Software Mechanisms of the Content Kinds

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Abstract

The semantics of agent-based DBS is 'grounded' in that the Content kinds *concept, indexical*, and *name* have their foundation in the agent's recognition and action. Each Content kind has its own computational Mechanism. For a concept it is computational pattern *matching* between the type provided by memory and raw data provided by the interface component. For an indexical it is *pointing* at a STAR value of the on-board orientation system (OBOS). For a name it is the address of a 'named referent,' which an implicit or explicit act of *baptism* inserts into a lexical name proplet as the core value.

Orthogonal to the Content kinds and their computational Mechanisms are the (a) Semantic kinds *referent, property,* and *relation* with their associated Syntactic kinds (a) *noun*, (b) *adj* and *intransitive verb*, and (c) *transitive verb*. It is shown that the Semantic kind of referent is restricted to the Syntactic kind of noun, but utilizes the computational Mechanisms of matching, pointing, and baptism. Conversely, figurative use is restricted to the computational Mechanism of matching, but uses the Semantic kinds referent, property, and relation.

keywords: Syntactic kinds of noun, adj, verb; Semantic kinds of referent, property, relation; Content kinds of concept, indexical, name; computational Mechanisms of matching, pointing, baptism; recognition vs. action; type vs. token; speak mode vs. hear mode; language vs. nonlanguage content

1 Apparent Terminological Redundancy

The notions noun, verb, and adjective from linguistics (philology) have counterparts in analytic philosophy, namely referent, relation, and property, and in symbolic logic, namely argument, functor, and modifier:

1.1 THREE TIMES THREE RELATED NOTIONS

	(a) *linguistics*	(b) *philosophy*	(c) *symbolic logic*
1.	noun	referent (object)	argument
2.	verb	relation	functor
3.	adj	property	modifier

We take it that these variants are not merely different terms for the same things, but different terms for different aspects of the same things. In particular, the linguistic terminology may be viewed as representing the syntactic aspect, the philosophical terminology as representing the associated semantic aspect, and the logical terminology as a step towards a computational implementation.

In DBS, the distinctions are related as follows:

1.2 1ST CORRELATION: SEMANTIC AND SYNTACTIC KIND

	Semantic kind	*Syntactic kind*
1.	referent	noun
2.	property	adn, adv, adnv, intransitive verb
3.	relation	transitive verb

The Semantic kinds *referent, property*, and *relation* correspond to argument, 1-place functor, and 2- or 3-place functor, respectively, in Symbolic Logic. Syntactically, *property* splits up into adn, adv, adnv (including prepnouns), and 1-place verb. *Relation* splits up into 2- and 3-place verbs.

The distinction between (i) Semantic and (iii) Syntactic kinds is complemented by a second, orthogonal pair of triple distinctions, namely (ii) Content kinds and associated (iv) computational Mechanisms:

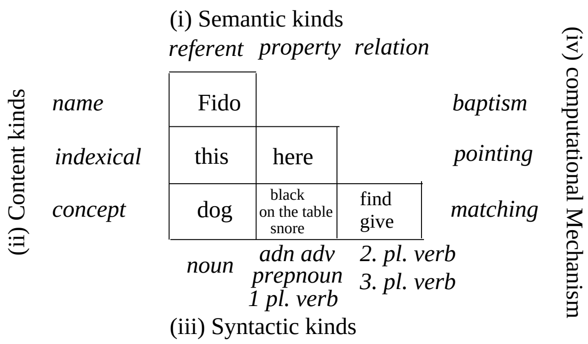
1.3 2ND CORREL.: CONTENT KINDS AND COMPUT. MECHANISMS.

	Content kind	*computational Mechanism*
a.	concept	matching
b.	indexical	pointing
c.	name	baptism

The terms of the three Content kinds and the correlated Mechanisms have had informal use in the literature,[1] but without an agent-based ontology. The essential points of the Mechanisms in DBS are their obvious computational realizations (10–12), which have not been utilized until now.

