Auke J.J. van Breemen & Janos J. Sarbo

The Machine in the Ghost: The Syntax of Mind

Abstract

Experience with static, fact-based Knowledge Representation (KR) in past decades has revealed its limitations: it is inflexible (for adjustments) and non-portable (knowledge in one domain cannot be directly used in another domain). We believe that dynamical, process-based KR offers better perspectives. Below we start our presentation with a philosophically informed underpinning of a process view of KR. The most important conclusion of this enterprise is that the processes of perception and cognition can be modeled in the same way. This part is followed by the introduction of a cognitively based, semiotically inspired model of KR that complies with our philosophical considerations. As computer science in its core meaning is necessarily fact oriented, due to the limitations of current computers, the proposed theory of KR is based in logic, but this logic is less articulate than predicate calculus (regarded as a language for the specification of recursively computable functions). Note that it is a limitation of syntax, not of expressive power. In knowledge representation, in the broader sense, including problem elicitation and specification, the restricted syntax may turn out to be more practical than the whole (i.e. predicate calculus).

Keywords: Knowledge representation, information process, logica utens, semiotics, Peirce

1 Introduction; theoretical background

In man the task oriented 'interpreting system' and his 'knowledge systems' are intertwined. It is in the course of history that knowledge representations were devised that exist in artifacts[1] and so the KR became severed from the interpretational system. Part of the knowledge representations explicitly aimed at capturing reasoning processes as is witnessed by the history of logic.[2] Eventually this led to a view of logic as an abstract calculus that is devoid of empirical content, depending on set theory for its extensional, semantical interpretation.[3]

1.1 Received view: ontology and representation

L. Wittgenstein furnished a prototypical example of this approach in his Tractatus Logico Philosophicus. With his picture theory of meaning, or also, correspondence theory of truth,

he provided a world view that is intimately connected with an extensional interpretation of the logical calculus. Although nowadays his philosophy regarded as a system has lost appeal, a basic trait of it is still quite common in thought about modeling and ontology in information science. It sets off with the conviction that there are two useful kinds of sentences: the tautologies of logic that provide the form on the one hand and the interpreted logical forms that state facts on the other. Along these lines a model, if true, represents part of reality. Based on this distinction between types of sentences is the belief that ontological work is concerned with a specification of the entities covered by statements of fact or, in other words, *domain specific* ontologies. If there is attention for distinctions of being at a more general level, than it is focused on the representational primitives of extensional logic or *general* ontology. T. Gruber nicely illustrates this line of thinking in information sciences when he writes (Gruber, 2008):

> In the context of computer and information sciences, an ontology defines a set of representational primitives with which to model a domain of knowledge or discourse. [. . .] In the context of database systems, ontology can be viewed as a level of abstraction of data models, analogous to hierarchical and relational models, but intended for modeling knowledge about individuals, their attributes and their relationship to other individuals.

It must be admitted that Wittgenstein intended to cover all of reality while Gruber modestly states that ontology in computer science is a technical term. The scheme of thinking, however, is the same: propositions form the key entrance to ontological thinking. But what if the formation of the proposition is the true ground on which to base the most general ontology?

In subsequent criticism of the picture theory Wittgenstein offers a line of thought that is worth to be mentioned here. In the Tractatus sentences that picture state of affairs were deemed meaningful if in a complete analysis of such a sentence the names that occur in the resulting atomic sentences are proxies of atomic objects. As the objects configure to form states of affairs, the atomic sentences configure to complex sentences that mirror those state of affairs. This mirroring relation puts the judge that has to compare sentences with states of affairs outside the system.

In the Philosophical Investigations (Wittgenstein, 1971) Wittgenstein shifts from a detached view to a more inside perspective. The meaning of an expression no longer depends solely on the pictured facts: instead meaning is determined by the role the expression plays in the language game in which it figures. Uttering a sentence is like

doing a move in a game of chess. Using language is rule governed. Learning language is learning to do the right moves and picturing facts is only one of the families of games, that has to be sub-divided according to its variant forms on top of that. And the foundational role of logic is at hazard.

The development of Wittgenstein's thought may be interesting for its own sake. Here, however, we only hinted at it because it is an efficient way to state the problem we face in general terms and next to point to the fact that in information science a similar tension between a *fact* oriented semantics and an *act* oriented semantics can be discerned. Maybe the tension can be resolved if only we can find a logic that is more foundational than the extensional calculus and are able to construct a method of modeling with it that respects the demands of representing facts and the demands of representing acts of interpretation. Again a small detour along the road of philosophy may prove efficient in our attempt to make clear the direction in which we seek our solution.

As a start we point to a distinction J. Bentham made between two different kinds of ontology.[4] The first type is idioscopic ontology. Its task is to investigate (skopeo=look at)[5] the properties that are peculiar to each of the different classes of being (idios=separate, distinct). The second form of ontology is cenoscopic ontology. Its task is to study the properties that all things have in common (koinos=common). Bentham's distinction differs, due to his nominalistic world view, from the one Gruber provides –the above mentioned domain specific ontologies and the ontological work on representational primitives– except for the distinction between a special and a general ontology. So, let's forget about the content Bentham provided, just keep the distinction and fill in on the idioscopic part of the distinction Gruber's domain specific ontologies. That leaves us with the question what alternatives there are for the representational primitives in the cenoscopic part of ontology.

1.2   A central precursor: I. Kant

I. Kant is a precursor of Gruber's interpretation of a general ontology as dealing with representational primitives. His starting point is an investigation of the different kinds of judgments (propositions) with which we think about objects (Kant, 1956). He comes up with a table of four dimensions (Quantity, Quality, Relation, Modality) with three subdivisions in each. See fig. 1.

The idea is that each judgment, if classified will score in each of the dimensions on one of the sub-divisions. In order to be applicable to objects Kant generalized the table of
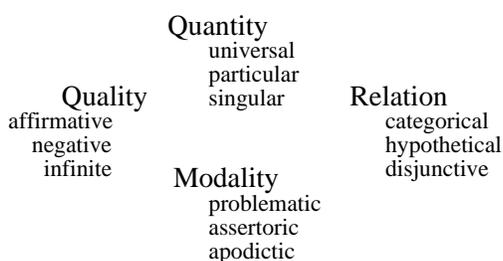
Quantity
universal
particular
singular

Quality
affirmative
negative
infinite

Relation
categorical
hypothetical
disjunctive

Modality
problematic
assertoric
apodictic

Figure 1: Kant's table of judgments

Quantity
unity
plurality
totality

Quality
reality
negation
limitation

Relation
inherence and subsistence
causality and dependence
community (reciprocity)

Modality
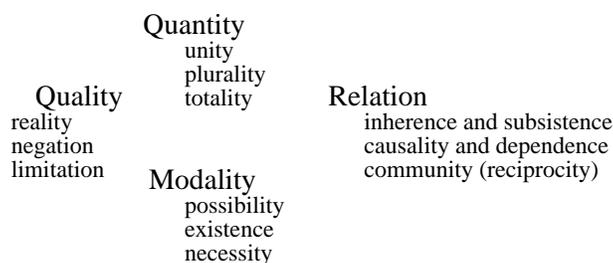possibility
existence
necessity

Figure 2: Kant's table of categories

judgments in a table of categories of being. The names for the categories (most general cenoscopic categories or short list) are the same as the names for the dimensions. The sub-divisions (one level less general cenoscopic categories or long list) however differ. See fig. 2.

Ch. S. Peirce recognized early in life that we can't start with the proposition in our quest for the most general categories. He also endorsed the idea that categories have to be founded on formal logic, but the table Kant presented did not convince him since he found to many faults in and interrelations between the different categorical sub-divisions (CP 1.545-1.548)[6]. He concluded that there must be a more general level at which we have to search for categories. That is what led him to search in the direction of a generalization of Kant's sub-divisions in threefolds. His assumption is that if we are looking for truly universal conceptions, we have to find out what is needed to bring the manifold of sensuous impressions or the content of consciousness to (the) unity (of the proposition). It is in the *formation* of the proposition, not just the result, the proposition itself, where we have to look. The formation of the proposition, as we will show later, can be analyzed as a less developed kind of argument or inference.

1.3 Ontology and interpretation

At this point we will not embark on a long journey into the depths of Peirce's philosophy in order to delve up the many shades of the categories he discerns in a systematic way. Instead we hook on to Kant's work and we will only present the results, not the derivation. Since, on top of that, the presentation is written form the post hoc perspective of Peirce's mature classification of the science's (CP 1.180-1.283) the treatment is not only superficial but also clearly not intended to be taken as a contribution to the understanding of Peirce's intellectual development.[7]

On the most general level the three categories resemble the sub-divisions of Kant's category of Quantity. They state differences in relational properties without any content:

> The first is that whose being is simply in itself, not referring to anything nor lying behind anything. The second is that which is what it is by force of something to which it is second. The third is that which is what it is owing to things between which it mediates and which it brings into relation to each other (CP 1.356).

Two remarks must be made here. First, categories of a lower ordinal number are involved in higher order categories, but not the reverse. Second, the category of Thirdness is the highest order category we need, because, in the Peircean view of categories, all still higher order relations can be reduced to a compound of triadic relations. We cannot do with less than Thirdness since a reduction of a triad to two dyads would eliminate the mediative character of Thirds. An example might illustrate this. Imagine the sudden appearance of strokes of pain. Eventually you locate it as a pain in a molar. The pain and the relation of the pain with its object (the molar) were there before you recognized, by an interpreting thought, the pain as a tooth ache. It is only through the thought that relates the pain to the molar that the pain is hypothetically recognized as a tooth ache caused by the molar.

Applied to consciousness the categories gain content, here a resemblance with Kant's sub-divisions of Quality prevails:

> [...] first, feeling, the consciousness which can be included with an instant of time, passive consciousness of quality, without recognition or analysis; second, consciousness of an interruption into the field of consciousness, sense of resistance, of *an external fact, of another something* (italics added by the authors);

third, synthetic consciousness, binding time together, sense of learning, thought
(CP 1.377).

The phrase we italicized may seem ill placed since the introduction of an object, as the cause of an interruption in the field of consciousness, is a result of operations of the synthetic consciousness, which task it is to glue successions of feelings together by providing explanations for the patterns in which they emerge. From this it follows that, strictly speaking, the attribution of objecthood as well as the ascription of external factuality is hypothetical and not pre-given. This however is not the direction of Peirce's thought here. Here he just distinguishes three different kinds of consciousness and feels compelled, in order to do so, to point to elements that only can become manifest by analyzing more developed stages of thought. Elsewhere, in the context of discussions on logic, he distinguishes the consciousness of quality, the sense of resistance and the sense of thought as quale consciousness (cf. CP. 6.230), consciousness of discrimination and consciousness of origin respectively (cf. CP 3.63). Since in higher order categories the lower ordered categories are involved, thought involves (consciousness of) discrimination and (consciousness of) qualities.

In the domain of representation the categories are applied to communication (between two persons or one person communicating with its future self in a stretch of time). It is the domain of the transfer and growth of thought, which, if signs didn't exist, would remain barren. Because this makes the sign concept of paramount importance, the first step we need to take is to find out the general nature of signs. Peirce provided several definitions, a representative one is the following.

> A Sign, or Representamen, is a First which stands in such a genuine triadic relation to a Second, called its Object, as to be capable of determining a Third, called its Interpretant, to assume the same triadic relation to its Object in which it stands itself to the same Object (CP 2.274).

A sign only fulfills its duty if it actually raises an interpretant thought. A representamen that is not regarded as actually standing in relation to an object only entails the *possibility* of becoming a sign. A sign that is regarded to stand in relation with an object, is *existing* as a sign, but as long as it does not give rise to an interpretant, it still does not actualize its sign function and thus is not a *real* sign (note the similarity with the subdivisions of Kant's category of modality, necessity being screwed down a little). From the above it follows that if we want to analyze signs and information processes we have to take

the monadic (sign in itself), the dyadic (sign–object, sign–interpretant) and the triadic relations (sign–object–interpretant) into account. It is possible to analyze the monadic aspect without paying attention to the dyadic and triadic relations, but the reverse is not possible because lower order categories are involved in higher ordered categories and have to be accounted for in the analysis of the later.

It is easily possible to enlarge the list of triadic categorical orderings each exemplifying another shade of the most basic concepts. What is more important, however, is that from these three basic categories Peirce develops his cenoscopic ontology in a systematic way by applying the categorical distinctions to themselves. Thus forging tools suited to analyze the process of interpretation, which in computer science can be adapted for systematic (ontological) specification. The three basic categories are Peirce's short list, equal to a generalization of the headings of Kant's sub-categories. The repeated application of the basic categories to signs, with the aim of finding out their most general characteristics, yields the long list of categories (*categorical aspects*). This Peircean cenoscopic science of signs, dedicated to an investigation of the representational primitives is more widely known as semiotics.[8]

We get the long list by recognizing that in phenomenology a feeling is truly monadic, present only for an instant and after that forever gone, but a representamen is not. A representamen is, so to speak, more persistent and entails the possibility of a relation with object and interpretant. A representamen is of a first category only *relative* to a second (its object) and a third (its interpretant). It is not on its own account a first category kind of being, as with a feeling, but on account of the relations it partakes in. What in one context is a representamen can be an interpretant or object in another, as, for instance, when we talk about a model itself. This more complicated character of signs can be analyzed in a very general way that specifies the rules the sub-categories must comply with:

1. [*monadic aspect of signs*] A sign regarded in itself involves a trichotomy. This yields the first three terms for the long list, covering the representamen itself. We number them 1.1, 1.2, 1.3. We use the first number for the category and the second for the categorical aspect.

2. [*dyadic aspects of signs*] The two dyadic relations of a sign –1st the relation of a sign to its object and 2nd the relation of a sign to its interpretant– can each be analyzed in two trichotomic relations. This yields six terms for the long list, three terms for each dyadic relation. We number them 2.1, 2.2, 2.3 if they belong to the relation between

sign and object and 3.1, 3.2, 3.3 for the relation between sign and interpretant.

3. [*triadic sign relation*] In order to produce an interpretant that assumes the same triadic relation to its object as the sign itself stands, no new terms are needed, but a process has to be run through in which all nine categorical terms, or alternatively, all nine sign aspects of the long list are involved. This is a consequence of the assumption that lower ordered (sub-)categories are involved in higher ordered (sub-)categories.

