A Semiotically Oriented Cognitive Model of Knowledge Representation

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by

József István Farkas
born in Szeged, Hungary
on October 8, 1954

Doctoral supervisor:

Prof. dr. ir. T.P. van der Weide

Co-supervisor:

Dr. ir. J.J. Sarbo

Names of the members of the Doctoral Thesis Committee:

Prof. dr. L.W.J. Boves

Dr. J.F. Sowa
(IBM Systems Research Institute, Stanford University, USA)

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József István Farkas
geboren op 8 oktober 1954
te Szeged, Hungary

Promotor:

Prof. dr. ir. T.P. van der Weide

Copromotor:

Dr. ir. J.J. Sarbo

Manuscriptcommissie:

Prof. dr. L.W.J. Boves
Dr. J.F. Sowa
(IBM Systems Research Institute, Stanford University, USA)

Preface

Since 1999 the author of this thesis has been working on knowledge representation in co-operation with J.J. Sarbo, and later also with A.J.J. van Breemen (since 2005). Studies on several subjects on this area resulted in a number of publications, forming the basis of the text presented in this thesis:

J.J. Sarbo, J.I. Farkas, and A.J.J. van Breemen. Natural Grammar. In R. Gudwin and J. Queiroz, editors, *Semiotics and Intelligent System Development*, pages 152–175, Hersey (PA), Idea Group Publishing, 2006.

J.I. Farkas and J.J. Sarbo. Mathematica Utens. In H. D. Pfeiffer, H. Delugach, and K. E. Wolff, editors, *Proceedings of ICCS'04*, pages 29–42, Hunstville (AL), Shaker-Verlag. 2004.

J.J. Sarbo and J.I. Farkas. Towards a theory of meaning extraction. In H. D. Pfeiffer, H. Delugach, and K. E. Wolff, editors, *Proceedings of ICCS'04*, pages 55–68, Hunstville (AL), Shaker-Verlag. 2004.

J.J. Sarbo and J.I. Farkas. Logica Utens. In A. de Moor and B. Ganter, editors, *Using Conceptual Structures*, pages 43–56, Dresden (Germany), Shaker-Verlag, 2003.

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J.I. Farkas and J.J. Sarbo. A Logical Ontology. In G. Stumme, editor, *Working with Conceptual Structures*, pages 138–151, Darmstadt (Germany), Shaker Verlag, 2000.

G.Y. Debrock, J.I. Farkas, and J.J. Sarbo. Syntax from a Peircean perspective. In P. Sandrini, editor, *5th International Congress on Terminology and Knowledge Engineering*, pages 180–189, Innsbruck (Austria), 1999.

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Jozsef Farkas
Budapest, January 2008

Contents

Chapter 1

Introduction

Knowledge pervades all human activity and with the advent of current technology those activities get more and more intertwined with the use of the computer. The possibilities offered by recent computer technology are limited, however. Simple data handling operations, such as searching in databases can be very well automated, but a realization of computer assistance in complex operations is yet less successful, basically due to the lack of knowledge available for the computer. This is opposed to the potentially unlimited amount of knowledge about the world, which explains the growing need for adequate knowledge representation (Nagy, 1984), (Piaget, 1970).

In this thesis I take as my starting point that knowledge arises from the cognition of phenomena, by means of signs. Accordingly, I introduce a model for knowledge representation that is based on an analysis of the properties of cognitive activity and signification. As knowledge may be defined as learned meaning, adequate knowledge modeling requires an adequate representation of meaning. Searle's famous Chinese room argument indicates, however, that the differences between the interpretation by humans, and current computers may not be resolved. Because the goal of this thesis is the introduction of a model for knowledge representation that also suits a computational interpretation, the reader may ask if in principle that goal can be achieved. In this thesis it is suggested that although we cannot represent the full potential of human interpretation, we may represent the important interpretation moments of human information processing, defining the brain's 'program'. This view may be explained with the metaphor of a recipe, as a generic notion. Such a prescription can precisely specify the meaning of the elementary events of a process, but it can at most point in the direction of the meaning of the ingredients and the final product.

But if we cannot represent the full potential of meaningful interpretation, is it possible to talk about that process in any sense? I believe the answer can be positive again. When we experience a phenomenon as meaningful, we usually do not grasp its full meaning (if ever), but we only understand it approximately, that is, from a certain point of view. In this thesis I will assume that meaning, be it full or approximate, is inherently related to the experience of completeness. When we understand a phenomenon approximately, we experience its completeness from a certain point of view. What makes this conjecture interesting is that the conditions for 'completeness from a certain point of view' can be formalized more easily than the conditions for 'the experience of full meaning'. In fact, this notion will be used as an indication that the representation generated may be meaningful (from a certain point of view). For example, in natural language, the experience of the input as a meaningful sentence may be understood approximately through the experience of its syntactic well-formedness (Grice, 1975), (Kiefer, 1992).

The element of completeness points in the direction of a teleological (goal-oriented) character of interpretation. I will capitalize on this property, by introducing a process model for knowledge. Following Debrock (Debrock, Farkas, & Sarbo, 1999), a *process* will be considered to be any sequence of events such, that (i) one event initiates the sequence and another terminates it, (ii) every event 'contributes' to the sequences 'yielding' the terminating event, (iii) the terminating event 'governs' the decision of which events make up the sequence, and (iv) the determinate character of the events making up the sequence necessitates the terminating event. An event will be considered as whatever makes a difference.

Although it will be assumed that meaning arises from phenomena interpreted as signs, the computational interpretation of the proposed model is not purely bottom-up. In this respect the theory of this thesis differs from some of those suggested by current research, for example, the theory of Gärdenfors (Gärdenfors, 2004), or the generative theory of Pribram (Pribram, 1971) and Prueitt (Prueitt, 1995), which is related to the fundamental work by Gibson (Gibson, 1997). These bottom-up theories, that aim at developing generic mechanisms for the definition of primary entities and complex process compartments in cognitive processing, cannot cope with the symbol grounding problem[1]

[1]This is the problem: How can the semantic interpretation of a formal symbol system be made intrinsic to the system?

raised by Harnad (Harnad, 1990), however. The theory proposed in this thesis circumvents Harnad's problem by only considering signs with regard to knowledge domains (Mackay, 1987). Roughly, a *knowledge domain* is defined as a 'closed' collection of signs representing a point of view of interpretation. Some of the most well-known knowledge domains are natural language, logic, and mathematics (Halassy, 1992). The abstraction of knowledge domains can be practical for modeling purposes. As the primary entities of the domains are intuitively meaningful, their formal properties can be easily defined. For example, in natural language syntax, the primary syntactic entities can be defined as the collection of morpho-syntactically complete 'words'.

1.1 The properties of meaningful interpretation

The observation of phenomena entails the existence of an interaction between two entities: observer and observed. Their interaction, which reveals itself as change, is interpreted by the observer as an event. Such an event interpretation of an interaction is what I shall call an *observation*, or the *actual meaning* of a phenomenon that I use interchangeably. By virtue of the general character of interaction, change, and event, it will be suggested that the model proposed in this thesis could be used as a uniform model for knowledge representation. I will attempt to justify this hypothesis by introducing a model for cognitive processing in different knowledge domains, including those mentioned earlier. By considering the observer occurring in a '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 that state.

The first step in meaningful interpretation is a perceptual judgment, the 'naive' or natural interpretation of a phenomenon by the brain. The interpretation of phenomena as meaningful signs depends on the observer's knowledge about similar phenomena and earlier response strategies. This knowledge (memory information) is invoked by the observed phenomenon as input (stimulus). By interpreting the relation between the input and the memory information, the actual meaning of the input is determined by the observer.

The assumption that knowledge arises from the observation of phenomena is not without consequences. As nature is inherently dynamic, adequate representation of cognitive activity must be dynamic as well. According to the received view of cognitive theory, however, the brain processes the external stimulus in samples, which are static snapshots. Is it possible to bridge the gap between the static input and its dynamic representation as meaning? Following Sarbo

(Sarbo, 2006) I shall maintain that dynamic representation may arise from the interpretation of static information, as a process. According to that view, the interpretation moments of input processing may contribute to the (full) meaning of the input, as 'proto-signs', that are in a process of becoming a sign.

That we are able to represent static information dynamically, can be illustrated by the phenomenon of apparent motion perception, that I use as a metaphor. This phenomenon consists of the presentation of a series of still pictures, and although each picture can be meaningful in itself, combined they are interpreted as parameters in the experience of the series of pictures as a whole, resulting in the experience of motion. It is a conjecture of this thesis that an analogous relation may exist between the interpretation moments of cognitive processing, on the one hand, and the experience of the entire process as meaningful, on the other (Roediger & Blaxton, 1987).

That 'naive' knowledge representation can be efficient is known from the brain's ability to recognize phenomena in 'real-time', which is formally equivalent to real-time or linear complexity. This assumed efficiency of 'naive' knowledge representation is in sharp contrast with traditional knowledge modeling, that is more complex. For example, unification based formalisms are known to be inherently exponential (Dwork, Kanellakis, & Mitchell, 1984). If we assume that this difference between the complexity of formal mathematical and natural representation is not due to the underlying hardware, such as the computation speed or the available memory size, we may ask the question: If the brain can be modeled as a Turing automaton, what could be its program that makes it so efficient? The answer given in this thesis is that 'naive' or natural representation is a certain kind of process. Also other representations of phenomena can be interpreted by the brain as meaningful, but their interpretation can be more troublesome. A conjecture of this thesis is that representations respecting the 'program' of cognitive activity can be more easily processed as knowledge by the human than representations that do not adhere to this program. The results of a recent experimental research by Draskovic, Couwenberg and Sarbo indicate that the above conjecture may be true (Couwenberg, 2007).

1.2 The role of cognitive and semiotic theory

Cognitive theory is concerned with the cognitive processes underlying the acquisition and use of knowledge. Peircean semiotics is a study of signs, and how meaning is constructed and understood.

This thesis is an attempt to introduce a model for knowledge representation respecting some of the important results of cognitive theory. One of them is the concept of qualia. According to cognitive theory we perceive the qualities of the 'real'-world in qualia. Following the theory of Categorical Perception (Harnad, 1987), qualia not only characterize the sensory level, but also the higher levels of information processing by the brain. Although in this thesis the relation with cognitive theory is unilateral, I believe that the uniform representation proposed in this work could also be interesting for cognitive theory, for example, in current research on information integration (Tononi, 2004), (Seith, Izhikevich, Reeke, & Edelman, 2006).

The role of Peircean semiotic theory for explaining our model as a meaningful representation is much more intricate. On the one hand, an embedding of the knowledge representation model in the Peircean semiotics is *not* a prerequisite for the theory of this thesis, however the existence of such an embedding can make the proposed representation more intelligible. As the focus of this thesis is not on the philosophical issues, but on the definition of a theory of knowledge representation, below I briefly summarize the concepts and theories adopted from the Peircean theory.

1.2.1 An overview of Peirce's theory of categories and signs

All phenomena, according to Peirce, are marked by three aspects which he, significantly, called *firstness*, *secondness* and *thirdness*, respectively (Peirce, 1931). Because whatever appears requires a certain shock or contrast, it may be said that the appearance itself, *i.e.*, the event of appearing requires two elements which by themselves must be said to be mere 'possibles'. Thus the appearance of red undoubtedly requires 'red' though this red does not *really* appear unless it is perceived. Thus the firstness of pure red appears only in the event of the perception consisting in the 'meeting' of the observer and the observed. And thus, the appearance itself, the event of appearing, constitutes the aspect of secondness. But the appearance itself, as it is the merely brute fact of meeting, appears only as it reveals itself as this particular perception, for instance in the perception of this color red. Thus, in order to appear as the perception of red, perception as an agent must do so according to the rule that applies when this sort of event occurs. It is the latter aspect of the appearance that constitutes thirdness which tells us in what respect the appearance as event reveals the 'possible' elements of thirdness.

We may know about phenomena through the mediation of signs. Peirce defines a *sign* as anything that stands for something else. That for which a sign stands, he calls the sign's *object*. But that is only part of the story. Equally important is that a sign always stands for something in some respect. Every sign must therefore have an element which tells us in what respect the sign stands for its object. For instance, it is usually acknowledged that smoke stands for fire. For a person lost in the wilderness, smoke may stand for fire in the sense that it indicates that people may be living there. But it may also indicate some danger.

The element of a sign in virtue of which a sign stands for its object is what Peirce calls an *interpretant*. Sign, object and interpretant (each of which can be a sign, recursively) form an irreducible relation, called the *triadic relation of sign*. According to Peirce, cognition without signs is unthinkable and, inasmuch as it represents what is known, it is a sign itself. The triadic relation of signs, or simply, (triadic) signs arise through authentic semiosis.

The complexity of the notion of a sign is due to its inherent ambiguity. To Peirce, the interpretant is an integral part of the sign in the sense that the interpretant together with the representamen (potential sign) and its object constitutes what is properly called a Sign. Thus, we could make a distinction between a Sign and a sign. The term 'Sign' stands for the triadic structure of sign, object and interpretant, while the term 'sign' stands for whatever it is that stands in place of its object. Thus, in the case of the smoke, the Sign is constituted by the smoke-signifying-fire-as-danger, while the sign is simply the smoke.

1.2.2 A classification of signs

Besides his definition of signs, Peirce introduced an ingenious classification of signs as aspects of meaning that surface if we are analyzing meaningful signs (Liszka, 1996), (A. Breemen & Sarbo, 2007). He introduced three signs: icon, index and symbol, which represent their object on the basis of *likeness*, *connection* and *convention*, respectively. Besides this taxonomy, Peirce also distinguished signs according to the categorical status of the sign and according to the relationship between object and interpretant. From a categorical perspective signs can be qualisigns, sinsigns or legisigns, which correspond to firstness, secondness and thirdness, respectively. In other words, a sign can be a *quality*, an *actual event*, or a *rule*. Seen from the perspective of the relationship between sign and interpretant, a sign may be a rheme, a dicent or an argument. In other words a sign may signify a *qualitative possibility*, a proposition of an *actual existence*, or a *proposition* in a process of thought. Thus we obtain nine kinds of signs as meaning aspects which may be arranged in a matrix, as shown in fig. 1.1 and

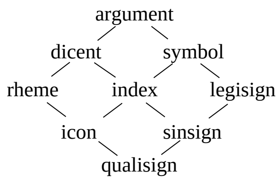

Figure 1.1: Peirce's nonadic classification of signs

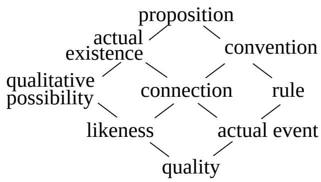

Figure 1.2: Peirce's classification of signs as meaning aspects

fig. 1.2. Although Peirce defined more complex systems of signs, we hold that his 'simple' classification is the most practical.

Following an example presented in (Sowa, 1999), Peirce's nonadic classification may be illustrated with the meaning aspects of a ringing telephone.

The representation of the sudden appearance of the ringing sound of the telephone as a quality, independent of its source, is a qualisign (quality). The representation of the simultaneity included in the appearance of the ringing sound and the telephone, is a sinsign (actual event). The representation of the habit that a ringing telephone means that someone is trying to call somebody else is a legisign (rule).

The representation of the similarity of this phenomenon to a certain shape and sound is an icon sign (likeness). The interpretation of that shape and sound as a pointer connecting the ringing telephone with its known properties is an index sign (connection). The interpretation of the ringing sound of the telephone as a telephone call is a symbol sign (convention).

A telephone as an abstract concept representing a range of possible interpretations is a rheme sign (qualitative possibility). The expression of one of the possible interpretations as an actually existent entity, for example, "this telephone", or "this ringing sound", is a dicent sign (actual existence). The representation of the actual situation as a proposition which is a premise in a process of reasoning, is an argument sign, e.g. "the telephone is ringing" (proposition).

The nine types of distinctions as well as their definition as a hierarchy play an important role in this thesis. Roughly, it will be suggested that Peirce's nonadic classification can be interpreted as a process 'generating' meaning aspects. In the rest of this thesis some familiarity with Peircean semiotics will be assumed. An introduction in his theory of signs can be found in (Tejera, 1988), amongst others.

1.2.3 Sign aspects and interpretation moments

According to Peirce, triadic signs exhibit each one of the sign types according to a rule (Liszka, 1996). Although in past research by (Farkas & Sarbo, 2000) it has always been assumed that the signs of Peirce's nonadic classification only function as parameters of (full) meaning, no attention has been paid to a proper embedding of the knowledge representation model in the Peircean theory. It took a long time to understand the consequences of the process view of sign interpretation (Sarbo, 2006) and to offer a Peircean justification of the theory (A. Breemen & Sarbo, 2007), that I briefly recapitulate below.

Peirce nonadic signs correspond to the kinds of distinctions that can be cognitively made. According to van Breemen and Sarbo (A. Breemen & Sarbo, 2007), those distinctions must also characterize the different interpretants that may exist. In the paper, the existence of a close relationship between Peirce's signs and interpretants is proposed. According to the authors, some of the interpretants correspond to interpretation moments representing the properties of the representamen (potential sign), others to interpretation moments expressing the properties of the relation between the representamen and the interpreting system. The important conclusion of their research is that the process view of interpretation, also adopted by this thesis, is compatible with the Peircean theory of signs.

Motivated by the results presented in (A. Breemen & Sarbo, 2007) and also in (A. Breemen, Sarbo, & Weide, 2007), in the rest of this thesis I will use the Peircean sign aspects as references to the various interpretation moments of the process model introduced. But this is all that is assumed. The results of this thesis are not depending on the results of the semiotic embedding.

An advantage of the Peircean terminology is due to its unconventional character that cannot be confused with the names introduced by traditional knowledge representation theories. Let me emphasize that throughout this thesis the Peircean nonadic signs will only be used as meaning aspects or parameters of (full) meaning. In order to prevent any confusion in this matter, I will use footnotes in the different chapters, to remind the reader of the restricted use of the Peircean concepts in this work.

1.3 Traditional knowledge representation

I cannot delve into a new model of knowledge representation without at least briefly recapitulating some of the merits and limitations of traditional knowledge modeling. A complete overview is beyond the goal of this thesis, however.

In the broad sense, knowledge representation theory includes all languages devoted to the representation of information on the Web, for example, the Semantic Web (T. Berners-Lee & Lassila, 2001), such as XML, RDF, and OWL, but also for the representation of common sense knowledge, for example, the CYC system (Lenat & Guha, 1989), as well as the many different formalisms for capturing linguistic meaning, such as Cognitive Grammar (Langacker, 1987), but this list is far from complete (Csapó, 1992). Traditional approaches can be commonly characterized by the absence of a property, being really based on a model of cognitive activity.

Although traditional knowledge representation is typically relational, its relations are basically meaningful only in the formal mathematical sense. Such relations can be favorably used for proving formal properties, such as the formal correctness of a representation, they can be less adequate in establishing a link between formal and 'real' world concepts.

Relational knowledge representation can be characterized by two extremes. The first one, which is capitalizing on a single type of relation, can be illustrated by the theory of Formal Concept Analysis (FCA), introduced by Rudolf Wille (Wille, 1982), (Wille, 1996). An advantage of FCA theory is that its world ontology is very close to the one taken by this research. According to this theory, the world consists of objects (O), attributes (A), and relations ($R \subseteq O \times A$). Formally, the knowledge representation by FCA theory can be defined as a Galois connection between the powersets of objects and attributes (Birkhoff & Bartee, 1970). The practical value of this framework is due to its potential for a closure, enabling the derivation of all information transitively related to the objects or attributes. FCA theory can also be applied to embedded relations, recursively, thereby enabling information structuring (Sarbo, 1996).

The other extreme, characterized by formalisms based on or using predicate calculus, such as Prolog, or Conceptual Graphs (Sowa, 1984), allow any number of types of relations. That the abundance of the types of relations may not be a solution for the problems of knowledge representation is witnessed by the inherently high complexity of such models. The goal of this thesis is an attempt to show that on the basis of an analysis of the properties of cognitive activity a process model can be defined, from which, a finite set of types of relations can be derived, enabling adequate and efficient representation of knowledge.

Knowledge representation is also closely related to natural language processing (NLP). A comparison of traditional approaches of NLP, such as dependency based formalisms as well as X-bar theory, with the theory proposed in this thesis is postponed until section 5.3.

1.4 The structure of this thesis

The focus of Part I is on the definition of a model for knowledge representation. This includes a study of the duality involved in phenomena, and an analysis of the consequences of duality for signification. On the basis of that analysis, a schema for cognitive processing of phenomena as signs is introduced. In conformity with the assumption of this thesis about the interactions included in phenomena, and the use of memory information involved in the recognition of phenomena, two instances of the processing schema are defined, that are called perception and cognition.

Part II is devoted to the application of the proposed model of knowledge representation. In this part I attempt to show that the theory of this work can be successfully applied to natural language, as a knowledge representation. To this end I introduce a model for (morpho-)syntactic symbols and illustrate its potential by the analysis of some morpho-syntactic and syntactic utterances taken from actual language use.

In Part III, the focus of the theory is extended, by including other knowledge domains, such as the domains of 'naive' semantic syntactic, reasoning, and mathematical signs. The models of the various knowledge domains are used for the introduction of a technique for meaningful text summarization. As knowledge representation itself appears in our experience as a phenomenon, in the summarizing final chapter I discuss the possibility of the application of the theory to itself, recursively.

Part I

Process model

This part is an attempt to introduce a model of knowledge representation on the basis of an analysis of the properties of cognitive activity and signification. It will be suggested that this representation can be uniformly used for modeling the different stages of cognitive activity, and that the interpretation moments introduced by the model show strong affinity with the distinctions identified by Peirce in his semiotic theory (Peirce, 1931). In addition, a logical account of the representation is given, and a cognitive mechanism potentially underlying the proposed model is discussed.