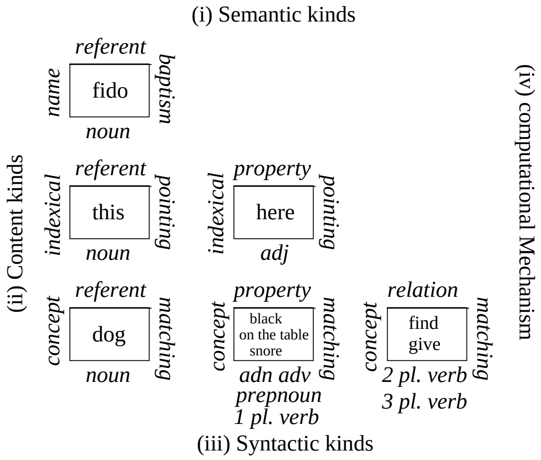
The dichotomies 7.2 and 7.3 provide 12 (2×2×3) basic notions. Empirically, they combine into six classes of proplets which constitute the semantic building blocks of DBS cognition in general and natural language communication in particular. The six classes form what we call the *cognitive square*:

1.4 COGNITIVE SQUARE OF DBS



The twelve basic notions of this NLC 2.6.9 extension are distributed over six basic proplets kinds such that no two are characterized the same:

1.5 CLOSER VIEW OF THE COGNITIVE SQUARE



The surfaces inside the rectangles have the following proplet definitions:

1.6 PROPLETS INSTANTIATING THE COGNITIVE SQUARE OF DBS

referent

name	sur: Fido noun: [dog x] cat: snp sem: nm m sg fnc: mdr: nc: pc: prn:	*baptism*

noun

	referent	*property*	
indexical	sur: noun: this cat: snp sem: -hum sg fnc: mdr: nc: pc: prn:	sur: adj: here cat: adnv sem: loc fnc: mod: nc: pc: prn:	*pointing*
	noun	*adj*	

[1]Examples in precomputational work are (i) matching for concepts but without the type-token relation and its computational implementation based on content and pattern proplets, (ii) pointing for indexicals but without an on-board orientation system (OBOS), and (iii) baptism but without the named referent as the core value for use in the speak and the hear mode.

	referent	*property*			*relation*		
	sur:	sur:	sur:	sur:	sur:	sur:	
	noun: dog	adj: black	noun: table	verb: snore	verb: find	verb: give	
	cat: snp	cat: adnv	cat: adnv snp	cat: n-s3′ v	cat: n-s3′ a′ v	cat: n-s3′ d′ a′ v	
	sem: def sg	sem: pad	sem: *on* def sg	sem: pres	sem: pres	sem: pres	
concept	fnc:	fnc:	fnc:	arg:	arg:	arg:	*matching*
	mdr:	mod:	mdr:	mdr:	mdr:	mdr:	
	nc:	nc:	nc:	nc:	nc:	nc:	
	pc:	pc:	pc:	pc:	pc:	pc:	
	prn:	prn:	prn:	prn:	prn:	prn:	
	noun	*adj*	*prepnoun*	*verb* 1-pl	*verb* 2-pl	*verb* 3-pl	

In a proplet, the Semantic kind (a) *referent* is limited to the core attribute noun with the cat values snp and pnp, (b) *property* is limited to the core attribute noun with the cat value adnv, and verb with the cat values adnv and for intransitive, and (c) *relation* is limited to verbs characterized by their cat value as transitive.

The Content kinds *name, indexical*, and *concept* are specified by the core value. In names, the corresponding computational Mechanism of *baptism* is implemented by inserting a 'named referent' as the core value into a lexical proplet, in indexicals by *pointing* at a STAR value of the onboard orientation system, and in concepts by computational type-token *matching*.

The cognitive square[2] of DBS is empirically important because (i) figurative use is restricted to concepts, i.e., the bottom row in 7.4–7.6, and (ii) reference is restricted to nouns, i.e., the left-most column. Thus only concept nouns may be used both figuratively and as referents, while indexical properties like here and now may not be used as either, and names and indexical nouns like this only as referents.

2 Restriction of Figurative Use to Concepts

To show the restriction of figurative use to the Content kind concept let us go systematically through the three Semantic kinds:

2.1 THREE CONTENT KINDS FOR THE SEMANTIC KIND *REFERENT*

concept	*indexical*	*name*
sur:	sur:	sur: tom
noun: animal	noun: pro2	noun: [person x]
cat: sn	cat: sp2	cat: snp
...	...	...

The three Content kinds of the Semantic kind *referent* all have literal use, but only the concepts allow figurative use.

[2] 'Triangle' would be appropriate as well, but the term "cognitive triangle" is already used by the cognitive behavioral therapists (CBT). Earlier it was used by Ogden&Richards (1923) for their "Semiotic Triangle." The term 'square' is well suited to express the orthogonal relation between the Syntactic_kinds-Semantic_kinds and the Content_kinds-computational_Mechanisms.