The long list of nine categories can be put to use in two directions. First, we can model the interpretation process that generates new signs. If we do this, then we are in need of all nine categorical aspects, as will be shown in sect. 4. We will call them *sign aspects*. They do not exist on their own outside the process. Second, we may ask whether different kinds of signs may result from the interpretative process, capable of entering new instances of interpretative processes. On the basis of the above analysis of signs, a *sign type* can be defined by giving three sign aspects, one out of each of the three categories. Following the rule that lower categories are involved in higher, but not the reverse, some constraints must be applied. A lower categorical aspect of a lower category cannot form a sign type together with a higher categorical aspect of a higher category (1.1, 2.2, 3.1 can not form a sign type, 1.1, 2.1, 3.1 do). The result is a list of 10 different sign types out of the 27 possible combinations. Since, in this article we will concentrate on the interpretative process and not on the sign types, we will close this subject with the remark that, since the ten sign types can be projected on different stages of our interpretation model, the lexical items in the library can be sorted according to type in terms of the interpretative model. Representation and interpretation are thus brought in a systematic relation. Later, see sect. 4.3.1, we will give an exposition of Peirce's long list of categories, here we would like to point to the fact that here we have an alternative interpretation of what counts as cenoscopic ontology that goes, so to speak, one ply deeper than approaches that take the predicate calculus as their point of departure. A nice feat of this approach is that it is systematic, by providing principles to build the system, and that it is dynamic, in the sense that it provides a model for the process and not just for the result of information processes.

Before we proceed a last remark about the relation between logic and the interpretational process is in order. The logic on which Gruber bases his ontology of representational primitives is the logic we learn in school. Peirce coined this the 'logica docens'. This logic grew out of the logic that uncritically is used in our everyday mental operations, the 'logica utens'. This logic is generalized by us and interpreted as a procedure. The result

we call 'naive' logic (see Appendix B). Thus we try in our Knowledge in Formation (KiF)[9] research program to push the logical approach one step further by taking the interpreting system as our point of departure instead of the representational system.

1.4 Outline

Interpretation, in our approach, starts at the moment something knocks at our mind. Here it is convenient not to focus on the question what mind is and how it is to be distinguished from the senses and from consciousness. Instead we ask what it is that knocks at our mind. Our, and Peirce's, answer, that qualia do the knocking, is akin to the answer provided by V.S. Ramachandran and W. Hirstein (1997). Qualia, according to them, are

> [...] the 'raw feels' of conscious experience: the painfulness of pain, the redness of red. Qualia give human conscious experience the particular character it has. For instance, imagine a red square; that conscious experience has (at least) two qualia: a color quale, responsible for your sensation of redness, and a shape quale, responsible for the square appearance of the imagined object (idem, pp. 437-438).

According to (Ramachandran & Hirstein, 1997) three laws apply to qualia:

(1) Qualia are irrevocable on the input side.
(2) What you can do with qualia is open ended (flexibility on the output side).
(3) Qualia must be retained long enough to enable subsequent processing.

Later on in the article the authors refine their view by distinguishing between perceived and imagined qualia. The experiential difference between the two types consists in the more vivid character of the experienced qualia. A consequence of this difference is that we can distinguish between what is independent of our mind and what is generated by it. A faculty that greatly enhances our chances of survival. There is more to it since the imagined qualia are, as a rule, far more vague[10] and can be exchanged according to purpose, although only in stretches of time. But, the processes of perception and cognition both rely on qualia that obey the aforementioned laws.

Peircean semiotic theory is too general and in too unfinished a state,[11] to be directly used for the development of a model for interpretational processes (semiotic model), let alone a computational one. Falling back on the underlying logica utens in a straightforward way is impossible because Peirce mainly uses the term to indicate the habits of reasoning

that grow naturally, i.e. without the aid of a logica docens, in the course of life, like, as he puts it "[...] the analytical mechanics resident in the billiard player's nerves" (cf. CP 1.623). He did not try to formulate the basic program of the mind in terms of a logica utens ('naive' logical model). Because such a logic provides a promising avenue to a computational model of interpretation, we had to formulate one ourselves. In order to be able to do so, we needed to construct a model in which the interpretation moments are described and ordered in a very general description of the process, one which is as close as possible to the assumed working of cognitive activity (relations on qualia or relational model).
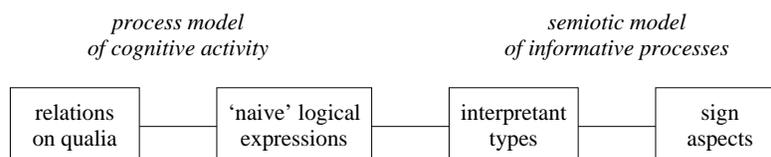

Figure 3: The isomorphic models of information processing

In this paper we will start (see fig. 3) with a process interpretation of cognitive activity, summarized in the relational model (sect. 2), already here we will distinguish the process of perception (sect. 2.1.1) from the process of cognition (sect. 2.1.2). We proceed by providing a logical interpretation of the relational model (sect. 3). In the next section (sect. 4) we provide a systematic [12] interpretation of Peirce's semiotic thought from the perspective of the model introduced before. Starting from the definition of a sign we introduce the different aspects a sign must have, according to Peirce, in order to be able to realize its sign function (sect. 4.1). After this is done the focus shifts from signs to the process of their interpretation (sect. 4.2). We provide the interpretant aspects distinguished by Peirce and complete his list of aspects (sect. 4.3). After the introduction of our theory, we shortly deal with questions of application (sect. 5.2) and we finish the article with conclusions and possibilities for further research (sect. 6). In the Appendix finally we briefly sketch the secondary literature on Peirce and provide a definition of our 'naive' logic.

2   Towards a model of cognitive activity

We assume that the 'real' world consists of phenomena that are interactions between entities which are in principle independent and that knowledge arises from observations of such phenomena, by means of signs. Note that entities that are not independent

(from a certain point of view) may not interact (from that point of view). For example, mixing paints of the same color may not appear as a color-phenomenon; we will not 'see' any difference. However, mixing paints may increase mass, which may appear as a mass-phenomenon.

An 'observation' or the *actual meaning* of a phenomenon is an interpretation of the interaction between an observed phenomenon and an observer, as an event. By considering the observer to be an interpreting system occurring in some 'state' at the moment of the interaction, the change brought about by the 'effect' due to the observed phenomenon can be interpreted as a 'transition' of the system's state to a next state. This includes the reaction by an interpreting system on the input effect as a stimulus. For example, if we observe the qualities of a bursting smoke (stimulus), then running away may be our reaction, interpreting smoke as a sign of danger.

Phenomena are interactions between independent qualities. Such interrelated and, at the same time, independent qualities we call dual qualities or a *duality*. There may be any number of qualities involved in an interaction, but, according to the theory of this paper, those qualities are always distinguished by cognition in two collections, state and effect, and, consequently, are treated as single entities.[13] As the real world is inherently dynamic, phenomena interpreted as signs may themselves become qualities in a subsequent inter-action. The dynamic character of phenomena is acknowledged in this paper, by modeling interpretation as a *process*, representing interactions by means of other interactions, in a recursive fashion.

2.1   Processing schema

Cognitive information processing by the brain can be modeled as follows (Solso, 1988). By virtue of the change caused by the appearing stimulus, the input qualities are sampled by the senses in a collection of qualia, called a percept[14] (Harnad, 1987), (Stillings, 1998). In a single operation, the brain compares the current percept with the previous one, and this enables it to distinguish between two sorts of input qualities: one, which was there and remained there, which can be called a 'state'; and another, which, though it was not there, is there now, which can be called an 'effect'.[15]

The reaction of an interpreting system is determined by its knowledge of the properties of the external stimulus (which other qualities it may co-occur with in an interaction) and its experience with earlier response strategies (habits). Such knowledge is an expression of the system's potential for interpreting, i.e. *combining* with, a type of input effect. This

potential depends on the system's state. These properties, which are stored in memory, we call the 'combinatory' properties of the input qualia or the complementary information defining the *context* of the observation. The input state and effect qualia (*input qualia*), and the context (which too is assumed to be present as a collection of qualia) collectively define the *input* for cognitive information processing by the brain.

The primary task of cognitive processing is the interpretation of the input qualia, in the light of their combinatory properties. Since the input for cognitive processing is assumed to consist of state (q_s), effect (q_e) and context (C) qualia, appearing in a 'primordial soup' ([q_s q_e C]), the stages of recognition can be defined as a *processing schema*, as follows (see also fig. 4). Below, square brackets are used to indicate that an entity is not yet interpreted as a sign; no bracketing or the usual bracket symbols indicate that some interpretation is already available.

(1) the identification of the different types of qualia in the 'primordial soup'
  sorting: [q_s], [q_e], [C]
(2) the separation of the collections of state and effect qualia
  abstraction: q_s, q_e
(3) the linking of the qualia with their combinatory properties ([C])
  complementation: (q_s,C), (q_e,C)
(4) the establishment of a relation between the completed qualia
  predication: (q_s,C)–(q_e,C)

Sorting may be explained as an operation in which the different types of qualia, constituting the input, are identified in the 'primordial soup'. For example, [q_s] is a representation of the input state qualia, accompanied by the remaining qualia of the 'primordial soup'. *Abstraction* is an operation representing the input state and effect qualia, separately from one another, as independent entities. *Complementation* is an operation representing the input qualia in context. *Predication* is an operation in which the input is represented as a reason or, a 'reaction' by the interpreting system. It explains why *this* effect occurs to *this* state.

The above model of cognitive activity, first presented in (Farkas & Sarbo, 2000), represents the input interaction by other interactions, in a recursive fashion. On the first or 'sensory' level, the interaction between the external stimulus and the observer is represented as a 'primordial soup'. The interaction between the collections of different types of qualia of the 'primordial soup' ([q_s q_e C]) or the interaction of the input with itself, is represented by [q_s], [q_e], and [C]. The interaction between the sorted state [q_s]

$$
\begin{array}{c}
(q_s,C) - (q_e,C) \\
(q_s,C) \quad\text{---}\quad (q_e,C) \\
q_s \quad\text{---}\quad [C] \quad\text{---}\quad q_e \\
[q_s] \quad\text{---}\quad [q_e] \\
[q_s \; q_e \; C]
\end{array}
\qquad
\begin{array}{l}
\textit{(4) predication} \\
\textit{(3) complementation} \\
\textit{(2) abstraction} \\
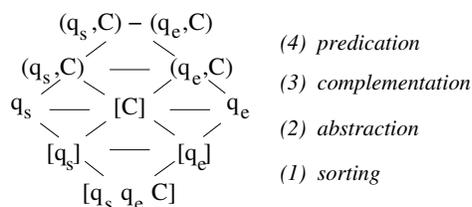\textit{(1) sorting}
\end{array}
$$

Figure 4: A schematic diagram of cognitive processing. A horizontal line designates an interaction, a diagonal a dependency relation (in step (2), there are relations between q_s and $[q_e]$, and between $[q_s]$ and q_e, but since they are used for separating collections from each other, these dependencies are omitted).

and effect $[q_e]$ is represented by q_s and q_e; the respective interactions between these two and the context ($[C]$), by (q_s,C) and (q_e,C). Finally, the interaction between (q_s,C) and (q_e,C) is represented by the final interpretation moment, $(q_s,C)–(q_e,C)$. Note that the final representation itself may be interpreted as a quale, in a subsequent interpretation process. The important conclusion of the above analysis is that each of the interpretation moments indicated by (1)-(4) can be defined as an interaction between neighboring interpretation moments. Such interactions are indicated in fig. 4 by horizontal lines.

There are two collections of input qualia, state and effect, that have to be interpreted (i) in relation to the context and (ii) in relation to each other. In the next section we will show that the two interpretations can be realized by means of two processes, which we call (i) *perception* and (ii) *cognition*.[16] In addition we show that these processes can be defined as isomorphic instances of the processing schema.

2.1.1 Perception

The 'goal' of *perception*, as a process, is the establishment of a relation between the input qualia and the memory (see fig. 5). The memory contains information about the properties of the input qualia, independently from their actual relations (which qualia may co-occur with which other qualia in an interaction). In this process, the relation between the input qualia themselves is of secondary importance. An example for a perception process, in language processing, is lexical analysis.

In the model of perception, state and effect type input qualia are indicated by a and b, respectively; memory response or context qualia by a' and b'. All four signs may refer to a type as well as a collection of qualia.

Among the representations[17] obtained by perception, only step 4, the final one is of interest for this section. Following the assumption that memory response is determined by the input qualia, $a'(b')$ arise by means of $a(b)$ qualia that trigger memory. Although
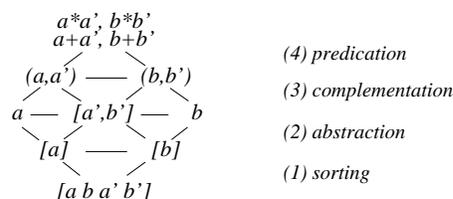
$$a*a', \; b*b'$$
$$a+a', \; b+b'$$
$$(a,a') \; —— \; (b,b')$$
$$a \; — \; [a',b'] \; — \; b$$
$$[a] \; —— \; [b]$$
$$[a \; b \; a' \; b']$$

(4) predication

(3) complementation

(2) abstraction

(1) sorting

Figure 5: A schematic diagram of perception as a process. Qualia comprising the input state and effect, as well as the complementary memory response appear in a 'primordial soup' ($[a \; b \; a' \; b']$). The relation between input and memory response (which are independent and, therefore, may interact) is represented by the expressions: $a*a'$, $a+a'$, $b*b'$, $b+b'$ (the symbols '$*$' and '$+$' designate a relation in the sense of agreement and possibility, respectively).

the two types of memory response signs are independent, they have a shared *common* meaning. This is due to the fact that there is an interaction between the two types of input qualia and that memory information stored by the brain arises from earlier observations via memorization.

Activation of the memory, defining the actual state of the brain/mind, as an interpreting system, enables us to distinguish between qualia in the memory response having an intensity (i) above or (ii) below threshold. The two responses refer to input qualia which either are in the brain's *focus* (i) or *complementary* (ii). A high intensity type (i) memory response signifies the recognition of the input as an *agreement* relation between the input and memory response: the input $a(b)$ is recognized or 'known' as $a'(b')$. A low intensity response of type (ii) refers to input recognition as a *possibility* relation only: the input $a(b)$ is not recognized or 'not known' as $a'(b')$. In this case, the memory response only represents it as a secondary or even less important aspect of the input qualia.