Chapter 2

A world of signs

The intimate relationship between knowledge and signification suggested in the Introduction is further developed by identifying an inherent property of phenomena and analyzing its consequences for an ontological definition of signs. The result of this chapter is a definition of a process model of cognitive activity.

2.1 The nature of observation

As explained in the Introduction, in this thesis it is assumed that the world consists of phenomena and that knowledge emerges from the observation of such phenomena. The Webster Dictionary defines the term 'phenomenon' as an "appearance, or immediate object of awareness in experience". Earlier it has been pointed out that an observation always involves an *interaction* between two entities, the phenomenon *observed*, and the *observer*. Because both entities are part of the 'real' world (i.e. nature), it follows that knowledge must emerge from interactions between phenomena. In addition, it was maintained that knowledge arises from interpretation by the observer. An interpretation, which is an *event*, may vary from direct responses, such as a *brute reaction*, to complex answers, involving reasoning. This broad understanding of interpretative acts is maintained in this chapter only. In the rest of the thesis, knowledge will be assumed to arise from interpretation by means of reasoning. Inasmuch as interactions are inherently related to *change*, and are the stuff of our experience, it follows that interaction and change must exist. Moreover, because nature may be defined as the set of interactions, nature must be inherently *dynamic*.

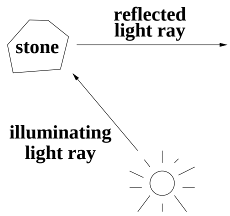

Figure 2.1: A sample interaction

In summary, it is assumed that knowledge emerges ultimately from interactions which reveal themselves as events in our experience of change. The condition for change is what shall be called *duality*, for no change can occur unless there are two independent qualities. For the sake of clarity, a distinction is made between interactions, change, and events. Though these three concepts are intimately related, the first, *interaction*, refers to what is assumed to occur, independently from any experience, the second, *change* refers to the duality of what is involved in an interaction, and the third, *event*, refers to the interaction and change as experienced, that is, to a phenomenon. Because interaction requires duality, and events require interaction, the three concepts are related to each other by a relation of subservience. Though the concept of *event* is the most complex, *duality* is the more fundamental.

2.1.1 Sample phenomena

The concept of duality may be illustrated by the interaction between a stone and an illuminating light ray that it reflects (see fig. 2.1). Due to its light reflecting properties, the stone changes the illuminating light ray by modulating its properties (as the properties of the stone are changed by the light ray – but that aspect shall be left out of consideration). That change may appear as a sign of the interaction between stone and light ray, if it is interpreted as such.

Because the reflected light ray may signify the interaction between stone and light ray (which we may know from experience), one is interested in the conditions for signification. In the current example, the interaction is occurring between two entities, the stone and the illuminating light, which are *qualities*, that is, primary entities of experience. Because the two qualities of our example are in principle *independent*, an adequate signification of their interaction requires a quality capable of representing them both. This thesis maintains that 'light' is such a quality. Indeed, any light phenomenon can be uniquely characterized by two independent qualities: frequency and intensity.[1] Therefore 'light' may function as a constituent (illuminating light ray), in interaction with the stone, but also as a duality (reflected light ray), when it is interpreted as a sign of its interaction with the stone. From this it follows that each one of interaction, change, and event is a duality, but which may also appear as a single entity.

A completely different illustration of a duality, in language syntax, is the noun phrase (a syntactic phenomenon): nice girls. As a single entity, this phrase is a representation of a syntactically meaningful concept (the syntactic modification of a noun by an adjective), defined by the interaction between the independent symbols, nice and girls, as syntactic qualities.

An interaction may only occur if the dual qualities (the constituents of the interaction) are compatible. The stone and the light ray, in the above thought experiment, are compatible for an interaction, as the stone possesses the quality of reflectancy (of light), and the light ray has the potential that it can be subject to reflection (by a stone). The compatibility involved in all interaction implies that the constituent qualities must have some shared *common* property.

For example, in the interaction between the stone and the light ray, both constituents can be interpreted as wave-type phenomena,[2] and their frequency and intensity qualities can be conceptually used for the definition of the properties of the arising new phenomenon, the reflected light. By assuming that the stone is affecting the light, the reflected light may be interpreted as a modulation of the illuminating light by the stone. Similarly, girls and nice are compatible for an interaction, as girls may be interpreted as a noun having the potential to be modified by an adjective, and nice as such a syntactic entity. The interaction between the two symbols as constituent qualities may 'generate' a new phenomenon: nice girls, representing girls (following the interaction) as a 'modulation' of girls[3] (preceding the interaction), due to nice.

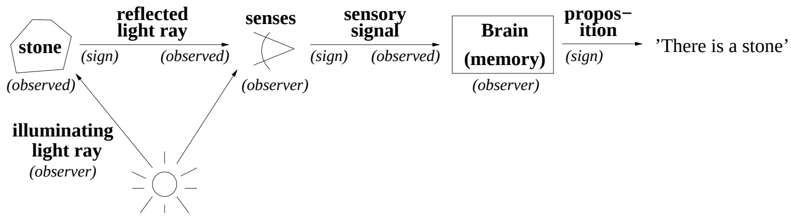

Figure 2.2: A sample sequence of interactions

2.1.2 Interactions

What makes the above example of stone and light interesting, is the fact that the reflected light ray, which is a sign, may become an observed phenomenon, as a quality, in the subsequent interaction with the eyes (the receptors of the retina). This interaction, which is represented from the point of view of the light (observer), is illustrated in fig. 2.2. The eyes (observer) generate a sensory signal capable of representing the interaction between the reflected light ray and the eyes, and transitively so, between the stone and the illuminating light ray. That signal, as an observed phenomenon, may then interact with the brain (observer) which, by comparing the sensory signal with memory information about the stimulus (cf. background light ray), may eventually generate the meaning of the observation in the proposition: 'There is a stone'.

As part of the observation of the reflected light ray, the eyes may compare the two light qualities, by making use of information about the properties of the background light obtained in a previous observation. As a result, the sensory signal of the eyes may represent the reflected light ray as a modulation of the background light ray. That modulation can be recognized by the brain, as a modulation of light due to an appearing stone or, briefly, as a stone.

The successive interaction and interpretation of qualities defines a *recognition process*, representing the observed input phenomenon as meaningful. This chapter is an attempt to introduce such a process model for cognitive activity. In addition, a logical analysis is offered to the model (in the next chapter),

[1]Which value of frequency and intensity may represent a certain phenomenon is not the issue here.

[2]The stone through its reflectancy.

[3]The combinatory potential of nice (as well as of girls) is satisfied. The consequences of the sequential character of language on the interpretation of language phenomena will be discussed later, in chapter 5.

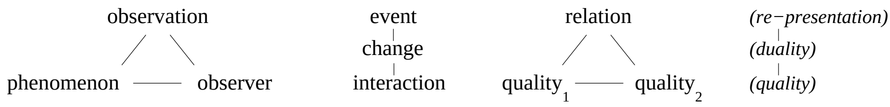

Figure 2.3: An overview of the introduced concepts. A horizontal line denotes an interaction, a diagonal one a representation, a vertical one a subservience relation. This convention will be used also in later diagrams.

in order to reveal the close relationship between the cognitive processual and logical concepts.

2.1.3 The concept of *re*-presentation

An interaction between dual qualities that are signs, will be called a *sign interaction*. The existence of an interaction is clearly a pre-requisite for its recognition as a sign. But a quality functions as a sign, and therefore is a sign, *if and only if* it is interpreted as such. Hence, the interpretation of a quality as well as of an interaction of qualities, as a sign, is the other condition for sign recognition, as a process.

Any event involves a duality between an observed phenomenon and an observer. When a phenomenon interacts with the observer, the representation by the observer of the event presented by nature is itself an event. The first event may be called nature's interpretation, the second the observer's. For example, the reflected light ray is nature's presentation of the stone-and-light-ray interaction (first event), the eyes are the observer and the sensory signal generated by the eyes functions as the observer's interpretation (second event).

Although the observed phenomenon as well as the observer are independent, and the event representing the (observed) phenomenon is 'conceived' by the observer, that conception is at least partly forced upon the observer by the interaction. Such an event representation of an interaction will be called an *observation* or actual meaning. Because the qualities of the two events must be related to each other by virtue of the interaction, it can be concluded that the observer is *re-presenting* the observed phenomenon. The concepts introduced so far are collected in fig. 2.3.

Fig. 2.1 contains sample types of dualities in 'natural' phenomena. Dilution and solubility refer to the independent qualities of the diluted substance, on the one hand, and the liquid, in which the substance is dissolved, on the other. Not all pairs of qualities can be interpreted as a duality. For example, the two

phenomenon	carrier	dual modulation
wave type	continuous stream	frequency–intensity
mechanical	energy	distribution–intensity
chemical	chemical bond	dilution–solubility
(sign)	(information)	(form–content)

Table 2.1: Sample dualities of natural phenomena

types of distribution of energy, potential and kinetic, are not independent, and therefore not dual. The examples of table. 2.1 are illustrations of types of phenomena, interpreted as signs. This relation is expressed by the parenthesized terms in the last line. The carrier of any phenomenon which is a sign, is information, carrying form and content as independent qualities. According to this view, which is in conformity with our earlier assumption, information is *potential* knowledge.

2.2 Towards a model of re-presentation

The duality involved in all signs, which is a fundamental assumption of the theory presented here, forms the basis for our model of cognitive activity as a process. The input of cognitive processing is the stimulus, which is recognized by the brain. An inherent property of all systems, including biological ones, is their potential for generating an answer (*re-action*) to the stimulus (*action*). For example, if we observe smoke, as a stimulus, then running away might be our reaction, interpreting smoke as a sign of danger. The 'goal' of cognitive processing is the generation of an *adequate* reaction to the stimulus, as an external effect. An important element of response generation is the *interaction* between the external effect, on the one hand, and the interpreting system, on the other. Interactions in the world are dynamic and since knowledge is assumed to be a *re*-presentation of these interactions, knowledge too must be inherently dynamic.

The external *effect* (stimulus) is affecting the recognizing system, appearing as a *state*. As any 'real' world entity (quality) can be an effect or a state, all phenomena can be considered as an interaction between independent qualities. It should be emphasized that there may be an infinite number of qualities involved in an interaction, but, according to the theory of this thesis, those qualities are always distinguished by cognition in two collections (state and effect) and, consequently, are treated as single entities.[4]

2.3 Processing schema

Phenomena are interactions appearing via the *mediation* of change, as an event (cf. reaction). Following the received view of cognitive theory (Harnad, 1987), the re-presentation of phenomena by cognition may be modeled as follows.

By virtue of the change caused by an appearing stimulus, the input qualities are sampled by the senses in a percept (Solso, 1988). 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 (in short, *input*): 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'[5] (Sarbo, Farkas, & Breemen, 2006). In cognitive theory, qualities as perceived are called *qualia*[6] (Stillings, 1998).

The change, signifying an interaction in the 'real' world, may be explained as follows. During input processing the stimulus may change, meaning that its current value and the value stored in the last percept are different. That difference may be interpreted by the brain, as a change, mediating the present value of the stimulus to its actual meaning. The reaction of an interpreting system is determined by the system's 'knowledge' of the properties of the external stimulus, and its experience with the results of earlier response strategies (habit). Such knowledge is an expression of the system's potential for interpreting, i.e. *combining* with, a type of input effect, depending on the system's state. Such properties shall be called the 'combinatory' properties of the input qualia, or the (complementary) *context* of the observation.

In complex biological systems, knowledge is concentrated in functional units such as the sensory, central, and motor sub-systems. The most important of these is the central system, which includes memory. The 'translation' from external stimuli to internal representation (qualia) is brought about by the sensory sub-system, which itself is an interpreting system, generating 'brute reactions' (translations). For the goals of this thesis, the role of the motor sub-system is ignored. The primary task of cognitive processing is the interpretation of the

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

[5]The importance of similarity (comparison) is also emphasized by (Goldstone & Barsalou, 1998).

[6]Qualia is plural for quale.

external stimuli, by making use of their combinatory properties. Since the input is assumed to consist of two types of qualia (state and effect), together appearing as a ‘primordial soup’ ($[\mathsf{q}_1\ \mathsf{q}_2]$), the stages of recognition may be defined as follows (see also fig. 2.4).

(1) the identification of the two types of qualia in the ‘primordial soup’.
sorting: $[\mathsf{q}_1]$, $[\mathsf{q}_2]$
(2) the separation of the collections of the two types of qualia.
abstraction: q_1, q_2
(3) the linking of the qualia with their combinatory properties ($[\mathsf{C}]$).
complementation: $(\mathsf{q}_1,\mathsf{C})$, $(\mathsf{q}_2,\mathsf{C})$
(4) the establishment of a relation between the completed qualia.
predication: $(\mathsf{q}_1,\mathsf{C})$–$(\mathsf{q}_2,\mathsf{C})$

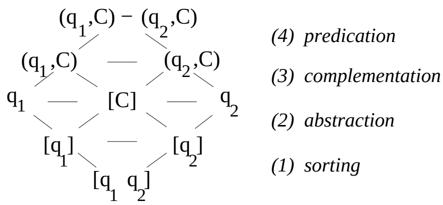

Figure 2.4: The schematic diagram of cognitive processing. Square brackets are used to indicate that an entity is not yet interpreted as a sign; no bracketing or the usual bracket symbols indicate that some interpretation is already available. A horizontal line denotes an interaction between neighboring entities.

Each of the above operations can be realized by means of an interaction between neighboring entities (such entities are connected by a horizontal line, in fig. 2.4). The only non-trivial operation is *abstration*, in which the abstract representations of the input qualia, q_1 and q_2, are generated by means of separating the qualia represented by $[\mathsf{q}_1]$ (the input state qualia, in the context of all other input qualia), from those represented by $[\mathsf{q}_2]$ (the input effect qualia, in the context of all other input qualia).

The entire input or the ‘universe of discourse’ of cognitive processing consists of the qualia of the input stimulus ($[\mathsf{q}_1\ \mathsf{q}_2]$), and the combinatory properties defined by the corresponding activation of the memory or the context ($[\mathsf{C}]$). This is illustrated in fig. 2.5. Because the context can be large, a specification of its qualia can be omitted in the input. It is tacitly assumed that $[\mathsf{q}_1\ \mathsf{q}_2]$ is

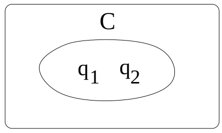

Figure 2.5: The entire input or the 'universe of discourse' of cognitive processing

actually standing for [q_1 q_2 C] and, that the *sorting* operation generates three different representations of the input: [q_1], [q_2], and [C]. Put differently, the input is assumed to contain *all* information necessary for its recognition as a sign.

2.3.1 Events and processes

The importance of processes demands that an earlier definition of this concept, given in the Introduction, is briefly recapitulated. A process will be considered to be any sequence of events such, that (i) one event initiates the sequence and another terminates it, (ii) every event that contributes to the sequences yielding the terminating event is regarded as part of the process and (iii) the terminating event governs the decision of which events make up the sequence. Although the events making up the sequence generate the terminating event (efficient causation), the whole process is governed by its goal (teleological causation). An event will be considered as whatever makes a difference ((Debrock et al., 1999)).

The above model of cognitive processing is compatible with the assumption laid down by the Peircean theory of perceptual judgments that the 'real' world is forced upon us in percepts (CP 2.142),[7] from which perceptual judgments are obtained through interpretation (CP 5.54), by means of a process which is utterly beyond our control (CP 5.115).

The interaction between the 'real' world phenomenon and the interpreting system, and the perceptual judgment correspond to the two events of (i); the events generated by the recognition process, to the events of (ii); and the teleological character of that process, to the governing property mentioned in (iii). The dynamic nature of phenomena is re-presented by the processual character of the model of cognitive activity. The interaction included in a 'real' world phenomenon is re-presented by a sequence of interactions, by the interpreting system.

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

Chapter 3

Perception and cognition

Adequate representation of the input stimulus requires that the two types of input qualia (state and effect) are recognized in themselves, as well as in relation to each other. This is acknowledged in the proposed model, by introducing two stages of cognitive activity, that are called perception and cognition.[1] It will be suggested that although those stages are different, their models may be defined as isomorphic instances of the processing schema introduced in the previous chapter. This part is followed by a logical analysis of the processing schema, proving the completeness of the model of cognitive activity, from the logical point of view.

3.1 Perception

According to this thesis, cognitive activity may be modeled by means of two processes that are isomorphic instances of the processing schema. The 'goal' of the first process, *perception*, is the establishment of a relation between the input qualia and the information stored in the memory (the relation between the input qualia is of secondary importance in this process). As a result, perception obtains an interpretation of the qualia in *themselves*. In accordance with perception's goal, the memory response, defining the context ([C]), contains 'iconic' information about the combinatory properties of the input qualia, independently from their actual relations. In the proposed model, the state and effect type qualia of the input are indicated by a and b, respectively; those of

[1] Cognition alternatively could be called *conception* [Van Breemen, pers. comm. 2006].

the memory by a' and b'. All four signs may refer to a type as well as to a collection of qualia.

Among the representations obtained by perception, only step 4, the final one is of interest for this section (a complete definition of all events of the perception process will be given in chapter 4). Following the assumption of this thesis, the $a'(b')$ memory response signs arise by means of the $a(b)$ input qualia, which trigger memory. Although 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 input qualia, and the assumption that the memory information stored by the brain arises from earlier observations, through memorization.

Depending on the actual activation of the memory, defining the state of the brain/mind as an interpreting system, there may be qualia in the memory response having an intensity: above (i) or below (ii) threshold, referring to an input meaning which is in the brain's *focus*, and which is only *complementary*, respectively. A high intensity type (i) memory response signifies the recognition of the input as an *agreement* 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* only: the input $a(b)$ is not recognized or 'not known' as $a'(b')$. In this case, the memory response only represents 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, to a *denial* of a positive identification).

In the model of perception, as a process, the four signs are represented as a single sign. The recognition of the difference between the four types of intensity relations is beyond the scope of this process (the ',' symbol separating the four types of signs above, is an expression of their synonymous interpretation, as the final signs of perception; it is *this* perspective that makes them synonymous). A schematic diagram of our model of perception is depicted in fig. 3.1.

3.2 Cognition

The second process, *cognition*, is an exact copy of the first one, perception, except that the 'goal' of cognition is the interpretation of the relation between

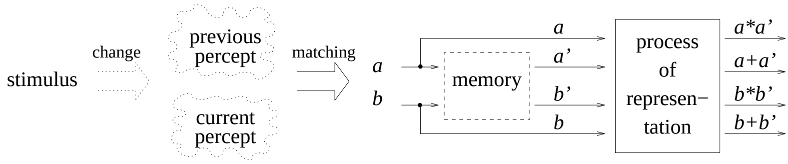

Figure 3.1: A schematic diagram of the model of perception. Triggered by a change, the current value of the input stimulus is sampled. The current percept is compared with the previous percept, which results in two types of input signs (a, b). The relation between these signs and the corresponding memory signs (a', b') is represented, on the basis of the intensity of the memory response, by the expressions: $a*a$', $a+a$', $b*b$', $b+b$'.

the input qualia, more specifically, the relation between the qualia that are in the 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 and the context that is of secondary importance). In accordance with cognition's 'goal', the context ([C]) contains 'indexical' information about the complementary properties of the input qualia. This means that by combining the input of the cognition process with the information of the context, the relation between A and B (and, transitively so, the relation between a and b) may be disclosed.

Similarly to perception, as a process, the input appears as a 'primordial soup', this time defined by the synonymous signs of perception. In fact, the difference between the four meaning elements ($a*a$', $a+a$', $b*b$', $b+b$') functions as a ground for the process of cognition. This is acknowledged in this 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 the 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. 3.2 (the input also contains the signs that are not in the focus ($\neg A$, $\neg B$); these are omitted in the input position, in this diagram).

The important interpretation moment is step 3 now (complementation), in which the link between input qualia and the context is established, in accordance with cognition's 'goal' as well as 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

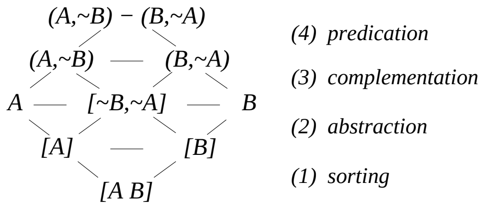

Figure 3.2: A schematic diagram of cognition as a process. The input signs appearing as a 'primordial soup' ($[A\ B]$) are sorted ($[A]$, $[B]$), abstracted (A, B), complemented by the context ((A,$\neg B$), ($\neg A$,B)) and, finally, combined in a single sign ((A,$\neg B$)–($\neg A$,B)) by means of predication (negation ('$\neg$') is denoted by a '$\sim$' symbol).

relation between A and $\neg A$, or B and $\neg B$.[2] The cognition process is completed in step 4 (predication), by establishing the relation between A and B.

There are three relations, that correspond to the three types of interactions between the input qualia, that may be characterized by means of the meaning of their constituents (from the computational point of view, these interactions are relations that are indicated by a '–' symbol):[3]

(1) A–$\neg B$: A is 'known', but B is 'not known';
the complementation of the input state ('actualization').
(2) B–$\neg A$: B is 'known', but A is 'not known';
the complementation of the input effect ('refinement').
(3) (A,$\neg B$)–(B,$\neg A$): both A and B are 'known';
the establishment of a relation between A and B ('proposition').