Next consider the Semantic kind *property*, which occurs as the Content kinds (i) *concept* and (ii) *indexical*, but not as *name*. Property proplets of the content kind concept may have the core attributes adj, noun, or verb if it is 1-place (7.6). If they have the core value adnv, they may be (a) elementary (fast) or phrasal (in the park), and (b) adnominal (tree in the park) or adverbial (walk in the park).[3]

2.2 Two Content kinds for the Semantic kind *PROPERTY*

concept	*indexical*	*name*
sur: adj: great cat: adn ...	sur: adj: now cat: adnv ...	
sur: adj: enough cat: adnv ...	sur: adj: here cat: adnv ...	
sur: noun: table cat: snp ...	sur: noun: pro2 cat: sp2 ...	
sur: verb: melt cat: n-s3′ v ...		

Of the Semantic kind *property*, only the concepts may be used nonliterally.[4]

The Grammatical kind transitive verb with its single Semantic kind *relation* exists as the Content kind *concept*, but not as *indexical* or *name*:

2.3 One Content kind for the Semantic kind *RELATION*

concept	*indexical*	*name*
sur: verb: steal cat: n-s3′ a′ v ...		
sur: verb: give cat: n-s3′ d′ a′ v ...		

Being concepts, transitive verbs have literal and nonliteral use.

[3] Phrasal modifiers, called prepnouns in DBS, are derived from a referent by means of a preposition or an affix, depending on the language. Therefore, a prepnoun like in the park refers by means of park, in contradistinction to the other modifiers, e.g., elementary fast or intransitive snore, which do not refer.

[4] For a nonliteral use of *on the table* see CC 9.2.4 and of *melt* CC 9.5.1.

3 Additional Constraint on Figurative Use

The restriction of figurative use to concepts is constrained further by the condition that the literal term and its figurative counterpart must be grammatically equivalent:

3.1 INVARIANCE CONSTRAINT

> A figurative use and its literal counterpart must be of the same Syntactic and Semantic kind.

Thus, one cannot use a 1-place verb like bark to refer figuratively to a dog unless bark is nominalized, as in the little barker (i.e., by turning the property of intransitive bark into the referent barker, sleep into sleeper, stink into stinker, etc.). Similarly for the adj fat, which for figurative use must be nominalized, as in the old fatso. Functionally, the constraint helps the hearer to find the literal counterpart of a figurative use by reducing the search space.

The systematic examples in CC 9 all satisfy the invariance constraint:

3.2 SYNTACTIC-SEMANTIC INVARIANCE OF FIGURATIVE USE

Semantic kind	Syntactic kind	nonliteral use	literal counterpart	in CC
referent	noun	animal	dog	9.1.2
property	prepnoun	on the table	on the orange crate	9.2.1
property	adn	great	greater than average	9.6.3
property	adv	enough	more than enough	9.6.6
property	intransitive verb	melt	disappear	9.5.1
relation	transitive verb	steal	take over	9.4.2

The Semantic kind *property* has several Syntactic kinds, while each Syntactic kind, e.g., prepnoun, has only one Semantic kind, i.e., *property*, regardless of whether it is used literally or figuratively. The other two Semantic kinds, i.e., *referent* and *relation*, each have only a single syntactic counterpart.

As an example of using all three Semantic kinds figuratively consider the following description of a dog contorting itself catching a frisbee in mid air:

3.3 EXAMPLE USING ALL THREE SEMANTIC KINDS FIGURATIVELY

> The animal flew acrobatically towards the disc.

The content obeys the invariance constraint: literal dog and figurative animal are both singular nouns, literal jumped and figurative flew are both finite verbs in the indicative past, literal in a spectacular gymnastic feat and figurative acrobatically are both adverbials (one phrasal, the other elementary), and literal frisbee and figurative disc are both singular nouns. For successful communication, the hearer-reader must relate figurative animal to literal dog and figurative disc to literal frisbee. The relation flew and the property acrobatically, in contrast, do not refer, but establish a relation between referents, or modify a referent, a relation, or a property.

4 Declarative Specification of Concepts for Recognition

Concepts are the only Semantic kind which interacts directly with the agent's cognition-external environment. The interaction consists of matching between (i) raw data provided by sensors and activators of the agent's interface component and (ii) concept types provided by the agent's memory.[5]

Consider the rule for the recognition of a color:

4.1 DECLARATIVE SPECIFICATION FOR RECOGNITION OF blue

concept type		*concept 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, ...		samples: ...
⇑		*analyzed output*

raw input sensory modality: vision
sensor values: 470nm
637 THz

The raw input data 470nm and 637 THz are provided by the agent's interface component and recognized as the color blue because they fall into the type's wavelength interval of 450–495nm and frequency interval of 670–610 THz. The analyzed output token results from replacing the wavelength and frequency intervals of the type with the raw data measurements of the input.

