The Grounding of Concepts in Science

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Abstract

Mammalian cognition interacts with the raw data of its external and internal surroundings by means of concepts for shape, color, smell, taste, temperature, etc. (exteroception), but also hunger, thirst, and emotion (interoception). Recent advances in molecular biology and biochemistry define these concepts in terms of receptors consisting of complex proteins matching the input of characteristic molecules, but also in terms of protons in vision and sound waves in audition (*natural science*).

In parallel, driven by industrial applications, the biological mechanisms have been modeled artificially for some of these concepts, notably the electronic nose and the electronic tongue (*engineering science*). After showing why the approaches to meaning in philosophy and linguistics (*humanities*) are unsuitable for the grounding of concepts in the computational cognition of an autonomous robot, this paper proposes to utilize the theoretical and practical advances of the neighboring sciences.

keywords: language-nonlanguage content, type-token, recognition-action, exteroception-interoception, receptor proteins, electronic nose and tongue

1 The Place of Concepts in a Content

DBS follows classical tradition in the humanities by distinguishing (i) three basic kinds of *content*, (ii) three basic kinds of *concepts*, and (iii) two basic forms of *combination* (the big C's). The elementary contents are (1) concept, (2) indexical, and (3) name. The concepts are (a) referent, (b) property, and (c) relation. The combinations are the semantic relations of structure, i.e., (α) functor-argument and (β) coordination. In α, relations combine two or three referents into propositions, and properties modify referents, relations, or properties. In β, several referents, relations, or properties of the same kind concatenate into conjunctions.

Consider the interaction of content, concept, and combination in the complex language content of Lucy found a big blue square.:

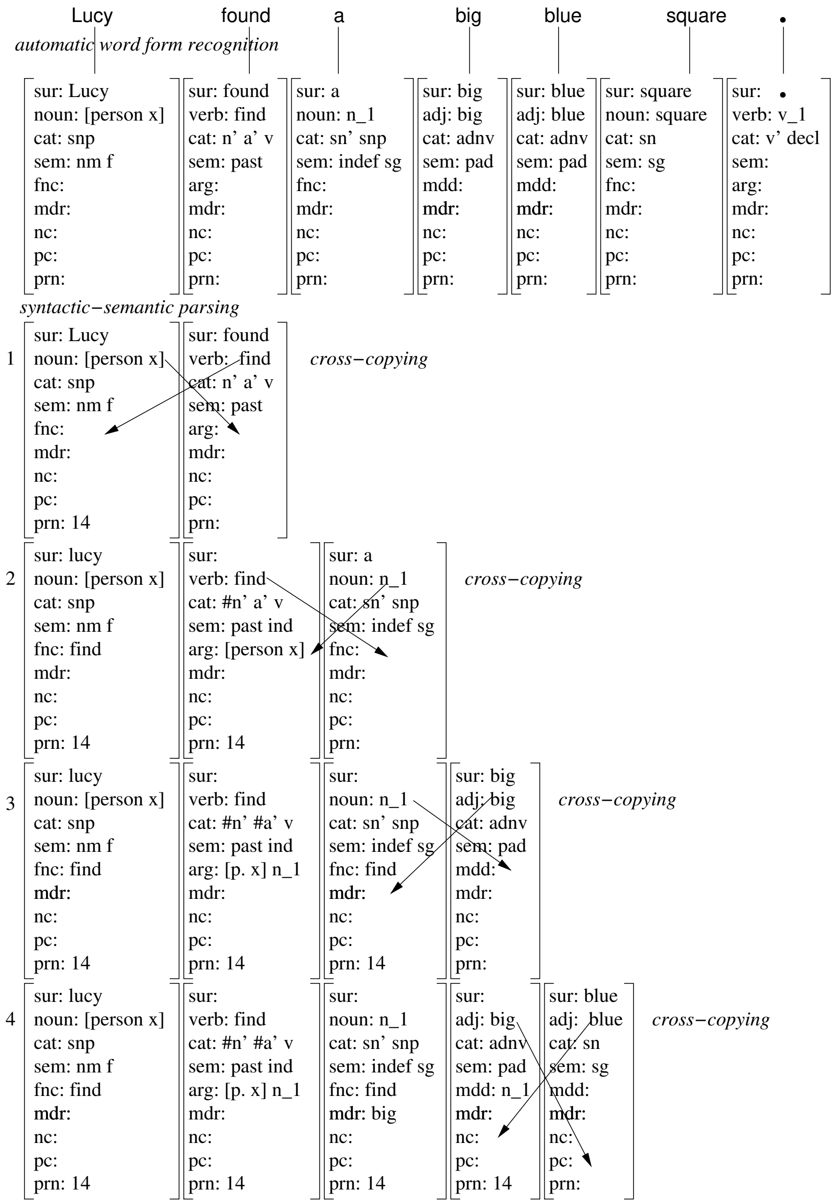
1.1 FUNCTOR-ARGUMENT AND COORDINATION IN LANG. CONTENT

referent (noun)	relation (transitive verb)	property (adn)	property (adn)	referent (noun)
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: 23	prn: 23	prn: 23	prn: 23	prn: 23

A content is a set of proplets, defined as nonrecursive feature structures with ordered attributes, connected by the semantic relations of structure, coded by address.

The hear mode takes the surface Lucy found a big blue square. as input and derives the content 1.1 as output. The following derivation is (i) *surface compositional* because each lexical item has a concrete sur value and there are no surfaces without a proplet analysis. The derivation order is (ii) *time-linear*, as shown by the stair-like addition of a next word proplet. The activation and application of operations is (iii) *data-driven* by input from automatic word form recognition:

1.2 TIME-LINEAR SURFACE-COMPOSITIONAL HEAR MODE DERIVATION



5	sur: lucy	sur:	sur:	sur:	sur:	sur: square	*absorption with simultaneous substitution*
	noun: [person x]	verb: find	noun: n_1	adj: big	adj: blue	noun: square	
	cat: snp	cat: #n' #a' v	cat: sn' snp	cat: adnv	cat: adnv	cat: sn	
	sem: nm f	sem: past ind	sem: indef sg	sem: pad	sem: pad	sem: sg	
	fnc: find	arg: [p. x] n_1	fnc: find	mdd: n_1	mdd:	fnc:	
	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: •	*absorption*
	noun: [person x]	verb: find	noun: square	adj: big	adj: blue	verb: v_1	
	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 operations of the hear mode use the connectives (1) $\times$ for cross-copying, (2) $\cup$ for absorption, and (3) $\sim$ for suspension. Cross-copying encodes the semantic relations of structure such as SBJ$\times$PRED (subject$\times$predicate, line 2). Absorption combines a function word with a content word such as DET$\cup$CN (line 1) 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). In a concatenation, the language-dependent sur value provided by lexical lookup is omitted.[1] 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.

In a graphical hear mode derivation like 1.2, cross-copying between two proplets is indicated by two diagonal arrows and the result is shown in the next line. This includes changes in the cat and the sem slots. For example, the canceling of the n′ (nominative) and a′ (accusative) valency positions in the cat slot of the *find* proplet of lines 2 and 3 is indicated by #-marking.[2]

[1] 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.

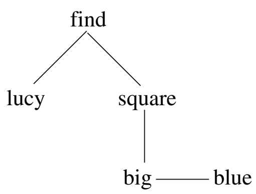
[2] Canceling by #-marking preserves the canceled value for use in the DBS speak mode. This is in contradistinction to Categorial Grammar (CG), which cancels valency positions by deletion (loss of information). As a sign-based system, CG does not distinguish between the speak and the hear mode.

The speak mode takes a content like 1.1 as input and produces a language-dependent surface as output. Graphically, the semantic relations of functor-argument are represented as the connectives / for subject/predicate, \ for object\predicate, and | for modifier|noun, modifier|verb, and modifier|modifier. The semantic relations of coordination are represented graphically as the connective (a) − for noun−noun, (b) verb−verb, (c) adn−adn, and (d) adv−adv.