By indicating the first type of intensity relationship between input and memory response by a '$*$' symbol, and the second type by a '$+$', the signs of perception can be represented as: $a*a'$, $a+a'$, $b*b'$, $b+b'$. For example, $a*a'$ is a representation of a positive identification of a by a', as opposed to $a+a'$ which signifies the event of the identification of a possible meaning of a by a' (in other words, a *denial* of a positive identification). In the model of perception, as a process, the four signs are represented as a single sign. An interpretation of the difference between the four intensity relations is beyond the scope of this process (the ',' symbol separating them above is an expression of their synonymous interpretation as the final signs of perception; it is *this* perspective that makes them synonymous).

2.1.2 Cognition

The second process, *cognition*, is an exact copy of the first one, perception, except that the 'goal' of cognition is the construction of a relation between the input qualia. More specifically it concerns the settlement of a relation between the qualia that are in focus ($a*a'$, $b*b'$), in the light of those that are complementary ($a+a'$, $b+b'$). Now it is the relation between the input qualia and the memory that is of secondary importance. In accordance with cognition's 'goal', the context ([C]) contains relational information about the input qualia (note that this process defines its own value of the context). This means that by combining the input of the cognition process with the information of the context, the relation between $a*a'$ and $b*b'$ (and, transitively so, the relation between a and b) may be revealed.[18]

As with the perception process, the input appears in cognition as a 'primordial soup', this time defined by the synonymous final signs of perception. In fact, the difference between the four meaning elements ($a*a'$, $a+a'$, $b*b'$, $b+b'$) functions as the ground for the process of cognition. This is acknowledged in our model, by introducing an initial re-presentation of the four relations generated by perception: $a*a'$ as A, $a+a'$ as $\neg A$, $b*b'$ as B and $b+b'$ as $\neg B$. The presence or absence of a '$\neg$' symbol in an expression indicate whether the qualia signified, are or are not in focus, i.e. identified (accordingly, '$\neg$' may be interpreted as a 'relative difference' operation with respect to the collection of a type of qualia, represented as a set). The instantiation of the processing schema for cognition is depicted in fig. 6.
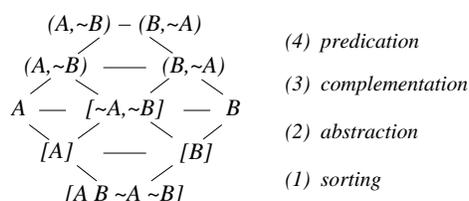
$$
\begin{array}{ll}
(A,{\sim}B) - (B,{\sim}A) & \\
\qquad (A,{\sim}B) \;\text{---}\; (B,{\sim}A) & \text{(4) predication} \\
\qquad\qquad\qquad\qquad & \text{(3) complementation} \\
A \;\text{---}\; [{\sim}A,{\sim}B] \;\text{---}\; B & \\
\qquad [A] \;\text{---}\; [B] & \text{(2) abstraction} \\
\qquad\quad [A\;B\;{\sim}A\;{\sim}B] & \text{(1) sorting}
\end{array}
$$

Figure 6: A schematic diagram of cognition as a process. The input, appearing as a 'primordial soup', is sorted ([A], [B], [¬A,¬B]), abstracted (A, B), complemented by the context ((A,¬B), (B,¬A)) and, combined in a single representation ((A,¬B)−(B,¬A)) by means of predication ('¬' is denoted by a '∼' symbol).

The important interpretation moment now is step 3 (*complementation*), in which a link between the input qualia and the context is established in accordance with cognition's 'goal' as well as with the duality of phenomena. This explains why there can be a relation between A and $\neg B$, and $\neg A$ and B, and why there is no relation between A and $\neg A$, or

B and $\neg B$.[19] The cognition process is completed by establishing a relation between A and B, in step 4 (*predication*).

3   Logical analysis

The above model of cognition suggests the completeness of this process (all possibly meaningful relations between A, B, $\neg A$, $\neg B$ are considered). A 'naive' logical analysis of the processing schema greatly enhances the force of this suggestion. In this section we make an attempt to elaborate such an analysis, on the basis of the model of cognition introduced above, but the results apply to the model of perception as well. Our analysis consists in two parts. In the first part, a 'naive' logical expression is associated with each interpretation moment by making use of common logical aspects. In this analysis, the term 'logical' is used to refer to an *aspect* of an event or an expression, not to a formally defined concept. In the second part, operations are introduced, generating those expressions according to a procedure. Accordingly, in this analysis, the term 'logical' receives a procedural interpretation. Besides we present definitions illustrating the possibility for those expressions to be generated by a procedure. That procedure is what we call 'naive' logic. As for the rest of this paper the existence of such a procedure can be sufficient, therefore the second part of our analysis, which is more technical, is moved to Appendix B. Since the focus of this section is on 'naive' logic, the prefix 'naive' can be omitted.

The hidden agenda of this section is a tacit introduction of logical concepts in the process model of cognition. What makes the use of such concepts especially important is that they have a well-studied, precise meaning. An essential element of the logical interpretation of the process model of cognition is the abstraction of a common meaning for the two different types of input qualia (state and effect), which is the concept of a *logical variable*. By virtue of the duality of the input qualia, the logical interpretation of cognition, as a process, requires the introduction of two variables, which we denote by A and B. The difference between qualia that are in focus and those that are complementary, is represented by the difference in their expression. Each of the two types of qualia is referred to by means of a logical variable which is either stated positively or negatively. Perceived state and effect qualia which are in focus are indicated by A and B, respectively; those which are complementary by $\neg A$ and $\neg B$. Note the use of '$\neg$' as a complementation operation on collections interpreted as sets. For example, the complementary sub-collections of A-type qualia are denoted by A and $\neg A$ (the label A is used ambiguously).

The relational operators introduced in the application of the processing schema for perception ('+' for possibility, '*' for agreement), are inherited by the process model of cognition and its interpretation as operations on expressions. In the definition of the logical expressions below we make use of the fact that the logical 'or' is involved in the meaning of possibility ('+') and the logical 'and' involved in the meaning of agreement ('*').

Conform the above mapping, the logical expressions associated with the events of the cognitive process may be defined in the following way.

$[q_s]=A+B$, $[q_e]=A*B$: the expression of the simultaneous presence of the input qualia which are in focus, as a simple, possible co-existence ($A+B$) and as a meaningful co-occurrence, in the sense of agreement ($A*B$). As A and B are commonly interpreted as logical variables, the separate representation of any one of the two types of input qualia contains a reference to both variables. However, as we may only observe a state by virtue of an effect, the occurrence of an effect always entails the existence of a state. This difference between the two types of input qualia is expressed by means of the difference between their two types of relations, represented by the operators '+' and '*'.

$q_s=A*\neg B$, $\neg A*B$: the expression of the abstract meaning of the focused input qualia, as constituents, irrespective of the actually co-occurring other type of qualia. It is *this* perspective that makes the two logical signs synonymous (note the use of ',' in the definition of q_s directly above, as a representation of this equivalence).

$q_e=A*\neg B+\neg A*B$: the expression of the input qualia as an abstract co-occurrence, logically represented by a compatibility relation of the two types of abstract constituents of the input (which are now interpreted differently).

$[C]=\neg A+\neg B$, $\neg A*\neg B$: the expression of the context as a possible co-existence ($\neg A+\neg B$) and as a meaningful co-occurrence relation ($\neg A*\neg B$) of the complementary qualia. The synonymous representation of these signs is an expression of their secondary (complementary) meaning, but also of the shared meaning included in the simultaneously present qualia, represented by $\neg A$ and $\neg B$, underlying the context ([C]).

$(q_s,C)=A+\neg B$, $\neg A+B$: the expression of the abstract constituents (q_s) completed with the information provided by the context ([C]) or, alternatively, the 'actual' or embedded meaning of the input qualia as constituents. For example, the actual meaning of A (perceived state) as a constituent, is signified by A itself and by $\neg B$, the complementary property connecting A with B (as the relation between A and B is not yet
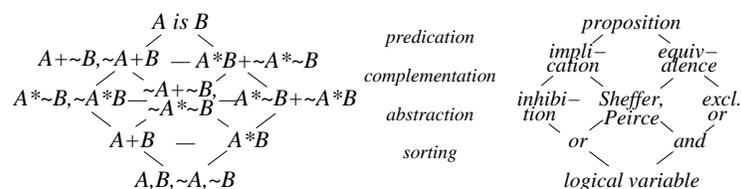
Figure 7: The logical expressions of cognitive processing (on the left) and the corresponding Boolean relations (on the right). Negation ('¬') is denoted by a '∼' symbol. Horizontal lines in the left-hand side diagram denote a relation (interaction) between neighboring expressions.

established, the B type qualia cannot contribute to the actual meaning of A, as a constituent). Alternatively, the meaning of $\neg A*B$ in context is defined by the qualia completing this abstract meaning, which are A and $\neg B$. As the two interpretations of A as an actual constituent are related to each other by the relation of co-existence, the logical meaning of (q_s,C) can be represented by $A+\neg B$. For the same reason, as in q_s, the two expressions of (q_s,C) are interpreted in the model, as synonymous.

$(q_e,C){=}A*B+\neg A*\neg B$: the expression of the abstract compatibility relation in context. This obtains the representation of the input qualia as a characteristic or conventional property which appears as an event. That event can be looked at from two different points of view. Through the glass of the qualia which are in focus it can be represented as an event between A and B; from the stance of the complementary context it can be described as an event between $\neg A$ and $\neg B$. The two signs represent the interaction which is in focus, respectively, positively and negatively. Alternatively, in the definition of (q_s,C) and (q_e,C) above, the complementary qualia are used to sort out those meanings from the possible meanings of the abstract signs, q_s and q_e, that may hold in context ([C]). In other words, the input is implicitly characterized by means of complementary information of the context. State qualia occurring in q_s are represented by themselves $(A(B))$ and by their context $(\neg B(\neg A))$;[20] and, similarly, effect qualia occurring in q_e are represented by themselves $(A*B)$ and, by their context $(\neg A*\neg B)$.[21]

$(q_s,C)–(q_e,C){=}A$ *is* B: the expression of the relation between the input qualia which are in focus, represented as a proposition.

The logical expressions assigned to the interpretation moments are presented in fig. 7, on the left-hand side; the corresponding Boolean relations (with the exception of the result of the process) are displayed on the right-hand side of the same diagram. '0' and '1', which are omitted, can be defined as representations of a 'not-valid' and a 'valid' input, respectively. Note, in fig. 7, on the left-hand side, the presence of *all* Boolean relations on

two variables, as meaning aspects, expressing the completeness of the cognitive process: We look at our input from *all* possible angles!

This closes the first part of our 'naive' logical analysis. In the second part, which is to be found in Appendix B, we introduce a procedure, generating 'naive' logical expressions of sign aspects by means of relations (interactions) between *neighboring* signs that are in need of settlement. In fig. 7, on the left-hand side, such expressions are connected by a horizontal line.

4 Signs, sign aspects and interpretants

In the introduction we presented Peirce's rules for the derivation of the long list of cenoscopic categories from the short list and we promised to give an exposition of the long list later. This section contains an introduction in Peircean semiotics.

Setting off with the definition of a sign, we will introduce the sign aspects that are discerned for each of the sign relations introduced in the introduction. Next we will make a first step from a classification of sign aspects to a model of interpretation processes by giving an overview of the different types of interpretant aspects Peirce distinguished.[22] Finally we will show that, with some amendments to Peirce's work, it is possible to model interpretation processes as sign processes.

4.1 Peirce's sign definition

We recall the sign definition given in the introduction:

> A Sign, or Representamen, is a First which stands in such a genuine triadic relation to a Second, called its Object, as to be capable of determining a Third, called its Interpretant, to assume the same triadic relation to its Object in which it stands itself to the same Object (CP 2.274).

In order to derive the long list we must analyze the 'genuine triadic relation' by which the sign, or representamen, is capable to determine an interpretant to assume the same relation to its object in which the sign itself stands. A triadic relation involves dyadic relations which in turn involve monads. From the categorical underpinnings of Peircean semiotics, it follows that lower ordered relations are involved in higher, but not the reverse. The object and the interpretant regarded as monads, however, are not part of the triadic sign relation. What is part of the sign relation are the dyadic relations of the sign with object and interpretant. Involved in those relations is only one monad, the sign regarded in

itself. Therefore, we will start the exposition of the long list with the sub-categories of the first category which covers the relation of the sign in itself (cf. sect. 4.1.1). From there on we will gradually work our way up through the sub-branches of the second category, which concern, first, the relation between sign and object (cf. sect. 4.1.2) and, second, the relation between sign and interpretant (cf. sect. 4.1.3). When we have specified those relations the elements, or cenoscopic categories, that compose the genuine triadic relation are given, but we still do not know how a sign (that determines an interpretant) fulfills its duty. Starting with section 4.2 we will gradually develop a semiotic model of the triadic sign relation.

Before we start the presentation of the long list of categories, some general remarks about the meaning of terms used by Peirce are in order.

- The notion of a sign is inherently ambiguous. It is so because on the one hand the term designates the representamen (potential sign) in combination with its relations with its object and its interpretant, in short, its *triadic structure*, while on the other hand it designates whatever it is that stands in place of its object, in short the representamen only.

- The sign definition has a large scope since, according to Peirce, cognition without signs is unthinkable and all we know we know through signs. The word sign is used here in the broad, triadic sense of which the word representamen only designates a small part.

- The interpretant should not be confused with an agent doing interpretation. The *interpreter* is an organism, organization or system performing sign processing, the *interpretant* is a next sign that represents whatever results from sign interpretation; it can be a thought sign, a language sign or any kind of behavior.

4.1.1 The sign in itself

Before we have the *possibility* that something functions as a sign some demands must be met.

(1.1) The first thing to note is that in order for something to function as a sign it must have certain qualities. Quality is taken here in the sense of a peculiar and essential character. Such a quality cannot be known if it is not embodied, but the embodiment is not part of the character it has. This character, when looked at in itself, disregarding its embodiment, is the first sign aspect recognized. It is termed the *qualisign* aspect.