The place holder value of the recognized token, i.e., the letter sequence b l u e, is used for lookup of the lexical proplet which contains the place holder as its core value (CC 1.6.3):

4.2 PLACE HOLDER VALUE OF CONCEPT USED FOR LEXICAL LOOKUP

	sur:
b l u e ⟶	adj: blue
	cat: adnv
	sem: pos
	mdd:
	mdr:
	nc:
	pc:
	prn:

Like the concept type, the proplet is retrieved from the artificial agent's memory (on-board database). Computationally, the lookup is based on string search (Knuth et al. 1977) in combination with a trie structure (Briandais 1959, Fredkin 1961).

The language counterpart to the recognition of nonlanguage concepts is the interpretation of language-dependent surfaces. As an example, consider the DBS

[5]From a theory of science point of view, computational pattern matching based on the type-token relation constitutes a fruitful interaction between the humanities and the sciences.

robot's recognition of the letter sequence blue by matching raw visual input data with letter patterns as shape types, resulting in a surface token:

4.3 RECOGNITION OF A WRITTEN LANGUAGE SURFACE

sensory modality: vision
input: raw data
⇓

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 u e		shape tokens: b% l% u% e%
samples: ...		samples: ...

Raw data input is matched by the shape types of the letters b l u e. The output replaces the matching shape types with the shape tokens b% l% u% e%[6] to record such accidental properties as the font, size, color, etc. in the sensory medium of print, and pronunciation, pitch, speed, loudness, etc. in the sensory medium of speech. The shape types are used for matching the raw data and the place holder for look-up of the lexical definition. For developing the linguistic side of automatic word form recognition, the type-token matching of raw data in different media may be cut short temporarily by typing the letters of the place holder directly into a standard computer.

5 Declarative Specification of Concepts for Action

The action counterpart to the recognition of nonlanguage concepts is their cognition-external realization as raw data. It consists in adapting a type to the agent's purpose as a token which is passed to the appropriate actuator. As an example, consider a cuttlefish Metasepia Pfefferi turning on the color blue:

5.1 RULE FOR PRODUCING THE COLOR blue

concept type		*concept token*
place holder: blue		place holder: blue
sensory modality: visual display		sensory modality: visual display
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, ...		samples: ...

⇓
sensory modality: vision
actuator values: 470nm *raw output*
637 THz

The type is adapted into a token by replacing the wavelength interval of 450–495nm and frequency interval of 670–610 THz with the agent-selected values of

470nm and 637 THz. In the cuttlefish, these values are realized by natural actuators for color control (chromatophores) as raw data.

The language counterpart to a nonlanguage action is the realization of a language-dependent surface in a medium of choice. As an example, consider the DBS robot's production of the surface blue as raw data in vision:

5.2 Realizing letter tokens as raw data in vision medium

surface type		*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 u e		shape tokens: b% l% u% e%
samples: ...		samples: ...

⇓

sensory modality: vision
actuator values: raw data *raw output*

The input to the actuator consists of a sequence of shape tokens representing roman letters. The output replaces the shape tokens, here b% l% u% e%, with matching raw data, for example, pixels on a computer screen.

6 Indirect Grounding of Indexicals and Names

In DBS, the second computational Mechanism is *indexicals* pointing at STAR values of the agent's on-board orientation system (OBOS) and is as such cognition-internal. However, because the STAR values originate as concept recognitions, past or present (CC 7, 8), indexicals rely indirectly on the Mechanism of computational pattern matching. More specifically, the indexical pro1 points at the A value of the STAR, pro2 at the R value, pro3 at the 3rd value, here at the S value, and now at the T value (with the S and T values nominalized).

The third computational Mechanism is *names*; it relies on an act of baptism, which inserts the 'named referent' as the core value into a lexical name proplet (CTGR'17). Because the named referent originates as concept cognition, names – like indexicals – rely indirectly on the first computational Mechanism of *concepts*, i.e., computational pattern matching.

After working out the basic functioning of the computational Mechanism for the recognition and action of certain concepts in a codesigned but real environment, more concepts of the same kind (semantic field) may be added routinely, as shown by the following example:

[6]The letter shapes are represented by the letters themselves, e.g., e (type) and e% (token).

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'', ...

Once the recognition and action side of these concepts is working as intended, more colors may be easily added as an efficient, transparent upscaling.[7]

Similarly for geometric forms: once the concepts of square (CC 1.3.2) and rectangle work as intended, more two-dimensional forms, such as triangle, heptagon, hexagon, and rhombus, may be added routinely. After implementing the concept pick including the associated hand-eye coordination and the semantic relation of object\predicate (CC 2.5.1, 2), the robot should be able to execute language-based requests like Pick the blue square or Pick the green rectangle correctly from a set of items in its task environment.