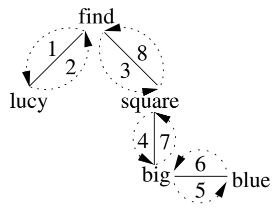
Based on the definition of graphical /, \, |, and − for the semantic relations of structure, DBS analyzes a content like 1.1 in four standard views:

1.3 SEMANTIC RELATIONS UNDERLYING SPEAK MODE DERIVATION

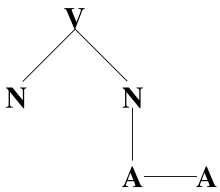
(i) SRG (semantic relations graph)



(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

The (i) SRG (*semantic relations graph*) uses the core values lucy, find, square, big and blue of 1.1 as nodes. The (ii) *signature* uses the core attributes N(oun), V(erb), and A(dj) as nodes. The (iii) NAG (*numbered arcs graph*) complements the SRG with numbered arcs which are used in the (iv) *surface realization* to show the content activation by the time-linear navigation through the semantic hierarchy in the think mode and to optionally realize language-dependent surfaces in a speak mode which rides piggyback on the think mode navigation.

In summary, the speak mode's time-linear navigation (1.3), iv) through the input content (1.1) achieves a *linearization* of a semantic hierarchy into a language surface which is suitable for an incremental content transfer from speaker to hearer. The hear mode's surface-compositional derivation (1.2) achieves a re-*hierarchization* of the speaker's content from the time-linear input surface.

2 Definition of Concepts at the Elementary, Phrasal, or Clausal Level?

In a syntactic-semantic analysis of a content like 1.1, the concepts (as the elementary building blocks of DBS cognition) are shown by placeholder values, using English base forms for convenience. Let us turn now to the topic of this paper, namely the question of how to complete place holder values with computational implementations suitable for the cognition of an artificial autonomous agent.

A rough semantic delimitation of a place holder concept is provided by its attribute in a proplet. The concept values of the core attribute noun and the continuation attribute arg are restricted to an *argument*. The concept values of the core attribute verb and the continuation attribute fnc are restricted to a one-, two-, or three-place *functor*. The concept values of the core attribute adj and the continuation attribute mdr are restricted to an adnominal or adverbial *modifier*. When using the semantic notion of 'property',the modifiers and the one-place verbs are *properties*, and the two- and three-place verbs are *relations* (CC 1.5).

For the computational cognition of an autonomous robot, the semantics must be plemented by an interface component with sensors for recognition and actuators for action. This requires the cooperation of all three branches of today's science, i.e., (a) the natural sciences, (b) the engineering sciences, and (c) the humanities.

Consider, for example, the type of the concept *blue* and an associated token:

2.1 Elementary Meaning analysis: concept definition

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 values of wavelength and frequency are intervals, but constants in the token.

The humanities provide the type-token distinction in philosophy (Peirce 1906, CP Vol.4, p. 375), which goes back to the distinction between the necessary and the accidental (Aristotle, Metaphysics, Books ζ and η); the natural sciences provide the wavelength interval 450–495nm in the type; and the engineering sciences provide the wavelength measurement 470nm in the token.

Alternative to an analysis at the elementary level of grammatical complexity, there are long standing proposals in the humanities which analyze meaning at the phrasal and at the clausal level. Unlike 2.1, they fail to fit into the core and continuation slots of a DBS content (1.1), but for the purpose of building a talking robot they have other disqualifying properties worth noting.

The most widely used meaning analysis is at the phrasal level and based on informally paraphrasing a definiendum with a definiens:

2.2 Phrasal meaning analysis: paraphrase

blue = the color of the cloudless sky

The definiendum is nominalized blue and the definiens the phrasal noun the color of the cloudless sky.[3] To be meaningful, the hearer must understand the words of

[3]The example is from `https://www.thefreedictionary.com/blue`.

the definiens and the semantics of their composition. Within a language community, this kind of meaning explanation is most effective. For a talking robot under hard- and software construction, however, it is unsuitable because the definition of a word in terms of other words runs into the problem of circular paraphrasing.[4]

Circular paraphrasing is avoided by a meaning analysis at the clausal level, namely the definition of a formal metalanguage (Tarski 1935, 1944):

2.3 CLAUSAL MEANING ANALYSIS: META-LANGUAGE DEFINITION

'der Himmel ist blau' is a true sentence if and only if the sky is blue.