If neither A nor B is 'known', interpretation terminates, meaning that cognition as a process does not actually occur (the process did not reach its goal). The reader may have noticed the mediational function of the context signs in step 3. Through the correspondence between $\neg A$ and $\neg B$, that are triggered by the same input, the context *implicitly* determines the actual relation between A and B. That relation can be called a 'proposition' resulting from a hypothetical inference, but only if we acknowledge, in accordance with the Peircean view of

[2] A and $\neg A$ (but also B and $\neg B$) arise due to the same input trigger, indicating that the two signs are *not* independent.

[3] The three types of interactions are also called a 1st, a 2nd, and a 3rd of meaningful representation (cf. sect. 6.3.1).

perceptual judgment, that the percept's "truth consists in the fact that it is impossible to correct it, and in the fact that it only professes one aspect of the percept" (CP 5.568).

3.3 Logical analysis

The interpretation of cognition above illustrates, to some extent, the completeness of this process. This becomes even more clear from the logical analysis of the underlying processing schema. In this section an attempt is made 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. First, a logical expression is associated to each interpretation moment, on the basis of common logical aspects. Second, operations are introduced generating those expressions according to a procedure. Third, derivations are presented, indicating that those expressions could be generated by a Boolean logic. 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. In this section, the term 'logical' is used as a reference to an aspect of an event or an expression, not to a formally defined concept. The operations mentioned above are only defined for the expressions associated to the interpretation moments of the processing schema. Their specification as a rewriting system is beyond the goal of this work.

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*. In virtue of the duality of the input, the logical interpretation of cognition, as a process, requires the introduction of two variables. These will be denoted by A and B. The difference between the qualia that are in the focus and those that are complementary, is represented by the difference in their expression. Each one 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 the focus are indicated by A and B, respectively; those which are complementary by $\neg A$ and $\neg B$. Notice the use of '$\neg$' as a complementation operation on collections. 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 and '$*$' for agreement), are inherited by the process model of cognition and its interpretation as operations on expressions.

The logical meanings of the expressions below are due to the meaning of a logical 'or' involved in the possibility meaning of '+', and the meaning of a logical 'and' in the agreement meaning of '$*$'.

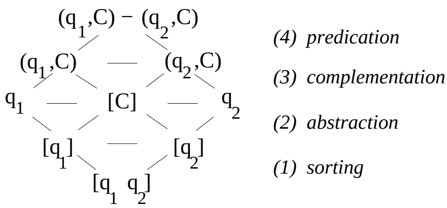

Figure 3.3: The schematic diagram of cognitive processing (recap.)

Conform the above mapping of state and effect qualia to logical variables, the logical expressions associated to the events of the cognitive process may be defined in the following way (the interpretation moments of cognitive processing are recapitulated in fig. 3.3).

$[\mathsf{q}_1]{=}A{+}B$, $[\mathsf{q}_2]{=}A{*}B$: the expression of the simultaneous presence of the input qualia which are in the focus, respectively, as a simple, possible co-existence ($A{+}B$); and in the sense of agreement, as a meaningful co-occurrence ($A{*}B$). 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, we may only observe a state by virtue of an effect, but the occurrence of an effect 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 '$*$'.

$\mathsf{q}_1{=}A{*}\neg B$, $\neg A{*}B$: 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 (notice the use of ',' in the definition of q_1 directly above, as a representation of this equivalence).

$\mathsf{q}_2{=}A{*}\neg B{+}\neg A{*}B$: the expression of the input as an abstract co-occurrence event, logically represented by a compatibility relation of the two types of abstract constituents of the input (which are now interpreted differently).

$[\mathsf{C}]{=}\neg A{+}\neg B$, $\neg A{*}\neg B$: the expression of the context as a co-existence ($\neg A{+}\neg B$) and as a co-occurrence relation ($\neg A{*}\neg B$) of the complementary input 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 $\neg B$, comprising the context.

$(\mathsf{q}_1,\mathsf{C})=A+\neg B$, $\neg A+B$: the expression of the abstract constituents (q_1) 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 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 $(\mathsf{q}_1,\mathsf{C})$ can be represented by $A+\neg B$. For the same reason, as in q_1, the two expressions of $(\mathsf{q}_1,\mathsf{C})$ are interpreted in the model, as synonymous.

$(\mathsf{q}_2,\mathsf{C})=A{*}B+\neg A{*}\neg B$: the expression of the abstract compatibility relation in context. This obtains the sign of the input 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 the 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 the focus, respectively, positively and negatively. Alternatively, in the definition of $(\mathsf{q}_1,\mathsf{C})$ and $(\mathsf{q}_2,\mathsf{C})$ above, the complementary qualia are used to sort out those meanings from the possible meanings of the abstract signs, q_1 and q_2, 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_1 are represented by themselves (A (B)),[4] and by their context ($\neg B$ ($\neg A$)); and, similarly, effect qualia occurring in q_2 are represented by themselves, ($A{*}B$)[5] and by their context ($\neg A{*}\neg B$).

$(\mathsf{q}_1,\mathsf{C})$–$(\mathsf{q}_2,\mathsf{C})=A$ *is* B: the expression of the relation between the input qualia which are in the focus, represented as a proposition.

The logical expressions assigned to the interpretation moments are presented

[4]Input qualia are commonly represented as variables.

[5]As the occurrence of an effect entails the existence of a state, it is $A{*}B$ that is representing the simultaneity included in the meaning of the input interaction.

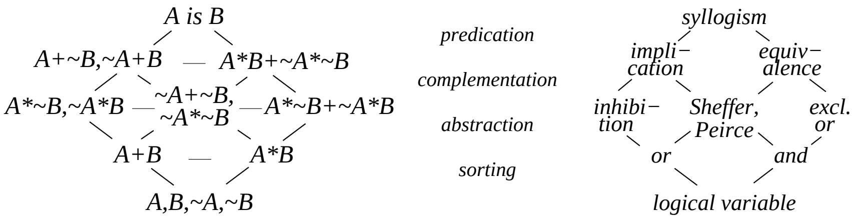

Figure 3.4: The logical expressions of cognitive processing (on the left) and the corresponding Boolean relations (on the right). Negation ('¬') is denoted by a '∼' symbol.

in fig. 3.4, on the left-hand side; the corresponding Boolean relations are displayed on the right-hand side of the same diagram. The logical signs, '0' and '1', which are omitted, can be defined as representations of a 'not-valid' and a 'valid' input, respectively. Notice in fig. 3.4 the presence of *all* Boolean relations on two variables,[6] reinforcing the earlier conjecture of this thesis concerning the completeness of the underlying cognitive process. The results of the analysis above show that logical signs (and thereby also the concepts of cognition, as a process) can be defined as a relation (interaction) between *neighboring* signs that is in need of settlement. In fig. 3.4, such signs are connected with a horizontal line.

3.3.1 Towards a Boolean interpretation

Fig. 3.4 can be interpreted as a procedure, generating expressions from other expressions, recursively.

In *sorting*, the expressions $A{+}B$ ($[\mathsf{q}_1]$) and $A{*}B$ ($[\mathsf{q}_2]$) are generated from the initial terms: A, B, $\neg A$, $\neg B$. A formal definition of this operation is trivial, therefore omitted.

In *abstraction*, the expressions of q_1 and q_2 are generated from the expressions of $[\mathsf{q}_1]$ and $[\mathsf{q}_2]$, by means of relative difference operators, "\" and "/". A derivation of the expressions of q_1 and q_2, including a definition of the two operators, is given as follows. For logical variables $X, Y{\in}\{A, B\}$, $X\backslash X$ as well as X/X are defined by the empty term, which can be omitted; $X\backslash Y$ and X/Y

[6] The Boolean relations as functions: $f_0{=}0$, $f_1{=}A{*}B$, $f_2{=}A{*}\neg B$, $f_3{=}A$, $f_4{=}\neg A{*}B$, $f_5{=}B$, $f_6{=}\neg A{*}B{+}A{*}\neg B$, $f_7{=}A{+}B$, $f_8{=}\neg A{*}\neg B$, $f_9{=}A{*}B{+}\neg A{*}\neg B$, $f_{10}{=}\neg B$, $f_{11}{=}A{+}\neg B$, $f_{12}{=}\neg A$, $f_{13}{=}\neg A{+}B$, $f_{14}{=}\neg A{+}\neg B$, $f_{15}{=}1$.

are identically defined by the expression $X{*}\neg Y$.

In the derivation below, the simultaneity meaning included in $[\mathsf{q}_2]$ $(A{*}B)$ is removed from the constituency meaning included in $[\mathsf{q}_1]$ $(A{+}B)$. That this operation can be feasible, is witnessed by the possible interpretations of $A{+}B$ as A, B, and $A{\cdot}B$ (the last term denotes 'both A and B', as a possible co-existence). The resulting expressions are not related to each other by a relation of constituency ('+'), but only by the weaker relation of a synonymous interpretation (from a certain point of view). Such a relation is expressed below by a "," symbol.

$[\mathsf{q}_1]\backslash[\mathsf{q}_2]$
$= (A{+}B)\backslash(A{*}B)$
$= A\backslash(A{*}B),\ B\backslash(A{*}B)$
$= A\backslash A,\ A\backslash B,\ B\backslash A,\ B\backslash B$
$= A\backslash B,\ B\backslash A$
$= A{*}\neg B,\ B{*}\neg A$

By removing the constituency meaning included in $[\mathsf{q}_1]$ $(A{+}B)$, from the simultaneity meaning included in $[\mathsf{q}_2]$ $(A{*}B)$, an expression can be generated, representing a relation between the input qualia, which is less tight than a simultaneity relation, but more close than a simple constituency relation. Such a meaning is included in the final expression below, representing the meaning aspect of an exlusive-or relation.

$[\mathsf{q}_2]/[\mathsf{q}_1]$
$= (A{*}B)/(A{+}B)$
$= (A{*}B)/A{+}(A{*}B)/B$
$= A/A{+}A/B{+}B/A{+}B/B$
$= A{*}\neg B{+}B{*}\neg A$

In *complementation*, the expressions of $(\mathsf{q}_1,\mathsf{C})$ and $(\mathsf{q}_2,\mathsf{C})$ are generated by means of complementation operators applied to the expressions of q_1 and q_2 (in conformity with its complementary character, in these operations the role of $[\mathsf{C}]$ is secondary). The two operators, which are ambiguously denoted by '$\neg$', are defined as an involution, for example, $\neg\neg A{=}\ A$. In the definition of $(\mathsf{q}_1,\mathsf{C})$ below, complementation recursively applies to the state, or the constituent(s) of an expression. For example, the constituents of $A{*}\neg B$ are A, $\neg B$, and the operator '$*$'. The complement of an operator is defined by the dual operator: $\neg(*){=}\ +$, $\neg(+)\ ={*}$.

$\neg\mathsf{q}_1$
$= \neg(A{*}\neg B),\ \neg(\neg A{*}B)$
$= (\neg A)(\neg{*})(\neg\neg B),\ (\neg\neg A)(\neg{*})(\neg B)$
$= \neg A{+}B,\ \ A{+}\neg B$

In the definition of $(\mathsf{q}_2,\mathsf{C})$ below, complementation recursively applies to the effect, or an expression as a whole. As state and effect qualia, which are different, are commonly interpreted as variables, complementation always applies to one of them in an expression, at the same time. This is indicated below, by the expressions given in square parentheses (in the first expression, '$\neg$' has been applied to A and $\neg A$, in $A{*}\neg B{+}\neg A{*}B$; in the second, it has been applied to $\neg B$ and B).

$\neg\mathsf{q}_2$
$= \neg(A{*}\neg B{+}\neg A{*}B))$
$= [\neg(A{*}\neg B){+}\neg(\neg A{*}B)]{+}[\neg(A{*}\neg B){+}\neg(\neg A{*}B)]$
$= (\neg A{*}\neg B){+}(A{*}\neg\neg B){+}(\neg\neg A{*}B){+}\neg A{*}\neg B)$
$= A{*}B{+}\neg A{*}\neg B$

The above interpretation of the processing schema, as a procedure generating logical expressions, is called in this thesis 'naive' logic. As mentioned in sect. 3.3, a definition of 'naive' logical operators, as a rewriting system or, as a Boolean algebra, is not part of this work. However, the possibility for a Boolean interpretation of the processing schema is illustrated below by derivations, indicating a close relationship between the expressions depicted in fig. 3.4, and their interpretation as (isomorphic) Boolean relations.

For example, the term associated to q_2 can be defined by a Boolean relative difference operation between the expressions of $[\mathsf{q}_1]$ and $[\mathsf{q}_2]$, this time interpreted as Boolean relations: $(A{+}B)\backslash(A{*}B){=}\ A{*}\neg B{+}B{*}\neg A$. The expressions associated to $(\mathsf{q}_1,\mathsf{C})$ and $(\mathsf{q}_2,\mathsf{C})$ can be defined by a Boolean negation of the expressions of q_1 and q_2, interpreted as Boolean relations, respectively: $\neg(A{*}\neg B)$, $\neg(\neg A{*}B){=}\ \neg A{+}B,\ A{+}\neg B$; $\neg(A{*}\neg B{+}\neg A{*}B){=}\ A{*}B{+}\neg A{*}\neg B$.

Finally, the expression of $(\mathsf{q}_1,\mathsf{C})$–$(\mathsf{q}_2,\mathsf{C})$ can be formally interpreted as a syllogistic conclusion, defined by the expressions of $(\mathsf{q}_1,\mathsf{C})$ and $(\mathsf{q}_2,\mathsf{C})$, interpreted as premises. In the derivation below Łukasiewicz's conception of a syllogism is used (Dumitriu, 1977), according to which a premise can be equivalently represented as an implication. The major and minor premises are, respectively, $A{*}B{+}\neg A{*}\neg B{=}\ A{+}B{\rightarrow}A{*}B$ and $A{\rightarrow}B{=}\ A{\rightarrow}A{+}B$, 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 synonymously represent the logical meaning of the input, respectively, in the 'active' and 'passive' sense). In the derivation below, quantifiers are omitted.

$$
\begin{array}{lllll}
 & A{+}B & IS & A{*}B & \\
 & A & IS & A{+}B & \\
\Rightarrow & A & IS & A{*}B & ;A{\rightarrow}A{*}B{=}\neg A{+}A{*}B{=}\neg A{+}B{=}A{\rightarrow}B \\
= & A & IS & B &
\end{array}
$$

3.4 Semiotic analogy

That the formal computational and the intuitive interpretation of a sign are tightly related to each other must be clear from the above explanation of the logical relations of cognition. This dependency forms the basis of the semiotic interpretation of the 9 types of relations, which can be explained as follows.

[q_1 q_2]: represents the appearing phenomenon as *qualities*.

[q_1]: represents that the constituents are trivially part of their collection, as a whole. Hence they are similar to it. So, the representation of the input, as a constituency relation, expresses *likeness* with respect to the input, which is represented as 'primordial soup'.

[q_2]: represents that the aspect of *simultaneity* is a primary element of the input, as an appearance (event) that happens now.

q_1: represents that the abstract conception of the input is an expression of its being as a *qualitatively possibility*.

q_2: represents that the compatibility of the abstract meaning of the input qualia is expressive of a *rule*-like relation.

[C]: represents that the relation between the input and the embedding or complementary context has the meaning of a *connection*.

(q_1,C): represents the meaning of the abstract constituents in context. It is a definition of the actual meaning of the input qualia, as something *existent*.

(q_2,C): represents the interpretation of the abstract compatibility relation in context as a characteristic property; it presupposes the existence of a consensus or *convention*.

(q_1,C)–(q_2,C): represents that the assertion of a relation between the input qualia involves the formation of a *proposition* which is a hypothesis.

From this semiotic interpretation of the logical relations, the analogy with the Peircean nonadic sign classification follows trivially.

3.4.1 Categories and signs

Throughout his philosophical career Peirce was occupied with attempts to classify signs in a systematic way. This work has led him believe that there are three basic categories: monadic Firstness (the possible), which appears in consciousness as feeling or the consciousness of quality without recognition or analysis; dyadic Secondness (the actual), which appears as a consciousness of interruption in the field of consciousness or as the brute intrusion of another quality; triadic Thirdness (the lawful), which synthesizes the content of consciousness or the mediation by thought of the different feeling spread out in time (cf. CP 1.377).

In his work on sign classification, Peirce repeatedly applied the three basic categorical distinctions to signs. It starts with the definition of a sign as "... something, A, which denotes some fact or object, B, to some interpretant thought C" (CP 1.346). This definition yields three ways in which signs may be considered. First, a sign may be considered in itself. If we do so, we neglect the relations a sign may have with its object and interpretant and we only regard the sign as a possible sign. Second, we may regard the sign in its relation with its object only and neglect the relation it has with its interpretant. If we do so, we regard the sign as an existing sign, but still without any effect. And third, we may look how the sign addresses its interpretant. If we do so, we regard the sign as a real or effectual sign. In this last case we try to unravel the full meaning or import a sign may have by figuring out how the sign manages to relate the interpretant of the sign with its object. If we concentrate on a sign-interpretant sequence in some concrete situation, we study embedded signs.[7]

Later Peirce applied the categorical distinctions to the sign relations just discerned. The first tenable result, the *nonadic classification*, is summarized at the left hand side of fig. 3.5, the bottom right-diagonal gives the relational aspects pertaining to the sign in itself, the intermediate gives the aspects pertaining to the way the sign may relate to the object, and the top right-diagonal gives the ways in which the sign may address its interpretant. On the right hand side of fig. 3.5 the technical terms that give the meaning aspects are stated in more mundane terms, which are also used in the semiotic interpretation of the nine types of relations above.

It is important to note that in this thesis the relational aspects of the nonadic classification are interpreted as the parameters of (full) meaning. The *isomorphism* between the cognitive process and Peirce's nonadic classification is a

[7]This analysis of Peirce's signs is based on lecture notes by Van Breemen (unpublished manuscript, 2007).

consequence of the isomorphism between the induced order of cognitive processing, on the one hand, and the interdependency of the Peircean signs, based on categorical distinctions, on the other. But this is all there is! The processing schema introduced in this thesis is suited for *computational* interpretation. But, although the above mapping established a link between the Peircean signs and the Boolean relations (see sect. 3.3), hence define a computational level of authentic semiosis, the full meaning of the Peircean signs is *qualitatively* more than such a logical relation.

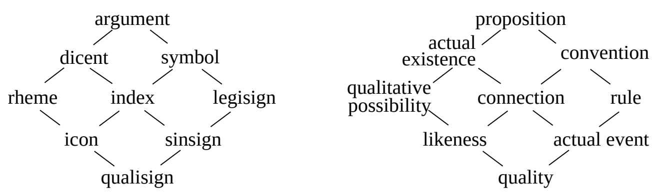

Figure 3.5: Peirce's classification of signs and their mundane aspects

By assuming that the full meaning of a sign emerges, through *embedding* in real life interactions with the world, from the relations 'generated' by cognitive processing, the nine sign aspects can be *hypothetically* considered to be a link between the computational and the semiotic level of meaning. Inasmuch as those aspects are enclosed in a process, which finally results in something that can be characterized as truly meaningful, it is probably best to consider the nine aspects as unfinished 'meaning elements', that is, as *signs* which are in a process of becoming signs (A. van Breemen & Sarbo, 2006). Such signs are called in (Sarbo, 2006), pre- or *proto*-signs.

The different characterizations of knowledge – a combinatory process of qualia (fig. 3.2); a representation of logical relations (fig. 3.4); a hierarchy of increasingly more complex 'meaning elements' (fig. 3.5), but also its other possible interpretations – are interrelated, and it is their collection that approaches full meaning. The conjecture of this thesis is that, if a uniform representation can be proved to exist, this can be the key for an efficient (computational) merging of knowledge obtained in different domains into a single representation.

3.4.2 Process interpretation

On the basis of Peirce's theory of interpretants, a model of semiosis was introduced in (A. Breemen & Sarbo, 2007). This is briefly recapitulated below. The different interpretation events are indicated by labels (i)–(iv).

The representamen (potential sign) enters the interpreting system represented as a Semiotic Sheet[8] (S_s). The effect of the representamen on the S_s, which is occurring in a certain state, is interpreted as a feeling (qualisign).

i) The feeling is sorted out as an icon and settled as a singularity (sinsign).

ii) Since it is a familiar *iconic* singularity, a legisign arises (rule); since it is a *singular* icon out of any context at this moment, a rheme arises.

iii) Assuming there is a strong habit that is connected to the legisign, by means of the connection (index sign), a conventional meaning is retrieved and the sign is interpreted as a request to stop (symbol sign).

iv) This interpretation event is, again through a connection with what is contained in S_s (index sign), placed under a rule of habit that covers this kind of case and a response is generated (argument sign).

The response sign, which is called in (A. Breemen & Sarbo, 2007) the dynamic interpretant response, may enter the S_s as a quality (for example, a premise) and initiate further interpretation. Following this view, the dicent sign exhibits the meaning aspect of a proposition about the relation between the original representamen and the S_s; this is opposed to the argument sign, which exhibits the aspect of a proposition which is a premise in a subsequent interpretation process.

The striking similarity between the process described above and the theory introduced in the previous chapter is beneficially used in this thesis in the presentation of the processing schema as a model of meaningful sign interpretation. Following the Peircean theory of interpretants presented in (A. Breemen & Sarbo, 2007), in the processual interpretation of Peirce's hierarchy of signs (see fig. 3.6), the four interpretation events (i)–(iv) can be mapped to the four sign events: sorting, abstraction, complementation and predication.

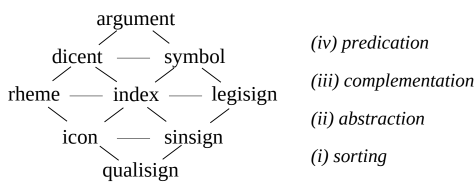

Figure 3.6: The process interpretation of Peirce's classification of signs

[8]The concept of the Semiotic Sheet is introduced by A.J.J. van Breemen.