Conclusion

In data-driven agent-based DBS, recognition and action must be *grounded* in the form of a computational interaction between raw data and a robot's digital cognition. For practical reasons, grounding may be temporarily suspended by the shortcut of typing place holder values into a standard computer's key board and displaying output on the screen. This allows systematic upscaling of an artificial cognition even today, yet prepares for integrating operational core values for referents, properties, and relations when they become available in robotics.

Computational upscaling has two basic aspects: the *declarative specification* and the *procedural implementation*. A declarative specification must be both, (i) tolerably readable by humans and (ii) easily translatable into a general purpose programming language like Lisp, C, Java, or Perl. From a humanities point of view, a declarative specification must represent the necessary properties of a software solution by omitting the accidental properties which distinguish the individual programming languages and make them difficult to read. Methodologically, a procedural implementation is important because it complements a declarative specification with automatic verification, which supports systematic incremental upscaling.

[7] Set-theoretically, the colors red, green, and blue are (i) disjunct and (ii) subsets of color. This structure is inherent in the color concepts, but regardless of being true, it is neither the only nor the predominant aspect of their meaning: knowing that red and green are disjunct, for example, is not sufficient for naming these colors correctly.

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1.	noun	referent (object)	argument
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We take it that these variants are not merely different terms for the same things, but different terms for different aspects of the same things. In particular, the linguistic terminology may be viewed as representing the syntactic aspect, the philosophical terminology as representing the associated semantic aspect, and the logical terminology as a preparatory step towards a computational implementation.

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2.	property	adn, adv, adnv, 1-place verb
3.	relation	2- and 3-place verb

The Semantic kinds *referent, property*, and *relation* correspond to argument, 1-place functor, and 2- or 3-place functor, respectively, in Symbolic Logic. Syntactically, *property* splits up into adn, adv, adnv (including prepnouns), and 1-place verb. *Relation* splits up into 2- and 3-place verbs.

The distinction between (i) Semantic and (iii) Syntactic kinds is complemented by a second, orthogonal pair of triple distinctions, namely (ii) Content kinds and associated (iv) computational Mechanisms:

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The dichotomies 7.2 and 7.3 provide 12 (2×2×3) basic notions. Empirically, they combine into six classes of proplets which constitute the semantic building blocks of DBS cognition in general and natural language communication in particular. The six classes form what we call the *cognitive square*[9]:

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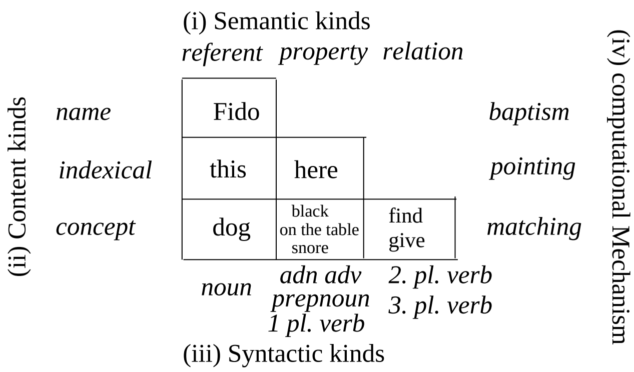

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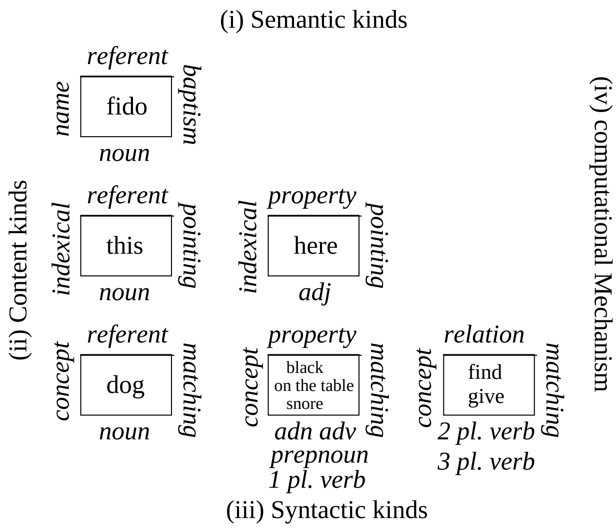

The surfaces inside the rectangles have the following proplet definitions:

7.6 PROPLETS INSTANTIATING THE COGNITIVE SQUARE OF DBS

referent (top), *name* (left), *baptism* (right), *noun* (bottom):

sur: Fido
noun: [dog x]
cat: snp
sem: nm m sg
fnc:
mdr:
nc:
pc:
prn:

indexical (left), *pointing* (right); *referent* / *noun* (first proplet), *property* / *adj* (second proplet):

referent	property
sur:	sur:
noun: this	adj: here
cat: snp	cat: adnv
sem: -hum sg	sem: loc
fnc:	fnc:
mdr:	mod:
nc:	nc:
pc:	pc:
prn:	prn:
noun	adj

[8] Examples of precomputational uses are (i) matching for concepts but without the type-token relation and its computational implementation based on content and pattern proplets, (ii) pointing for indexicals but without an on-board orientation system, and (iii) baptism but without the named referent as the core value for use in the speak and the hear mode.