To avoid logical inconsistency, the metalanguage must be (i) formally constructed, (ii) its notions must be mathematically obvious (such as set relations), and (iii) the object language may not contain the truth predicates true and false (FoCL 19–21). For building a talking robot, the first and the second condition are impractical, and the third makes the solution incomplete.

3 Extending a Concept to its Class

The explicit concept definition 2.1 may be generalized routinely to other colors:

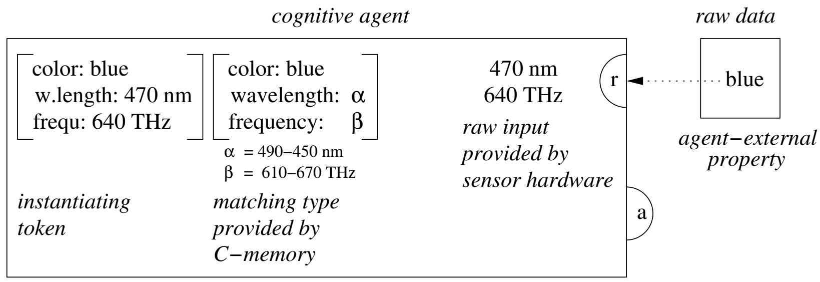
3.1 SIMILARITY AND DIFFERENCE BETWEEN COLOR CONCEPT TYPES

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.

Computationally, the use of a DBS concept in recognition is based on matching the type pattern with raw data, resulting in an instantiating token:

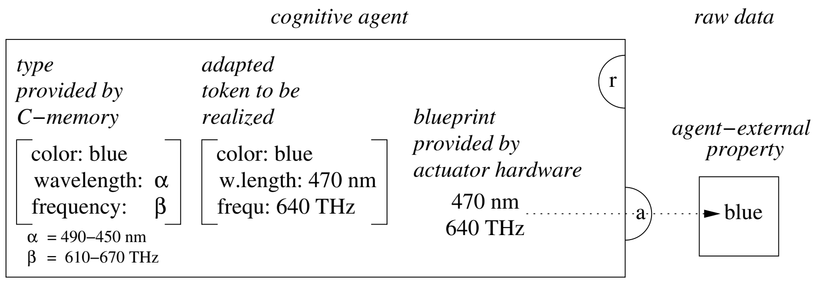
3.2 RECOGNITION OF blue



[4]Noted by de Saussure ([1916]1972) and explicated further by D. Lewis (1969).

In action, the use of a DBS concept is based on adapting the type to a purpose, resulting in a token, realized by the agent's interface component as raw data:

3.3 ACTION OF REALIZING blue



An example is a cuttlefish (metasepia pfefferi) using its chromatophores.

Another place holder value for a concept in 1.1 is square:

3.4 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, angle 1/2: 90°, edge 2: α cm, angle 2/3: 90°, edge 3: α cm, angle 3/4: 90°, edge 4: α cm, angle 4/1: 90°]	shape: [edge 1: 2 cm, angle 1/2: 90°, edge 2: 2 cm, angle 2/3: 90°, edge 3: 2 cm, angle 3/4: 90°, edge 4: 2 cm, angle 4/1: 90°]
samples: a, b, c,...	

The edge value of the type is a variable which matches an infinite number of square tokens with different edge lengths.

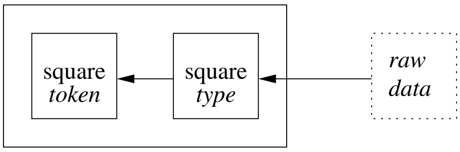
Just as the definition of the concept *blue* may be generalized routinely to other colors (3.1), the definition of the concept *square* may be generalized to other shapes in two-dimensional geometry, such as *equilateral triangle,* and *rectangle*:

3.5 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, angle 1/2: 60°, edge 2: α cm, angle 2/3: 60°, edge 3: α cm, angle 3/4: 60°, samples: a, b, c,...]	shape: [edge 1: α cm, angle 1/2: 90°, edge 2: β cm, angle 2/3: 90°, edge 3: α cm, angle 3/4: 90°, edge 4: β cm, angle 4/1: 90°]	shape: [edge 1: α cm, angle 1/2: 90°, edge 2: α cm, angle 2/3: 90°, edge 3: α cm, angle 3/4: 90°, edge 4: α cm, angle 4/1: 90°]
samples: a, b, c,...	samples: a′, b′, c′,...	samples: a″, b″, c″,...

