

Grounding of Concepts in Science

Roland Hausser

Universität Erlangen-Nürnberg (em.)

©Roland Hausser, January 3, 2021

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 soundwaves in audition.

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. After showing why the approaches to meaning in philosophy and linguistics are unsuitable for building the computational cognition of a talking robot, this paper proposes to utilize the theoretical and practical advances of the neighboring sciences for the grounding of concepts which are suitable for language and nonlanguage cognition alike.

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 *contents*, (ii) three basic kinds of *concepts*, and (iii) two basic forms of *combination*. The contents are (1) name, (2) indexical, and (3) concept. The concepts are (x) referent, (y) relation, and (z) property. The combinations are (a) functor-argument and (b) coordination. In functor-argument, a relation combines two or three referents into a proposition and a property modifies a referent or a relation. In coordination, several referents, relations, or properties concatenate into a conjunction. This is illustrated by the following content:

1.1 LANGUAGE CONTENT

referent (noun)	relation (transitive verb)	property (adn)	property (adn)	referent (noun)
[sur: Lucy noun: [person x] cat: snp sem: nm f fnc: find mdr: nc: pc: prn: 23	[sur: found verb: find cat: #n' #a' decl sem: ind past arg: [person x] square mdr: nc: pc: prn: 23	[sur: big adj: big cat: adn sem: pad mdd: square mdr: nc: blue pc: prn: 23	[sur: blue adj: blue cat: adn sem: pad mdd: mdr: nc: pc: big prn: 23	[sur: square noun: square cat: snp sem: indef sg fnc: find mdr: big nc: pc: prn: 23

The concepts are embedded as core and continuation values into the DBS data structure of proplets, defined as nonrecursive feature structures with ordered at-

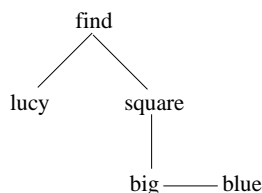
tributes. The two-place relation *find* combines the referents [*person x*] and *square* into the proposition [*person(x)*] *find square*. The property (modifier) *big* combines with *square* by functor-argument and with *blue* by coordination.

Language and nonlanguage contents are alike except that language contents have language-dependent *sur*(face) values. In the hear mode, a language content is turned into a nonlanguage content by deleting the values of the *sur*(face) slot.¹ In the speak mode, a nonlanguage content is turned into language content by constructing language-dependent *sur*faces from the core, *cat*, and *sem* values.

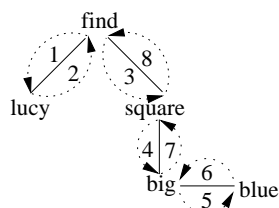
Using the operators /, \, | and —, the variants of the functor-argument relation are coded as (1) subject/predicate, (2) object \ predicate, (3) modifier|noun, and (4) modifier|verb, and the variants of coordination as (a) noun—noun, (b) verb—verb, and (c) adn—adn. Accordingly, the semantic relations in the content 1.1 may be shown graphically as follows:

1.2 SEMANTIC RELATIONS UNDERLYING SPEAK MODE DERIVATION

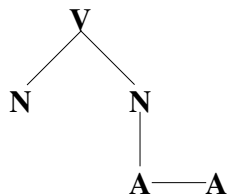
(i) SRG (semantic relations graph)



(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 semantic relations are shown in four views. Based on the proplets of the content 1.1, view (i), called the semantic relations graph (SRG), uses the core *values* *lucy*, *find*, *square*, *big* and *blue* as nodes. View (ii), called the signature, uses the core *attributes* N for noun, V for verb, and A for adj as nodes. View (iii), called the *numbered arcs graph* (NAG), supplements the SRG with numbered arcs which are used in (iv), called the *surface realization*, to show the navigation which activates content in the think mode and optionally realizes the language-dependent surfaces in a speak mode which rides piggyback on think mode navigation.