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	referent	*property*			*relation*	
concept	sur:	sur:	sur:	sur:	sur:	sur:
	noun: dog	adj: black	noun: table	verb: snore	verb: find	verb: give
	cat: snp	cat: adnv	cat: adnv snp	cat: n-s3′ v	cat: n-s3′ a′ v	cat: n-s3′ d′ a′ v
	sem: def sg	sem: pad	sem: *on* def sg	sem: pres	sem: pres	sem: pres
	fnc:	fnc:	fnc:	arg:	arg:	arg:
	mdr:	mod:	mdr:	mdr:	mdr:	mdr:
	nc:	nc:	nc:	nc:	nc:	nc:
	pc:	pc:	pc:	pc:	pc:	pc:
	prn:	prn:	prn:	prn:	prn:	prn:
matching	*noun*	*adj*	*prepnoun*	*verb* 1-pl	*verb* 2-pl	*verb* 3-pl

In a proplet, the Semantic kind *referent* is limited to the core attribute noun, *property* is limited to the core values adn, adv, adnv, and to verbs characterized by their cat value as intransitive, and *relation* is limited to verbs characterized by their cat value as transitive.

The Content kinds *name, indexical*, and *concept* are specified by the core value of a proplet. In names, the corresponding computational Mechanism of *baptism* is implemented by inserting a 'named referent' as the core value into a lexical proplet, in indexicals by *pointing* at a STAR value of the on-board orientation system, and in concepts by computational type-token *matching*.

The cognitive square of DBS is empirically important because (i) figurative use is restricted to concepts, i.e., the bottom row in 7.4–7.6, and (ii) reference is restricted to nouns, i.e., the left-most column. Thus only concept nouns may be used both figuratively and as referents, while indexical properties like here and now may not be used as either, and names and indexical nouns like this only as referents.

8 Restriction of Figurative Use to Concepts

To show the restriction of figurative use to the Content kind concept let us go systematically through the three Semantic kinds:

8.1 Three Content kinds for the Semantic kind *REFERENT*

concept	*indexical*	*name*
sur:	sur:	sur: tom
noun: animal	noun: pro2	noun: [person x]
cat: sn	cat: sp2	cat: snp
...	...	...

The three Content kinds of the Semantic kind *referent* all have literal use, but only the concepts allow figurative use.

Next consider the Semantic kind *property*, which occurs as the Content kinds (i) *concept* and (ii) *indexical*, but not as *name*. Property proplets of the content kind concept may have the core attributes adj, noun, or verb if it is 1-place (7.6). If they have the core value adnv, they may be (a) elementary (fast) or phrasal (in the park), and (b) adnominal (tree in the park) or adverbial (walk in the park).[10]

[10]Phrasal modifiers, called prepnouns in DBS, are derived from a referent by means of a preposi-

8.2 TWO CONTENT KINDS FOR THE SEMANTIC KIND *PROPERTY*

concept	*indexical*	*name*
sur: adj: great cat: adn ...	sur: adj: now cat: adnv ...	
sur: adj: enough cat: adnv ...	sur: adj: here cat: adnv ...	
sur: noun: table cat: snp ...	sur: noun: pro2 cat: sp2 ...	
sur: verb: melt cat: n-s3′ v ...		

Of the Semantic kind *property*, only the concepts may be used nonliterally.[11]

The Grammatical kind transitive (i.e., 2- or 3-place) verb with its single Semantic kind *relation* exists as the Content kind *concept*, but not as *indexical* or *name*:

8.3 ONE CONTENT KIND FOR THE SEMANTIC KIND *RELATION*

concept	*indexical*	*name*
sur: verb: steal cat: n-s3′ a′ v ...		
sur: verb: give cat: n-s3′ d′ a′ v ...		

Being concepts, transitive verbs have literal and nonliteral use.

9 Additional Constraint on Figurative Use

The restriction of figurative use to concepts is constrained further by the condition that the literal term and its figurative counterpart must be grammatically equivalent:

tion or an affix, depending on the language. Therefore, a prepnoun like in the park refers by means of park, in contradistinction to the other modifiers, e.g. elementary fast or intransitive snore, which do not refer.