Most abstractly, the recognition of a square may be shown as follows:

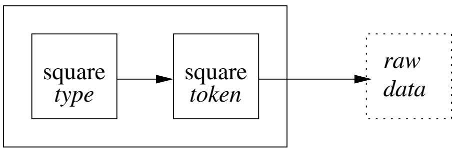
3.6 USING A CONCEPT TYPE IN NONLANGUAGE RECOGNITION



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°.

The type of square may also be used in action, as when drawing a square:

3.7 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).

4 Language Communication

The speak mode is the language variant of nonlanguage action. It re-uses type-token adaptation for the production of language-dependent surfaces. In the medium of speech, a surface token differs from its type by specifying volume, pitch, speed, timbre, etc., and in the medium of writing by specifying font, size, color, etc., i.e., what Aristotle would call the accidental properties.

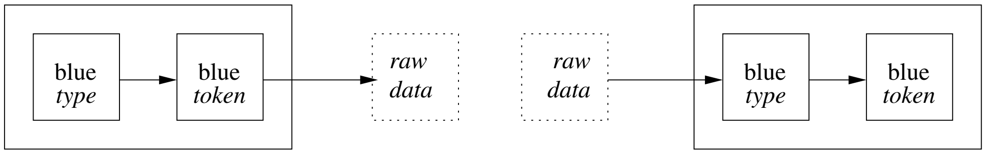
The hear mode is the language variant of nonlanguage recognition. It re-uses token-type matching for assigning language-dependent types to raw surface data. Re-use of earlier mechanisms in the evolutionary transition from nonlanguage to language cognition is in the spirit of Charles Darwin and out of reach for theories based on a sign-based substitution-driven ontology.

Because the transfer of content is based on raw data, (a) the concept types, (b) the language dependent surface types, and (c) the conventions connecting (a) and (b) exist solely in the respective cognitions of speaker and hearer (anything else would be reification). Successful communication presupposes that speaker and hearer have learned the same natural language. In addition, the speaker must be able to produce surface types as tokens and the hearer must be able to recognize surface tokens by means of matching types.

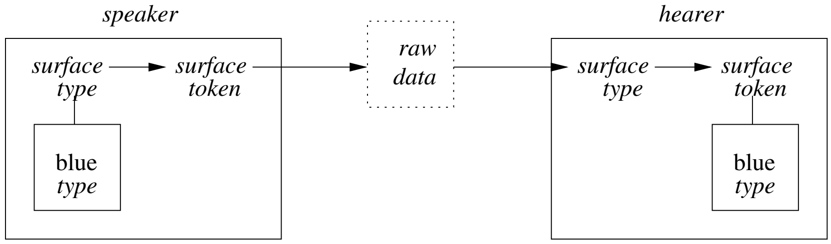
The extension of type-token matching from nonlanguage cognition to language cognition may shown schematically as follows:

4.1 COMBINING NONLANGUAGE INTO LANGUAGE COGNITION

(i) nonlanguage action and recognition



(ii) language action and recognition



Graph (i) shows activation and recognition of the color blue, possibly by the same agent, e.g., metasepia pfefferi, at different occasions.

Graph (ii) explains the transfer of content with raw data, e.g., sound waves or pixels, from a speaker to a hearer. The language-dependent surfaces have no meaning or grammatical properties and their meaning$_1$ exists solely in the agents' cognition.

In the medium of writing, the type-token adaptation of a surface production may be illustrated in more detail as follows:

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

input: proplet token

[sur:
adj: blue
cat: adn
sem: pad
fnc: have
mdr:
nc:
pc:
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

The input, i.e., the proplet token *blue* of nonlanguage cognition, retrieves the corresponding language-dependent surface, here the type of German b l a u e s from the agent's memory, based on a list which provides allomorphs using the input proplet's core, cat, and sem values, and the rules of morphological composition (FoCL 13, 14). The type shapes of this output serve as input to an actuator of the agent's interface component which adapts the surface type into a token and realizes it as raw data.

