b, c,...		edge 4: β cm		edge 4: α cm
samples: a, b, c,...			angle 4/1: 90°		angle 4/1: 90°
		samples: a', b', c',...		samples: a'', b'', c'',...	

The operational implementation of color and two-dimensional geometric shape recognition and action is essential for building the computational cognition of a

DBS robot. For example, assuming eye-hand orientation, the robot could effectively pick blue squares from any sample of geometric shapes in different colors.

3 'Natural Categories' as Concepts

The concepts grounded in science, e.g. 2.2 and 2.4, are treated by Rosch (1973) as a subclass of the 'natural categories,' called *physiological categories*. The focus, however, is on categories like fruit, which are not 'physiological'. Based on psychological tests, Rosch shows empirically that the elements dominated by a higher category are not sets (unordered), but cognitively structured around a culture-dependent *prototype*.

For example, for most people in Western Europe the prototype dominated by fruit is apple, surrounded by plums, pines, and olives as less typical representatives, with a decrease in prototypicality from left to right (Rosch 1973: 130ff.). This prototype information of 'fruit' differs markedly from the biological definition:

3.1 BIOLOGY-BASED LEXICAL DEFINITION OF 'FRUIT'

> The fleshy or dry ripened ovary of a flowering plant, enclosing the seed or seeds. Thus, apricots, bananas, and grapes, as well as bean pods, corn grains, tomatoes, cucumbers, and (in their shells) acorns and almonds, are all technically fruits.
>
> Encyclopedia Britannica

The DBS definition of concepts as *nonrecursive* feature structures with *ordered* attributes (like proplets) is a simple and efficient computational format for combining (i) well-established lexical definitions, including those grounded in science ('physiological categories'), with (ii) prototypes and their (iii) satellites:

3.2 TYPE AND TOKEN OF THE CONCEPT 'FRUIT' IN DBS FORMAT

type	*token*
placeholder: fruit	placeholder: fruit
part of: flowering plant	part of: flowering plant
prototype: apple	prototype: apple
satellites: plums, pines, olives	instantiation: plum
use: edible	use: edible
samples: a, b, c,...	samples: b

This combination of (i) the lexical definition 3.1 via the place holder fruit, (ii) the prototype apple, and (iii) its satellites supports different kinds of reasoning.

4 Technical Concepts as a Subclass of 'Natural Categories'

Another subclass of elementary concepts besides the physics-based (2.2, 2.4) and the biology-based (3.1) are the technological-based, for example, the concept of airplane. Lexically, the concept airplane has been defined follows:

4.1 Lexical definition of ‘airplane’

> Also called aeroplane or plane, any of a class of fixed-wing aircraft that is heavier than air, propelled by a screw propeller or a high-velocity jet, and supported by the dynamic reaction of the air against its wings.
>
> Encyclopedia Britannica

In analogy to the transition from 3.1 to 3.2, this definition may be integrated into the following nonrecursive feature structures with ordered attributes:

4.2 DBS Concept Type and Token of ‘airplane’

type	*token*
placeholder: airplane	placeholder: airplane
part of: top node[2]	part of: top node
prototype: Boeing 373 MAX	prototype: Boeing 373 MAX
satellites: Airbus A320, Cessna 172, Diamond DA40 NG, ...	instantiation: Cessna 172
use: transport	use: transport
samples: a, b, c,...	sample: b

A cognitive prototype and its satellites are culture dependent and a statistical foundation alone is unlikely to be sufficient for a well-functioning computational cognition. It is therefore advisable to equip a talking DBS robot with both, prototypes as well as well-established lexical definitions, which is easy enough (3.2, 4.2).

5 Grammatical Categories

The *categories* of philosophy and cognitive psychology are called *concepts* in linguistics, which uses the term category for the *grammatical* categories. The DBS data structure of proplets specifies the basic categories with the core attributes, i.e., noun, verb, or adj. These are differentiated further by the values of the cat and sem attributes. The combination of the core attribute and the cat and sem features in a proplet is called the *category complex* in DBS. In the following content (set of concatenated proplets), the category complexes are shown in *italics*:

5.1 Category Complexes in Lucy found a big blue square.

sur: Lucy	sur: found	sur: big	sur: blue	sur: square
noun: [person x]	*verb:* find	*adj:* big	*adj:* blue	*noun:* square
cat: snp	*cat: #n′ #a′ decl*	*cat: adn*	*cat: adn*	*cat: snp*
sem: nm f	*sem: ind past*	*sem: pad*	*sem: pad*	*sem: indef 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: K	prn: K	prn: K	prn: K	prn: K