(1.2) By recognizing that this character can only be effective through its embodied oc-

currences, we acknowledge that the qualisign only offers the possibility for a sign and at the same time arrive at the second sign aspect, i.e. the notion of the singular sign, the here and now embodiment of the qualisign. This sign aspect is termed *sinsign*. Existence being a notion of the second category.

(1.3) Although a qualisign can only be effective by being embodied, the singular embodiment is not sufficient for its being known. Therefore we must assume a convention, a habit or a law that determines an interpreter to deal with the different singular occurrences of a qualisign as instances of the same type of sign. This 'rule of identity' is termed the *legisign* aspect of a sign. Since it mediates the qualisign to its sinsign occurrences, it is the third categorical sign aspect of the first category.

Example: We may have an experience of some shape constituted by different tones of grey. The shaped collection of qualities (qualisign aspect) occur at that moment (sinsign aspect). If the shape is familiar, for instance because it has a pre-dominant vertical orientation, starts at a point on earth and expands but also is more diffused the higher it comes, we may recognize it as an instance of smoke (legisign), without, however, at this point any word or meaning attached to it, but just as a familiar form(ation).

Sub-categories of the sign regarded in itself: Different occurrences (sinsigns 1.2) of a similar character (qualisign 1.1) are glued together by a habit (legisign 1.3) that states the identity of the instances.

4.1.2   The sign in relation to its object

In order to *be* a sign a representamen must relate to some object. Here the question is in what principal ways a sign may present its object. The sign may present its object through characters it has or *iconically*, through contiguity or *indexically* and, finally, through a convention or *symbolically*.

(2.1) The relation is iconic if the sign may relate to any object to which it is similar in some respect. Through this similarity, it conveys something about its objects. But, although the iconically related sign conveys information, it does not determine any specific object to which it professes to relate. It represents the objects that are similar only possibly, which makes it a first category kind of relation.

(2.2) With the indexical relation between sign and object the opposite is the case, an indexical relation excels in pointing to an object since there is an existential relation, but such a *relation* does not convey any information about the object at all. Since it is on the basis of the contiguity of sign and object that the sign represents its object,

this is a relation belonging to the second category.

(2.3) From the above we may conclude that in order to convey information about some specific object both an iconic and an indexical relation are needed. If a sign is symbolically related with its object, conveying information about an object or even just pointing towards an object depends on rules of interpretation that are attached to the interpretant thought. Since an interpretant is needed that mediates the sign to its object this is a third category type of relation.

Symbols can be sub-divided in two main kinds according to whether their function is to convey information about their object (cf. the word *smoke*) or to point to an object (cf. the word *this*). If symbols convey information typically some iconicity is involved in the interpretation rule as when we vaguely imagine some smoke on hearing the word. If a symbol only points to its object it has an indexical function, the indexicality, involved in symbolic relations, can only be presented by means of icons, as when we use the image of a pointing finger in order to explain the word *this*.

Examples: The smoke drawn on a painting has an iconic relation with the smoke of any fire and, besides that, with all objects of similar shape. The smoke rising from an actual fire has an indexical relation with that fire and can, on top of that, have an iconic relation with all the objects that accidentally have the same shape. Smoke signals are indexically related to the fire from which they rise, but they are symbolically related to what is stated in the message they convey. Language of any kind is the most important example of symbolically related signs.

Sub-categories of the relation between sign and object: An icon (2.1) is related to all objects to which it is similar, but only possibly so. An index (2.2) actually relates to the object it is contiguous with. A symbol (2.3) conventionally relates to its object by means of a rule of interpretation that has to be brought to life by the interpretant.

4.1.3   The sign in relation to its interpretant

In order to *realize* its signhood a sign must produce an interpretant. It is important to remark at the outset that there is a difference between the relation of the sign to the interpretant and the interpretant of a sign. The way in which a sign relates to an interpretant is a character of a sign. The interpretant is a new sign that at least is partially determined by the sign that precedes it. The mode of determination of the interpretant sign is what is covered by 'the relation of the sign to its interpretant'. The mode of determination can be only suggestive, just constative and, to some degree, coercive.

(3.1) The relation between sign and interpretant is suggestive or *rhematic*, if the sign merely raises an idea.

(3.2) The relation is constative or *propositional*, if the sign expresses a fact with which an interpreter can agree or disagree.

(3.3) The relation is coercive to some degree or *argumentative*, if the sign actually convinces by reason.

Note that the difference between a rhematic, a propositional and an argumentative relation has nothing to do with the composition of the representamen. As a matter of fact a term, a prototypical case of a rhematic address of the interpretant, has an argumentative relation with the interpretant, when part of the argument is transferred to the rule of interpretation involved in the symbol or when the context provides additional information. For instance, 'Halt!' being shouted by a warden in a jail, has argumantative force for the prisoner addressed. Just so, an argument can have a rhematic relation with its object, most typical in those cases that the argument is irrelevant for the interpreter that generates an interpretant of the argument. This line of thought brings us to the categorical background of the distinctions introduced. A rhematic relation between sign and interpretant exists if the sign leaves its object and its interpretant what it may be. It is for the interpretant a mere possible, which makes it a first category type of relation. A propositional relation between sign and interpretant exists if the sign distinctly indicates its object, but leaves its interpretant what it may be, which makes it a second category type of relation. An argumentative relation between sign and interpretant, finally, is a relation that distinctly indicates its object and the conclusion or interpretant, which it intends to determine (cf. CP 2.95). This makes it a relation of the third type of category.

Examples: When visiting a museum the smoke pictured on one of the paintings normally has a rhematic relation with the interpretant thought. It raises an idea and that's it. When two scouts of a raiding party ride through the country and the one says to the other 'I see smoke signals', the relation between the sign pointed at and the interpretant generated by the second man is propositional. The implied question being 'Do you agree with the fact I observed?' When you sit in your room and smoke is coming in from underneath the door and through the cracks between the planks of a wooden floor, the relation between sign (smoke coming in) and interpretant (looking for an escape)[23] is, although the major premiss is suppressed, argumentative.

Sub-categories of the relation between sign and interpretant: The relation between sign and interpretant is rhematic (3.1) if the sign only raises an idea. The relation
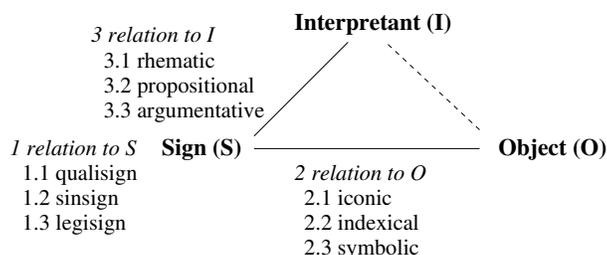
3 relation to I   **Interpretant (I)**
   3.1 rhematic
   3.2 propositional
   3.3 argumentative

1 relation to S   **Sign (S)**   **Object (O)**
   1.1 qualisign   2 relation to O
   1.2 sinsign   2.1 iconic
   1.3 legisign   2.2 indexical
               2.3 symbolic

Figure 8: Sign model completed with sign aspects

is propositional (3.2) if the sign professes to state a fact. The relation is argumentative (3.3) if the sign convinces by providing reasons to accept the interpretant sign it suggests.

4.2 Towards a theory of interpretation

When we accept that lower ordered (sub) categories are involved in higher ordered (sub) categories and also accept that the only sign that brings forth an interpretant on its own account, is a sign that is argumentatively related to its interpretant, we also must accept that in such a sign type all sign aspects are involved. This opens up interesting possibilities that can best be illustrated by a comparison with Kant's use of his categories.

In fig. 8 the long list of categories is organized in a way that shares a characteristic with Kant's scheme. As it is possible with Kant's schema to classify all propositions by indicating the sub-categorical value for each of the categories, at least in theory, it is possible with Peirce's scheme to classify all signs in types by giving its highest sub-categorical value on each of the categorical relations. In both cases the labels for the categories are class names.

The rule that higher (sub) categories involve the lower, but not the reverse, however, opens up a possibility not present in Kant. In fig. 9 all sign aspects are given. Since in an argument sign all aspects are involved in an ordered way, here we have a first approximation of what is needed for a description of the process of interpretation that leads to a response. For a better approximation of this process it is necessary to analyze the way in which a sign generates an interpretant, that in its turn may function as a sign. Since the interpretant, once developed, is a sign itself all sign aspects must be present.

In the process of generating a new sign, which possibly includes transformation and enrichment, the sign aspects appear as moments in the process of interpretation. This ideally implies that through interpretation increasingly better approximations of the import of the sign are realized. In this process, information pertaining to the sign is explicated in each interpretation moment, for otherwise subsequent interpretation moments would
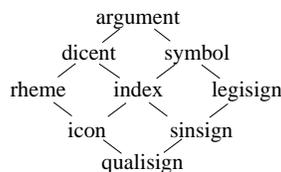
Figure 9: Peirce's classification of signs. As the sign aspects can be hypostatized as moments in a process of interpretation their adjectival expression can be replaced by a nominal form, for example, 'iconic' can be replaced by the term 'icon'. Note however that by doing this an ambiguity is introduced since the term icon is often used as a shorthand for a sign type, for instance when we use the term icon to indicate a rhematic, iconic legisign.

not be more than a mere re-generation of already existing states. As this growth of information involves a contribution by the interpreting system itself and assuming there is a single sign offering itself for interpretation, we need a shift of view and must consider the sign (S) to be an effect, affecting the interpreting system occurring in a state. As the interpretation, representing the system's reaction on the input steadily develops, it can occasion the 'generation' of further interpretation moments that themselves may be regarded as signs. Such a process is schematically illustrated in fig. 10.

In order to keep a clear distinction between the sign and the interpretant perspective we term these interpretation moments interpretant aspects, or simply, following Peirce, interpretants. By prefixing the term interpretant with an adjective we are able to distinguish the different characteristic contributions to the development of the import of a sign.
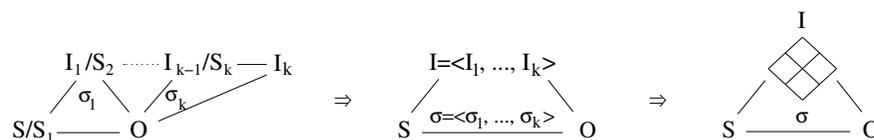

Figure 10: Interpretation depicted as a series of events (left) and a single event (middle), paraphrased as an instance of the processing schema (right). I_j, S_j, σ_j for $1{\leq}j{\leq}k$ $(1{\leq}k)$ stand for interpretants, signs, and states, respectively; O is the shared, common object of $S_1, S_2, \ldots, S_k$. The symbol "/" expresses the possibility of a change of view from result of a former to start of a subsequent interpretation process. This enables I_j to be looked at from two perspectives as the interpretant generated in σ_j and, as a representation of the next state, as a potential sign. Angle parentheses are used for a series interpreted as a single entity.

The individual interpretation events change the state of the interpreting system. In fig. 10, this is indicated by the sequence of states $\sigma{=}{<}\sigma_1, \ldots, \sigma_k{>}$, for $1{\leq}k$. We use the convention that in state σ_j $(1{\leq}j{\leq}k)$, the interpreting system is involved in the generation of I_j, the interpretant of S_j. O designates the shared, common object of S_j for $1{\leq}j{\leq}k$.
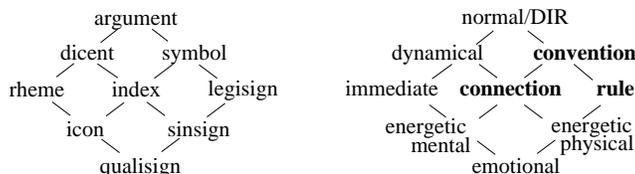
Figure 11: The Peircean sign aspects (left) and the identified interpretant aspects (right) projected on it (the three new interpretant aspects are given in boldface). The DIR represents the current approximation of the normal interpretant).

The triadic relation, (S_j,O,I_j), or the next state of the interpreting system functions as a potential sign in a subsequent interpretation event. For instance, $\sigma_2=(S_1,O,I_1)$ is interpreted as S_2. Note that k may stand for any natural number, as the set of states define a non-strictly monotonous ordering of increasingly better approximations of the meaning of S for a given interpreter.[24]

On the basis of this model, nine classes of interpretants can be defined, in conformity with the nine classes of sign aspects. Among these nine interpretants, six are due to Peirce himself, and three to the first author who derived them from the assumption that, given the fact that according to the sign definition an interpretant becomes a sign itself, it is sensible to assume that all nine sign aspects discerned have to reappear in the process of interpretation (Breemen & Sarbo, 2007). The coordination of sign aspects with the different interpretants proved only possible after the introduction of the assumption that interpretation must involve an interaction between an observer (interpreting system) and a sign (representamen) (Farkas & Sarbo, 2000).

4.3 Peirce's theory of interpretants

In this section we present Peirce's interpretant aspects and we will match them with the sign aspects. For three sign aspects there are no corresponding interpretant aspects. For those sign aspects we will introduce corresponding interpretants. After that we will illustrate the complete set of interpretants with an example.

Peirce identifies "the first proper significate effect of a sign," with the term emotional interpretant (cf. CP. 5.475). It designates the moment in semiosis in which a sign intrudes our mind as a series of impressions in their unanalyzed form. This series of qualities give rise to a feeling of complexity that needs to be resolved (cf. CP 1.554). Note the correspondence between the unanalyzed impressions and the concept of a *qualisign* as a mere possible. See also fig. 11.

In CP 5.475 Peirce continues: "If a sign produces any further proper significate effect,

it will do so through the mediation of the emotional interpretant, and such further effect will always involve an effort. I call it the energetic interpretant." Peirce made a distinction between two kinds of energetic interpretants, a physical and a mental energetic interpretant.[25] The physical interpretant indicates that the series of feelings has a here and now existence. Without it the impressions can at most appear as background noise without leaving a trace and no further significate effect could be produced. Note the correspondence of the energetic physical interpretant with the concept *sinsign*.

The mental energetic interpretant designates the moment in semiosis in which the series of impressions appears as a one time (single act) ordered collection of qualisigns, a form. Note the correspondence with the concept *icon*. Also note that the two energetic interpretants will simultaneously arise out of the emotional interpretant. But they are independent in the sense that the interpretant sign to be developed may *either* focus on the significance of the existence of the input (that a sign is inscribed) *or* on the significance of the form (what the sign conveys).