The type-token instantiation in the corresponding surface recognition may be illustrated in more detail as follows:

4.3 HEAR MODE: FROM RAW DATA TO SURFACE TYPE TO CONTENT

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: ...

⇑
sensory modality: vision
input: raw data

The input consists of raw data which are provided by vision sensors in the agent's interface component 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. Shown as b% l% a% u% e% s%, they record the accidental properties. However, the value crucial for the reader's understanding is the place holder, here *blue*, for the lexical look-up of the correct nonlanguage concept.

5 Combining Concepts into Content

At this point, we have explicit definitions of the three color concepts red, green, and blue (3.1), and the three shape concepts triangle, rectangle, and square (3.5). Instantiated as tokens, they combine into nine two-concept contents.

5.1 Three out of nine two-concept contents

sur:	sur:	sur:	sur:	sur:	sur:
noun: red	noun: triangle	noun: green	noun: rectangle	noun: blue	noun: square
cat: adnv	cat: sn	cat: adnv	cat: sn	cat: adnv	cat: sn
sem: pad	sem: sg	sem: pad	sem: sg	sem: pad	sem: sg
mdd: triangle	fnc:	mdd: rectangle	fnc:	mdd: square	fnc:
mdr:	mdr: red	mdr:	mdr: green	mdr:	mdr: blue
nc:	nc:	nc:	nc:	nc:	nc:
pc:	pc:	pc:	pc:	pc:	pc:
prn: 23	prn: 23	prn: 24	prn: 24	prn: 25	prn: 25

Tweaking the core and continuation values in the tokens results in infinitely (theoretically, using reals) many different contents. If the values are kept constant, adding a new color and a new shape increases the number of resulting contents polynomially: 1·1, 2·2, 3·3, 4·4, etc. If language-dependent surface types are added, the number of instantiations depends on the number of languages.

The definitions of the color types (3.1) and tokens are suitable for robotic cognition because they are represented by numbers which have interpretations as measurements in the color spectrum. It is similar for the definition of shape types (3.5) and tokens because they are represented by numbers which have interpretations as measurements of line lengths and angle degrees in two-dimensional geometry.

This is different from, for example, Bjørner's (1978) program for keeping track of a grocery store's inventory:

> p. 34
> 'A grocery is here selectively abstracted by abstractions of its shelves and store, i.e., inventory, its cash register, and its catalogue.'

The program allows inferencing such as the following:

> pp. 36/37
> 'ii. If the ware additionally is further stored in the back room, then the number of items on the shelves must actually fall between the minimum, lower and maximum, upper bounds;'

Relying on human understanding of the English words, the program is suitable for an English speaking human grocer to keep track of the inventory. An autonomous robot, however, requires an interpretation of the concepts based on the natural and engineering sciences. Bjørner's program is not a metalanguage in the sense of Tarski (2.3), but a procedural implementation of some numerical aspects abstracted from the subject matter.

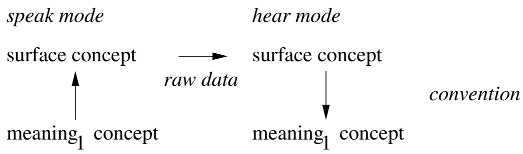
6 Language Surfaces and Meaning$_1$ Concepts in Communication

Natural language communication requires the use of two different but *complementary modalities*, one for the speak and the other for the hear mode, whereby speaker and hearer are different individuals, with the exception of soliloquy. For example, in the medium of speech the sensory modality of vocalization must be used for action (surface production in the speak mode) and the complementary modality of audition for recognition (surface interpretation in the hear mode). In the medium of writing the sensory modality of manipulation must be used for action and the complementary modality of vision for recognition, and accordingly for braille and signing.

The two complementary modalities (tcm) requirement is limited to cooperative behavior, specifically surface processing in natural language communication (4). In other areas of cognition, an individual may freely select one or more single modalities (sm). For example, in manipulation, an individual may button a shirt (action) without looking (recognition). In vision, an individual may be bird watching (recognition) without moving (action). In short, for using several modalities simultaneously, they must be compatible but there is no requirement of being complementary, as when eating while watching tv or talking while driving.