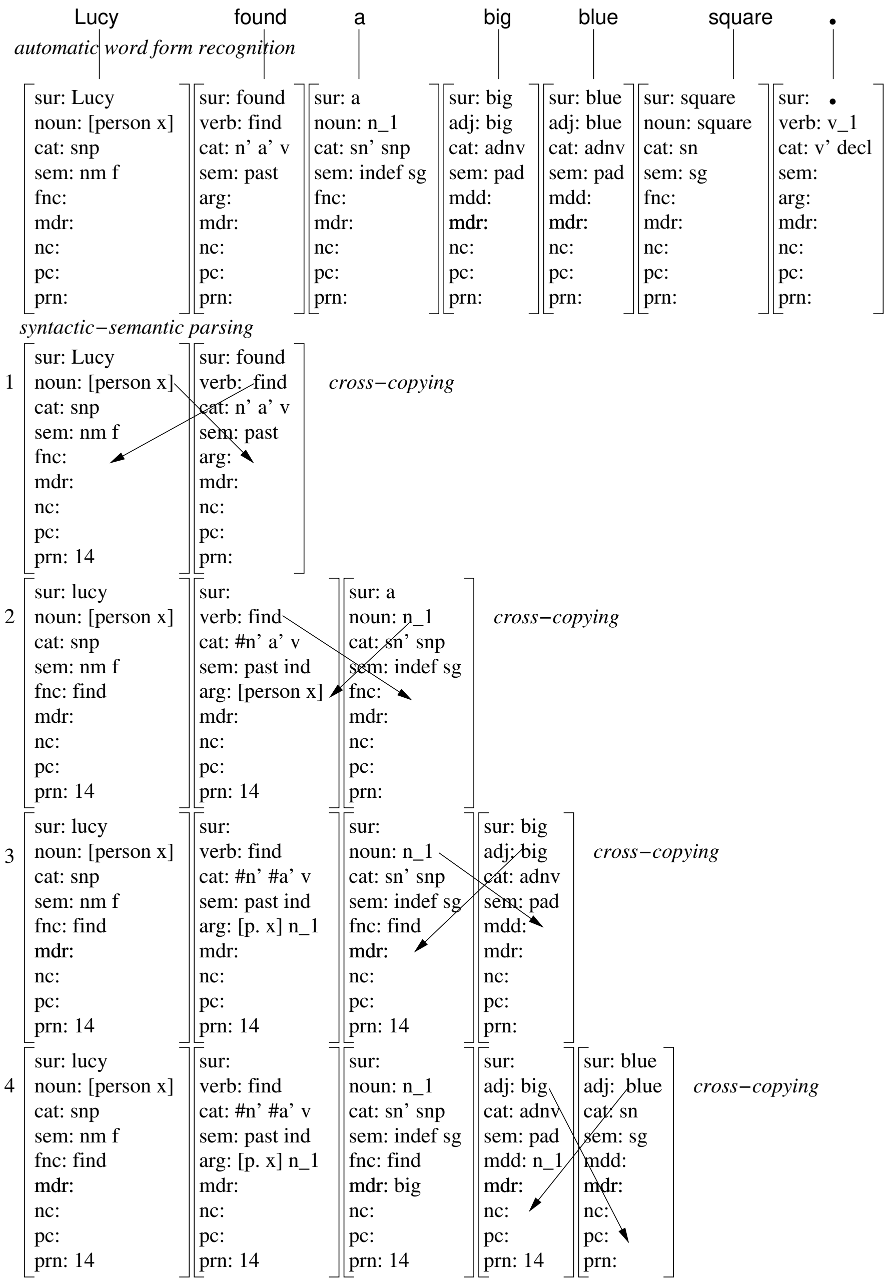
[2] ‘Vehicle’ in the context of airplanes seems to be reserved for ‘unmanned aerial vehicle’ (UAV).

The core values *blue* and *square* are defined in 2.1 and 2.3. For the other core values in 5.1, i.e., [*person x*], *find,* and *big*, explicit definitions are assumed.

6 Hear Mode: Concatenating Proplets into Complex Content

The derivation order of the DBS hear mode is *time-linear* by always concatenating a sentence start and a next word with a semantic relation into a new sentence start:

6.1 TIME-LINEAR SURFACE-COMPOSITIONAL HEAR MODE DERIVATION



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

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

result

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

The hear mode operations use the connectives (i) $\times$ for cross-copying (lines 1–4), (ii) $\cup$ for absorption (line 5), and (iii) $\sim$ for suspension. Cross-copying encodes the semantic relations of structure such as SBJ$\times$PRED. Absorption combines a function word with a content word such as DET$\cup$CN or with another function word as in PREP$\cup$DET (preposition$\cup$determiner, CLaTR 7.2.5). Suspension such as ADV$\sim$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 $\sim$ Fido (slept.).