3.5 Combinatory relations and properties

As earlier mentioned, we may observe an entity, as a state, only by virtue of an appearing effect, but the occurrence of an effect always entails the existence of a state. This asymmetry between state and effect is also the ground for a semiotic interpretation of the differences between the three types of relations recognized by cognitive processing. This can be exemplified for the model of cognition, as a process (see fig. 3.2):

(1) A–$\neg B$: A is a potential meaning, which is actualized by $\neg B$.
(2) B–$\neg A$: B, which is in principle self-sufficient, receives its full meaning from its association with $\neg A$.
(3) (A,$\neg B$)–(B,$\neg A$): A and B, which both are self-sufficient, together generate a new meaning.[9]

These (cognitive) relations can be interpreted as a representation of the three types of a nexus between signs, which in turn correspond to the three Peircean categories. An example of the three types of relations in language syntax are a syntactic modification of a noun (e.g. by an adjective), a syntactic complementation of a verb (e.g. by a verb-complement), and a syntactic predication (subject and predicate forming a sentence), respectively. The important consequence of this transitive relation between cognition and the categories is the existence of a necessary and sufficient condition for ontological specifications, which are typically syntactical too, in particular those which are meant to be used in computer applications. The analysis of the meaning of the constituents, in the three types of relations, proves that the specification of the (combinatory) properties of qualia can be restricted to three cases. The specification of

(1) the qualia in themselves
(2) with respect to other qualia
 (i) which are complementing it or
 (ii) which they are complementing
(3) with respect to other qualia, together with which, they can generate a new meaning.[10]

Such a specification will be called a trichotomic specification or, briefly, a *trichotomy*. In virtue of the dependency between the Peircean categories, the

[9]In line with the assumption that all interaction is between state and effect, the constituents of the three relations above show an analogous difference.

[10]Notice that (1) allows a single interpretation, (2) provides two and (3) can be expanded in three meanings, that differ from each other in the question which one of the qualia has a dominant function in the relation (either the one, or the other, or both).

meaning of a more developed class contains the meaning of a less developed one, in a trichotomy. By assuming that the three types of meanings can be defined in each trichotomic class, recursively, we have in front of us the hierarchical schema of ontological specification suggested by the theory of this thesis. Trichotomies will be extensively studied in the domain of ‘naive’ semantic syntactic signs (see chapter 6).

In sum, there are three types of relations between signs, in accordance with the three types of the categories of phenomena. As each sign interaction introduced by the processing schema can be interpreted as an interaction between some state and some effect, the constituents of a sign interaction can be characterized as:

(1) a quality, which is a potential existence
(2) a state, which appears by virtue of an effect
(3) an effect, which implicates the existence of a state

The three categories are not independent from each other. Though thirdness is the most developed, it nevertheless requires secondness and firstness (the latter via the mediation of secondness). Analogous with the categorical relations, an effect can be said to contain a state and, transitively so, a potential existence. By means of the induced ordering of the dependency between the categories (‘$<$’), as a polymorphic operation, the relation between the cognitive types can be abstracted as follows: $a<b$ and $A<B$. For example, the meaning of a quale which is an effect, implies the existence of its meaning as a state.

3.5.1 Example

The running example of this, and the next chapter is the recognition of the ‘real’ world phenomenon ‘smoke’, as the sign of ‘danger’. In this section the focus will be on some of the important interpretation moments of that process, a full analysis of the example will be given in the next chapter.

Assume, you are watching for some time the dark cloud of smoke (**smoke**) above a roof (**roof**), and suddenly you ‘see’ that the cloud is rising upward (**rising-air**) and that fire is burning on the roof (**burning**). The input qualia of perception, and the memory response signs triggered by that input are illustrated as follows (**boldface** and Sans Serif symbols are used for denoting input and memory signs, respectively; danger and thermal are the memory signs generated for **burning** and **rising-air**, respectively):

a= **smoke**, **roof**
b= **burning**, **rising-air**

$a'=$ smoke, roof
$b'=$ danger, thermal

The final signs of perception, re-presented as the initial signs of cognition:

$A=$ **smoke**$*$smoke
$\neg A=$ **roof**$+$roof
$B=$ **burning**$*$danger
$\neg B=$ **rising-air**$+$thermal

For instance, **smoke** is identified as smoke, but **roof** is only 'guessed' as a possible for roof (for example, because you cannot see the whole roof, only a part of it). The recognition of the above signs by cognition, as a process, obtains the following representations of the input qualia:

$(q_1,C)=$**smoke**$*$smoke
$(q_2,C)=$**burning**$*$danger

Finally, the interaction of these signs is represented as a proposition, by making use of '**rising-air** above the **roof**, as a mediating context:

(q_1,C)–$(q_2,C)=$ (**smoke** as smoke) *IS* (**burning** as danger)

or, briefly, 'smoke *IS* danger'. This sign can be re-presented, possibly through a recursive process, by shouting "Fire!" or running away, as a reaction. In order to enable the recognition of the input as a meaningful relation, the input qualia have to be adequately specified, by means of suitable trichotomies. This may be exemplified with the specification of smoke (hence implicitly also of **smoke**):

(1) in itself: an entity which is a quale, having properties underlying its combinatory potential, such as a dark color, a density, etc.
(2) in relation to another quale
  (i) which is complementing it: e.g. blowing (as a smoke producing effect) or,
  (ii) which it is complementing: e.g. rising-from-the-chimney (as a state undergoing smoke production)
(3) as a self sufficient sign: such as the subject of any-burning.

Notice that the qualia of (1) function as the ground for the connections of (2), that in turn underlie the meaningful relations of (3). For example, smoke as an entity 'rising-from-the-chimney' contains the meaning of smoke as an entity having dark color etc. In turn, smoke as the subject of 'any-burning' contains the meaning of smoke as an entity 'rising-from-the-chimney'.

This completes the brief overview of the example of this section. In the next chapter the example will be further elaborated, by defining all signs 'generated' by perception and cognition, as processes. The reader who only wants to skim this thesis may safely skip the next chapter and catch on later, with chapter 5, in which an important application of the theory in language modeling is introduced.

3.6 Natural representation

An advantage of the model of knowledge representation of this thesis lies in its potential for generating information, by the computer, that could be more directly processed as knowledge, by the human user. The essence of such 'natural' processing of information may be illustrated with the metaphor of apparent motion perception. If a series of pictures is presented correctly, one may experience it as motion. If the presentation is not correct, for example, if the pictures are in a wrong order, or the difference between consecutive pictures is too large, adequate interpretation may still be possible, but will be more difficult.

The idea behind the theory introduced in this thesis is that an analogous 'correct' presentation of computations by the computer may enable a 'natural' interpretation of those computations, as signs of the recognition of a suitable phenomenon, that is, the signs of the interaction between some state and effect. More specifically, the hypothesis of this thesis is that information processing respecting the nine types of relations of cognitive processing, and their ordering, may *enhance* the interpretation of the input information, as meaningful (through the mediation of proto-signs, that are in a process of becoming a sign).

The potential relation between the cognitive and semiotic concepts of meaning is the key to a *natural* definition of the combinatory properties of the qualia as a rule-like *habit*. Also, the dynamic interpretation of the Peircean classification is the key to the conception of sign recognition as a process, generating increasingly better *approximations* of the final meaning of observed phenomena. It can be shown that there exists a correspondence between the types of relations generated by cognitive processing, and the interactions between sign aspects that are each other's neighbors, according to Peirce's classification.[11]

[11] A neighborhood relation between signs is indicated by a horizontal line in fig. 3.4.

3.7 Related research

A framework which is remotely related to the one presented in this thesis, is the theory of Nonagons (Guerri, 2000), that has been introduced originally for supporting the completeness of a design, for example, an architectural design. Nonagons are also based on Peirce's signs and a recursive expansion of his nonadic classification. There is however an important difference between the two approaches in regard to the interpretation of a sign, either as an entity which emphasizes its character as a single unit (the Nonagon approach), or, as an entity which stresses the inherent duality implied by authentic semiosis (the view maintained by this thesis).[12] A practical advantage of the latter view lies in its capacity for defining the nine classes as a product of (dual) trichotomies, thereby simplifying the specification task, potentially. An example in text summarization, illustrating the benefits of a recursive specification of the properties of qualia, will be given in chapter 9.

[12]Both models depart from a triadic definition of signs, but the difference in goals served puts a different emphasis on the properties of signs. In this thesis it is maintained that full understanding of semiosis is only possible when the different perspectives are combined.

Chapter 4

Process model revisited

In this chapter the model of cognitive activity is further elaborated. This includes an analysis of the necessary conditions for the representation of memory information, an overview of the cognitive concept of qualia (sect. 4.2), a full definition of the perception process (4.3), the introduction of degenerate representation (4.4), a comparison of 'naive' and Boolean logic (4.5) and, finally, a complete elaboration of the example introduced in the previous chapter.

4.1 Memory representation

The reader may agree that the processing schema proposed in the previous chapter is astonishingly simple. In fact, all it does is that it consistently links the input qualia with memory information obtained in earlier observations. This raises the questions: How is memory information represented, and how are links established between the input and the memory responses?

Although the number of observations by the brain/mind is in principle unlimited, its storage capacity is finite and, therefore, the representation of memory information must be economic. Economic representation may be illustrated with the earlier example of smoke. Smoke can be interpreted as a sign of life, but also as a warning for danger. In both cases the sign (smoke) mediates its object (fire) to its interpretant (either the iconic sign of thermal or the symbolic sign of danger). The fact that there may exist different interpretants indicates that mediation is *context* dependent. This may be due to the activation of the brain (what is in its focus) and/or the presence of low intensity input qualia that are not in the brain's focus and are only recognized in the sense of possibility (complementary qualia). In the example of the previous chapter it has been assumed that, besides smoke, other qualia that represent the context of the observation, are present in the sensory input: quale like the burning roof (in the case of smoke as danger), or that of the rising air in the background (in the case of smoke as the sign of a thermal).

A specific case of the context is memory, in particular memory response signs triggered by the input. Because memory information is assumed to arise from sensory qualia, that have two types, it will be assumed that also memory information can be distinguished in two classes: focused and complementary.

A consequence of the assumed economic representation of information by the brain is that all signs must possess *combinatory* properties. For example, it is *not* 'smoke of the burning roof' which is a sign, but 'smoke'+'the burning roof'. Even this may not be sufficient for an economic representation of knowledge, however. Other processes might contribute to economic storage as well. That we recognize all kinds of appearances of smoke simply as 'smoke' might be due to generalization (abstraction) and the application of threshold values. This issue will be addressed in chapter 6. For the time being it will be assumed that the combinatory properties of an entity may arise from the observation of the properties of similar entities through generalization (cf. habits). The combinatory properties of (primary) input qualia can be used for the definition of the properties of complex entities. In virtue of the importance of qualia for the theory of this thesis, in the next section the cognitive theoretical interpretation of this concept will be briefly recapitulated.

4.2 Qualia

Following a theory of categorical perception (Harnad, 1987), it is assumed that input stimuli are perceived in qualia. According to (Harnad, 1987) (p. 387), the essence of categorical perception is that

> *[...] stimuli that are equally spaced on a physical continuum are perceived as if they belonged to one or another perceptual category, rather than appearing to vary continuously as a function of their physical values.*

An example of categorical perception is the speech frequency spectrum as it is subdivided into phoneme discriminations (e.g. formants). One of the possible mechanisms for categorical perception is selective attention (idem, p. 323), which is a mechanism used in cases in which categorization of certain stimuli has to be learned.

> *If, through experience with human language or with animal calls, phonemes and call elements that differ only in the position of a parameter on a single physical continuum are perceived again and again, it is conceivable that their relative position on the continuum is learned. If only a few alternatives occur, their positions receive specific labels.*

The existence of such parameters is the ground for the classification of phenomena. The assumption that a single physical continuum can be sufficient for the characterization of a domain of qualia is also adopted by this thesis, in particular, in the representation of memory information (see also chapter 6). Qualia arising through learning characterize human knowledge representation possibly in all domains.

A potential property closely related to selective attention could also be possessed by 'physical' phenomena. For example, in the sample interaction between a stone and a light ray the air around the stone is not involved. That in our experience of this phenomenon the light ray is interacting only with the stone but not with the air, is a consequence of the physical properties of these entities: from our point of view, stone and air cannot 'combine'. Following this line of thinking, the potential of an entity for an interaction with other entities can be identified as a kind of 'knowledge' underlying brute reactions.

4.3 The process model of perception

The concept of qualia first appears in the definition of a model of perception as a process. This section is an attempt to give a full account of the interpretation moments of that process (see also fig. 4.1).

Earlier it has been assumed that the input of perception is defined by the collection of a and b qualia (see sect. 3.1). In the initial sign interaction, sorting, the input qualia are represented type-wise. The fact that the two types of qualia are related to each other in the 'primordial soup' is acknowledged in the representation of the signs of sorting, by making use of subscripts. Thus, 'a-type qualia occurring in the presence of b-type ones' are denoted by a_b.

In the subsequent interpretation moment, the interaction between the sorted qualia, a_b and b_a, is represented as an abstraction of the input phenomenon. By taking the relative difference of a_b and b_a, thus removing the reference of

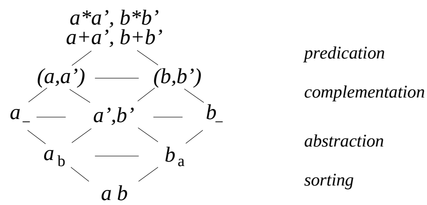

Figure 4.1: The signs generated by perception, as a process

the b-type qualia from a_b, and the reference of the a-type qualia from b_a, the input is represented as an abstract *state* ($a_{\_}$), and abstract *effect* ($b_{\_}$).

According to the current model, memory information is interpreted as (memorized) state and effect qualia, that are dual by definition. As mentioned earlier, memory response signs arise due to the two types of input qualia separately triggering memory. This defines the context of the observation ([C]) as a pair of interrelated collections of state and effect qualia (a',b'). The interaction between the abstract input signs ($a_{\_}$ and $b_{\_}$) and the context ([C]) (complementation) is interpreted as the *actual* meaning of the input state and input effect, denoted by (a,a') and (b,b'), respectively. These two signs, finally, are used for the generation of the final sign of perception. By means of predication (interpreted degenerately, in the logical sense), the signs (a,a') and (b,b') are merged into a single sign, representing the relation between the input qualia and the memory response signs identified as 'known' ('$*$') or 'not-known' ('$+$'), by the expressions: $a{*}a'$, $a{+}a'$, $b{*}b'$, $b{+}b'$. Notice that the information, whether a memory sign is 'known' or 'not-known' (or, alternatively, focused or complementary) was already present in the memory response. However, at that stage it was not recognized as meaningful.

As earlier mentioned, memory information necessarily partakes in all observations, therefore memory qualia could already be included in the representation of the input, as a 'primordial soup'. For explanatory purposes and for the sake of consistency with the previous chapter this possibility is omitted in fig. 4.1.

4.3.1 The completeness of representation

In sect. 3.4 it has been shown that the interpretation moments of the processing schema may be related to Peirce's signs as meaning aspects. On the basis of the properties of signification Peirce maintained that his nonadic classification of signs is complete. The aim of this section is to prove that this completeness property of the Peircean signs is also shared by the interpretation moments of the processing schema of cognitive activity.

Not all signs recognized by perception are independent. Those that are not independent cannot interact and cannot contribute to the generation of a meaningful interpretation of the input qualia. Sample signs that are *not* dual, are: a_{-} and a_b, as well as a_{-} and b_a, due to their shared qualia and shared references to qualia, respectively; a_{-} and b_{-}, by virtue of their common complementary qualia (a,a') and a_{-}, as well as (a,a') and a', due to their shared references; (a,a') and b_{-}, as (a,a') is not independent from a_{-}, which in turn is not independent from b_{-}. Other signs that are not independent, are the symmetrical pairs of those mentioned above.

This analysis indicates that the process model of perception considers all possible interactions between the input qualia, as well as their representations, reinforcing the earlier hypothesis of this thesis about the completeness of cognitive activity as a process. Of course, a similar analysis could also be given for the process of cognition (see sect. 3.2).

4.3.2 The two types of input–memory relations

The two types of relations between input and memory, in the sense of agreement ('$*$') and possibility ('$+$'), arise from the same input trigger. This is acknowledged in the current model, by assuming that the two relations contain a shared common meaning. An illustrative example is the input quale **stone**,[1] and the corresponding memory signs, *stone* (in the sense of agreement) and *something-one-can-smash-with* (in the sense of possibility). The two meanings are obviously related, as *something-one-can-smash-with* includes the meaning of a *stone*. The relation does not hold the other way around, since the interpretation of the input as 'known' can only represent qualia that are related to the input stimulus in the sense of agreement. The 'known' meaning of an entity can only be used for the representation of its meaning as 'not-known' through degenerate interpretation (this point will be explained in sect. 4.4).

Although the above containment relation between the two types of interpretations of an entity might be obvious for a human interpreter, its implementation by a computer may put a great burden on the encoding of qualia as formal entities. Nevertheless, optimal encoding is theoretically possible due to the finiteness of the set of input and memory qualia at every stage of interpretation. The above mentioned containment relation between the signs of

[1]Such as the graphical representation of a stone (see fig. 2.1).

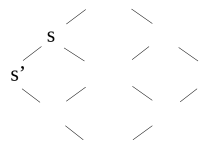

Figure 4.2: Sample degenerate representation

perception may be justified by means of a logical analysis of their expressions, $a{*}a'$ and $a{+}a'$. Conform the meaning of a 'naive' logical 'or' ('+'), $a{+}a'$ can be interpreted as a, a', or $a{\cdot}a'$ (short for a-and-a'). The interesting term is $a{\cdot}a'$, degenerately representing the 'known' meaning of $a{*}a'$ as a possibility. The other way around, the degenerate representation of $a{*}a'$, as a or a', trivially contains the meaning of a and a', as a 'constituent'.

4.4 Degenerate representation

This section is an account of the potential of the proposed model of cognitive activity for a degenerate representation of its interpretation moments. From the dependency relation between the constituents of a sign interaction, and the sign representing the interaction as a whole, one may derive an induced ordering relation on signs ('<'). This relation can be used for a definition of degenerate representation, as follows. For two signs, s, and s', s is *degenerately represented* by s', if s'<s (see fig. 4.2).

The possibility of a degenerate representation of a sign will be extensively used in the model of 'naive' or natural language (see chapter 5), but it also plays an important role in the representation of *nested* phenomena. In that case, the proposition sign (argument sign) of a nested phenomenon is represented as a quale in the recognition of the *nesting* phenomenon. This may be illustrated with the following example. Assume, the observed phenomenon is 'crossing the road' (by some person). Also assume that during this act of crossing the road, suddenly a car appears, raises a lot of dust, and disappears. This complex phenomenon may be recognized, by interpreting the 'appearing car' as a nested phenomenon, and by representing its final sign as a single quale (which itself has a complex meaning), e.g. the 'presence of dangerous traffic'. That quale, together with the other qualia of the nesting phenomenon ('crossing the road') could then be recognized, for example, as: 'crossing the road in the presence of

(input)	(trigger)		(memory)	(representation)
s_1	s_1	$\rightarrow$		
		$\leftarrow$	s_2	
				s_3 (a)
				s_4 (a')
s_1	$s_1 \backslash s_4$	$\rightarrow$		
		$\leftarrow$	s_2	
				s_3 (b)
				s_4 (b')
s_1	$s_1 \backslash s_4$	$\rightarrow$	...	...

Figure 4.3: The generation of input signs of cognitive processing. The input is sampled in s_1. This value is used as a trigger, generating memory response represented by s_2. The intersection and the union of s_1 and s_2 are stored in s_3 and s_4, respectively. s_3 is representing the input, as a state. By comparing s_4 with the new value of s_1 ($s_1 \backslash s_4$), a change in the input can be discovered. If there is a change (that is, $s_1 \backslash s_4$ is not the emptyset), it can be recognized by means of an analogous procedure, as an effect.

dangerous traffic', or simply, 'carefully crossing the road'.

4.4.1 A possible mechanism underlying perception

Why perception as a process generates precisely four representations of the input? The senses and the brain, that are basically independent, are linked by means of bio-electric signals. This continuous stream of information of the senses in principle can be blocked by the brain allowing it to work 'stand-alone', without taking in additional sensory input, but this type of operation shall be left out of consideration. In this section, it will be assumed that the sensory signal is the input processed by the brain. A change occurring in that signal can be detected by means of a mechanism that shows similarity with the perception of apparent motion phenomena, mentioned earlier. An important element of this analogy is that information processing by the brain too is based on subsequent samples of qualia (cf. snapshots), that are analyzed and manipulated individually.

In the first step (see fig. 4.3), the actual value of the sensory input is sampled by the brain in a percept. According to the current model, the value of the neurons of the corresponding working area, representing its state, is used by the brain as a trigger, in order to generate a memory response. At the moment that the returned information arrives in the working area, there are two samples available: one representing the input qualia (s_1), and another representing the memory response (s_2). By comparing them, the brain is able to determine the values that are present in both samples, and represent them in a third snapshot (s_3) for later use. The 'intersection' of the input stimulus and the memory response qualia, generates a stationary view of the observed phenomenon. The common elements occurring in the two samples represent an agreement relation between the input and the memory qualia that are in the focus, or 'known' by the brain.

But the input, as well as the memory response may also contain qualia that are not in the focus. I assume that, inn order to avoid any loss of information, the brain makes a fourth snapshot (s_4), containing all qualia that are present in the input and in the memory response. This completes the recognition of the input as a state.