Together, 1.1 and 1.2 show the compositional semantics of cognition in DBS. Thereby the concepts, as the elementary building blocks, 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 supplement the place holder values with a computational implementation of concepts in recognition and action.

2 Should Concepts be defined at the Elementary, Phrasal, or Clausal Level?

The syntactic-semantic analysis of the content 1.1 is complete except for the place holder values for concepts in the core and the continuation slots. The values are constrained, however, by their attributes. In terms of symbolic logic, values of the core attribute *noun* and the corresponding continuation attribute *arg* are restricted to an argument, the values of core attribute *verb* and the corresponding continuation attribute *func* are restricted to a one-, two-, or three-place functor, and the values of the core attribute *adj* and the corresponding continuation attribute *modr* are restricted to an adnominal or adverbial modifier. If the semantic notion of ‘property’ is used instead of ‘modifier,’ the two- and three-place verbs are relations and the one-place verbs and the modifiers are properties (CC Sect. 1.5).

The reconstruction of concepts for the computational cognition of a talking robot requires the cooperation of all three branches of modern science, i.e. (a) the natural sciences, (b) the engineering sciences, and (c) the humanities. As a simple example, consider the definition of the concept type *blue* and an associated token:

2.1 MEANING ANALYSIS AT THE ELEMENTARY LEVEL

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

The humanities provide the type-token distinction from 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 this 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 MEANING ANALYSIS AT THE PHRASAL LEVEL

blue = the color of the cloudless sky

¹A partial exception is the surface of names: instead of being deleted it is turned into a marker for potential use in the speak mode. The core value, e.g. [person x], is called the *named referent*. For the explicit time-linear surface compositional hear mode derivation of 1.1 see CC 2.1.2.

The definiendum is nominalized **blue** and the definiens the phrasal noun the color of the cloudless sky.² To be meaningful, the hearer must understand the words of 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.³

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

2.3 MEANING ANALYSIS AT THE CLAUSAL LEVEL

‘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 sets), and (iii) the object language may not contain the truth predicates **true** and **false** (FoCL, Chaps. 19–21). For building a talking robot, the first and the second condition is 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:

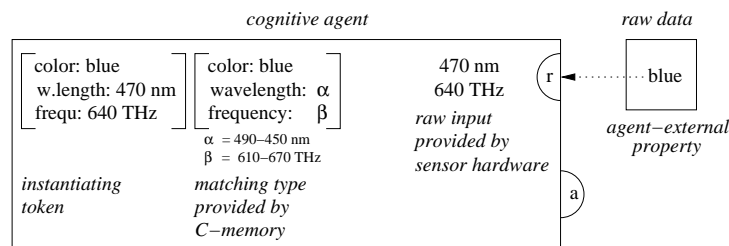
3.1 SIMILARITY AND DIFFERENCE BETWEEN COLOR CONCEPT TYPES

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

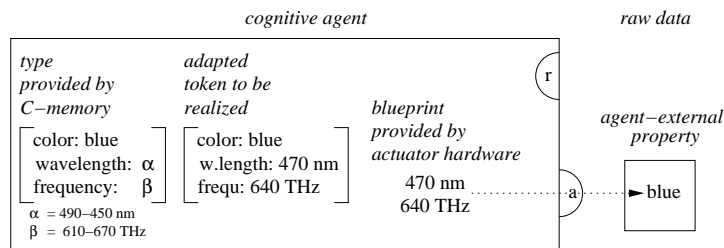
Computationally, the use of a DBS concept in recognition is based on matching the type pattern with raw data, resulting in an instantiating token:

3.2 RECOGNITION OF blue



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

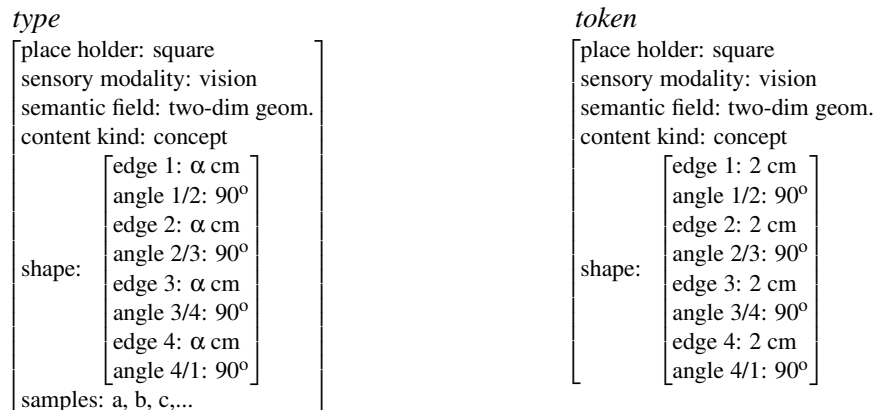
3.3 ACTION OF REALIZING blue



An example is a cuttlefish (*metasepia pfefferi*) turning on the color blue using its chromatophores.

Another place holder value in 1.1 is *square*. In analogy to the analysis of the place holder *blue* in 2.1, its type and a token may be defined as follows:

3.4 TYPE AND TOKEN OF THE CONCEPT square



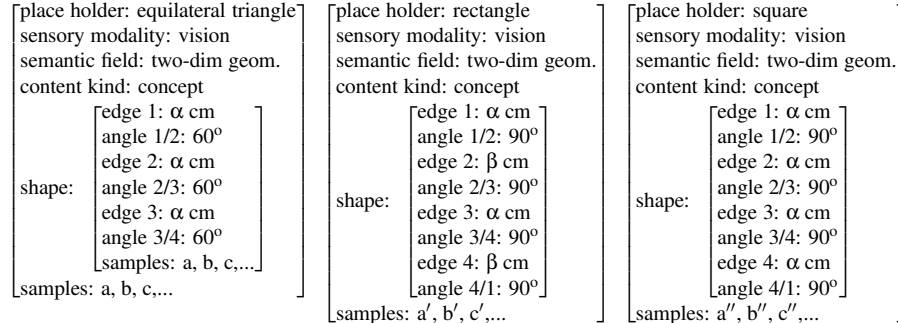
The type matches an unlimited number of tokens with different edge lengths. The type and the token share an ordered column of attributes which specify (i) the number of equally long edges and (ii) the angle of their intersections (necessary properties). The type and the token differ solely in their edge values. The edge value in the token is the constant 2cm, which is accidental in that the variable α of the type matches an infinite number of square tokens with different edge lengths.

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

³The example is from <https://www.thefreedictionary.com/blue>.

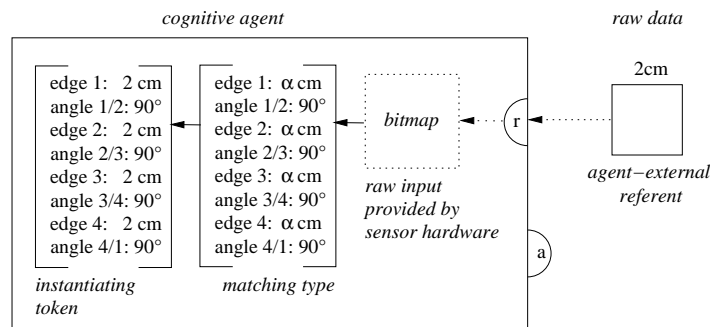
³Noted by de Saussure ([1916]1972) and explicated further by D. Lewis (1970).