[11] For a nonliteral use of *on the table* see CC 9.2.4 and of *melt* CC 9.5.1.

9.1 INVARIANCE CONSTRAINT

> A figurative use and its literal counterpart must be of the same Syntactic and Semantic kind.

Thus, one cannot use a 1-place verb like bark to refer figuratively to a dog unless bark is nominalized, as in the little barker (i.e., by turning the property of intransitive bark into the referent barker, sleep into sleeper, stink into stinker, etc.). Similarly for the adj fat, which for figurative use must be nominalized, as in the old fatso. Functionally, the constraint helps the hearer to find the literal counterpart of a figurative use by reducing the search space.

The systematic examples in CC 9 all satisfy the invariance constraint:

9.2 SYNTACTIC-SEMANTIC INVARIANCE OF FIGURATIVE USE

Semantic kind	Syntactic kind	nonliteral use	literal counterpart	in CC
referent	noun	animal	dog	9.1.2
property	prepnoun	on the table	on the orange crate	9.2.1
property	adn	great	greater than average	9.6.3
property	adv	enough	more than enough	9.6.6
property	intransitive verb	melt	disappear	9.5.1
relation	transitive verb	steal	take over	9.4.2

The Semantic kind *property* has several Syntactic kinds, while each Syntactic kind, e.g. prepnoun, has only of one Semantic kind, i.e., *property*, regardless of whether it is used literally or figuratively. The other two Semantic kinds, i.e., *referent* and *relation*, each have only a single syntactic counterpart.

As an example of using all three Semantic kinds figuratively consider the following description of a dog contorting itself catching a frisbee in mid air:

9.3 EXAMPLE USING ALL THREE SEMANTIC KINDS FIGURATIVELY

> The animal flew acrobatically towards the disc.

The content obeys the invariance constraint: literal dog and figurative animal are both singular nouns, literal jumped and figurative flew are both finite verbs in the indicative past, literal in a spectacular gymnastic feat and figurative acrobatically are both adverbials (one phrasal, the other elementary), and literal frisbee and figurative disc are both singular nouns. For successful communication, the hearer-reader must relate figurative animal to literal dog and figurative disc to literal frisbee. The relation flew and the property acrobatically, in contrast, do not refer, but establish a relation between referents, or modify a referent, a relation, or a property.

10 Declarative Specification of Concepts for Recognition

Concepts are the only Semantic kind which interacts directly with the agent's cognition-external environment. The interaction consists of matching between (i) raw data provided by sensors and activators of the agent's interface component and (ii) concept types provided by the agent's memory.[12]

Consider the rule for the recognition of a color:

10.1 DECLARATIVE SPECIFICATION FOR RECOGNIZING THE COLOR blue

concept type		*concept token*
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 samples: ...
⇑		*analyzed output*
raw input sensory modality: vision sensor values: 470nm 637 THz		

The raw input data 470nm and 637 THz are provided by the agent's interface component and recognized as the color blue because they fall into the type's wavelength interval of 450–495nm and frequency interval of 670–610 THz. The analyzed output token results from replacing the wavelength and frequency intervals of the type with the raw data measurements of the input.

The place holder value of the recognized token, i.e., the letter sequence b l u e, is used for lookup of the lexical proplet which contains the place holder as its core value (CC 1.6.3):

10.2 PLACE HOLDER VALUE OF CONCEPT USED FOR LEXICAL LOOKUP

b l u e ⟶	sur: adj: blue cat: adnv sem: pos mdd: mdr: nc: pc: prn:

Like the concept type, the proplet is retrieved from the artificial agent's memory (on-board database). Computationally, the lookup is based on string search (Knuth et al. 1977) in combination with a trie structure (Briandais 1959, Fredkin 1961).

[12] From a theory of science point of view, computational pattern matching based on the type-token relation constitutes a fruitful interaction between the sciences and the humanities.

The language counterpart to the recognition of nonlanguage concepts is the interpretation of language-dependent surfaces. As an example, consider the DBS robot's recognition of the letter sequence blue by matching raw visual input data with letter patterns as shape types, resulting in a surface token:

10.3 SENSOR INTERACTING WITH LANG. CONCEPT TYPE (SURFACE)

sensory modality: vision
input: raw data
⇓

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 u e		shape tokens: b% l% u% e%
samples: ...		samples: ...