If the sensory input signal is not blocked by the brain, the value of the input stimulus may change (its earlier value was represented by s_1), before the information returns to the working area. This explains the necessity for the generation of s_4. This sample, that contains information about the input, and the memory response qualia of the previous sampling moment, is used now for the detection of the input change (by sampling the current value of the input stimulus, the previous value of s_1 disappears).[2]

If there is no change in the input, the brain may 'know' that the input refers to a stationary phenomenon. But, if the qualities represented by s_1 and s_4 differ, the observed phenomenon must be a dynamical one. Since a difference can be important, it has to be interpreted by the brain. This is realized by means of making a second comparison. The common part of the input trigger and the responding memory qualia is used now as a representation of the type and measure of the change of the observed input state. Again, the brain generates the 'union' of the input and the memory samples, representing all qualia involved in the change, as a possible co-occurrence.

In sum, the brain samples the sensory input signal in a percept, and links it with the corresponding memory information. Since the sensory input is a continuous stream, but retrieval of information from memory may not be instantaneous, the previous and the current values of the input stimulus may not match. In that case, the difference between the two values can be interpreted as

[2]It is assumed that the representation of the input and the memory qualia is such that a separate identification of the two types of signs is possible. For example, their representations make use of different frequency and intensity values.

an effect, generating a 'next' state. This difference, in relation to the previous sample, is underlying the meaning of a change, as well as its representation as knowledge, by the brain.

The samples generated by the process of perception are depicted in fig. 4.3 (the symbol, '\', stands for relative difference). As a more convenient representation for the different instances of s_3 and s_4, expressive labels have been introduced: *a*, *a'*, *b*, *b'*. From the logical point of view, the comparison of percepts involves the dual operators *intersection* and *relative difference*, which are also the basic operators involved in the interpretation of the process of sign recognition as a 'naive' logic. The comparison of s_1 with s_4 is the key to a recursive analysis of input information, realizing the 'goal' of cognitive processing. This can be summarized as follows: As long as there is a change in the sensory context, sign processing may not terminate.

This closes the refined definition of the process model of perception. In the rest of this chapter a complete elaboration of the example introduced in the previous chapter will be given. Preceding the example, 'naive' and Boolean logic are briefly compared.

4.5 Naive vs. Boolean logic

Although the model of logical signs introduced in sect. 3.3 contains all Boolean relations on two variables, it represents those concepts only in a 'naive' logical sense. Boolean logic differs from 'naive' logic in three aspects, which are the following. The first is the uniform representation of the collections of different types of qualia as a universe, and state and effect as logical variables. The second is the interpretation of the logical operations, as operations of sets (Boolean logic), not as operations on collections ('naive' logic). The third is the non-synonymous interpretation of cognitively synonymous expressions, such as $A{*}\neg B$ and $\neg A{*}B$.

Besides these, there are also some technical differences between the two systems. One of them is the potential of Boolean logic for the combination of variables, as well as of logical operations, in arbitrary order. This is opposed to the limitations of 'naive' logic (which is a procedure), specifying that a relation may only be established between two variables at a time, and that the order of the operations is dictated by the order of the sign interactions, in the processing schema. Another difference is the interpretation of *true*/*false* as a representation of the status of cognitive processing ('naive' logic) or as a constant (Boolean logic).

The results of this research indicate that 'naive' logic has a crucial role in the interpretation of natural language (see sect. 5), and it is suggested that it may have a similar important function in all knowledge representations that are 'close' to perception, and, therefore, are natural or 'naive' too.

4.6 A complete example

This section contains a full account of sign recognition as a process. To this end, the example of 'smoke-as-danger' introduced in sect. 3.5.1 is revisited and the various interpretation moments of its recognition process are elaborated step by step.

In the example below the existence of the following input and memory qualia are assumed. Memory response qualia that are in the focus are underlined; complementary sensory input qualia are omitted. In this example too, **boldface** and Sans Serif symbols are used for denoting input qualia and memory signs, respectively; *slanted* symbols are used for indicating the signs generated by the recognition process.

a =	**smoke**, **roof**;	a'=	$\underline{\mathsf{smoke}}$, roof;
b =	**rising-air**, **burning**;	b'=	$\mathsf{thermal}$, $\underline{\mathsf{danger}}$;

In other words, the qualia of the dark cloud of smoke (**smoke**) above the roof (**roof**) are identified as smoke and possibly also as roof, and the suddenly observed qualia of the cloud rising upward (**rising-air**) and those of the burning fire on the roof (**burning**) as danger and possibly also as thermal.

A major problem with phenomena such as smoke is due to the difficulty with an adequate specification of their combinatory properties. That is, which entities may co-occur with which other entities, in our experience. Although this can be a serious problem for a computational interpretation, it may not be a problem for the human interpreter, who is almost certainly familiar with the properties of this and similar phenomena through experience. The analysis below capitalizes on this knowledge of the reader. In the presentation of the example the various interpretation moments can also be referred to by means of their logical expressions. Comments are preceded by a '%' sign.

4.6.1 Perception

Perception, as a process, begins with the representation acts *sorting* and *abstraction*, which are defined as follows. An overview of the signs generated the perception process is given in fig. 4.4.

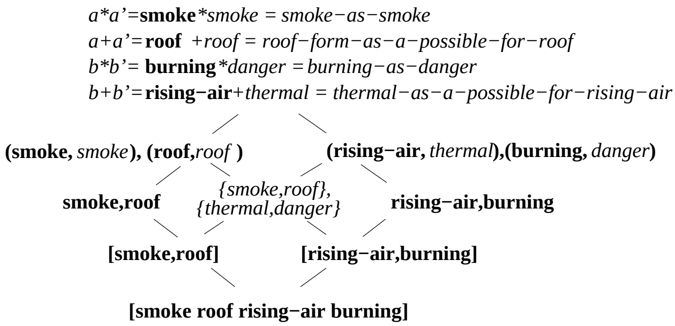

Figure 4.4: The signs generated by the process of perception

Sorting

a_b	=	**smoke**, **roof**	% in the presence of **rising-air** and **burning**
b_a	=	**rising-air**, **burning**	% co-occrring with **smoke** and **roof**

Abstraction

$a_{\_}$	=	**smoke**, **roof**;	% independently from the input effect
$b_{\_}$	=	**rising-air**, **burning**;	% independently from the input state

Next, the abstract signs above are interpreted in context (complementation) and the resulting representations are merged in a single sign (predication). In the first operation, the abstract meaning of the input qualia is completed with the prototypical meaning of the memory signs. The abstract meaning of **smoke** ($a_{\_}$) is complemented with anything 'smoke-like' (a'), which may include the steam of a locomotive or even a picture of smoke. In the current example it is assumed that **smoke** is 'known' as smoke, and **roof** (that is not in the focus of the brain/mind) is recognized as some roof-like form, indicating that it is 'not-known' as a roof. Similarly, **burning** is completed with danger ('known'), and **rising-air** is completed with thermal ('not-known'). It should be mentioned that a single input quale can very well trigger memory responses both in the sense of agreement and in the sense of possibility. For instance, in another phenomenon, **smoke** could be associated with smoke ('known') and with roof ('not-known'). Such a possibility is not considered in the current example.

Complementation

$$(a,a') = (\{\textbf{smoke},\mathsf{smoke}\}),\ (\{\textbf{roof},\mathsf{roof}\});$$
$$(b,b') = (\{\textbf{rising-air},\mathsf{thermal}\}),\ (\{\textbf{burning},\mathsf{danger}\});$$

Predication

$a{*}a'$	=	**smoke**∗smoke;	% **smoke**-as-smoke
$a{+}a'$	=	**roof**+roof;	% roof-as-a-possible-for-**roof**
$b{*}b'$	=	**burning**∗danger;	% **burning**-as-danger
$b{+}b'$	=	**rising-air**+thermal;	% thermal-as-a-possible-for-**rising-air**

4.6.2 Cognition

In cognition as a process the context is represented by $\neg A{+}\neg B$ and $\neg A{*}\neg B$, indicating that the context signs arise from the complementary qualia, by means of an analogous procedure of 'sorting'. This conceptually renders $\neg A$ and $\neg B$ the meaning of the qualia of a complementary phenomenon, and interaction. Interpretation begins with a re-presentation of the final signs of perception as the input qualia of cognition. An overview of the signs generated by the process of cognition may be found in fig. 4.5.

A	=	$a{*}a'$=	**smoke**∗smoke=	*smoke*
$\neg A$	=	$a{+}a'$=	**roof**+roof=	*roof-like-form*
B	=	$b{*}b'$=	**burning**∗danger=	*burning-as-danger*
$\neg B$	=	$b{+}b'$=	**rising-air**+thermal=	*rising-hot-air*

Sorting

$A{+}B$	=	*smoke* + *burning-as-danger*;
		% there is smoke and some dangerous burning
$A{*}B$	=	*smoke* ∗ *burning-as-danger*;
		% smoke appears with some dangerous burning
$\neg A{+}\neg B$	=	*roof-like-form*+ *rising-hot-air*;
		% there is a roof-like thing and rising hot air in the background
$\neg A{*}\neg B$	=	*roof-like-form*∗ *rising-hot-air*;
		% hot air is rising above the roof, in the background

At this stage, the input may be 'known' as a collection of qualia that are constituents, and as a co-occurrence event of those qualia, that is happening now.

However, it is not known yet that *smoke* is related to 'burning' hence also to 'danger' and, therefore, the fire department should be called. That interpretation of the input may come later.

Abstraction

$A*\neg B$ = *smoke* $*$ *rising-hot-air*;
% smoke in relation to any rising-like motion,
% e.g. smoke may rise, whirl, etc.
$\neg A*B$ = *roof-like-form*$*$ *burning-as-danger*;
% dangerous burning, in relation to anything roof-like,
% e.g. balks, piles, etc. can burn

The synonymous representation of the above signs may be summarized as the representation of the input as 'something smoke or burning': $A*\neg B$, $\neg A*B$ (see also sect. 3.3). The other result of the abstraction operation is the following.

$A*\neg B+\neg A*B$ =
smoke $*$ *rising-hot-air* $+$ *roof-like-form*$*$ *burning-as-danger*
% the possible co-occurrence of the rising smoke and burning roof, as an
% expression of the rule-like meaning: 'where smoke is, there is burning'

Here, *smoke* indicates the smoke that is 'rising as hot air', and 'burning as danger' refers to the 'dangerous burning of the roof'. The observed phenomenon can be viewed in two different ways, but it is their compatibility that is recognized in this interpretation of the input as an abstract event: the co-occurrence of smoke and burning, in a rule-like sense.

Complementation

The meaning of the input as an actual existent is obtained from its abstract sign, through complementation by the context. The context signs are:

$\neg A*\neg B$ = *roof-like-form* $*$ *rising-hot-air*,
$\neg A+\neg B$ = *roof-like-form* $+$ *rising-hot-air*;

A synonymous interpretation of these signs is 'rising hot air above the roof'.

The meaning of the input, as an actual constituent, is signified, respectively, by a roof-like 'thing' in the background ($\neg A$) and the burning itself (B) and, by the smoke (A) and the rising hot air in the background of the observation ($\neg B$).

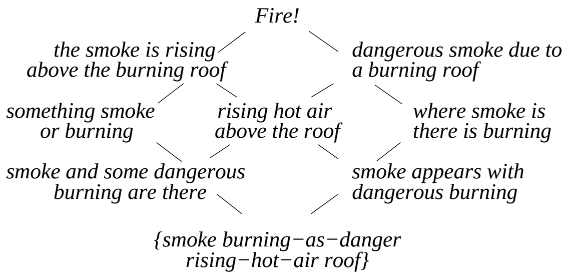

Figure 4.5: The signs generated by the four stages of the process of cognition

$\neg A{+}B$	$=$	*roof-like-form* + *burning-as-danger*,
		% this dangerous burning on the roof
$A{+}\neg B$	$=$	*smoke* + *rising-hot-air*;
		% this rising smoke

A synonymous interpretation of the above two signs is 'smoke is rising above the burning roof'. Another representation of the input, this time, as a characteristic or conventional property, is defined as follows.

$A{*}B{+}\neg A{*}\neg B =$
smoke $*$ *burning-as-danger* + *roof-like-form* $*$ *rising-hot-air*
% dangerous smoke due to burning like hot air rising above the roof
% or, dangerous smoking due to a burning roof

This property, the association of smoke with danger, and rising hot air with its location on the roof, applies to the input, signified as an actual existent. That relation can be important, either because we are familiar with its meaning (we may know what could be an adequate reaction on this input), or because something or somebody draws our attention to it, and we learn its importance now.

Finally, by combining the two signs, by means of predication, the sign recognition process generates the representation of the entire input, as a hypothesis:

A *is* B	$=$	*smoke* IS *burning-as-danger*
		% . . . smoke IS . . . danger

An alternative representation of this proposition may be derived by means of reasoning. For example, from 'smoke IS danger', one may deduce that it is fire that smoke signifies as danger. By assuming the existence of lexical information about fire, for example, that its meaning contains the meaning of danger (as the effect meaning of danger implies its interpretation as a state), the above representation of the input can be paraphrased as: '*Fire!*'

Part II

Language as knowledge

This part is a first attempt to illustrate that the theory of this thesis could meet the requirements set out for knowledge representation earlier in this book. A formal proof may not be possible as knowledge is not some 'thing' that can be captured in formal rules. What can be done is test whether the theory can be applied to modeling phenomena, in different domains of knowledge. An application shall be called potentially adequate, if the concepts suggested by the model of a domain form a subset of the 'naive' or natural concepts of the same domain, known from experience. Although testing can be weaker than a formal proof, the introduction of potentially adequate models for some new domains may increase the confidence in the theory presented, that it could be used for the representation of knowledge in any domain.

As part of this program, the model of cognitive activity will be applied to natural language processing. To this end, a model for the 'naive' syntactic and morpho-syntactic domains of symbols will be elaborated. A formal specification of the syntactic model introduced in this chapter, as well as a proof that its complexity is linear in the number of input symbols and operations on them may be found in (Sarbo & Farkas, 2002). The important result of this part is the definition of a sequential version of the processing schema, enabling the recognition of complex phenomena as signs.

Chapter 5

Language as a process

Natural language consists of symbols that can be considered as signs (Squire et al., 1993), (Squire, 1992), (Debrock et al., 1999), (Jakobson, 1980). What makes language symbols especially interesting is that their interactions can be interpreted as relations between lexically defined combinatory properties. Because natural language appears 'naturally' in our experience, by defining a model for language we also make an attempt to answer the question: What is 'natural' in natural language?

A model for natural language as a process requires a representation of primary language symbols as input qualia. The lexical definition of qualia is an expression of their combinatory properties, representing 'naive' language rules be they of syntactic, semantic or of any other kind.[1] As a full scale definition of those properties is beyond the scope of this work, a systematic comparison with traditional language modeling is omitted.

The focus of this chapter is on the introduction of a model for 'naive' syntactic and morpho-syntactic symbols. The language of illustration is English. The word classes used in the definitions are restricted to the major types such as verbs, nouns, adjectives and adverbs.

Natural language processing is sequential, implicating that language signs are typically complex, containing nested signs recursively. The definition of a model for language processing requires that the processing schema introduced in sect. 2.3 is equipped with facilities enabling the recognition of a series of phenomena as a single phenomenon. In general, language symbols may be

[1] A preliminary version of a lexicon for syntactic symbols can be found in the Appendix.

interpreted in two different ways: as independent entities contributing to the sign of an encompassing language phenomenon, for example, the sentence; or, as qualia underlying that phenomenon, which is interpreted as a sign. This chapter is concerned with the the first interpretation which is also the more natural one, as in our experience of language, subsequent input symbols may appear so fast that an interpretation of their full individual meaning cannot be realized, only a recognition of their meaning with respect to the input as a whole. This implies that in the interpretation of the event(s) triggered by the next input symbol, proto-signs (see sect. 3.4) of earlier input symbols may have to be considered. The other interpretation of language symbols is postponed until chapter 9, introducing a method for text summarization.

In conformity with previous chapters, in the examples, lexically defined language symbols (memory signs), and symbols generated by the recognition process are presented in Sans Serif and *slanted* fonts, respectively.

5.1 Towards a model of language signs

The processing schema can be easily adapted to the domain of language symbols. The input qualia may be defined by the primary morpho-syntactic entities and words (morpho-syntactically finished symbols), in a morpho-syntactic and a syntactic analysis, respectively. In the model of cognitive activity (see sect. 2.3), earlier it has been assumed that the entire input is presented as a single collection of qualia ('primordial soup'), derived from previous and current percepts in a comparison operation. In the proposed language model, this 'feature' of the input qualia is implemented, by means of interpreting the interactions between the existing previous symbols, representing the state of the interpreting system (cf. S_s, in sect. 3.4.2), and the appearing next symbols, as effects. In these interactions, the appearing new symbol is represented as a collection of potential combinatory properties or relational needs. Although the symbol interactions are always between the interpreting system (state) and the appearing next symbol (effect), defining the 'primordial soup', it is the encompassing phenomenon, for example, the sentence, from the point of view of which those symbol interactions are interpreted.

Similarly to the model of cognitive activity, the model of language introduced in this chapter has two stages: perception, i.e. the linking of the input qualia with memory information (lexical analysis); cognition, i.e. the establishing of a relation between lexically analyzed symbols (syntactic/morpho-syntactic parsing). Roughly, in a syntactic phenomenon, nominals, appearing as a state,

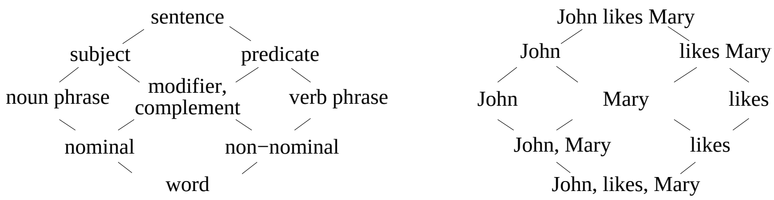

Figure 5.1: A classification of basic syntactic concepts (left), and the concepts of the sample utterance 'John likes Mary' (right)

undergo effects due to non-nominals. An example are the syntactic modification and predication of nouns, by means of adjectives and verbs, respectively. Which existing symbols (proto-signs) are transitively effected by the appearing next symbol, that is, how the state of the interpreting system is eventually changed, can be derived by interpreting the sequence of symbol interactions triggered by the next symbol. Such a sequence of events is called an *evaluation step*, in the language model of this chapter.

Due to its minor importance for the goals of this thesis, a definition of the perception process (lexical analysis) is omitted; perceived language symbols are represented by their lexical definitions. The final signs of perception, representing the input symbols of cognitive analysis are taken for granted.

In the model of English syntactic symbols it will be assumed that the primary nominal entities are nouns, and the primary non-nominal symbols are verbs, adjectives, adverbs and certain prepositional phrases.[2] A classification of the basic syntactic concepts and their dependencies are depicted in fig. 5.1 (on the left-hand side). The reader may compare the syntactic meaning of these concepts with the corresponding meaning aspects displayed in fig. 3.5. For example, words, nominals and noun phrases have the meaning aspect of a syntactic quality, a constituent and a qualitative possibility (for undergoing a syntactic modification), respectively. On the right-hand side of fig. 5.1, the reader may find an analogous classification of the meaningful syntactic entities and relations of the utterance: 'John likes Mary'.

In the processing schema, *sorting* corresponds to the classification of the input symbols as a nominal ($[\mathsf{q}_1]$) and non-nominal entity ($[\mathsf{q}_2]$). Which input symbol is in the focus, and which one is only complementary can be derived from the symbol's type, or from the interactions the symbol may potentially

[2]Non-nominal entities are interpreted as a representation of an appearing new property occurring as an effect.

partake in (relational need). Adjectives and adverbs are taken as symbols capable of representing the context of a language phenomenon ([C]). The other sign interactions of the process model of cognition may be characterized as follows. *Abstraction* corresponds to the identification of nominals and non-nominals as noun phrases (q_1) and verb phrases (q_2), but also as modifiers and complements ([C]); *complementation* to syntactic modification ((q_1,C)) and syntactic complementation ((q_2,C)); *predication* to syntactic predication ((q_1,C)–(q_2,C)).

5.1.1 Sequential processing

Different from the earlier example of smoke-and-fire (see sect. 3.5.1), the sentence 'John likes Mary' (in short 'JIM') contains more than two qualia. However, those qualia are distinguished by the language model in two interrelated collections, [JM] and [I]: '[I] happens to [JM]'. The linguistic meaning of this phenomenon is clearly more refined. The relation between I and J is different from the one between I and M. This difference is signified, in English, by the order of appearance of the input symbols. That ordering, together with the combinatory properties of the input symbols are finally recognized by the language user as a syntactically meaningful phenomenon. On 'surface level', the input symbols appear one after the other. Because each symbol may only contribute to the meaning of the entire sequence (the sentence) as a proto-sign, the processing schema is generalized such that the recognition of individual input entities may *overlap*, that is, their events may be merged in a single process. Assuming the input is a continuous stream of symbols, the recognition of subsequent utterances may overlap as well.

This line of thinking has led us to the definition of a sequential version of the process model of syntactic sign recognition (Sarbo & Farkas, 2002), in which the meaning of the input symbols is defined in terms of the nine Peircean aspects introduced in the previous part (in sect. 3.4).[3] In the sample sentence above (see fig. 5.1 and also fig. 5.2), the input symbols appear one after the other, and J is recognized as a qualisign. As the input symbols are in principle independent and partake in the phenomenon presented by the entire sentence, the appearance of the next symbol, I, forces a re-evaluation of the earlier interpretation of J (qualisign).[4] A possible solution is the *re*-presentation of J as a constituent of the entire input (icon), in conformity with the principle of economy, that a less

[3]Please note that the Peircean signs are only used as *pointers* to the status of language symbols in the process of recognition.