3.5 SIMILARITY AND DIFFERENCE BETWEEN CONCEPT SHAPE TYPES



Similar to recognizing the color blue (3.2), the recognition of a square may be shown as follows:

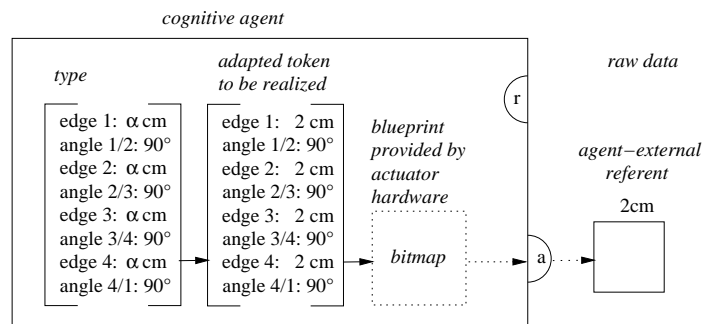
3.6 RECOGNITION OF THE GEOMETRIC SHAPE square



The functional order is from right to left: the raw data are supplied as input by a vision sensor of the interface component.

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

3.7 ACTION OF REALIZING THE GEOMETRIC SHAPE OF A square



The functional order is from left to right: the type is adapted into a token for the agent's current purpose. The token is used as a blueprint for action, which is performed by the agent's interface component in the modality of manipulation and

results in the production of raw data, as when drawing a square. Many concepts may be used only for recognition or only for action (Sect. 7).

4 Dimensions of Concepts

The three content kinds (i) concept, (ii) indexical, and (iii) name are universal in that they occur in all natural languages. Thereby names occur only as the semantic kind referent, and indexicals only as referent and property, while concepts are semantically complete in that they occur in all three semantic kinds: referent, property, and relation (CC, Sect. 1.5).

Furthermore, individual concepts like *square*, *blue*, or *find* are not restricted to a semantic kind like referent, or referent and property, but may serve as the values of all three, shown here with the corresponding syntactic kinds noun, verb, and adj:

4.1 USING THE SAME CONCEPT AS A noun, verb, AND adj VALUE

Lucy found a *square* (noun, referent).
 Lucy *squared* (verb, relation) her account.
 Lucy bought a *square* (adj, property) table.

Lucy *found* (verb, relation) a square.
 Lucy is on a *finding* (adj, property) mission.
 Lucy made a new *find* (noun, referent).

Lucy likes *red* (adj, property) wine.
 Lucy preferred the other *red* (noun, referent).
 The rising sun *reddened* (verb, relation) the sky.

In addition there is the distinction between adnominal and adverbial use, as in *square table* and *squarely facing the challenge*. The different syntactic-semantic uses of the concept *square* are defined as the following lexical proplets:

4.2 CORE VALUE IN NOUN, ADJ_{adn}, ADJ_{adv}, AND VERB

<i>square</i> ⇒	$\left[\begin{array}{l} \text{sur: square} \\ \text{noun: square} \\ \text{cat: sn} \\ \text{sem: sg} \\ \text{fnc:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:} \end{array} \right]$	$\left[\begin{array}{l} \text{sur: square} \\ \text{adj: square} \\ \text{cat: adn} \\ \text{sem: pad} \\ \text{mdd:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:} \end{array} \right]$	$\left[\begin{array}{l} \text{sur: squarely} \\ \text{adj: square} \\ \text{cat: adv} \\ \text{sem: pad} \\ \text{mdd:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:} \end{array} \right]$	$\left[\begin{array}{l} \text{sur: squared} \\ \text{verb: square} \\ \text{cat: n' a' v} \\ \text{sem: ind past} \\ \text{arg:} \\ \text{mdr:} \\ \text{nc:} \\ \text{pc:} \\ \text{prn:} \end{array} \right]$
-----------------	--	---	---	--

These lexical proplets share the core value *square*, i.e. the type defined in 3.4, but take different sur, cat, and sem values.