In the complexus of the mental and physical energetic interpretant the immediate interpretant is potentially present. It is the: "[...] interpretant represented explicitly or implicitly in the sign itself" (MS339, 276r, April 2, 1906).[26] Looked at from the typical Peircean, general standpoint it is not what a given interpreter at a particular time takes that meaning to be, but it is the meaning in general that any interpreter in the right understanding of the sign would develop. Looked at from a more individual perspective it indicates all interpretational possibilities of a given interpreting system. The immediate interpretant is related to the meaning of the sign in a given case as the dictionary meaning of a term is related to the same term in actual use. Note the correspondence with the concept *rheme*.

The field of possible meanings of the sign must be 'narrowed down' to one specific interpretation in order to enable the interpretive system to generate a response. "The actual effect produced on a given interpreter on a given occasion in a given stage of his consideration of a sign" (MS 339, 288r, October 23, 1908) is labeled by Peirce with the term dynamical interpretant. Note the correspondence of the dynamical interpretant with the concept *dicent* (proposition). Also note that the dynamical interpretant can be defined as a sign that specifies the meaning of the immediate interpretant for a specific context (possible explanation).

At another place Peirce illustrated the concept of a dynamic interpretant differently:

For instance, suppose I awake in the morning before my wife, and that after-

> wards she wakes up and inquires, "What sort of a day is it?" [...] This is a sign, whose Object, as expressed, is the weather at that time, but whose Dynamical Object is the impression which I have presumably derived from peeping between the window-curtains. Whose interpretant, as expressed, is the quality of the weather, but whose Dynamical Interpretant, is my answering her question (CP 8.314).

Here the dynamic interpretant is a responding sign, not an interpretant aspect. This is acknowledged in this paper by calling it the Dynamical Interpretant Response (DIR). The DIR is a term that designates a new sign arising from a specific clash between a sign and a given interpreter or, alternatively it designates the sign that results from the aforementioned process.

Finally, Peirce indicated a normal interpretant, designating the movement of thought, expressible as an argument, in which the sign together with habits inscribed in the receptive mind, as premises, generate a conclusion.[27]

> The commanded act in the mere doing of it as influenced by the command is the dynamical interpretant (DIR; the authors). But insofar as that conduct involves the recognition of the command and is obedient to it and recognizes this correctly, it is the representative (the more usual Peircean term is 'normal'; the authors) interpretant. (MS 339, 253r, October 9, 1905)

Note the similarity with the concept *argument*. The tendency of the normal interpretant to generate 'satisfactory' responses in the long run can only be accounted for if we suppose a sequence of arguments aiming at a final interpretant. In this case each argument as a whole is taken as a sign itself and confronted with higher level habits until a response pattern is reached that does not yield falsifying consequences.

Peirce did not define interpretants for each of the sign aspects. Interpretant counterparts are missing for the *indexical*, the *legisign*, and the *symbolic* aspects. For the index this is not surprising since the original, pure indexical relation of contiguity that exists between sign and object (cf. an instance of smoke indicating a fire) cannot, qua indexical relation, be present in an interpretant without losing its indexicality. It has to be represented in the interpreting system by other, symbolic means. This does not mean, however, that indexicality does not play a role in the domain of interpretant aspects. Before it is possible to represent the instance of smoke as indicating fire, the symbolic, convential meaning of the form has to be recognized by the interpreting system as an
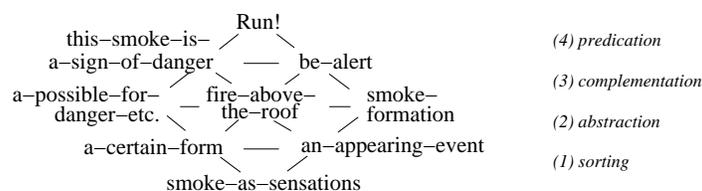
Figure 12: Interpretants of a visual observation of smoke as a sign of danger

instance of a type (legisign). The construction of the legisign and the symbolic meaning aspects of a sign demand a contribution of the interpreting system. This is only possible if the perceived energetic mental interpretant (icon) is connected (indexicality), in the receptive brain/mind, with the legisign and, mediated by the legisign, with the symbol. In the next section we show that the missing interpretants can be identified if we assume a contribution of the interpreting system.

4.3.1 From sign interpretation to sign processes

A sign only functions as a sign if it is involved in an interpretive process and generates interpretants. From this we conclude that a semiotic model of interpretative processes must account for the fact that such a process sets of at the moment a sign gets inscribed in an interpreting system, which is capable of generating DIR's. The interpreting system must also be a sign, otherwise it could not grow in information. In his semiotic writings Peirce acknowledges this when he writes that man is a sign, but he did not systematically draw out the consequences of this thought. In his logical system, the existential graphs, a system of logic equivalent to Frege's Begriffschrift, however, Pierce introduced the Sheet of Assertion:

> It is agreed that a certain sheet, or blackboard, shall, under the name of The Sheet of Assertion, be considered as representing the universe of discourse, and as asserting whatever is taken for granted between the graphist and the interpreter to be true of that universe. The sheet of assertion is, therefore, a graph (CP 4.396, 1903).

This sheet is enriched by inscribing graphs in it, just as an interpreting system grows when it acquires new information. We transpose this idea to the domain of semiotics with the introduction of the Semiotic Sheet (S_s). This sheet, as it is itself a sign too, has, as all signs have, three modalities: the Possible (P), the Actual (A) and the Lawful or Habitual (L). In its P-modality the sheet is conceived to contain whatever is inscribed

and potentially can be used if a sign offers itself for interpretation. In its A-modality it is conceived to be in the state it is in at the moment a sign inscribes itself (this has a sinsign as well as an icon aspect).[28] In its L-modality it contains the habitually inscribed goals[29] that govern the production of a DIR on the occasion of a sign offering itself.

In order to give an impression of how the sign interpretation process works according to the model we provide a sketchy example (see also fig. 12). The interpretation events are indicated by (1)-(4). Let us assume that what knocks at the door of consciousness is 'smoke', appearing as a visual sign. It enters the S_s as a series of impressions (emotional interpretant; qualisign). Only if spontaneous, habitual interpretation fails, the input triggers a feeling that urges further interpretation.[30]

(1) The impressions get sorted out as a form (mental energetic interpretant; icon) and settle as a singularity (physical energetic interpretant; sinsign).

(2) Since it is a familiar *iconic* singularity the form is recognized as an instance of smoke formation (rule; legisign). Since it is a *singular* icon out of any context at this moment, all kinds of interpretations become possible such as smoke as a sign of danger, comfort, and so on (immediate interpretant; rheme).

(3) Assuming the smoke formation occurs in a specific context (there is smoke above a roof on fire) a conventional meaning of the legisign is developed (convention; symbol). But, of course, in a different context, the smoke formation could mean that one may expect comfort, if one is lost in a forest for instance. Those possibilities are contained in the rheme. If, later on, the strong convention proves wrong, a new run of the process may delve up those possibilities. Doubt is time consuming after all. Through the connection with what is contained in the S_s about the present situation (smoke is rising above a roof on fire), the conventional meaning gets embedded in an understanding of the situation at hand (this smoke above the roof is a sign of danger) (dynamical interpretant; dicent).

(4) This dynamical interpretant is, again through a connection with what is contained in S_s, placed under a rule of habit that covers this kind of case and a response (DIR) is generated (if there is danger, then run as fast as possible; this smoke above the roof is signifying danger; therefore we should run away as fast as possible) (normal interpretant; argument). Since experience with the effect of different types of response will be fed back in the mechanism, successful responses tend to strengthen interpretation habits (final interpretant).

But also note that if the S_s is in the state of expecting a sign, a 'top down' response speeds up the process considerably by action on expectation; the child in the candy store says in that particular voice "Mom,..." and gets "No!" as an answer before being able to finish.

If sign interpretation consists in a sequence of interpretants generated by a process then the (full) meaning of a sign must contain the meaning of all of its less developed approximations. This line of thinking brought us to a model of interpretation, which is isomorphic and analogous to the model of cognitive activity introduced in sect. 2.1.

5   Isomorphic models of informative processes

The Peircean interpretants also can be pinpointed in the interpretation process of smoke. Let us assume that at the moment the visual sign of an agressively rising smoke (S) is inscribed in the semiotic sheet of the observer (S_s), the observer possesses contextual information about earlier observations of smoke phenomena and corresponding response strategies. It is by virtue of that knowledge that the observer is capable of representing the appearing rising smoke (sign), in relation to the interpreting system (which too is a sign), as a combinatory potential. For example, if in earlier observations we experienced smoke and rising (of smoke) to co-occur, we may represent this fact as a potential of these signs to combine with each other. Such a combination of signs is what we call a *sign interaction*.

The interpretation of smoke as a sign of danger may proceed as follows. The qualia of smoke (observer's state) and rising (input effect), as well as the observer's background knowledge about the present situation appear as a 'primordial soup' ($[q_s \ q_e \ C]$), representing the input as impressions.

(1) The qualia of the observer's state in the 'primordial soup' are represented as a one time ordered collection, which is a sign ($[q_s]$). Also the qualia of the input effect are represented as a sign. As the appearance of an effect always entails the existence of a state (but not the other way around), the qualia of rising (of smoke) are represented as a singular event that occurs now ($[q_e]$). Finally, also the observer's background knowledge is represented by a pointer to a collection of interrelated state and effect qualia ($[C]$) or the context in which the interaction between the qualia of rising and the qualia of smoke as imprinted in the interpreting system (S_s) takes place.

(2) The qualia of the rising, independent from the actual state of the S_s is represented as a rule-like compatibility relation (q_e), expressing the habitual knowledge pertaining

to the current occurrence of rising smoke. The collection of qualia of the observer's state, independent from the qualia of rising is represented as a range of possible interpretations, capable of being combined with any appearing smoke related property or effect (q_s).

(3) This is followed by a representation of the observer's state in context ((q_s,C)), narrowing down the range of possible interpretations of q_s to an actually existent one. Also the habitual knowledge about rising (of smoke) is represented in context, expressing the conventional interpretation of the input effect ((q_e,C)).

(4) Finally, the rising (of smoke), combined with the actual state of the S_s is represented as a sign of danger, (q_s,C)–(q_e,C), on the basis of the observer's knowledge about smoke phenomena ([C]), which is only implied.

The isomorphism between the process model of cognitive activity (see sect. 2.1) and the Peircean hierarchy of sign aspects enables the cognitive model to be interpreted as a meaning generating process. More specifically, the events of the model can be associated with Peircean sign aspects this time interpreted as *proto-signs*[31] that are becoming signs (Sarbo, 2006). In turn, the above isomorphic relation enables the Peircean sign hierarchy to be interpreted as a process, representing interactions between qualities (phenomena) by means of interactions between proto-signs. Below we will use the Peircean sign aspects as references to interpretation moments or positions of the processing schema, for instance, qualisign as a reference to [q_s q_e C].

In the interpretation process, the input interaction is represented by collections of qualia in the qualisign position ([q_s q_e C]). The interaction between those collections or, the interaction within the 'primordial soup' is represented in the icon ([q_s]), sinsign ([q_e]) and index sign positions ([C]). As [q_s] and [q_e] too are independent, they can interact. Their interaction is represented in the rheme (q_s) and legisign (q_e) positions. In q_s, the relations included in [q_s] (icon) and [q_e] (sinsign) are represented dominantly and suppressed, respectively. This is opposed to q_e, in which the relation included in the sinsign position is represented dominantly and the one included in the icon suppressed. This dependency between q_s (rheme) and q_e (legisign) is revealed by their logical expressions: $q_s=A*\neg B,\neg A*B$, $q_e=A*\neg B+\neg A*B$ (cf. fig. 7). As q_s (rheme) and q_e (legisign) are not independent, the interpretation process cannot proceed without additional signs. It is at this point where the importance of the index position ([C]) becomes clear. By virtue of the independence of [C] from q_s as well as from q_e, the interpretation moments (q_s,C), (q_e,C) and, finally, (q_s,C)–(q_e,C), can be generated.
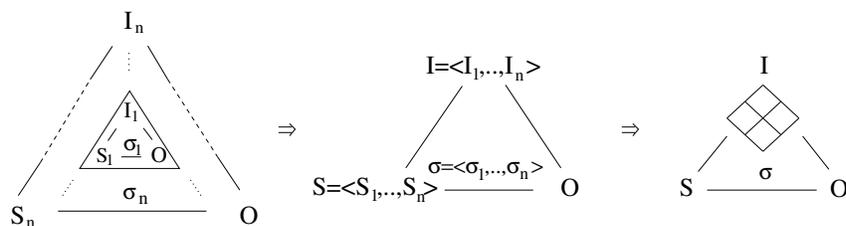
Figure 13: A schematic view of the interpretation of complex phenomena. For $1 \leq i \leq n$ $(1 \leq n)$, S_i are input signs, O their shared common object, σ_i are states of the S_s. In σ_i, the interpretant of the change due to S_i is represented by I_i. For $1 \leq i \leq n$, the triadic relations (S_i, O, I_i), depicted by a triangle, represent an instance of the interpretation process as shown in fig. 10. Angle parentheses are used for a series interpreted as a single entity.

We may talk about a sign realizing its purpose only if the argumentative sign aspect is realized. For only a proto-sign in the argument position is capable of generating a reaction. This implies that all less developed interpretant aspects or sign aspects must be involved (cf. fig. 9). It is in *this* sense that the cognitive process is generating increasingly better approximations of the import of the input sign. In this process, all events are modeled as interactions between dual proto-signs (sign aspects), interpreted as states and effects.

5.1 Modeling complex phenomena

We call a phenomenon *complex* if its interpretation involves the processing of nested and more simple phenomena. As the processing of those nested phenomena is necessary for the interpretation of the complex phenomenon, the nested phenomena can be modeled as signs having a shared, common object (O). Examples of complex phenomena are images in commercial design and sentences in natural language processing. Words occurring in a sentence stand for the sentence (O) and signify it from a certain point of view. The similarity between fig. 10 and fig. 13 shows that the processing of simple and complex signs can be identically modeled. This expresses that the model is *scalable*.