Each derivation step 'consumes' exactly one next word (reading). The language-dependent sur value provided by lexical lookup is omitted in the operation output.[3] Lexical lookup and syntactic-semantic concatenation are incrementally intertwined: lookup of a new next word occurs only after the current next word has been processed into the current sentence start.[4]

7 Speak mode: Linearization of a Content by Navigation

The speak mode takes a content like 5.1 as input and produces a language-dependent surface as output. Graphically, the semantic relations of functor-argument are represented by the connectives / for subject/predicate, \ for object\predicate, and | for modifier|noun, modifier|verb, and modifier|modifier. The semantic relations of

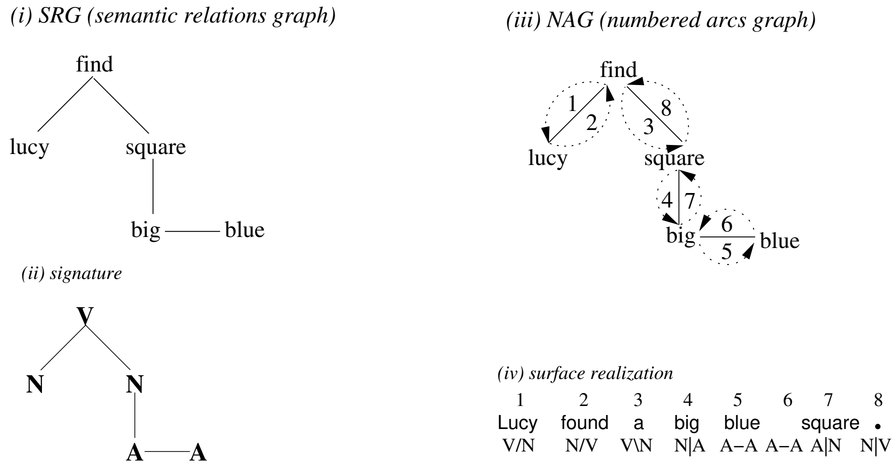
[3]A partial exception are name proplets, which preserve their sur value in the form of a marker written in lower case default font, e.g., lucy. In the speak mode, the marker is converted back into a regular sur value written in Helvetica, e.g., Lucy.

[4]The data coverage of DBS is shown in TExer with the explicit definition of 24 linguistically informed examples of English in the hear and the speak mode.

coordination are represented graphically by the connective (a) − for noun−noun, (b) verb−verb, (c) adn−adn, and (d) adv−adv.

Based on the definition of graphical /, \, |, and − for the semantic relations of structure, DBS analyzes a content like 5.1 in four standard views:

7.1 SEMANTIC RELATIONS UNDERLYING SPEAK MODE DERIVATION



The (i) SRG uses the sur marker of lucy and the core values find, square, big and blue of 5.1 as nodes. The (ii) *signature* uses the core attributes N(oun), V(erb), and A(dj) as nodes. The (iii) NAG completes the SRG with traversal numbers and shows content activation by the time-linear navigation through the semantic hierarchy in the think mode. The traversal numbers are used in the (iv); it optionally realizes language-dependent surfaces in a speak mode which rides piggyback on the think mode navigation.

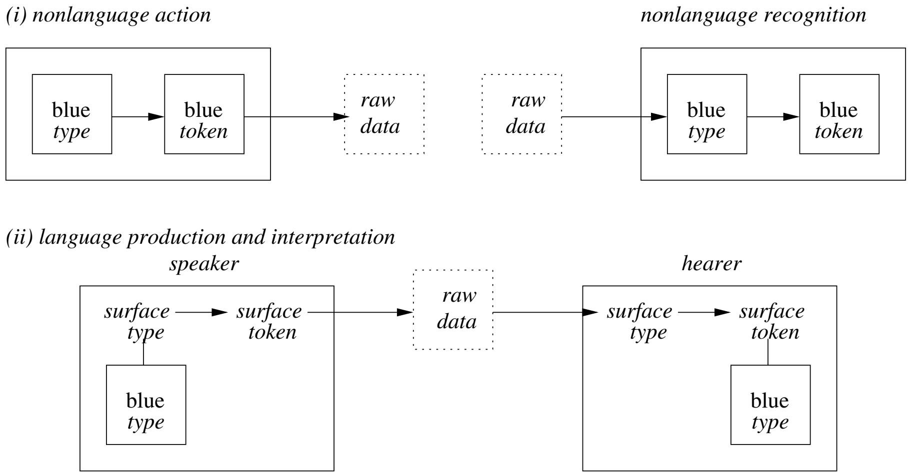
In summary, the input to the speak mode is a hierarchical content (5.1). The speak mode's time-linear navigation (7.1) through the input content achieves a *linearization* of the semantic hierarchy into a sequence of raw surface data as output. The raw data are produced from types by type-token adaptation.