The intralanguage dimension of using the same concept in different core attributes, illustrated in 4.1, is complemented by the extralanguage dimension, which may be illustrated by the same content in different languages:

4.3 SURFACE VARIATION FOR THE SAME CONCEPT

Lucy sat in an easy chair. (English)
Lucy s'assit dans un fauteuil. (French)
Lucy si sedette sulla poltrona. (Italian)
Lucy sass im Sessel. (German)

All four variants use the core value *easy chair* for the language-dependent surfaces *easy chair*, *fauteuil*, *poltrona*, and *Sessel*.

The use of the same concept in analogous constructions in different languages, as in 4.3, does not always work, even in such comparatively similar languages as English, French, Italian, and German. Consider the use of the concept *square* in the following variants:

4.4 DIFFICULTY OF USING THE SAME CONCEPT IN TRANSLATION

Lucy came upon a square. (English)
Lucy vienne sur une place. (French)
Lucia si imbatté in una piazza. (Italian)
Lucy stieß auf einen Platz. (German)

The correct translation of *square* in the English example into French, Italian, and German refers to a public space called *place*, *piazza*, and *Platz*, respectively, and not to a two-dimensional geometric form. In DBS, this is handled by restricting the semantic field⁴ value of the concept *square* to two-dimensional geometry in French, Italian, and German, but define a lexical reading in English with the semantic field *public space* and appropriate samples, in which use one may even speak of a 'round square' (Majid 2015).

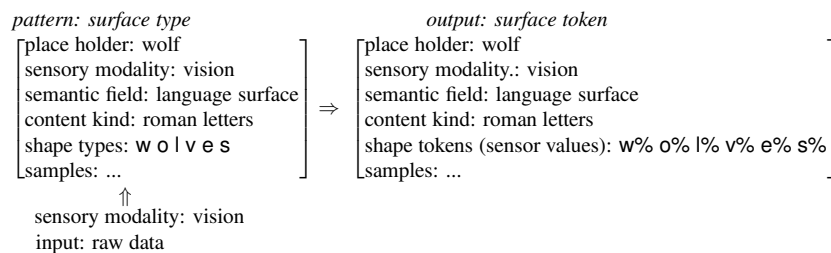
5 Language Surfaces in Recognition and Action

A special kind of concept are the language-dependent surfaces. The recognition and action of nonlanguage concepts like *square* and *blue*, and the interpretation and production of language-dependent surfaces like *Quadrat* and *blau*, are alike insofar as they are based on a computational pattern matching between types and raw data⁵ resulting in tokens (recognition), and adapting types to tokens resulting in raw data (action).

⁴A semantic field (Trier 1928; Ullmann 1957; Andersen 1990) is a lexical classification which goes back at least to W.v.Humboldt. Brinton (2000) calls the semantic field relation a loose form of hyponymy, which in turn may be viewed as a containment relation between a set and its subsets.

For the hear mode, consider the DBS robot's recognition of the surface **wolves** in the medium of writing by matching raw visual input data with a surface type:

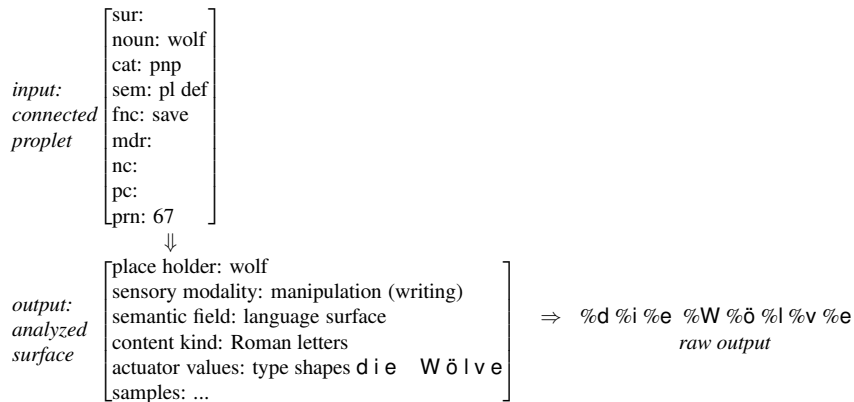
5.1 LETTER TYPES MATCHING RAW DATA IN THE VISION MODALITY



The format is analogous to 3.2 and 3.6, except that the multiple type-raw_data matchings of the different letters are summarized as **shape types** and **sensor values**. Given that natural language surfaces as raw data have neither meaning nor any grammatical properties whatsoever, the crucial function of surface recognition is lexical lookup of the concept *wolf*, based on the **place holder** value. The **shape tokens** merely monitor such accidental properties as font, color, and size.