Let us assume that the interpreting system (S_s) is involved in the processing of a complex sign S:=$<S_1,\ldots,S_n>$ (see also fig. 13). In conformity with the process view of sign interpretation, in state σ_i $(1 \leq i \leq n)$, the S_s is involved in the generation of the interpretant, I_i, representing the change due to S_i, as well as the generation of the next state, (S_i, O, I_i). The processing of S can be modeled by means of a series of interpretation processes, representing the change due to subsequent input signs, S_i, by proto-signs in the interpretation of the entire series, S. As a consequence of nesting σ_i contains all earlier interpretants, I_j $(1 \leq j \leq i)$. As each σ_i can be represented as an instance of the processing schema, each state can be defined by a series of interpretation moments,

as shown in fig. 10. In contrast to the limited number of different sign aspects and interpretation moments, a complex phenomenon may consist of any number of nested signs. How interpretation of complex phenomena can be modeled with a single instance of the processing schema is the subject of the next section on language processing.

5.2 Language sign processing

In past research (Sarbo, Farkas, & Breemen, 2006) we have shown that natural language processing can be modeled by a sequential version of the processing schema. For a sequence of input signs, S=<S_1,...,S_n>, each state σ_i ($1 \leq i \leq n$) can be represented by a collection of proto-signs. In the processing of a single input sign, the previous and current percepts can be defined by the collection of proto-signs included in the actual state of the S_s (σ_i), and the collection of qualia introduced by the next input sign (S_i), respectively. As the current and previous percepts are different, if only by virtue of their different temporal properties, the condition for an interaction is satisfied. Because the proto-signs included in σ_i are uniquely marked by their sign aspect, the next state can be defined as a change of σ_i brought about by the interaction with S_i interpreted as a qualisign. This requires S_i to be treated as a combinatory potential with respect to the sign aspects or positions of the processing schema, i.e. it asks specifying in which positions S_i can establish a relation with another sign. Below we assume that less developed interpretations are generated before the more developed one (economic representation). Although in theory the term proto-sign is associated with the interpretation moments introduced in our process model, in order to make a distinction between signs to be interpreted and signs that comprise the process of interpretation, below, because it is a relative distinction, for the sake of simplicity we omit the prefix. Having said this, we define our model of language processing, as follows.

For the sake of convenience we suppose the qualisign position on the S_s to be empty at the moment the first input sign offers itself for interpretation. This enables us to represent the appearing first sign in the qualisign position. The interaction between the subsequent input sign and the already existing representation in the qualisign position forces the latter to be represented by a more developed proto-sign,[32] which can be a sign in the icon ([q_s]) or the sinsign positions ([q_e]). Such a sign interaction between an existing sign and an appearing new sign triggering a representation of the already existing sign by a more developed one[33] is called a *coercion*. See fig. 14(a), for the icon position. As [q_s] and [q_e] are representations of the (same) 'primordial soup', but the input signs are in principle
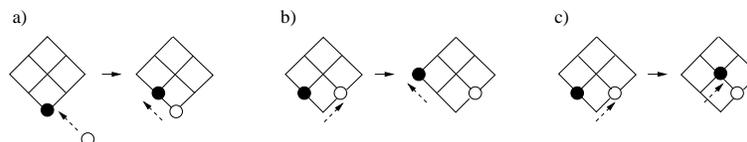
Figure 14: Sample coercion sign interactions. A '•' indicates an already existing sign, a '∘' an appearing new one; a '→' designates a state transition of the S_s; dashed arrows are used for indicating traces of sign interpretation.

independent from each other, in sequential sign processing the icon and sinsign positions cannot be simultaneously realized in any state of the S_s. This means that the generation of signs in the icon and sinsign positions will trigger further interpretation events (cf. sect. 4.3). If there is a sign in the icon or sinsign position, it will become represented by a sign in the rheme (q_s), index ([C]) or legisign position (q_e). See fig. 14(b), for the rheme position.

In sequential sign processing, we may not know in advance if an appearing input sign conveys information in focus or complementary with respect to the entire input or the sentence. In our model we assume that, initially, each input sign is representing information which is in focus and only if this hypothesis fails[34] we assume it to be complementary and represent it, for instance, by a sign in the index position. Since a validation of the above hypothesis necessary involves the representation of an input sign either in the icon or the sinsign positions, a representation of the input in the index position trivially can be generated by means of coercion. See fig. 14(c).

The generation of a sign in the rheme or legisign position may trigger further sign interactions. Besides a coercion, a sign interaction can be either a *binding* or an *accumulation*. In a binding, the sign representing the interaction has a higher position in the processing schema, than the position of the interacting signs themselves (constituents). This is opposed to accumulation, in which the position of the representation of the sign interaction and the positions of the interacting signs are identical. For example, the binding of signs in the rheme and index positions can be represented by a sign in the dicent position; the accumulation of signs in the rheme position can be represented by a more complex rheme sign. In our model we allow sign interactions to be represented degenerately, meaning that the position of the representation of a sign interaction is equivalent to the position of one of the constituents. Looking at accumulation and coercion from this perspective, these two operations can be considered to be degenerate versions of a binding (note that coercion and accumulation satisfy the condition for a non-strictly monotonic representation of increasingly better approximations of the final sentence sign). The importance of
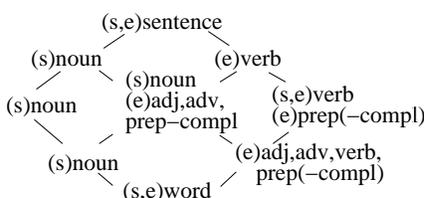
Figure 15: A classification of the syntactic signs used, on the basis of the relational properties of the types of word classes. The status of a sign in a syntactic sign interaction, which can be state of effect, is designated by (s) and (e), respectively.

degenerate representation is due to its potential for enabling positions of the processing schema to be re-used, thereby allowing a processing of sentences of arbitrary length.

In language processing, input signs are interpreted from the perspective of their contribution to the entire input, which is the sentence. In our model of syntactic language processing, the combinatory potential of input signs, which are symbols, is defined on the basis of their language types. Nouns are represented as state-type symbols (s); adjectives, adverbs, verbs, etc. as effect-type symbols (e). The combinatory potential of types of language symbols in different positions of the processing schema is depicted in fig. 15. For example, in syntactic language processing, a verb in the legisign position (e.g. run) has the potential for interaction with an adverb in the index position (e.g. fast). Pending sign interactions are forced to be realized by means of sentence closing dot symbols. In our model we assume that the input is closed by a constant number of dot symbols. An illustration of the above model of language processing is given in the next section. In the examples, the combinatory potential of symbols is assumed, but not defined. Examples illustrating that level of detail may be found in (Farkas, 2008), in which also questions concerning the definition of a syntactic lexicon are discussed. A formal definition, including a proof of the linear complexity of our model of syntactic language processing may be found in (Sarbo & Farkas, 2002).

5.2.1 Examples

Our first example is the syntactic analysis of an utmost simple sentence: 'John likes Mary' (in short 'J I M'). See also fig. 16. In this and later diagrams, the states of the S_s are referred to by subsequent letters of the alphabet given in parentheses. In (a), the appearing first symbol, J (state-type), is interpreted as a qualisign. As the input symbols are in principle independent and partake in the syntactic phenomenon expressed by the entire sentence, the appearing next symbol, I (effect-type), forces the parser to reconsider the earlier interpretation of J (qualisign) and represent it via coercion, in (b), as a constituent
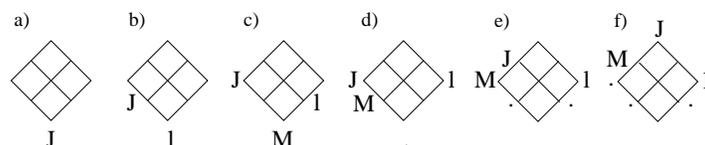
Figure 16: A failing syntactic analysis of 'John likes Mary'. As, in (f), a final representation, J (argument position) is already available but it does not represent the entire input, parsing fails. Conceptually, each state (except the first state) contains the interpretations included in the previous state, as traces. For instance, (b) includes the trace of J as a qualisign, introduced in (a). In the diagrams such traces are omitted.
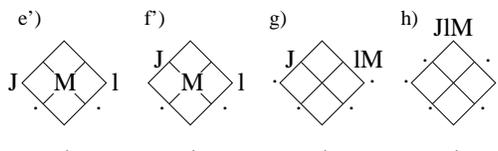

Figure 17: A successful syntactic analysis of 'John likes Mary', after backtracking to stage (e), in fig. 16

(icon) of the entire input.

In (c), the appearance of M (state-type) has similar consequences on the interpretation of l (qualisign) and, transitively so, on the interpretation of J (icon). The latter is a consequence of an earlier assumption that signs in the icon and sinsign positions are incompatible for a binding, except in a 'negative' sense through their relative difference, via coercion (cf. *abstraction*). For this reason, J has to be represented again, this time as an abstract term or a possible for the subject of the sentence (rheme). The subsequently appearing dot symbol, in (d), triggers the representation of M (icon) by a more developed sign. By following the same strategy as in the case of J, parsing eventually will fail, as it will not be possible to represent the entire input by a single (sentence) sign. The failure will make the parser backtrack[35] until the first choice-point providing another alternative.[36] Such a choice-point is available in (d), in which M (icon) can be represented as a complementary sign (index). This is illustrated in fig. 17(e'). A representation of M by a sign in the index position is possible due to the existence of l (legisign), anticipating M as a complement.

The analysis of another example, 'Mary eats pizza with a fork' (in short 'M e p w_af'), is depicted in fig. 18 and fig. 19. We assume the existence of a morpho-syntactical parsing: (Mary)(eats) (pizza)(with a fork).[37] The combination of a semiotic, syntactic and 'naive' logical interpretation of the input symbols reveals that, in fig. 18, Mary (A) can be interpreted as a possible for the subject (rheme; $A*\neg B$), and eats (B) as the rule-like meaning underlying the predicate of the sentence (legisign; $A*\neg B+\neg A*B$). The two signs are interrelated by
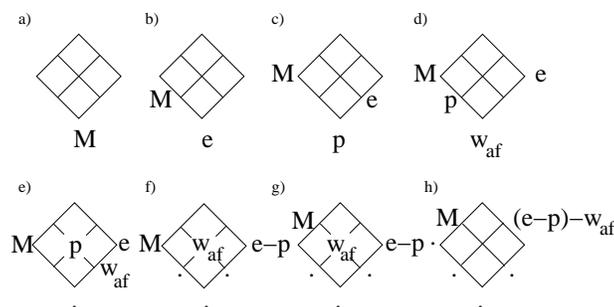
Figure 18: A syntactic analysis of 'Mary eats pizza with a fork' (alternative #1) yielding *Mary eats-pizza with-a-fork* (a representation of the final predication symbol interactions is omitted)
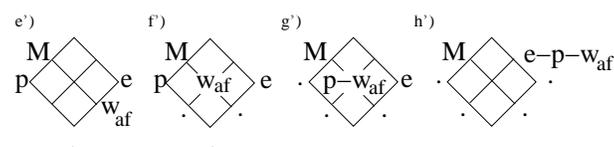

Figure 19: A syntactic analysis of 'Mary eats pizza with a fork' (alternative #2) yielding *Mary eats pizza-with-a-fork* (the missing parsing events, stages (a)-(d), are identical to those presented in fig. 18)

the complementary state pizza and, in a later interpretation moment, by the complementary effect with-a-fork (index; $\neg A + \neg B$). This is opposed to the interpretation depicted in fig. 19, in which pizza (A) is temporarily considered to be a candidate for the subject (rheme), preceding its interaction with with-a-fork (B). This forces the interpretation of pizza to be reconsidered, this time as a complementary sign, in order to represent pizza-with-a-fork as a complementary expression of the context (index; $\neg A * \neg B$).

6 Conclusion and further research

Past experience with traditional, static knowledge representation (KR) revealed its limitations in current information processing characterized by complex, interrelated data. In this paper we suggest that the growing complexity of KR can be more adequately coped with if we respect the dynamic nature of the input data. To this end we developed a model for knowledge representation on the basis of a Peircean theory of signs. As Peirce's theory cannot be directly interpreted as a KR, let alone a computational one, we took a step back and, first, introduced a process model of cognitive activity. By analyzing this model from a 'naive' logical point of view we were able to assign a logical expression and, eventually, a Peircean sign aspect, to the interpretation moments of the process. As a result, we could define a representation that satisfies the conditions set by cognitive

activity on the one hand, and complies with Peirce's semiotic theory on the other.

An advantage of a cognitive and semiotic foundation of our approach is due to its potential for a *uniform* representation of knowledge. Although this hypothesis formally cannot be proved, for knowledge is not some 'thing' that can be captured in (formal) rules, it can be tested, by applying the theory in different domains, as we did in past research. An attractive feature of uniform representation is its potential for merging knowledge from different domains in a single representation, by means of structural co-ordination, which must be more efficient than the use of translations between different representations. Some evidence supporting this assumption is found in (Hagoort, Hald, Bastiaansen, & Petersson, 2004), experimentally justifying that information processing in the syntactic and semantic domains can be quasi-simultaneous. An interesting consequence of a uniform representation is its *scalability*; low- and high-level knowledge, but also conceptualization by a single actor or, by different stake-holders can be modeled in the same fashion.

An advantage of the processual interpretation of the proposed KR method is that it gives insight in the events of informative processes, thereby enabling a systematic lexical definition of data. By using the dependencies between the events in our model, the efficiency of conceptualization processes can be improved. For instance, in problem elicitation, we are able to raise more pointed questions and, because the meta-level information (sign aspects) provides handles to fill in the gaps in the knowledge of the object domain, elicitation becomes more economic. Stake-holders' time can be expensive, after all.

In this paper, our focus is on knowledge modeling in the 'naive' logical, and syntactic domains of symbols. In past research we tested our theory for modeling information processing in the morpho-syntactic, semantic syntactic, 'naive' mathematical and reasoning domains (Sarbo & Farkas, 2002), (Sarbo & Farkas, 2003), (Farkas & Sarbo, 2004), (Sarbo et al., 2006). The theoretical possibilities of our knowledge representation have been illustrated with an extended example in text summarization (Sarbo & Farkas, 2004). Scalability has been subject of theoretical and experimental research in problem elicitation, by individuals[38] (Couwenberg, 2007) as well as organizations (Breemen, Sarbo, & Weide, 2007), (Klomp, 2008).[39] The results comply with our conjectures, including the aspect of scalability.