In communication, (i) the complementary modalities of surface concepts needed for content transfer between individuals and (ii) the contents of nonlanguage cognition serving as literal meanings$_1$ are inextricably connected by convention in the language community:

6.1 MEANING$_1$ TRANSFER BY MEANS OF A SURFACE TOKEN



In addition to language communication and nonlanguage recognition and action, meaning$_1$ may be used abstractly in reasoning as content *per se*.

7 Extero- and Interoception

Research in molecular biology and biochemistry explains the cognitive mechanism of concepts in terms of complex receptor proteins which match specific kinds of molecules, resulting in the associated sensation. Driven by practical needs in industry, this biological mechanism has been recreated artificially in some instances.

For example, the taste concepts sweet, sour, salty, bitter, and umami (savoriness) have been modeled as an 'electronic tongue' (Winquist 2008). In pharmaceutics and the food-beverage sector, these artificial receptors are used to analyze flavor ageing in beverages, quantify taste masking efficiency of formulations, and monitor biological and biochemical processes.

Also of interest for industry are odors and flavors, which led to the rapid development of an 'electronic nose.' Persaud and George (1982) tuned their artificial receptor to an axis ranging from very pleasant (rose) to very unpleasant (skunk). It appeared that odorant pleasantness is tightly linked to molecular structure (Haddad et al. 2010). Therefore, the concepts of smell, like those of taste, may be based on molecules (raw input data) which are matched by receptor proteins (type).

The technology of the electronic tongue and nose satisfies the theoretical and practical necessity of grounding concepts in DBS. It suggests the construction of artificial receptors also for other domains.

Natural receptors at the periphery of the agent's body, as for taste and smell, are called exteroceptors. They include vision, hearing, touch, and thermoception, i.e., the feeling of hot and cold. Also called the conductive modality (Filingeri 2016), termoception is based on receptors in the skin.

Receptors inside the agent's body are called interoceptors (Connell et al. 2017). Triggered by body-internal deviations from a state of homeostasis, they are responsible for the 'drive states,' e.g., hunger and thirst. For example, a low glucose level in the blood stream is recognized by receptors in the brain (Rolls 2000), interpreted as hunger, and countered by raising the glucose level to the set point by ingesting food (negative feedback in control theory, Wiener 1948).

In addition to the concepts for physiological states, there are the concepts which recognize psychological states such as fatigue, vigor, relaxation, and boredom. Of these, fatigue has drawn special attention in medicine because of post-infectious fatigue (Kazuhiro Kondo 2006), but also because of the Chronic Fatigue Syndrome (CFS), including the Gulf War Syndrome.

8 Emotion

In the humanities, emotion has been intensely researched from an outside observer's point of view. Ekman (1999, p. 46) explains the function of emotion as a pathway for fast, comprehensive access 'to deal quickly with important interpersonal encounters,' like running for dear life triggered by the emotion of fear. Rimé (2009) describes the social mechanisms of sharing emotions. Lerner et al. (2015) investigate the influence of emotions on decision making, specifically in business.

But what about the emotion concepts, such as anger, surprise, fear, disgust, happiness, and sadness? They are also based on protein receptors, here in the brain, matching certain molecules, here in the blood stream, which explains why 'emotions are unbidden, not chosen by us' (Ekman op. cit. p. 54).

9 Conclusion

The ultimate standard of verification for the DBS theory of language is the construction of a robot capable of communicating freely in natural language. The method is incremental upscaling of a declarative specification with an operational implementation for the automatic evaluation of systematic test scenarios.

To achieve this standard, the century old division (Snow [1959] 2001) between the humanities, on the one hand, and the natural and the engineering sciences, on the other, must be overcome. It is as much a need for connecting the sciences to the humanities as for connecting the humanities to the sciences.

A case in point is the treatment of elementary meanings in the humanities, specifically philosophy and linguistics, on the one hand, and the natural and engineering sciences, specifically molecular biology and biochemistry, on the other. Written from the humanities' perspective of computational linguistics, it is suggested that the sciences provide a grounding of concepts suitable for building a talking robot.

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