For the speak mode, consider the corresponding surface production in German:

5.2 FROM CONNECTED PROPLET TO RAW SURFACE OUTPUT



This format is analogous to 3.3 and 3.7, except that the production of raw data from letter shapes, based on multiple type-token adaptations, is summarized as the sequence of **actuator values**.

The surface type of German **d i e W ö l f e** is based on a language-dependent list which provides German surface allomorphs for the relevant proplet values, here the allomorph **Wölf** from [noun: wolf], and the plural suffix **-e** and the language-dependent determiner **die** from [sem: def pl].⁶

⁵The interpretation and production of language-dependent surfaces is in the domains of optical character recognition (ocr), automated speech recognition (asr), and text to speech (tts), which, driven by industrial use, have made considerable progress.

⁶The most detailed DBS analysis of surface realization so far may be found in NLC Sects. 12.4

6 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.

6.1 Three out of nine two-concept contents

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

(verbs), 12.5 (nouns) and 12.6 (adjs) for English.

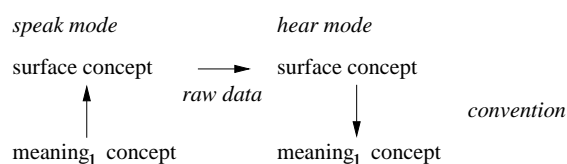
7 Language Surfaces and Meaning₁ Concepts in Communication

Natural language communication requires the use of two different but *complementary modalities* for the speak and 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 must be used 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 (Sect. 5). 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 watch a bird (recognition) without moving (action). When several modalities are used 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 transfer between two individuals (tcm) and (ii) the single modalities (sm) meaning₁ concepts needed (a) as input to surface production and (b) as output of surface interpretation are inextricably connected by convention in the language community:

7.1 MEANING₁ TRANSFER BY MEANS OF A SURFACE TOKEN



In language cognition, elementary content types are used as literal meanings (meaning₁) which are attached by convention to language-dependent surface types. In the speak mode, the surface types are adapted into surface tokens and realized as raw data to be passed to the intended hearer. In the hear mode, the raw data are recognized by a matching surface type which provides the meaning₁. In nonlanguage cognition, the meaning₁ concept types are used not only for recognition and action based on pattern matching, but also abstractly as elementary content, for example in reasoning.

8 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** (savoryness) have been modeled as an ‘electronic tongue’ (Winqvist 2008). In pharmaceuticals 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), thermoception 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.

9 Emotions

In the humanities, emotions have been intensely researched from an outside observer’s point of view. Ekman (1999, p. 46) explains the function of emotions as pathways 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.

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).

10 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.