[4]Because J and I are independent, they cannot be represented as synonymous signs.

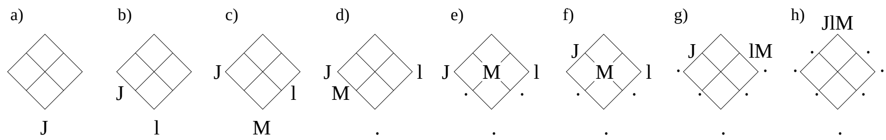

Figure 5.2: The syntactic analysis of 'John likes Mary'

developed representation of a phenomenon has to be generated before a more developed one.

The appearance of M has similar consequences on the representation of l as a qualisign and, transitively so, on the representation of J as an icon. The latter is a consequence of the earlier assumption that the signs obtained by a sorting operation (see sect. 2.3) are incompatible and cannot generate a new symbol by means of binding, except in the negative sense, through the interpretation of their relative difference (cf. abstraction operation). For this reason, J has to be re-presented again, but this time as an abstract representation of the input (rheme). The subsequently appearing dot symbol (the role of dot symbols will be explained later) trigger M (icon) to be represented as an index sign. This is possible due to the presence of l, anticipating M as a possible for a complement. The remaining representation events leading to a correct analysis are depicted in fig. 5.2.

The sequential nature of the input introduces two new cases of symbol interaction. The first is *accumulation*, in which signs having identical meaning aspects are merged in a single sign (this includes the merging of their combinatory properties).[5] The second is *coercion*, which is a 'pseudo' interaction, that is, an interaction that does not actually happen. What does happen in a coercion is that an existing sign (s) is forced to be re-presented by, or 'coerced to' a sign having a more developed meaning aspect. Formally, s is re-presented by s', which is an immediate successor of s in the '$<$' ordering of signs. A coercion may occur, if s and some other symbol, which are about to interact, are not compatible for a syntactic binding. After a coercion, the symbolic representations of s and s' are identical. *Accumulation* and *coercion* are degenerate versions of a genuine binding, respectively, in the first and the second degree.

The specification of qualia with respect to other qualia which they are complementing corresponds to syntactic modification and complementation, indicating that the two types of phenomena can be treated *uniformly* in the model

[5]As all signs generated by the process model are proto-signs, except the final sentence sign (argument), in the rest of this thesis the 'proto' prefix can be omitted.

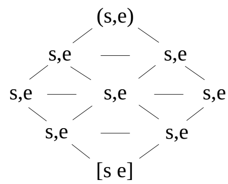

Figure 5.3: The constituents of syntactic bindings, functioning as a state (s) or an effect (e). In the qualisign and argument positions this potential of a language symbol is represented as a possibility, actualized by the current, and the encompassing recognition process, respectively. Syntactic symbols as interpretants of a binding symbol interaction are not indicated.

proposed (Aarts & Aarts, 1982). Lexical definitions typically specify the combinatory potential of a symbol, from the point of view of the symbol itself. For example, verb complements are traditionally specified in the verb's entry. From the semiotic point of view, however, it is the complement that points to the verb and defines its (more) specific meaning.

5.1.2 Relational needs

The three types of constituents of a syntactic sign interaction or binding: (1) a quality which is a potential existence, (2) a state which appears by virtue of an effect, and (3) an effect which implicates the existence of a state (see sect. 3.5, but also fig. 5.3), underlies their interpretation as the three types of syntactic relational needs: (1) neutral, (2) passive, and (3) active, in short, *n*-need, *p*-need and *a*-need; an *n*-need is a substitute for 'no relational need'. The goal of 'naive' syntactic language processing is the establishing of syntactic well-formedness (see sect. 3.2). This is formally interpreted by requiring that the final representation of the (entire) input does not have any unsatisfied relational needs; it must be neutral, syntactically. The different types of binding can be characterized, from this point of view, as follows. A *coercion* satisfies an *n*-need, conceptually; in an *accumulation*, two relational needs of the same type are merged in a single need; a (genuine) *binding* satisfies a pair of *a*- and *p*-needs. A relation which is fulfilled is conceptually removed.

A language symbol is formally defined as a *set*, consisting of references to types of interactions the symbol may partake in as a constituent. Such a set, defining a symbol's formal *relational potential*, is a list of relational properties labeled by a sign class (a class name is abbreviated by a four-letter name). For example, the relational potential of likes can be defined as the set: $\{n_{sins}, p_{legi}, a_{legi}, a_{symb}\}$, indicating that likes can be modified (p_{legi}), can take a complement (a_{legi}) and can predicate the subject of the sentence (a_{symb}).

A language symbol is called an *A-type* sign, if its relational potential only consists of p- and n-needs; otherwise it is called a *B-type* sign. A-type symbols represent a 'thing', B-type symbols refer to an 'event'.

5.1.3 Towards a formal model

Fig. 5.4 summarizes the relational potential of syntactic symbols for the types of word classes, according to the model of this chapter. The input qualia, represented as qualisigns, are defined as follows:

$A=$ noun
$B=$ verb, adjective, adverb, prep(-compl)

where 'compl' can be a noun, verb, adjective or adverb. A precise definition of 'prep-compl' qualia is postponed until sect. 5.2. In accordance with the asymmetry between the interpretation of qualia as a state or an effect, lexically defined a-needs need to be satisfied, whereas p-needs need not. As syntactic signs almost always have a p-need and n-need (that is, in all sign classes), in the examples of this chapter the definition of the relational potentials of the symbols is restricted to the specification of their a-needs. For example, the above definition of likes reduces to: $\{legi, symb\}$.

A 'dot' symbol is defined as an A *and* B type sign, that cannot bind with any other symbol except its own type. Dot symbols may be used to force the 'realization' of pending interactions. The entire input is assumed to be closed by maximally nine dots.

The relational potential of syntactic symbols can be classified as follows. A-type symbols can have a relational potential as an (1) icon, (2) rheme or index, and (3) dicent sign; B-type symbols as a (1) sinsign, (2) legisign or index, and (3) symbol sign, allowing for a trichotomic specification of the relational needs of language symbols. A more elaborate analysis of this potential of the current model is postponed until chapter 6.

The category-related dependency between the different interpretations of a symbol, as an A-, or a B-type quale, can be used for modeling modification phenomena such as 'runs quickly' (notice that both 'runs' and 'quickly' are B-type symbols). In this example, the a-need of quickly (index) satisfies the p-need of runs (legisign), indicating that in this interaction the effect due to the verb

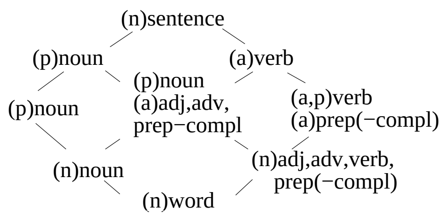

Figure 5.4: The classification of the syntactic symbols used, on the basis of the relational properties of the types of word classes

run is only considered as a state. Object complementation phenomena, for example, 'painted black' can be modeled analogously (Quirk, Greenbaum, Leech, & Svartvik, 1985).

5.1.4 Complementary syntactic qualia

The analysis depicted in Fig. 5.2 illustrates how the recognition process may discover if an input symbol is part of the complementary context. In general, the potential of an input symbol to function as a context sign follows directly from the symbol's relational potential. This is clearly the case when a symbol has an a-need in the index class. Examples of such symbols are the adjectives, adverbs, and prepositional phrases. Symbols having a p-need in the index class have to be treated differently, however. Such symbols can be re-presented as an index sign for two reasons. First, if there exists a legisign with an a-need which anticipates the p-need of the symbol in question; second, if any other interpretation of the symbol in question eventually fails, and such a legisign arises in a subsequent interpretation event.

An example is the utterance: 'Mary, John likes'. The initial analysis assuming Mary (A-type) to be the subject, eventually fails (see fig. 5.5). As a result, the sign recognition algorithm backtracks[6] down to step (b), which is the first choice-point[7] providing another alternative for Mary. Parsing is continued by coercing Mary to an index sign (see fig. 5.6) based on the potential of this symbol to function as the syntactic complement of a verb (likes), which appears later.

[6]Nondeterminism is assumed to be implemented by backtracking (Aho & Ullman, 1972).

[7]As earlier mentioned, an evaluation step is defined by the set of events triggered by the appearing (next) input symbol. Such a set of events is represented by a single 'diamond'.

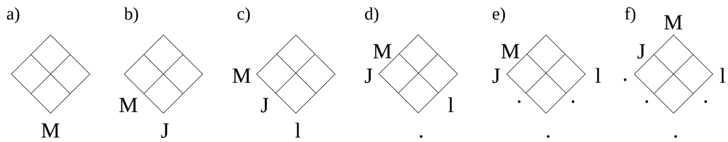

Figure 5.5: The 'naive' syntactic analysis of 'Mary, John likes'

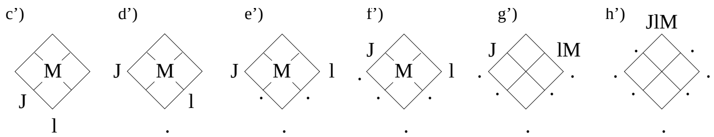

Figure 5.6: The 'naive' syntactic analysis of 'Mary, John likes' (cont.)

5.1.5 Nesting

Nested phenomena frequently occur in language. In conformity with the earlier assumption that the input of an observation is defined by a single collection of qualia ('primordial soup'), the proposed model of language processing assumes syntactic phenomena always to be defined by a *contiguous* segment of input symbols. Nested phenomena, such as subordinate clauses and complex phrases are degenerately represented as input qualia in the recognition of the nearest nesting phenomenon. The recognition of nested phenomena can be implemented by means of recursion. As in principle any input symbol may start or end a nested segment, and the number of different types of nested segments is finite, the potential of language symbols for nesting can be modeled by a finite set of lexically defined relational needs as usual. Recursive parsing can be applied to other phenomena as well. Besides embedded clauses, it can be applied to multiple modification and complementation, amongst others.

5.1.6 Coordination

The above framework of syntactic sign recognition can be successfully applied to the complex phenomenon of coordination. A description of the kernel of such an algorithm is as follows. Three phases of coordination are distinguished. In the first phase, the input symbols preceding the coordinator are analyzed in the way described above. In the second phase, first, all existing signs are saved (their relational needs are remembered as 'traces'). Then, the remaining input

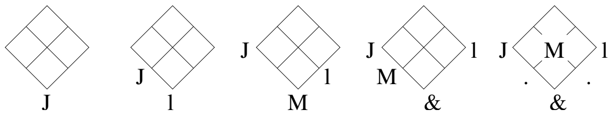

Figure 5.7: The syntactic analysis of '$\mathsf{John\ likes\ Mary\ and\ Kim}$' (until the coordinator)

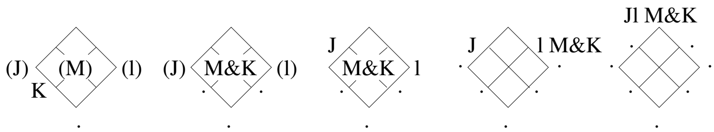

Figure 5.8: Coordination (alternative #1)

is analyzed recursively as a nested sign. In this process, actually generated and saved signs of corresponding identical classes are coordinated (this may include the inheritance of syntactic properties). In the last phase, saved signs that are not coordinated, are restored. Save and restore can be preceded or followed by the elaboration of a number of pending symbol interactions, respectively (Sarbo & Farkas, 2004). The number of such interactions is limited by the number of simultaneously existing proto-signs and by the number of their relational needs, which both are finite.

The analysis of a sample coordination structure is shown in fig. 5.7-5.9 (saved signs having the potential for coordination with another sign are indicated by parenthesized expressions). The analysis depicted in fig. 5.9 assumes that, preceding coordination, the signs generated by the recognition process displayed in fig. 5.7 undergo an extra coercion and complementation operation: J is coerced to the dicent position; the complementation of l by M is represented by lM in the symbol position. Notice in fig. 5.8 the use of the 'traced' a-need due to l (legisign), in the coercion of K (icon) to a syntactic complement (index). The sentence John likes Mary and Kim is not ambiguous, but it can be, if it is used for the utterance John likes Mary and Kim (too). Nesting plays also an important role in the modeling of subordination phenomena (see sect. 5.4).

5.1.7 Syntactic and logical meaning compared

Syntactic signs can also be characterized from the logical point of view (the corresponding logical meaning, this time as an operation, is given in parenthe-

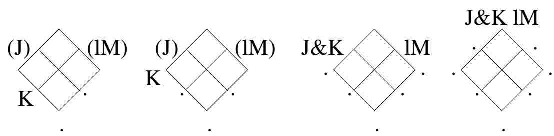

Figure 5.9: Coordination (alternative #2)

ses). Syntactic icon and sinsign symbols arise through sorting the input symbols in two types, nominal and non-nominal. The first type exhibits the aspect of a constituent or some 'thing' (*or*); the second type exhibits the aspect of an 'event' that occurs now (*and*). A syntactic rheme sign may represent the abstract meaning of a noun (cf. lexical meaning), lacking any actual properties. Those properties refer to qualia that are omitted in the definition of the rheme (*inhibition*). A syntactic index sign may be an adjective, or adverb, indicating a complementary fact or property (*negation*). A syntactic legisign may refer to the rule-like abstract event meaning of an (unsaturated) verb, which can be explained either from the verb's or from the complement's point of view (*exclusive-or*). A syntactic dicent sign may be a nominal representing the input as an actual existent (syntactic subject), which is intimately related to the event signified by the predicate (*implication*). A syntactic symbol sign may be an expression of the agreement relation between the verb and its complement(s), representing the input as a characteristic or conventional property (*equivalence*). A syntactic argument sign may be a representation of a syntactically well-formed sentence, arising from a hypothetical inference as a proposition (*syllogism*). Besides the above analysis, syntactic signs also can be characterized from the point of view of the realization of their logical meaning. That analysis, which shows a striking similarity with the model of cognition (see fig. 3.2), is recapitulated in fig. 5.10. A nominal and a non-nominal entity is indicated by A and B, respectively.

5.2 Morpho-syntactic signs

A model for 'naive' morpho-syntactic symbols can be defined analogously to the model of 'naive' syntactic signs, introduced in sect. 5.1.3. Morpho-syntactic symbols deserve our attention, because of the earlier assumption in the model of syntactic symbols that certain prepositional phrases ('prep-compl') can function as syntactic input qualia. The results of this section show that the definition

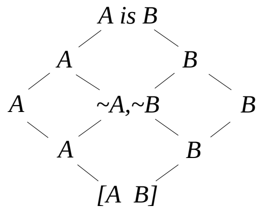

Figure 5.10: The logical interpretation of syntactic signs. In virtue of the sequential nature of language, syntactic signs may either be a representation of a state (A) or an effect (B), and this property is inherited by their logical interpretation as well (in the qualisign position this is indicated by $[A\ B]$). For example, the logical expression of a syntactic icon sign is A, degenerately containing the meaning of $A{+}B$.

of other primary syntactic symbols can be sharpened as well. Although the explanation of the model of 'naive' morpho-syntactic symbols below is concise, this section might also be interesting from another point of view: How the specification of a complex domain may be developed by means of the nine meaning aspects used as 'pigeonholes'.

Syntactic and morpho-syntactic symbols are different. In the syntactic domain, well-formed input symbols are the sentences (argument sign), in the morpho-syntactic domain such entities are the 'words'. There is a hierarchical dependency between the two domains: syntactic input sign (qualisign) are defined as morpho-syntactically finished symbols (argument sign). Of course, both domains have their own types of relational needs. For example, the morpho-syntactic relational need of a symbol is a representation of the symbol's potential in a morpho-syntactic sign interaction.

Morpho-syntactic signs may be characterized as follows. A morpho-syntactic proposition sign (argument sign) refers to a morpho-syntactically finished symbol. In conformity with the 'flat' structure of morpho-syntactic signs arising from adjacent input symbols by means of 'gluing' them together, the proposed model assumes that morpho-syntactic dicent and symbol signs cannot establish a binding. This indicates that morpho-syntactic dicent and symbol signs are in principle finished. However, the two types of signs exhibit different properties and this is respected by their morpho-syntactic interpretation. Morpho-syntactic symbol signs such as adjectives have the (syntactic) property, or satisfy the *convention* that they must be adjacent to their complement in the input, that is, on 'surface level'. Morpho-syntactic dicent signs, for example, nouns and verbs do not have this property, indicating that such signs can represent the input as an *actually existent*, therefore such dicent signs are morpho-syntactically complete signs.

Morpho-syntactic rheme, index and legisign symbols have the aspect of a qualitative possibility, connection and rule, respectively. A morpho-syntactic rheme, that can be a noun or a verb, may function as a *possible* for a dicent. A legisign can be a prep(-compl), representing the *rule*-like meaning of morphological structures. An index sign, that can be an article or a morpho-syntactic complement, may *connect* a rheme with its referential property, and a legisign with its morpho-syntactic complement.

In conformity with the goal of morpho-syntactic sign recognition, which is the generation of primary syntactic entities, the above three types of signs are involved in the generation of *syntactic* relational needs. For example, the morpho-syntactic complementation of girl (rheme) by the (index) can be used for the definition of the syntactic p-need of the girl; the complementation of with (legisign) by a fork (index) can be used for the generation of the adverb-like syntactic a-need of with a fork.

Morpho-syntactic icon and sinsign symbols arise through sorting, from input symbols represented as qualisigns. An interaction between an icon and a sinsign, for example, a verb (icon) and a participle affix (sinsign), respectively, may generate a morpho-syntactic sign (index or legisign), having adjective-like syntactic properties. In English, such symbols are typically written as one word. The classification of the used morpho-syntactic symbols, on the basis of their lexical relational properties, is displayed in fig. 5.11. This diagram seems to indicate that morpho-syntactic icon and sinsign symbols have the potential of establishing a binding, but this is not the case. The proposed model tacitly assumes that such phenomena (affixation) can be recognized by means of *nesting*, recursively. In order to simplify the specification of this 'feature' of affixation, the final symbol interaction (predication) of a nested segment is allowed to overlap with the first non-degenerate sign interaction event (abstraction) of the nesting phenomenon. This optimization of the model of morpho-syntactic sign recognition is illustrated in fig. 5.12.

The relational potential of morpho-syntactic input symbols (qualisigns) are specified, as follows:

$A=$ noun, verb, adjective, adverb
$B=$ preposition, article, particle, affix

Space symbols are represented as generic A *and* B symbols, incompatible for

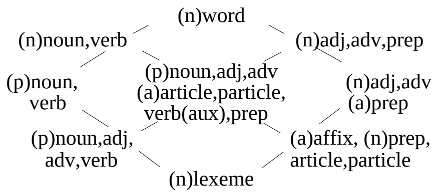

Figure 5.11: The classification of morpho-syntactic symbols

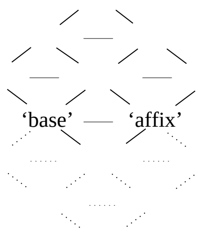

Figure 5.12: Overlapping symbol interactions in affixation phenomena

binding, except for accumulation (with the symbol triggering such an interaction) and coercion. Space symbols may be used to 'sweep out' morpho-syntactically finished signs. Contrary to syntactic symbols, in the model of morpho-syntactic signs, the use of recursion is not assumed, except in affixation phenomena (a consequence of the 'flat' structure of such symbols, in English). The analysis of a sample morpho-syntactic phenomenon: 'John ␣ like -s ␣ Mary', is shown in fig. 5.13 (the analysis of embedded affixation phenomena, as well as the treatment of accumulated space symbols are omitted). Similarly to the model of syntactic symbols of this chapter, the recognition processes of subsequent morpho-syntactically finished symbols may overlap.

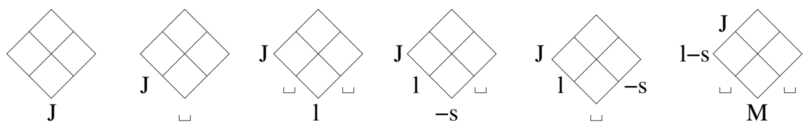

Figure 5.13: The initial part of the morphological analysis of John like -s Mary

5.3 Summary and related work

The introduction of a model for natural language processing the previous section also makes an attempt to answer the initial question of this chapter: What is 'natural' in natural language? Following the view taken by (Sarbo et al., 2006), it is the *types of distinctions* that can be made cognitively, the organization of their recognition events in a *process*, and the appearance or '*feeling*' of such a process as knowledge (the last is beyond the scope of the current model).

The potential semiotic foundation of the approach presented entails the proposed model with the property of robustness. If the parser encounters a yet unknown language phenomenon, it is only the lexicon, specifying the combinatory properties of language symbols, that may have to be adjusted, the parsing algorithm can be invariantly used (Solso, 1988). Systematic adaptations of the lexicon can be enabled by a systematic use of trichotomic specifications, that can be more simple and intelligible than traditional specification using formal grammars, which are less easily manageable.

The language model of this chapter bears similarity to the dependency based formalisms of cognitive linguistics such as Word Grammar (Hudson, 1984). Word Grammar is a branch of Dependency Grammar in that it uses word–word dependencies as a determinant for linguistic structure. As a result it presents language as a network of knowledge that links concepts about words, such as their meaning (e.g. grammatical function) to the form, the word class, etc. Such grammars do not rely on phrasal categories. But the language model of this chapter is also remotely related to constituency based approaches, in that its types of rules define an induced triadic classification of language concepts which show some analogy to that of X-bar theory (Chomsky, 1975), (Cowper, 1992), (Pollard & Sag, 1994). The three concepts of X-bar theory, which are denoted by X, X', and X", are a representation of a lexical category, a relation, and a phrase, respectively. In turn, the three categories of X-bar theory correspond to the operations: sorting, abstraction, and complementation.