The input to the hear mode is a time-linear sequence of raw surface data. The hear mode's surface-compositional derivation (6.1) achieves a re-*hierarchization* into a content; in successful communication, the speaker's input content equals the hearer's output content.

8 Natural Language Communication in Speech and Writing

In phylogenetic and ontogenetic evolution, nonlanguage cognition precedes language cognition. In the spirit of Charles Darwin, DBS extends nonlanguage action and recognition to the additional function of language surface production in the speak mode and surface interpretation in the hear mode. Extending the type-token distinction from nonlanguage recognition and action to the hear and speak mode of language cognition may be shown schematically as follows:

8.1 EXTENDING NONLANGUAGE INTO LANGUAGE COGNITION



In (i), action and recognition are alike in that they start with the type of the type-token relation. They differ in that the trigger of action is cognition-internal while the trigger of recognition is cognition-external. The output is in complementary distribution, i.e., cognition-external in action and cognition-internal in recognition.

In (ii), action and recognition are moved up to language-dependent surfaces which are connected to content by conventions every speaker-hearer of the language community had to learn (de Saussure 1916, first law: l'arbitraire du signe). As in nonlanguage cognition, production and interpretation of language surfaces have in common that they start with the type of the type-token relation, and differ in that the trigger of the speak mode (production) is cognition-internal while the input to the hear mode (interpretation) is cognition-external. The output is in complementary distribution, i.e., cognition-external in the speak mode and cognition-internal in the hear mode.

Type-token adaptation in speak mode surface production may be illustrated as follows (shown for the medium of writing):

8.2 SPEAK MODE: FROM CONTENT TO SURFACE TYPE TO RAW DATA

input: proplet token

[sur:
adj: blue
cat: adn
sem: pad
fnc: have
. . .
prn: 67]

⇓

output: surface type

[place holder: blue
sensory modality: manipulation
semantic field: language surface
content kind: Roman letters
actuator values: type shapes b l a u e s
samples: ...]

⇒ %b %l %a %u %e %s
raw output (pixels)

The core value of the proplet token *blue* (content) retrieves the language-dependent surface, here the type of German b l a u e s, based on a list which provides allomorphs using the input proplet's core, cat, and sem values (5, category complex). This output serves as input to a realization operation of the agent's interface component which adapts the surface type into a token, realized as raw data.

Type-token recognition in the hear mode may be illustrated as follows:

8.3 HEAR MODE: RAW DATA TO SURFACE TYPE TO SURFACE TOKEN

pattern: surface type		*output: surface token*
place holder: blue		place holder: blue
sensory modality: vision		sensory modality.: vision
semantic field: language surface	⇒	semantic field: language surface
content kind: roman letters		content kind: roman letters
shape types: b l a u e s		sensor values: shape tokens b% l% a% u% e% s%
samples: ...		samples: ...
⇑		
raw input (pixels)		

The input consists of raw data, provided by the agent's vision sensors and matched by the letters' shape types provided by the agent's memory. The output replaces the shape types, here b l a u e s, with the matching raw data resulting in shape tokens; they are shown as b% l% a% u% e% s% and record the accidental properties. The value crucial for the hearer's understanding, however, is the place holder, here *blue*, for the lexical look-up of the correct nonlanguage concept (2.1).

The language dependent surface types, the content types, and the conventions connecting the surface types with the content types exist solely[5] in the respective cognitions of speaker and hearer. This accounts for the fact that for communication to be successful, speaker and hearer must have *learned* the same natural language, including the ability to produce surface types as tokens in the speak mode and recognizing the surface tokens by means of matching types in the hear mode.

9 Conclusion

In natural language communication, the transfer of content from speaker to hearer is achieved incrementally by a time-linear sequence of raw data (sound waves in the medium of speech, light waves in writing, etc.) produced as output by the speak mode and serving as input to the hear mode. This constitutes the *language channel* of data-driven agent-based DBS. While (i) navigating the semantic hierarchy in the speak mode (7.1) and (ii) reconstructing the semantic hiearchy in the hear mode (6.1) have found efficient software solutions in DBS (linear, TCS'92), an operational reconstruction of cultural concepts remains a challenge. In search for a solution, it is proposed to combine the culture-dependent prototypes of Rosch (1973, 1974) with well-established lexical definitions, accommodated by the computational data structure of proplets (3), defined as nonrecursive feature structures with ordered attributes.

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[5] Anything else would be reification, which is uniquely inappropriate for building a talking robot.