Raw data input is matched by the shape types of the letters b l u e. The output replaces the matching shape types with the shape tokens b% l% u% e%[13] to record such accidental properties as the font, size, color, etc. in the sensory medium of print, and pronunciation, pitch, speed, loudness, etc. in the sensory medium of speech. The shape types are used (i) for matching the raw data and (ii) for look-up of the lexical definition. For developing the linguistic side of automatic word form recognition, the type-token matching of raw data in different media may be cut short temporarily by typing letters directly into a standard computer of today.

11 Declarative Specification of Concepts for Action

The action counterpart to the recognition of nonlanguage concepts is their cognition-external realization as raw data. It consists in adapting a type to the agent's purpose as a token which is passed to the appropriate actuator. As an example, consider a cuttlefish Metasepia Pfefferi turning on the color blue:

11.1 RULE FOR PRODUCING THE COLOR blue

concept type		*concept token*
place holder: blue		place holder: blue
sensory modality: visual display		sensory modality: visual display
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, ...		samples: ...

⇓
sensory modality: vision
actuator values: 470nm *raw output*
637 THz

The type is adapted into a token by replacing the wavelength interval of 450–495nm and frequency interval of 670–610 THz with the agent-selected values of 470nm and 637 THz. In the cuttlefish, these values are realized by natural actuators for color control (chromatophores) as raw data.

The language counterpart to a nonlanguage action is the realization of a language-dependent surface in a medium of choice. As an example, consider the DBS robot's production of the surface blue as raw data in vision (medium of writing):

11.2 Realizing letter tokens as raw data in vision medium

surface type		*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 u e		shape tokens: b% l% u% e%
samples: ...		samples: ...

⇓

sensory modality: vision
actuator values: raw data *output*

The input to the actuator consists of a sequence of shape tokens representing roman letters. The output replaces the shape tokens, here b% l% u% e%, with matching raw data, for example, pixels on a computer screen.

12 Indirect Grounding of Indexicals and Names

In DBS, the second computational Mechanism is *indexicals* pointing at STAR values of the agent's on-board orientation system (OBOS) and is as such cognition-internal. However, because the STAR values originate as concept recognitions, past or present (CC 7, 8), indexicals rely indirectly on the Mechanism of computational pattern matching. More specifically, the indexical pro1 points at the A value of the STAR, pro2 at the R value, pro3 at the 3rd value, here at the S value, and now at the T value (with the S and T values nominalized).

The third computational Mechanism is *names*; it relies on an act of baptism, which inserts the 'named referent' as the core value into the lexical name proplet (CTGR). Because the named referent originates as concept recognition, names – like indexicals – rely indirectly on the first computational Mechanism of *concepts*, i.e., computational pattern matching.

After working out the basic functioning of the computational Mechanism for the recognition and action of certain concepts in a codesigned but real environment, more concepts of the same kind (semantic field) may be added routinely, as shown by the following example:

[13]For ease of illustration, the letter shapes are represented by the letters themselves, e.g. e (type) and e% (token).

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'', ...

Once the recognition and action side of these concepts is working as intended, more colors may be easily added as an efficient, transparent upscaling.[14]

Similarly for geometric forms: once the concepts of square (CC 1.3.2) and rectangle work as intended, more two-dimensional forms, such as triangle, heptagon, hexagon, and rhombus, may be added routinely. After implementing the concept pick including the associated hand-eye coordination and the semantic relation of object\predicate (CC 2.5.1, 2), the robot should be able to execute language-based requests like Pick the blue square or Pick the green rectangle correctly from a set of items in its task environment.

Conclusion

In data-driven agent-based DBS, recognition and action must be *grounded* in the form of a computational interaction between raw data and a robot's digital cognition. For practical reasons, grounding may be temporarily suspended by the shortcut of typing place holder values into a standard computer's key board and displaying output on the screen. This allows systematic upscaling of an artificial cognition even today, yet prepares for integrating operational core values for referents, properties, and relations when they become available in robotics.

Computational upscaling has two basic aspects: the *declarative specification* and the *procedural implementation*. A declarative specification must be both, (i) tolerably readable by humans and (ii) easily translatable into a general purpose programming language like Lisp, C, Java, or Perl. From a humanities point of view, a declarative specification must represent the necessary properties of a software solution by omitting the accidental properties which distinguish the individual programming languages and make them difficult to read. Methodologically, a procedural implementation complements a declarative specification with automatic verification, which supports systematic incremental upscaling.

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[14] Set-theoretically, the colors red, green, and blue are (i) disjunct and (ii) subsets of color. This structure is inherent in the color concepts, but regardless of being true, it is neither the only nor the predominant aspect of their meaning: knowing that red and green are disjunct, for example, is not sufficient for naming these colors correctly.

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