A fundamental difference between the above two approaches and the one presented in this chapter lies in the character of the rules. Contrary to cognitive linguistics, which aims at incorporating the conceptual categories of language in rules that are dictated by a formal theory, the rules of our model are derived from 'real' world phenomena, on the basis of an analysis of the properties of cognitive activity and the processing of signs. The linear complexity of the model,[8] indicates that the proposed representation can be practical.

[8]This is formally proved by J.J. Sarbo in (Sarbo & Farkas, 2002).

5.4 Examples

The potential of our model for parsing complex linguistic phenomena is illustrated in this section, with non-trivial examples. The analysis of a couple of more complex utterances taken from actual language use will be presented later, in chapter 9.

The presentation of an analysis is simplified by introducing a tabular form for the sign 'matrix', in which a column corresponds to a sign aspect, and a row to re-presentation act(s) due to the application of *rules*, that are indicated in last column.[9] The following abbreviations are used: input(i), accumulation(a), coercion(c), binding(b). Degenerate representation is indicated by the subscript 'd'; accumulated signs are separated by a "/" symbol. Input symbols are written in boldface; sign classes are abbreviated to a four letter name, as in earlier examples. The parsing of space and dot symbols, as well as the generation of the final sign yielded by parsing, is omitted. Also now, the Peircean signs are only used as pointers, indicating the status of a symbol in the process of (morpho-)syntactic sign recognition. A lexical definition of the input symbols used is given 'on the fly' (but see also the Appendix).

5.4.1 PP-attachment

The first example is the utterance 'Mary eats pizza with a fork'. The 'naive' morpho-syntactic analysis of this input is depicted in fig. 5.14 and table 5.1. In step 8 (table 5.1), a (index) binds with fork (rheme), thereby complementing it with the property 'non-definiteness'; a fork is represented degenerately, as an index sign. That sign is used, in turn, as a context symbol, in the complementation sign interaction with the preposition with (legisign). This is represented by the expression, with a fork (symbol), which is a prep-complement sign having potential adjective-, or adverb-like syntactic properties. The final signs obtained by the morpho-syntactic analysis are: *(Mary)(eats)(pizza)(with a fork)*, where an item enclosed in parentheses indicates a morpho-syntactically complete sign (argument).

Preceding a syntactic analysis, the syntactic relational needs of the morpho-syntactically finished symbols are defined by a perception process (cf. lexical analysis).

[9]The elements of row i (i>0) are either a representation of the current input symbol, or, of elements introduced in row $i-1$. The corresponding recognition events are indicated in the last column of row i.

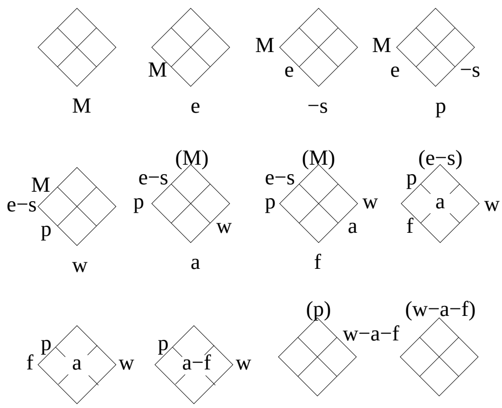

Figure 5.14: The morpho-syntactic analysis of ‘Mary eat -s pizza with a fork’ yielding *(Mary)(eats)(pizza)(with a fork)*

eats= $\{legi, symb\}$
with a fork= $\{indx\}$

The ‘naive’ syntactic analysis of the current example is displayed in table 5.2 (and fig. 5.14), and in table 5.3 (in the second table only those entities are indicated that are different from the first analysis).

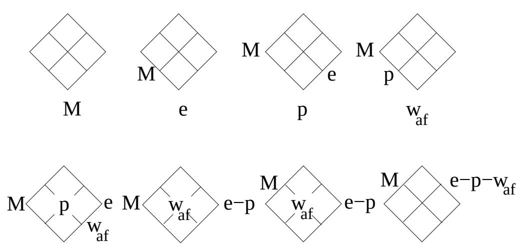

Figure 5.15: The syntactic analysis of ‘Mary eats pizza with a fork’ (alternative #1) yielding *Mary eats pizza-with-a-fork*

nr.	qual	icon	sins	rhme	indx	legi	dcnt	symb	*rule*
0	Mary(M)								i
1	eat(e)	M							i, c
2	-s	e		M					i, c, c
3	pizza(p)	e	-s	M					i, c
4	with(w)	p		e-s			M		i, c, b, c
5	a(a)		w	p			e-s		i, c, c, c
6	fork(f)		a	p		w	e-s		i, c, c
7		f			a	w	p		c, c, c, c
8				f	a	w	p		b_d
9					a-f	w	p		b, c
10								w-a-f	c

Table 5.1: A tabular representation of the morpho-syntactic analysis of 'Mary eat -s pizza with a fork' displayed in fig. 5.14

nr.	qual	icon	sins	rhme	indx	legi	dcnt	symb	*rule*
0	Mary(M)								i
1	eats(e)	M							i, c
2	pizza(p)		e	M					i, c, c
3	with a fork(w_{af})	p		M		e			i, c, c
4			w_{af}	M	p	e			c, b_d
5				M	w_{af}	e-p			c
6					w_{af}	e-p	M		b
7							M	e-p-w_{af}	b

Table 5.2: A tabular representation of the syntactic analysis of 'Mary eats pizza with a fork' (alternative #1) displayed in fig. 5.15

nr.	qual	icon	sins	rhme	indx	legi	dcnt	symb	*rule*
3'	with a fork(w_{af})	p		M		e			i, c, c
4'			w_{af}	p		e	M		c
5'				p	w_{af}	e	M		b_d
6'					p-w_{af}	e	M		b
7'							M	e-p-w_{af}	b

Table 5.3: The syntactic analysis of 'Mary eats pizza with a fork' (alternative #2) yielding *Mary eats-pizza with-a-fork*

nr.	qual	icon	sins	rhme	indx	legi	dcnt	symb	*rule*
0	Mary(M)								i
1	is(i)	M							i,c
2	a democrat (ad)		i	M					i,c,c
3	and(&)	ad		M		i			i,c,c
4					ad	i	M		c,c
save									
5	proud(p)								i
6	of it(oi)		p						i,c
7			oi		p				c,c
8					p/oi				c,a
coordination									
9					ad&p/oi				
restore									
10					ad&p/oi	i	M		
11							M	i-ad&p/oi	b

Table 5.4: The syntactic analysis of 'Mary is a democrat and proud of it'

5.4.2 Coordination

The second example is the coordination structure 'Mary is a democrat and proud of it', which is morpho-syntactically analyzed as: *(Mary)(is)(a democrat)(and)(proud)(of it)*. The syntactic relational needs of the symbols are defined as follows:

is= $\{legi, symb\}$
proud= $\{indx\}$
of it= $\{indx\}$

The syntactic analysis of this utterance is depicted in table 5.4. In step 8, two index signs, proud and of it, are bound through accumulation in a single expression: proud of it, having a single *a*-need in the index class. The coordination of proud of it with a democrat is possible, as both symbols can be 'is'-complements, syntactically.

5.4.3 Discontinuous modification

The last example is the sentence 'A man entered who was covered with mud', which is morpho-syntactically analyzed as: *(A man)(entered)(who)(was covered)(with mud)*. In the syntactic parsing (see table 5.5), the segment beginning with the symbol who and ending with the sentence ending dot is analyzed recursively.

nr.	qual	icon	sins	rhme	indx	legi	dcnt	symb	*rule*
0	a man (a_m)								i
1	entered(e)	a_m							i,c
2	who(w_h)		e	a_m					i,c,c
recursion									
3	was covered (w_{cd})	w_h							i,c
4	with mud (w_m)		w_{cd}	w_h					i,c,c
5			w_m	w_h		w_{cd}			c,c
6				w_h	w_m	w_{cd}			c
7					w_m	w_{cd}	w_h		c
8							w_h	w_{cd}-w_m	b
return									
9	who-...-mud(w_{cm})		e	a_m					i
10			w_{cm}	a_m		e			c,c
11				a_m	w_{cm}	e			c
12						e	a_m-w_{cm}		b
13							a_m-w_{cm}	e	c

Table 5.5: The syntactic analysis of 'A man entered who was covered with mud'

The syntactic relational needs of the symbols of the current example are:

entered= $\{legi, symb\}$
was covered= $\{legi, symb\}$
with mud= $\{indx\}$

In the recursively analyzed segment, who is considered as the syntactic subject. In the end, the sentence sign of this nested segment is degenerately represented as a single quality (w_{cm}). By virtue of the referential properties of who, w_{cm} is represented in the nesting phenomenon as quale, having adjective-like syntactic properties.

Part III

Knowledge domains

Testing the uniform representation potential of the theory developed so far is pursued in this part by applying it to other domains of knowledge, besides 'naive' logic and language. To this end, the theory is refined by means of the introduction of a more elaborate model for the representation of memory signs. The extended theory is applied to 'naive' semantic syntactic, 'naive' reasoning and mathematical sign processing.

By leaving the domain of 'naive' syntactic signs, characterized by the availability of a lexical definition of combinatory properties of qualia, we are facing with less well studied domains, in which such a definition may not be available. As a consequence, the elaboration of the examples given in this part will capitalize on the reader's intuitive understanding of the input qualia, including their combinatory properties. Having said this, this part also considers the question how a lexical definition of qualia can be systematically derived in any knowledge domain.

Chapter 6

Semantic syntactic signs

Signs that fall outside the domain traditionally acknowledged as syntactic, but that nevertheless can be treated syntactic-like are called in this thesis 'naive' semantic syntactic signs. The above definition indicates that the difference between 'naive' syntactic and 'naive' semantic syntactic symbols can be reduced to a difference in the way their symbols call for another symbol in a symbol nexus. In order to simplify the presentation below, the expressions 'semantic' and 'semantic syntactic' are used interchangeably. As the focus of this thesis is on 'naive' language processing, the 'naive' prefix can be omitted.

Besides illustrating the potential of the theory of this thesis for modeling semantic sign processing, the question will be discussed how knowledge obtained in different domains can be amalgamated in a single representation. This is not the first time that we are facing with different interpretations of the same representamen (potential sign). For example, input symbols may be interpreted from the syntactic point of view, as syntactic signs, but the same entities also may be interpreted from the logical stance, as logical signs. For instance, in sect. 5.4.1, 'with a fork' is syntactically interpreted as a syntactic complement (syntactic modifier), but the same expression may as well be interpreted as a logical complement ($\neg B$).[1]

A distinguishing property of 'naive' semantic signs is that they can more aptly capture the diversity of 'real' world phenomena than 'naive' logical or syntactic signs. By leaving the domain of (morpho-)syntactic symbols, this chapter enters a new domain in which a lexical definition of combinatory (rela-

[1]Cf. figure 5.10 and 5.15.

tional) properties of symbols may not be available. The premise of this chapter is that, on the basis of the Peircean categorization of phenomena, a systematic specification of the relational properties of the symbols of a domain is possible, nevertheless.

Preceding the introduction of a model for semantic sign processing, this chapter begins with a brief overview of the properties of semantic qualia (sect. 6.1). This is followed by the presentation of a theory for memory representation (sect. 6.2) and a discussion of some of the consequences of that representation for a trichotomic specification of semantic qualia (sect. 6.3 and 6.4). The chapter is closed with an example (sect. 6.5).

6.1 'Naive' semantic syntactic qualia

Memory qualia are a representation of input qualia (re)cognized in earlier observations. This may also include qualia arising from complex signs, through a degenerate representation. Input qualia can be interpreted from different points of views. One of them is the logical stance, which is traditionally accepted as the most general interpretation of a phenomenon.

Evidence for information processing by the brain in knowledge domains is found, amongst others, in neuro-physiological research on language comprehension and production (Deacon, 1997). Results of that study indicate that syntactic symbol processing in one's mother tongue shows such a degree of automatism (cf. habitualness) that its rules are evolutionary organized in separate unit of the brain, the Broca area (Rizolatti & Arbib, 1998), (Arbib, P.Erdi, & Szentagothai, 1997), (Musso, Moro, Glauche, Rijntjes, & Reichenbach, 2003), amongst others.

In the proposed theory of 'naive' language processing, memory is modeled by the lexicon, containing information about the relational properties of primary language entities, represented as memorized states (a') and effects (b').[2] Following the assumption of sect. 5.1.2, the combinatory potential of syntactic symbols can be modeled as a neutral (n), passive (p), and active (a) relational need, defining the induced hierarchy: $n<p<a$ (throughout this chapter, '<' is used as a polymorphic order relation).

Syntactic signs may uniformly represent different relations existing between symbols, as constituency relations. For example, the relation between nice and girls, and interesting and girls, but also the relation between runs and slowly, and runs and fast can be uniformly represented as syntactic modification relations.

[2] Effect qualia may also refer to an appearing new fact or property.

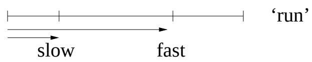

Figure 6.1: The continuous domain of 'run' effects. Slow and fast are symbolic representations of different measures of this domain.

However, there is a clear difference between those relations, from a semantic syntactic stance. In the first two examples, girls can be semantically interpreted as a possible constituent (rheme),[3] and nice and interesting as expressions of different semantic values. This relation between the two adjectives can be expressed as an ordering of *discrete values* of some states: nice<interesting, assuming interesting contains the more meaningful aspect of selection, as opposed to nice which is only interpreted as a general reference.[4] In the last two examples, run can be semantically interpreted as a rule-like property (legisign), and slow and fast as different *measures* of the continuous domain of 'run' effects: slow<fast (see fig. 6.1). This hidden potential of semantic syntactic signs will be explored in the classification of their relational needs, as value/measure elements of semantic trichotomies. In 'naive' language processing, syntactic values/measures (cf. syntactic relational needs) can be captured in a few trichotomies. This is opposed to semantic values/measures that may be more abundant.

6.2 Memory representation

In this section, a representation satisfying the requirements set for memory signs above is introduced on the basis of an analysis of the properties of the neural organization of the brain. It will be assumed that in cognitive processing, (re)cognized input qualia are always stored in a non-deleting memory. According to the model of sect. 2.3 input qualia can be interpreted either as a state or as an effect, depending on their appearance in the current and previous input percepts. From the assumption of economic information processing by the brain, it follows that the representation of memory qualia must be *homogeneous*. In turn this implies that the collection of *a'* and *b'* memory signs may arise through different interpretations from same memory qualia. The benefits of a homogeneous representation of memory information may be illustrated by

[3]In this chapter too, the Peircean signs are used as references to the status of a sign in the process of sign recognition.

[4]This point will be explained later, in sect. 6.3.1.

the potential of memory qualia of '`run`' events to be interpreted as a nominal state (*a*') or as a verbal effect (*b*').

The input of cognitive activity too is homogeneous, as the input percepts are 'static' representations of observed phenomena. It is due to the interpretation of those percepts, as an interaction between some state and effect, that they are conceived as an event.

6.2.1 Practical limitations

The assumption of a finite non-deleting memory of the brain may not be consistent with the assumption of a potentially infinite number of different observations. The impact of this mismatch can be reduced by making use of *filtering*, that is, rejecting input qualia if the difference between their value and the value of the triggered memory response is below a certain threshold. A consequence of filtering is that memory signs always stand for a generalization of perceived sensory qualia.

Another practical problem is the limited speed of information processing by the brain. This problem can be tackled by refraining from the interpretation of individual memory response qualia, and interpreting signs as representing qualia collections.

6.2.2 Average value representation of state qualia

Motivated by the solution of the problem of processing speed by the brain, *a*'-type memory signs are defined as an average value of the memory qualia responding the *a*-type input trigger (see fig. 6.2, on the left-hand side). This representation may be called 'natural', in virtue of the brain's potential for storing qualia of some sort, in brain areas. By reacting on the input stimulus, neurons of a brain area may simultaneously become active and generate a response. In the current model it is metaphorically assumed that the average value of *a*'-type memory signs could be generated from qualia stored by the neurons of a responding brain area.

6.2.3 Dense domain representation of effect qualia

Stored values of *b*-type input qualia of some sort are assumed to be collected by the brain in dense domains. Effect type memory signs (*b*') are representations of such collections (see fig. 6.2, on the right-hand side). These representations too may be called 'natural', in virtue of the potential of the brain to organize

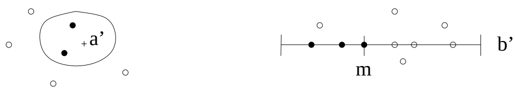

Figure 6.2: Average value (*a'*) and dense domain (*b'*) representation of memory qualia. A '•' and a '∘' symbol refer to a responding and a non-responding neuron, respectively; *m* is a representation of a measure; the average value represented by *a'* is indicated by a '+'.

neurons in linked structures. Conceptually, a domain of effect qualia can be represented as a *chain* of neurons. A chain, as an ordered set (Birkhoff & Bartee, 1970), may be favorably used for deciding whether the input effect precedes or succeeds a certain element of the chain, simply by means of comparing their values. According to (Goldstone & Barsalou, 1998), comparison is a 'natural' binary operation of the brain.

6.2.4 The duality of representation

Memory qualia are representations of input qualia obtained in earlier observations. As memory signs arise from individual memory qualia by means of generalization, they may not refer to actual phenomena, indicating that their meaning is *prototypical.* Because the representations of memory qualia (memory information) as averaged values (*a'*) and dense domains (*b'*) are independent, memory response signs contain the meaning of a *duality*.

Following the process model of perception introduced in sect. 3.1, the representation obtained through the complementation of input qualia with memory information can be interpreted as a sign of an actually existent entity: *a*- and *b*-type input qualia are represented as an instance of a prototypical state (*a'*) and a prototypical effect (*b'*), respectively. Inasmuch as *a'* stands for an average value, the perception process represents the observed input state (*a*) as a possible discrete value, and by the a pair: (*a*,*a'*). This is opposed to the interpretation of the input effect (*b*) as a measure of a dense domain (*b'*) of memorized effects, and by the pair: (*b*,*b'*).

The proposed memory model assumes the existence of monotonous functions mapping domains (*b'*) to linearly ordered sets of values. If those values can be associated with a symbolic representation, the domain is called a '*scale*'. A measure *m* of a domain *b'* is represented as a *relative* value, defined by the distance of *m* from the first value or *zero point* of *b'* (see fig. 6.1). Conceptually, the zero point of a domain can be defined by the threshold value of sensory perception of the corresponding effect qualities.

6.2.5 Economic memory representation

The above representation of memory qualia enables a flexible use of symbols. As qualia of different observations can be associated with identical average values and measures, the symbolic representation of memory signs can be efficiently re-used. For example, the measure 'fast' can be equivalently used for the representation of the observed motion of a race car or a rabbit, in the domain of 'race-car-speed' and 'rabbit-run-speed', respectively, in spite of the obvious differences between the absolute values of their speed. Similarly, the average value 'chair', prototypically representing anything that can be sat on, can be used to enrich any observed chair-like quality (state) with the general properties of chairs.

6.2.6 'Naive' semantic sign processing

According to the model of chapter 3, the initial signs of cognitive processing arise from the final signs of perception. In semantic sign processing the final signs of perception arise as value/measure representations of the input stimulus ($a*a$', $a+a$', $b*b$', $b+b$'). Due to the close relationship between the perception and the cognition process, also the qualisigns of cognition contain this meaning of the input. More specifically, A and $\neg A$ include the meaning of a value, B and $\neg B$ the meaning of a measure. In virtue of the dependency relation between of the signs generated by cognition, this meaning of the qualisigns is included in the meaning of all of its representations.

$A+B$, $A*B$: the expression of the input as a co-occurrence of values, represented as constituents (icon) and an event (sinsign).

$A*\neg B$, $\neg A*B$: the expression of the input as a relation between the value of the perceived state (A) and the measure of a possible effect ($\neg B$); and the other way around, as a relation between a value of a possible state ($\neg A$) and the measure of the observed effect (B). The two expressions are synonymously interpreted as a representation of a range of possible values.

$A*\neg B+\neg A*B$: the expression of a compatibility relation between the representation of the input as a possible value ($A*\neg B$) and measure ($\neg A*B$). Or, alternatively, the specification of the values (A and $\neg A$) and measures ($\neg B$ and B) that can be rule-like combined with each other. The legisign is interpreted as a representation of such a combination as a possible measure of an effect.

$\neg A + \neg B$, $\neg A * \neg B$: the expression of the context, as a relation between the values/measures indicated by the complementary input qualia.

$A + \neg B$, $\neg A + B$: the expression of the input as an implication relation between the value of the observed state (A) and the measure of the observed effect (B). The value of A implies the measure of B, and the other way around. The two expressions are synonymously interpreted as a representation of an actually existent value.

$A * B + \neg A * \neg B$: the expression of A as a value affected by the measure indicated by B, in the light of a similar interpretation of the complementary qualia. Or, alternatively, a representation of the input as a measure of a conventional property appearing as an effect.

A *is* B: the expression of the state A undergoing the effect of B. A is interpreted as a value affected by the measure represented by B, and the other way around, indicating the potential of the argument sign to be used as a state or as an effect, in a subsequent recognition process.