In current research, our first priority is the definition of an extended version of our theory, capable of combining 'bottom-up' input processing with 'top-down' anticipatory interpretation. The development of such a model is necessary for an application of the theory to practical problems in information processing.

Note that it is not the implementation of the process model (processing schema), but the definition of the combinatory properties of qualia that can be most laborious. In traditional KR, the relation between parser and lexicon is usually the reverse. The potential of Peirce's categories to be recursively applied to themselves enables lexical definitions to be systematically defined. Finally we remark that the machine of the 'ghost' proposed raises interesting venues for brain research. This minimally requires a mapping of the interpretation moments to units in the brain that realize the informational functions.[40]

Notes

[1]For a thoughtful attempt to structure this history from an art historical perspective see (Elkins, 1999).

[2] For an account of this history see (Krämer, 1988). For a source history of its formalization see (Heijenoort, 1967).

[3]Cf. (Cocchiarella, 2001) for a discussion of logic as language (primacy of the predicative function) vs logic as calculus (primacy of set theory) in questions of ontology.

[4]The Works of Jeremy Bentham, Edinburgh, 1843, viii, 83, footnote (cited in (Peirce, 1931-58), vol. 1, para. 241, footnote 1, p.110).

[5]We thank Y. Senden for his advice on ancient Greek.

[6]A reference to (Peirce, 1931-58) is given by volume and paragraph, separated by a point.

[7]With regard to Peirce's intellectual development a multitude of opinions can be found in the secondary literature. For an overview see Appendix A.

[8]"It seems to me that one of the first useful steps toward a science of semeiotic (sémeiötiké), or the cenoscopic science of signs, must be the accurate definition, or logical analysis, of the concepts of the science" (CP 8.343).

[9]See www.cs.ru.nl/kif.

[10]Vague is to be preferred over general here for two reasons. First, because the qualia in question are less vivid, for instance, than the qualia that are filled in by the mind in the blind spot (cf. (Ramachandran & Hirstein, 1997)). Second, because the words 'more general' point in the direction of a loss of comprehension and a growth in extension. While here we are concerned with: "The vague memory of a sensation is just an aggregate, whether continuous or not makes no difference, of ideas which are called up together by a suggesting idea" (CP 7.407).

[11]Peirce made a classification of sign types, different classifications of sign aspects and a lot of scattered remarks point in the direction of a processual line of thinking, but he did not make a model for the interpretational process.

[12]'Systematic' is used here in contrast with historical.

[13]In cognitive theory, the potential for treating a collection of qualities as a single entity is known as 'chunking'.

[14]The terms quality and quale designate, so to speak, the outside and inside perspective on an entity, from the point of view of the interpreting system; qualia is plural for quale.

[15]During input processing the stimulus may change, meaning that its previous and current value can be different. That difference can be interpreted by the brain, as a change, mediating the current value of the stimulus to its supposed meaning.

[16]Alternatively, cognition could be called *conception*.

[17]We call the interpretation moments generated by the processing schema *representations* (of the input qualia).

[18]The term context is used ambiguously, in its potential ($[q_s\ q_e\ C]$) and its actual contribution ($[C]$) to information processing.

[19]As A and $\neg A$ (but also B and $\neg B$) arise due to the same input trigger, the two collections are *not* independent.

[20] As the two types of input qualia are commonly interpreted as variables, a reference to the state qualia contains a reference to the effect qualia as well. $\neg B$ and $\neg A$ are contributed by the context ($[C]$).

[21] The occurrence of an effect entails the existence of a state. This simultaneity included in $B(\neg B)$ is represented by $A*B(\neg A*\neg B)$.

[22]For some words on the interpretation of Peirce's explorative work on the different kinds of interpretants see Appendix A.

[23]Note that in a detailed analysis 'looking for an escape' is one of the interpretants in the cascade of interpretants that constitutes the interpretational process.

[24] For $k>9$, there must be states that are *degenerately* represented. In such states there is no increase in the approximation of S. We do not come any closer to the generation of all signs aspects.

[25]Since, in our opinion, he stacks to much in the concepts (cf. CP 5.475), below we take from his description only what appears as essential from our perspective.

[26]We refer to Peirce's Logic Notebook (Peirce, 1865–1909) through its manuscript number according to the Robin catalog, MS 339, followed by page number, recto (r) or verso (v), and date.

[27]The relation between premises and conclusion may be abductive, inductive or deductive.

[28]In fig. 10, the state of S_s or the interpretational system is represented by σ_j ($1 \leq j \leq k$).

[29]For the importance of goal orientation see (Breemen et al., 2007).

[30]Both kinds of interpretation comply with our model, but since habitual (automatic) interpretation does not give handles for an analytical treatment, it is not in our focus.

[31]Proto-signs are a procedural equivalent of sign aspects.

[32]In conformity with the assumption that qualisigns are independent by definition.

[33] The dependencies between the different sign aspects of Peirce's classification define an induced partial ordering with the qualisign position as the bottom element.

[34]Interpretation may fail if the entire input cannot be represented by a single (sentence) sign.

[35]We assume nondeterminism to be implemented by backtracking (Aho & Ullman, 1972).

[36]Note that this laborious procedure is a consequence of the assumed bottom-up flow of information.

[37]Morpho-syntactically complete symbols are given in parentheses. A model for morpho-syntactic parsing, on the basis of the theory presented in this paper, may be found in (Farkas, 2008).

[38]This involved the conceptualization of a non-trivial mathematical problem. 28 elementary school students took part in the experiment.

[39]In this experiment, a real-life problem has been analyzed by three clients/stakeholders, in co-operation with a professional elicitator provided by Sogeti Nederland.

[40]J.I. Farkas, personal comm., 2009.

References

Aho, A., & Ullman, J. (1972). *Parsing* (Vol. 1). Prentice-Hall.

Apel, K. (1970). *Der Denkweg von Ch. S. Peirce*. Frankfurt am Main: Suhrkamp.

Bergman, M. (2004). *Fields of Signification; Explorations in Charles S. Peirce's Theory of Signs* (No. 6). PhD Thesis, Philosophical Studies from the University of Helsinki.

Breemen, A. van, & Sarbo, J. (2007). Sign Processes and the Sheets of Semeiosis (S_s). In K. Liu (Ed.), *10th International Conference on Complexity in Organisational and technological systems (ICOS)* (pp. 89–98). Sheffield (UK).

Breemen, A. van, Sarbo, J., & Weide, T. van der. (2007). Towards a Theory of Natural Conceptualization. In K. Liu (Ed.), *10th International Conference on Complexity in Organisational and Technological Systems (ICOS)* (pp. 24–32). Sheffield (UK).

Cocchiarella, N. (2001). Logic and Ontology. *Axiomates*, *12*, 117–150.

Couwenberg, M. (2007). *Analyse van ontwikkeling van kenniselementen* (Master Thesis). Nijmegen (NL): Radboud Universiteit.

Driel, H. van. (1993). *De Semiotiek van C.S. Peirce in verband gebracht met het verschijnsel 'film'*. PhD thesis, Landegem, Nevelland.

Dumitriu, A. (1977). *History of logic* (Vols. 1–4). Tunbridge, Wells, Kent: Abacus Press.

Elkins, J. (1999). *The Domain of Images*. Ithaca and London: Cornell University Press.

Esposito, J. (1980). *Evolutionary Metaphysics: the Development of Peirce's Theory of Categories*. Ohio: Ohio University Press.

Farkas, J. (2008). *A Semiotically Oriented Cognitive Model of Knowledge Representation*. PhD thesis, Radboud University, Nijmegen.

Farkas, J., & Sarbo, J. (2000). A Logical Ontology. In G. Stumme (Ed.), *Working with Conceptual Structures: Contributions to ICCS'2000* (pp. 138–151). Darmstadt (Germany): Shaker Verlag.

Farkas, J., & Sarbo, J. (2004). Mathematica Utens. In H. D. Pfeiffer, H. Delugach, & K. E. Wolff (Eds.), *Proceedings of ICCS'04* (pp. 29–42). Hunstville (Alabama): Shaker Verlag.

Feibleman, J. (1960). *An Introduction to Peirce's Philosophy*. New York: George Allen and Unwin Ltd.

Fitzgerald, J. (1966). *Peirce's Theory of Signs as Foundation for Pragmatics*. The Hague: Mouton.

Gallie, W. (1966, 1950). *Peirce and Pragmatism*. Westport, Connecticut: Greenwood Press.

Goudge, T. (1950). *The Thought of C. S. Peirce*. Toronto: University of Toronto Press.

Gruber, T. (2008). Ontology. In *Encyclopedia of Database Systems.* Springer Verlag.

Haas, W. (1964). *The Conception of Law and Unity of Peirce's Philosophy*. Fribourg: The University Press.

Hagoort, P., Hald, L., Bastiaansen, M., & Petersson, K.-M. (2004). Integration of word meaning and world knowledge in language comprehension. *Science*, *304*, 438–441.

Harnad, S. (1987). *Categorical Perception: The groundwork of cognition*. Cambridge: Cambridge University Press.

Heijenoort, J. van. (1967). *From Gödel to Frege: A Source book in Mathematical Logic, 1879-1931*. Cambridge: Harvard University Press.

Kant, I. (1956). *Kritik der Reinen Vernunft*. Würzburg: Felix Meiner Verlag.

Klomp, E. (2008). *Conceptualisatie in een requirements development proces* (Master Thesis). Nijmegen (NL): Radboud Universiteit.

Krämer, S. (1988). *Symbolische Machinen; Die Idee der Formalisierung in geschichtlichem Abriss*. Darmstadt (Germany): Wissenschaftlische Buchgesellschaft.

Lakatos, I. (1970). Falsification and the Methodology of Scientific Research Programmes. In I. Lakatos & A. Musgrave (Eds.), *Criticism and the Growth of Knowledge.* New York: Cambridge University press.

Lalor, B. (1997). The Classification of Peirce's Interpretants. *Semiotica*, *114*(1/2), 31-40.

Murphy, M. (1961). *The Development of Peirce's Philosophy*. Cambridge: Harvard University Press.

Parker, K. (1998). *The Continuity of Peirce's Thought*. Nashville and London: Vanderbilt University Press.

Peirce, C. (1865–1909). *Logic notebook*. Houghton Library, Harvard university: Unpublished manuscript on microfilm.

Peirce, C. (1931-58). *Collected Papers of Charles Sanders Peirce*. Cambridge: Harvard University Press.

Peirce, C. (1992, 1998). *The Essential Peirce: Selected Philosophical Writings, 2 volumes*. Bloomington: Peirce Edition Project, Indiana University Press.

Ramachandran, V., & Hirstein, W. (1997). Three Laws of Qualia. *Journal of Consciousness Studies*, *4*(5-6), 429–458.

Ransdell, J. (2007). T.L. Short on Peirce's Semeiotic. *Transactions of the Charles S. Peirce Society*, *43*(4), 654–662.

Rosensohn, W. (1974). *The Phenemonology of Charles S. Peirce*. Amsterdam: Grüner B. V.

Sarbo, J. (2006). Peircean Proto-Signs. In D. M. Dubois (Ed.), *AIP Conference Proceedings* (Vol. 839, pp. 474–479). Liege, Belgium.

Sarbo, J., & Farkas, J. (2002). A linearly complex model for knowledge representation. In U.Priss & D. Corbett (Eds.), *Conceptual structures: Integration and interfaces (ICCS'2002)* (Vol. 2193, pp. 20–33). Borovets (Bulgaria): Springer Verlag.

Sarbo, J., & Farkas, J. (2003). Logica Utens. In A. de Moor & B. Ganter (Eds.), *Using conceptual structures* (pp. 43–56). Dresden (Germany): Shaker Verlag.

Sarbo, J., & Farkas, J. (2004). Towards a theory of meaning extraction. In H. D. Pfeiffer,

H. Delugach, & K. E. Wolff (Eds.), *Proceedings of ICCS'04* (pp. 55–68). Hunstville (Alabama): Shaker Verlag.

Sarbo, J., Farkas, J., & Breemen, A. (2006). Natural Grammar. In R. Gudwin & J. Queiroz (Eds.), *Semiotics and Intelligent System Development* (pp. 152–175). Hersey (PA): Idea Group Publishing.

Short, T. (1981). Semiosis and Intentionality. *Transactions of the Charles S. Peirce Society*, *17*(3), 197-223.

Short, T. (2004). The Development of Peirce's Theory of Signs. In C. J. Misak (Ed.), *The cambridge compendium to peirce.* Cambridge, UK: Cambridge University press.

Solso, R. (1988). *Cognitive Psychology*. New York: Harcourt Brace Jovanovich.

Stillings, N. (1998). *Cognitive Science*. Cambridge (MA): MIT Press.

Wittgenstein, L. (1971). *Philosophische Untersuchungen*. Frankfurt am Main: Suhrkamp.

Zeman, J. (1977). Peirce's Theory of Signs. In T. A. Seboek (Ed.), *A Perfusion of Signs.* Bloomington: Indiana University Press.

Appendix

A   Notes on the secondary literature

A.1   The interpretation of Peirce's philosophy

From a historical perspective the views on Peirce's philosophy as a system can be arranged as follows. In the first phase the question is whether Peirce's philosophy forms a system. The editors of the Collected Papers, Feibleman (1960) and Gallie (1966, 1950) hold it does, Goudge (1950) disagrees by maintaining the thesis that Peirce's way of thinking is problem directed and plagued by a dual tendency: transcendentalism vs naturalism. In the next phase the main question is whether Peirce worked throughout his life on one system or whether he developed multiple, successive systems. This phase starts, to our knowledge, with the appearance of an influential book by Murphy (1961). He distinguishes four systems. Each shift of system is informed, according to him, by developments in the domain of logic. Apel (1970) follows the path set out by Murphy, but with him the defining characteristic for what instigates a change is the methodological principle of pragmatism. Opposing Murphy are those that hold that Peirce's philosophy must be looked at as one system in development. Proponents of that view are Rosensohn (1974) and Esposito (1980). About the nature of the system however opinions vary considerably. Rosensohn sees a gradual grow towards a system that emerges in 1902 when Peirce introduces his phenomenology. Esposito holds that a dialectical view on reality and experience is developed early on and that although the elements of the dialectic change the underlying form remains the same. So, the three main positions are: 1) There may well be no system at all, therefore let us start with the investigation of interesting ideas (Haas, 1964). 2) There are several successive systems (Murphy, 1961), (Short, 2004). 3) Peirce worked throughout his life on one system. An important proponent of that view is Ransdell (2007). This list of positions may seem neat, but proves to be less helpful when one realizes that also within the positions there is little consensus as to what are the defining characteristics.