Bibliography

- Andersen, P.B. (1990) *A theory of computer semiotics: semiotic approaches to construction and assessment of computer systems*, Volume 3 of Cambridge series on human-computer interaction. CUP
- Biederman, I. (1987) "Recognition-by-components: a theory of human image understanding," *Psychological Review*, Vol. 94:115–147
- Bjørner, D. (1978) *Programming in the Meta-Language: A Tutorial*, in LNCS 61:337–374, Springer
- Brinton, L.J. (2000) *The structure of modern English: a linguistic introduction*. Amsterdam: John Benjamins
- CC = Hausser, R. (2019) *Computational Cognition: Integrated DBS Software Design for Data-Driven Cognitive Processing*, pp. i–xii, 1–237, lagrammar.net
- CoL = Hausser, R. (1989) *Computation of Language*, Springer
- Connell, L., D. Lynott, and B. Banks (2017) "Interoception: the forgotten modality in perceptual grounding of abstract and concrete concepts," *Phil. Trans. R. Soc. B373*: 20170143 <http://dx.doi.org/10.1098/rstb.2017.0143>
- Delgado, P.L. (2000) "Depression: the case for a monoamine deficiency," *J Clin Psychiatry* Vol. 61.6:7–11
- Ekman, P. (1999) "Basic Emotions," Chapter 3 in *Handbook of cognition and emotion*, T. Dalgleish and M. Powers (eds), John Wileys
- Filingeri, D. (2016) "Neurophysiology of Skin Thermal Sensations," *Comprehensive Physiology* Vol. 6.3:2–78

- FoCL^{1,2,3} = Hausser, R. (1999, 2002, 2014) *Foundations of Computational Linguistics*, Springer
- Haddad, R., A. Medhanie, Y. Roth, D. Harel, N. Sobel (2010) “Predicting Odor Pleasantness with an Electronic Nose,” *PLoS Comput Biol* Vol. 6.4:e1000740
- Kondo, K. (2006) “Post-infectious fatigue” *JMAJ* Vol. 49.1:27–33
- Lerner, J.S., Ye Li, P. Valdesolo, and K.S. Kassam (2015) “Emotion and Decision Making,” *Annual Review of Psychology*, Vol. 66:799–823
- Majid, A. (2015) “Comparing lexicons cross-linguistically,” *The Oxford Handbook of the World*, John R. Taylor (ed.)
- NLC = Hausser, R. (2006) *A Computational Model of Natural Language Communication – Interpretation, Inferencing, and Production in Database Semantics*, Springer, pp. 360; preprint 2nd Ed. 2017, pp. 363, at lagrammar.net
- Peirce, C.S. (1931–1935) *Collected Papers*. C. Hartshorne and P. Weiss (eds.), Cambridge, MA: Harvard Univ. Press
- Persaud, K., and D. George (1982). “Analysis of discrimination mechanisms in the mammalian olfactory system using a model nose.” *Nature* Vol. 299:352–5
- Rimé, B. (2009) “Emotion Elicits the Social Sharing of Emotion: Theory and Empirical Review,” *Emotion Review*, Vol. 1.1:60–85
- Rolls, E.T. (2000) “The Representation of Umami Taste in the Taste Cortex” *The Journal of Nutrition*, Vol.130.4:960–965
- Rosch, E. (1975) “Cognitive representations of semantic categories,” *J. of Experimental Psychology*, General 104:192–253
- Saussure, F. de (1916/1972) *Cours de linguistique générale*, Édition critique préparée par Tullio de Mauro, Paris: Éditions Payot
- Snow, C.P. ([1959] 2001) *The Two Cultures*, London: CUP
- Tarski, A. (1935) “Der Wahrheitsbegriff in den Formalisierten Sprachen,” *Studia Philosophica*, Vol. I:262–405
- Tarski, A. (1944) “The Semantic Concept of Truth,” *Philosophy and Phenomenological Research*, Vol. 4:341–375
- Trier, J. (1928) *Der deutsche Wortschatz im Sinnbezirk des Verstandes. Von den Anfängen bis zum Beginn des 13. Jahrhunderts*. Heidelberg 1973: Winter, ISBN 3-533-00535-6 (Habilitationsschrift, Universität Marburg 1928).
- Ullmann, S. (1957) *The Principles of Semantics*, Oxford: Blackwell
- Wiener, N. (1948) *Cybernetics: Or the Control and Communication in the Animal and the Machine*, Cambridge, MA: MIT Press
- Winquist, F. (2008) “Voltammetric electronic tongues - basic principles and applications,” *Microchimica Acta*, Vol. 163.1-2:3–10