We are not working on an interpretation of Peirce's development, but on subject matters that were important for Peirce and for which Peirce's work is of paramount importance. However, if asked for an opinion, we would argue in favor of Ransdell's suggestion with regard to Peirce's research program (research program in the sense of Lakatos (1970)) while at the same time admitting that Short has a point when he asserts that there are several successive theories, but we would immediately add that they are

developed within the same research program. It is against this background that we refer the reader, interested in an early and detailed treatment of the categories to (Murphy, 1961). The reader interested in the interrelations between Peirce's architectonic and the categories, a topic of great interest to our approach, we advise (Parker, 1998).

A.2 The interpretation of Peirce's semiotic

Since our interpretation of the relation between the two triads of interpretants (the emotional, energetic and logical on the one hand and the immediate, dynamical and normal on the other) probably will be the most controversial, here we only will superficially indicate our position against the background of other interpretations proposed.
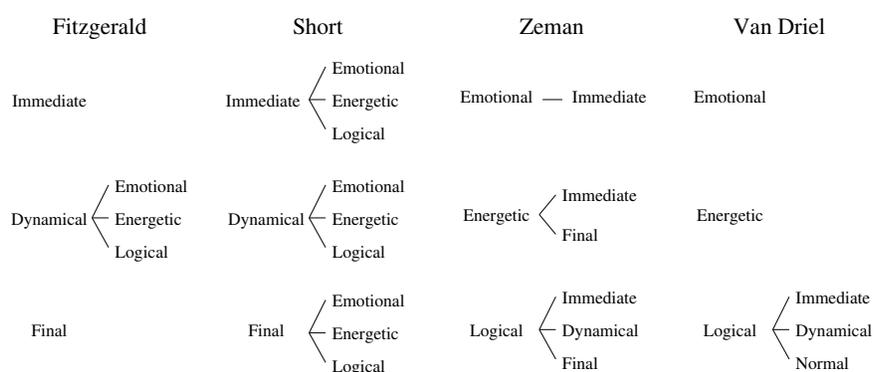

Figure 20: Four solutions for the relation between the two interpretant trichotomies. The first three are reconstructed by Bergman, the last is due to van Driel.

Bergman (2004) nicely summarizes the propositions of Fitzgerald (1966), Zeman (1977) and Short (1981). In fig. 20 we present Bergmans diagrammatic reproduction of those positions together with the proposal we followed, that of Van Driel (1993). Zeman can be looked at as complementary to Van Driel, but is far less explicit. Regrettably, Van Driel does not give arguments for his way of combining both trichotomies. Probably because, given his background in language and communication studies, for him it is evident that the apprehension of the sign as an object should be taken into account. For Peirce this may well have been less evident given the fact that he did not combine both trichotomies himself and remarked that:

> It seems best to regard a sign as a determination of a quasi-mind; for if we regard it as an outward object, and as addressing itself to a human mind, that mind must first apprehend it as an object in itself, and only after that consider it in its significance; and the like must happen if the sign addresses itself to any

quasi-mind. It must begin by forming a determination of that quasi-mind, and nothing will be lost by regarding that determination as the sign. (Peirce, 1992, 1998) Vol.2, p.391.

Lalor (1997) seems to draw a similar conclusion with regard to the way in which both triads ought to be combined as we do, however with an important difference. Lalor holds that the emotional, energetic, logical classification reflects the human case, the human experience of semiosis. We agree that it reflects the experience, the apprehension of the sign, but we agree with Peirce that it is not here that the difference between semiosis in humans and artificial or quasi-minds must be looked for. It is for human and quasi minds alike that both trichotomies must be combined as we do. A significant difference between processes of semiosis in human and in quasi minds resides in the way in which esthetics and ethics, the subject of the two normative sciences that precede semiotics, play their role in the utens of interpretation.

Note that paying attention to the way in which the (quasi)-mind apprehends the object, calls for an approach in which the process of interpretation is supposed to set off at the moment a sign inscribes itself in a (quasi)-mind (semiotic sheet). Note also that in the Van Driel scheme the term normal interpretant is used instead of the term final interpretant. We agree with Van Driel's choice of terms because in our opinion the final interpretant ought to be looked at as the limit to which the normal interpretant tends.

B   A definition of 'naive' logic

The hierarchy of logical expressions depicted in fig. 21 can be interpreted as a procedure, generating expressions from other expressions in a recursive fashion. This procedure is what we call 'naive' logic. In this section we introduce this procedure as operations on expressions interpreted as relations between collections. The initial expressions are defined by the collections: A, B, $\neg A$, $\neg B$. Below, $X, Y \in \{A, B\}$ are used as variables on collections. The operators '$+$' and '$*$' are assumed to be commutative; '$\neg$' is defined on collections: $\neg(X) = \neg X$, $\neg(\neg X) = X$, as well as operators: $\neg('*') = '+'$, $\neg('+') = '*'$. Synonymous expressions are separated from each other by a ',' symbol as usual.

In *sorting*, the expressions of $[q_s]$ and $[q_e]$ are generated from the initial expressions: $[q_s] = A + B$, $[q_e] = A * B$. This step is trivial.

In *abstraction*, the expressions of q_s and q_e are generated from the expressions of $[q_s]$ and $[q_e]$, by means of a relative difference operation. Due to the differences between $[q_s]$ and $[q_e]$ this requires two versions of this operation, that are designated by "\" and
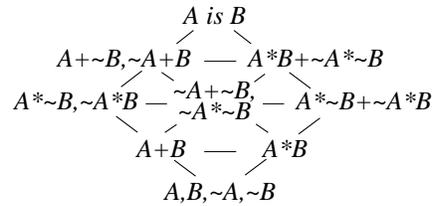
$$A \text{ is } B$$
$$A{+}{\sim}B, {\sim}A{+}B \quad\text{---}\quad A{*}B{+}{\sim}A{*}{\sim}B$$
$$A{*}{\sim}B, {\sim}A{*}B \text{ --- } \begin{array}{c}{\sim}A{+}{\sim}B,\\ {\sim}A{*}{\sim}B\end{array} \text{ --- } A{*}{\sim}B{+}{\sim}A{*}B$$
$$A{+}B \quad\text{---}\quad A{*}B$$
$$A, B, {\sim}A, {\sim}B$$

Figure 21: Logical expressions associated with the processing schema

"/" (their definition is given below). For $X{=}Y$, $X{\backslash}X$ as well as X/X are defined by the empty expression, which can be omitted; for $X{\neq}Y$, $X{\backslash}Y$ and X/Y are identically defined by $X{*}{\neg}Y$.

In the derivation below, the simultaneity relation included in $[q_e]$ is 'removed' from the constituency relation included in $[q_s](A{+}B)$. This operation can be feasible as is witnessed by the synonymous interpretations of $A{+}B$ as constituents: A, B, $A{\cdot}B$ ($A{\cdot}B$ is short for 'both A and B'). Each one of these terms is an expression of a possible co-existence of A and B. For instance, A is an expression of the input state, co-occurring with the input effect in the sense of possibility (alternatively, A could be denoted by A_B). In the derivation below, we interpret $A{\cdot}B$ as A or as B (ambiguously).

$$
\begin{aligned}
q_s \;=\; & [q_s]{\backslash}[q_e]\\
=\; & (A{+}B){\backslash}(A{*}B)\\
=\; & A{\backslash}(A{*}B),\; B{\backslash}(A{*}B)\\
=\; & A{\backslash}A,\; A{\backslash}B,\; B{\backslash}A,\; B{\backslash}B\\
=\; & A{\backslash}B,\; B{\backslash}A\\
=\; & A{*}{\neg}B,\; B{*}{\neg}A
\end{aligned}
$$

The other way around, by 'removing' the constituency relation included in $[q_s]$, from the simultaneity included in $[q_e]$, a relation can be obtained which is less tight than simultaneity, but more close than constituency. The resulting relation, defined by the final expression in the derivation of q_e below, exhibits the aspect of an exclusive-or relation.

$$
\begin{aligned}
q_e \;=\; & [q_e]/[q_s]\\
=\; & (A{*}B)/(A{+}B)\\
=\; & (A{*}B)/A{+}(A{*}B)/B\\
=\; & A/A{+}A/B{+}B/A{+}B/B\\
=\; & A{*}{\neg}B{+}B{*}{\neg}A
\end{aligned}
$$

In *complementation*, the expressions of (q_s,C) and (q_e,C) are generated by means of complementation operators ('$\neg$') from the expressions of q_s and q_e (the complementary

meaning of [C] is represented by complementation as an operations). In the definition of (q_s,C) below, the operand of '$\neg$' is interpreted as a collection of constituents ('state' view). For example, the constituents of $A*\neg B$ are 'A', '$\neg B$', '$*$'.

$$(q_s,C) = \neg q_s$$
$$= \neg(A*\neg B),\ \neg(\neg A*B)$$
$$= (\neg A)(\neg *)(\neg \neg B),\ (\neg \neg A)(\neg *)(\neg B)$$
$$= \neg A + B,\ \ A + \neg B$$

This is opposed to the the definition of (q_e,C) in which the operand of '$\neg$' is interpreted as something whole ('effect' view). As the existence of an effect always implies the existence of a state, '$\neg$' can be applied to an expression interpreted as a state or an effect. The two interpretations are indicated below by means of square brackets and boldface symbols. For example, in the first term of (i), '$\neg$' is applied to expressions representing a state ($\mathbf{A}$, $\neg \mathbf{A}$); in the second term, it is applied to expressions representing an effect ($\neg \mathbf{B}$, $\mathbf{B}$).

$$(q_e,C) = \neg q_e$$
$$= \neg(A*\neg B + \neg A*B))$$
$$= [\neg(\mathbf{A}*\neg B) + \neg(\neg \mathbf{A}*B)] + [\neg(A*\neg \mathbf{B}) + \neg(\neg A*\mathbf{B})] \qquad \text{(i)}$$
$$= [(\neg \mathbf{A}*\neg B) + (\neg \neg \mathbf{A}*B)] + [(A*\neg \neg \mathbf{B}) + (\neg A*\neg \mathbf{B})]$$
$$= A*B + \neg A*\neg B$$

For the sake of completeness let us mention that the final expression, (q_s,C)–(q_e,C), can be formally interpreted as a syllogistic conclusion, defined by the expressions of (q_s,C) and (q_e,C) used as premises. In the derivation below we make use of Łukasiewicz's conception of a syllogism (Dumitriu, 1977), according to which a premise can be equivalently represented as an implication. The major and minor premises are $A*B+\neg A*\neg B = A+B \rightarrow A*B$ and $A \rightarrow B = A \rightarrow A+B$, respectively, from which $A\ is\ B$ syllogistically follows (by taking $A+\neg B$ or $A \leftarrow B$ as the minor premise, $B\ is\ A$ can be obtained; the two propositions are synonymously representing the logical meaning of the input, in an 'active' and a 'passive' sense). In the derivation below, quantifiers are omitted.

$$A+B\ \ IS\ \ A*B \quad \text{;premise 1}$$
$$A\ \ \ \ \ IS\ \ A+B \quad \text{;premise 2}$$
$$\Rightarrow A\ \ \ \ \ IS\ \ A*B \quad \text{;} A \rightarrow A*B = \neg A + A*B = \neg A + B = A \rightarrow B$$
$$= A\ \ \ \ \ IS\ \ B$$

A definition of 'naive' logic as a rewriting system or a Boolean algebra is not part of this book. However, the possibility for a Boolean interpretation of the processing

schema is illustrated below by derivations indicating a close relationship between some of the expressions of fig. 21 and syntactically equivalent Boolean relations (this requires an interpretation of A and B as logical variables which is taken as granted).

For example, the expressions associated with q_e can be defined by means of a relative difference operation on the expressions of $[q_s]$ and $[q_e]$ this time interpreted as Boolean relations: $(A+B)\backslash(A*B)= A*\neg B+B*\neg A$. The expressions associated with (q_s,C) and (q_e,C) can be defined by means of a Boolean negation on the expressions of q_s and q_e interpreted as Boolean relations, respectively: $\neg(A*\neg B)$, $\neg(\neg A*B)= \neg A+B$, $A+\neg B$; $\neg(A*\neg B+\neg A*B)= A*B+\neg A*\neg B$.

The above close relationship between 'naive' and Boolean logic does not hold for the other expressions and 'naive' logical operations, however. From a more general perspective, Boolean logic can be said to differ from 'naive' logic in three aspects. The first is the uniform representation of the collections of different types of qualia as a universe and the collections of state and effect qualia as logical variables (Boolean logic). The second is the interpretation of the logical operations as operations on sets (Boolean logic), not on different types of collections ('naive' logic). The third is the non-synonymous interpretation (Boolean logic) of synonymous expressions ('naive' logic), such as $A*\neg B$ and $\neg A*B$ (cf. fig. 21).

There are other, less important differences between the two systems as well. One of them is the potential of Boolean logic for a combination of any number of variables and logical operations in a single expression. This is opposed to the limitations of 'naive' logic, capable of establishing relations between two variables at a time and a realization of operations in an order that is dictated by the order of symbol interactions according to the processing schema. Finally, the two systems differ in their interpretation of logical values ($true/false$), as a representation of the status of cognitive processing ('naive' logic) and a constant value (Boolean logic).

Finally, let us mention the potential of [C] (index) for deductively selecting an actual interpretation from the range of possibilities offered by q_s (rheme), as well as its potential for being tested for q_e (legisign) hence inductively generalizing its habitual meaning. Through this deductive and inductive potential of *complementation*, the processing schema is capable of generating the 'naive' meaning of '$\exists$' and '$\forall$', respectively, used by 'naive' predicate calculus. A reasoning interpretation of the processing schema may be found in (Farkas, 2008).