6.3 Semantic symbol processing

As the model of 'naive' semantic syntactic symbols is not fundamentally different from the earlier model of syntactic signs (see sect. 5.1.3), a definition of a model for semantic sign processing is omitted. However, syntactic and semantic syntactic concepts are different. For instance, semantic dicent signs (cf. syntactic subject) may represent the 'patient' or 'agent' of the predicate of a sentence. Because the semantic terminology used here is restricted to a small subset, semantic syntactic concepts will be introduced in the examples on the fly.

The existence of a close relationship between 'naive' syntactic and semantic syntactic sign processing is an assumption also shared by traditional language modeling. According to that view, the semantic structure of the input can be built upon or developed in parallel with the syntactic structure. Following the theory of this thesis, the two types of interpretations can be developed independently and their results can be merged in a single representation by means of structural coordination. The isomorphism between their models supports the view that syntactic and semantic syntactic sign processing could be simultaneously established by the brain/mind. Experimental evidence supporting this view is found in (Hagoort, Hald, Bastiaansen, & Petersson, 2004).

6.3.1 Trichotomic specification

According to the proposed model, the combinatory properties of 'naive' semantic signs can be specified by means of trichotomies (see sect. 3.5). While 'naive' syntactic symbols can be characterized by a relatively small collection of general properties, semantic syntactic signs may require a vast number of specific rules. Although semantic signs too can be specified in terms of (semantic) n-, p-, and a-needs, the diversity of semantic syntactic phenomena may demand a recursive classification of combinatory properties by means of trichotomies. Recursive classification is possible, as the signs of the 'naive' semantic domain can be classified on the basis of the category exhibited by their objects. As a result, a hierarchical ontology of in principle arbitrary depth can be constructed. Notice that it is always the combinatory potential of states and effects, represented as values and measures, respectively, that can be recursively specified as a trichotomy. Theoretically, such a specification can be given for any knowledge domain.

Recursive classification could also be practical for the specification of 'naive' syntactic qualia, for example, for a classification of verb complementation phenomena. A verb can have a number of complements and an a-need for each one of them. A recursive classification of the a-needs of a verb may be useful for the specification of an order for the realization of verb-complement relations. In English, the number of verb complements can be zero, one, or two, indicating the possibility for a trichotomic specification. For example, give, give a book, and give Mary a book, respectively.[5].

Potential evidence for the use of semantic trichotomies in natural language processing, more specifically, in the recognition of adjective-noun combinations, has been experimentally proved by (Draskovic, Pustejovsky, & Schreuder, 2001). The results of that study indicate that such combinations can be distinguished in three types (defining a trichotomy): intersective, subsective compatible and subsective incompatible.

An intersective type of adjective–noun combination is a 1st (cf. sect. 3.5), representing something existing. An example is yellow car, referring to an entity that is both yellow and is a car, intersectively:[6] yellow is a potential meaning, which is actualized by car (see fig. 6.3).

[5]Although in certain cases there may be a third complement, it is always subordinated to one of the other complements, that together form a single unit, for example, John gave Mary her coffee black.

[6]Assume there are many things around, some of which are yellow. Then the utterance, "Show me a yellow one", can be meaningful.

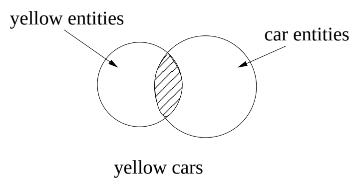

Figure 6.3: A sample intersective nomen-adjective relation

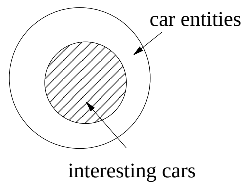

Figure 6.4: A sample subsective nomen-adjective relation

A subsective compatible adjective–noun combination is a 2nd, including the meaning of a link between two entities that are both meaningful. An example is interesting car. There can be various cars around, and we may select a subset of them by means of pointing to certain cars through interesting.[7]. This is illustrated in fig. 6.4. The meaning of car is restricted by means of interesting, which entity is complementing car in a negative sense (cf. logical complementation as negation).

A subsective incompatible combination is a 3rd, representing the conventional use of a rule involved in the meaning of certain adjective-noun combinations. An example is fast car. A car can be fast, because its meaning contains the meaning of speed, which in turn can be modified by fast in the intersective or subsective compatible sense of combination. Car and fast that are meaningful symbols both, together define the meaning of fast car.

The findings obtained in the experiments testing the semantic interpretation of the three types of combinations show the differences in terms of computational complexity with intersective combinations being the simplest and the two subsective types being progressively more complex (Draskovic et al., 2001).

[7] "Show me an interesting one", can only be interpreted, if a collection of entities is already selected.

6.3.2 Semantic syntactic relational needs

A trichotomic specification of qualia enables the definition of a natural order relation ('$<$') on semantic relational properties, representing semantic signs. An element of a trichotomic classification will be called a 1st, a 2nd, or a 3rd, indicating the category exhibited by the semantic sign potentially obtained by establishing the semantic relation of the element in question. In the examples of this chapter, the category associated with the semantic combinatory potential of a symbol is expressed by means of an integer given in parentheses. In this chapter, trichotomic specification is restricted to sign classes. For example, semantic rheme signs expressing the abstract meaning of states represented by nouns can be classified as a possible existence(1), an actual reference(2), and a conventional function(3).[8] A recursive analysis of the elements of a reference(2) division of rheme signs (referential rhematic signs) may reveal their meaning as a general(1), an indefinite(2), or a definite reference(3). For example, girl, a girl, and the girl, respectively. Similarly, semantic legisigns expressing the habitual meaning of effects represented by verbs can be distinguished, for instance, as an act of existence(1), a modification(2), or a transformation(3). For example, is, covered with mud, and disappeared, respectively. In these examples it is assumed that covered with mud may modify a state by enriching it with a property which may be removed as well, but disappeared definitely changes the state effected.

The duality involved in index signs ($\neg A{*}\neg B$, $\neg A{+}\neg B$) representing the context of a phenomenon is utilized in the present model as a potential for the expression of a relation of 'conversion' (see (Sarbo, Hoppenbrouwers, & Farkas, 2002)). An illustrative example is the verb escape ($\neg A{*}\neg B$) and its converse, the nominal running ($\neg A{+}\neg B$): if we observe the event of escaping, then there must be somebody in the state of running.

6.4 Merging different types of knowledge

According to this thesis, structural coordination is the key to an efficient merging of knowledge. The focus of this section is on the potential of the proposed representation for that operation.

The full interpretation of a symbol may arise from its interpretations in different domains, each representing a different view or aspect. As there can be numerous such aspects (and domains), and since information processing by the brain must be efficient, language symbols frequently are used ambiguously.

[8] An example for the last may be the potential thematic function of a noun, in the sentence.

For example, if we recognize 'Mary' as the syntactic subject of the sentence, and also identify 'Mary' as the agent of the predicate, then we can commonly refer to those interpretations by the symbol 'Mary', synonymously representing the two concepts.

From the analytical point of view, a synonymous interpretation of signs can be obtained through *coordination* (in the broad sense). An advantage of the uniform representation proposed in this thesis is that such an interpretation can be realized by means of *structural coordination*, merging signs exhibiting identical meaning aspects in a single representation. This potential of the proposed model can be favorably used for the definition of a simple calculus on 'meaning'. An illustrative example may be the following. Assume the recognition of symbols, in different sentences, such as (i) girl, (ii) a girl and (iii) Mary,[9] that are syntactically represented as rheme signs. In addition, assume that also a semantic syntactic analysis is offered to these symbols recognizing them as referential rhematic signs (cf. sect.6.3.2). By making use of the trichotomy of the semantic referential meaning of rheme signs, represented by the induced ordering: general<indefinite<definite, the above semantic rheme signs can be ordered as: girl<a girl<Mary (notice that synonymous semantic and syntactic signs are denoted by the same symbol). Because in an order relation a smaller (less meaningful) element can be safely omitted in favor of a larger (more meaningful) entity of the same ordering, the above three signs can be summarized in the symbol: Mary.

This simple calculus will be used, in chapter 9, for the definition of a technique for text summarization. Trichotomic specification can be applied to all signs (and interpretation moments), enabling a nonadic classification for the representation of sign interactions. This potential of trichotomic definition shall not be considered in this thesis, however.

6.5 Example

'Naive' semantic syntactic information processing is illustrated in this section by the analysis of the sample phenomenon of a running rabbit, depicted in fig. 6.5. The rabbit is on the run, perhaps because it is chased by a fox, but this information is not part of the observation. In the analysis below it is assumed that in a semantic trichotomy the linguistic expression of a less meaningful element can be derived from a more meaningful one. For instance, that escaping(3)

[9] Here Mary is assumed to refer to somebody who we are familiar with, as opposed to girl that is assumed to refer to any person.

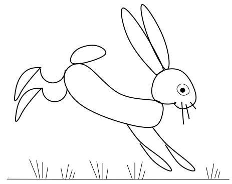

Figure 6.5: The phenomenon of 'a rabbit on the run'. The focus is on the qualia of the observed rabbit, such as its greyish form, long ears, and kind of motion. The qualia of the background, for example, the qualia of the grass, are complementary.

contains a kind of(2) running(1) event, which can be derived from the interpretation of escaping. For the analysis of the example of this section, a recursive classification of semantic signs is not needed (an illustration of such a definition will be given in chapter 9). In this section the focus is on the impact of the value/measure interpretation of memory signs on the signs generated by the recognition process.

Semantic syntactic qualia are represented as a collection of relational needs, defined on the fly. As the input qualia of a phenomenon always exhibit the category of firstness (1), this information can be omitted. An essential property of 'naive' syntactic sign recognition is that sign interactions can be represented by means of the combinatory properties of the constituent symbols. From the point of view of knowledge representation, the aspect of sequential processing is secondary. In fact, sequential sign processing is modeled in sect. 5.1.1 by considering the sequential order of appearance of input symbols, as a quale, and interpreting such qualia as a parsing algorithm (cf. coercion, accumulation and binding). In the example below, the sequential character of 'naive' semantic information processing is not considered. It will be assumed that all input qualia are present in a single observation.

The input qualia of the perception process are defined as follows. As in earlier examples, **boldface**, Sans Serif and *slanted* symbols are used for denoting input and memory signs, and the signs generated by the recognition process, respectively.

a = **observed-rabbit** (the state qualia of the observed rabbit, for example, a grayish form, long ears)
a' = prototype-rabbit (information about rabbits, such as their parts of body(2), that rabbits can become a prey(3))
b = **observed-motion** (the effect qualia of the observed motion, for example, that it is fast, rabbit-like)
b' = prototype-motion (information about rabbit-like motion, for example, that rabbits can hop(1), walk(1), run(1), escape(3))

The above definition makes tacit use of the trichotomic classification of a'-type memory signs, as an existence(1), a form(2), and a function(3). For example, potential similarity(1) with the input state, a factual list of the 'parts of body'(2) of rabbits, including a reference(2) to their known color and approximate size, and the potential of rabbits to function as a prey(3). An analogous classification of b'-type memory signs may reveal their meaning as a possible occurrence(1), an actual property(2), and a conventional use of some rule(3), for example, the property of similarity(1) with the observed motion effect with hopping and walking, the qualification of that effect as fast or galloping(2), and its interpretation as an act of escaping(3).

Following earlier observations of this chapter, semantic signs are processed analogously to syntactic signs (cf. sect. 5.1.3). A remark on the linguistic representation of semantic signs is in place, however. In 'naive' syntactic processing, the representation of a symbol interaction usually can be easily derived from the constituent symbols. An example may be nice girls, representing the syntactic modification of girls by nice. The representation of semantic syntactic symbol interactions can be more sophisticated. For example, the semantic qualification of running by fast can be represented by escaping. Nevertheless, throughout this chapter it will be assumed that adequate linguistic representations can be derived from the constituent symbols, also in the case of semantic sign interactions.

The elaboration of the perception process is restricted to a definition of its initial and final signs. In this section, the focus is on the definition of the signs generated by the cognitive process.[10]

A = $a{*}a'$: **observed-rabbit** '$*$' parts-of-body
$\neg A$ = $a{+}a'$: **observed-rabbit** '$+$' prey
B = $b{*}b'$: **observed-motion** '$*$' {running, escaping}
$\neg B$ = $b{+}b'$: **observed-motion** '$+$' {hopping, walking}

[10] In this chapter too, Peircean signs and 'naive' logical expressions are used as pointers to the status of a sign in the process of sign recognition.

A=a∗a' stands for an agreement relation between the value of the observed qualia (a) and their similarity with the average value of the parts of a rabbit's body (a'). This is represented by the symbol *rabbit(ness)* or, simply, *rabbit*. $\neg A$=a+a' represents the observed rabbit as a possible *prey*. B=b∗b' is a representation of the observed effect as an act of *escaping* motion; running(1), which is contained in the meaning of escaping(3), is expressing the observed effect as a measure in the domain of 'rabbit-run' effects. This is represented by the symbol *escaping*. $\neg B$=b+b' is an expression of the input effect as a possible 'rabbit-like motion', represented by the symbol *running*. Complementary qualia referring to the background of the observed phenomenon, such as the grass in which the rabbit is running, are not included in the current specification.

In sum, cognitive processing is engaged with the recognition of the following qualisigns:

A	=	*rabbit*
$\neg A$	=	*prey*
B	=	*escaping*
$\neg B$	=	*running*

The interpretation moments of cognitive processing are defined as follows.

A+B: the expression of the simultaneously present(2) input qualia, *rabbit* and *escaping*, as constituent values(1).

A∗B: the expression of the co-occurring input qualia as a *rabbit-like-running* event(2) that happens 'now'(1).

$\neg A$+$\neg B$, $\neg A$∗$\neg B$: the expression of a relation between(2) the complementary information of *prey* and *running*. The synonymous representation of the two index signs is an expression of their common meaning. For example, the conversion relation between *prey* as an appearing grayish form ($\neg A$+$\neg B$), and *running* as a kind of motion event by some agent ($\neg A$∗$\neg B$).

A∗$\neg B$: the expression of the potential of the observed state (*rabbit*) for moving in a rabbit-like fashion (*running*), as a relation between their value and measure, respectively. For example, if the rabbit is perceived as a certain form and color (A), then now it is known that potentially it may be able to hop, walk, and run ($\neg B$). This rheme sign is referring to the input as an abstract entity represented as a range(3) of possible(1) values, that may be called *abstract-rabbit*.

$\neg A$∗B: the expression of the range(3) of possible(1) entities (*prey*) capable of rabbit-like galloping (*escaping*). This may be called *rabbit-like-running* (as a value). Notice that galopping(2) is contained in the meaning of escaping(3), and rabbit-like is contained in the meaning of prey(3).

The synonymous interpretation of the two rheme signs obtains the abstract meaning of the input state as *a-rabbit-that-may-be-a-prey*.

$A{*}\neg B{+}\neg A{*}B$: the expression of the rule-like compatibility of 'abstract rabbit' ($A{*}\neg B$) and 'rabbit-like running' ($\neg A{*}B$), as measures of some effects. This may be called *running-as-a-rabbit*.

$A{+}\neg B$: the expression of the input as an actually existing *rabbit*(3) undergoing(2) some rabbit-like running motion(2). As $\neg B$ contains the meaning of the perceived effect (B) as a possibility, this dicent sign represents the fact that our rabbit is actually affected by the observed event (*escaping*).

$\neg A{+}B$: the expression of the input as an actually occurring *escaping* event(3) of some entity qualifying(2) for a *prey*. As $\neg A$ contains the meaning of the perceived state (A) as a possibility, this dicent sign represents the potential of the observed *escaping* effect to also apply to the observed state (*rabbit*).

The two dicent signs above synonymously represent the input as *a-rabbit-escaping-as-a-prey* or as an entity *running-as-a-rabbit*. Because *escaping* is an active expression of the verb, the dicent sign can be interpreted as a representation of the observed rabbit as the agent of the observed event.

$A{*}B{+}\neg A{*}\neg B$: the expression of the conventional property(3) of the input as an escaping rabbit (*rabbit*escaping*), in the light of(2) its possible interpretation as a prey (*prey*running*). This may be called *running-as-a-rabbit-escaping-as-a-prey*.

A *is* B: the expression of the hypothesis that the observed *rabbit IS escaping*, representing the input as a proposition(3) of a perceptual judgment(3). Finally, this proposition may be paraphrased as *a-rabbit-on-the-run*.

6.6 Summary

'Naive' semantic syntactic signs are an example of a domain in which a definition of the combinatory properties of the primary symbols may not be available. The results of this chapter indicate that such a definition could be systematically given by means of trichotomies. The trichotomic specification of qualia is compatible with the process model of cognitive activity. This is illustrated by the signs of the semantic processing of a sample phenomenon. The idea is suggested that, due to its uniform character, the representation proposed in this thesis may enable the merging of interpretations found in different domains, by means of structural coordination.

Chapter 7

Reasoning signs

Reasoning can be defined as our potential for deriving conclusions from premises, using a given methodology. The goal of this chapter is the introduction of a model for 'naive' reasoning as a kind of sign recognition. An account of the properties of the major methods of reasoning is given by means of Peirce's analysis of logical reasoning as a form of authentic semiosis. The focus of this presentation is way more restricted however, as it only attempts to justify that reasoning, interpreted as a process, contains Peirce's nine signs as meaning aspects. The results of this chapter reinforces an earlier conjecture of this thesis, that *all* representation of human knowledge or 'logos', be it low- or high-level, could be based on a single type of process.

The structure of this chapter is the following. After a Peircean analysis of the properties of reasoning, as a methodology, a process model for 'naive' reasoning is introduced. This is followed by an illustration of the proposed model, by an extended example. Finally, in a closing section, the model of 'naive' reasoning is analyzed from the syllogistic point of view.

7.1 Logica Utens

In ordinary life everybody has a reasoning instinct or habits of reasoning by which he forms his opinions concerning many matters of great importance (Fann, 1970). We not only have a reasoning instinct but we have an instinctive *theory of reasoning*, for every reasoner "has some general idea of what good reasoning is" (CP 2.186). According to Peirce, such a theory of reasoning, antecedent to any systematic study of the subject, constitutes our *logica utens* (CP 2.189), the acritical and implicit or 'naive' logic of the common man. Because we do not possess a full stock of instincts to meet all occasions, we study the process of reasoning and inquire the methods by which we can most efficiently advance our knowledge. The result of such a study is called *logica docens*, or formulated, scientific and critical logic (see CP 2.204).

By our logica utens we are able to guess right in many instances. This ability may be regarded as the result of the adaptation of the brain/mind to the universe. But, where our instinctive reasoning power begins to lose its self-confidence, as when we are confronted with extraordinary or unusual problems, we look to the help of our logica docens (Fann, 1970). Though "reasoning, properly speaking, cannot be unconsciously performed" (CP 2.182), in this chapter the hypothesis is raised that our logica utens naturally follows from our potential for sign processing and, in turn, the logica docens may stem from this implicit or 'naive' logic of the brain.

7.1.1 The three modes of inference

Thoughts are the ground for any inference, and any thought is a proposition which is a premise. As our propositions are hypotheses, inferences and hypotheses are closely related.

The three major modes of inferencing can be characterized as follows. Deduction explicates hypotheses, deducing from them the necessary consequences which may be tested. Induction consists in the process of testing hypotheses, that is, the determination of a value. Abduction is the process of forming explanatory hypotheses (see CP 5.171). From this specification, the following properties of the three types of reasoning can be derived.

In *deduction*, initially, we know something (a hypothesis or belief) and in the end we know something more. This 'increase' of knowledge is due to the additional information deduced about the object that is in our focus, revealing its *other* properties.

Induction consists in testing whether an entity does or does not possess a certain property. That we have knowledge about the property to be tested implies the existence of other entities we learned in earlier inductive inferences. Successful testing indicates that the current entity is found to be similar to the entities that we are already aware of. This similarity can be expressed as a measure of the property inductively derived from those entities. An example for such a property can be 'motion', such measures can be 'walking', 'running', or 'galloping'.

The above specification does not reveal the properties of *abduction*, except that abductive reasoning must be a process, 'generating' propositions that are hypotheses. Insofar as, in logical reasoning, propositions appear as premises and such premises are hypotheses, the conclusion can be drawn that all knowledge must initially arise from abductions. Peirce defined abductive inferencing as follows:

> *The surprising fact C is observed. But if A were true, C would be a matter of course. Hence, there is reason to suspect that A is true (CP 5.189).*

Such a process is inferential, because the hypothesis "is adopted for some reason, good or bad, and that reason, in being regarded as such, is regarded as lending the hypothesis some plausibility" (CP 2.511). As Peirce pointed out, abduction is "the only logical operation which introduces any new idea" (CP 5.171).

The goal of this chapter is to show that this corollary of abduction may be the key to an explanation of the relation of abduction with the other two modes of inference. By revealing the properties of that relation, this chapter makes an attempt to justify the conjecture that sign recognition, as a process, contains the meaning of the three modes of inference, as meaning aspects. But the results of this chapter can be of interest also for another reason. By proving that 'naive' reasoning can be modeled isomorphically to 'naive' logical, (morpho-)syntactic and semantic syntactic information processing, the possibility for the definition of a practical calculus of signs are significantly increased.

7.2 Towards a model for 'naive' reasoning

This section is an attempt to show that the interpretation of memory signs, according to the theory of this thesis (see sect. 6.2), provides the ground for establishing a link between Peirce's nonadic signs, as meaning aspects, and his concept of perceptual judgments. According to Peirce (Murphy, 1961):

> *Every judgment consists in referring a predicate to a subject. The predicate is thought, and the subject is only thought-of. The elements of the predicate are experiences or representations of experience. The subject is never experimental but only assumed. Every judgment, therefore, being a reference of the experienced or known to the assumed or unknown, is an explanation of a phenomenon by a hypothesis, and is in fact an inference.*

Perceptual judgments are propositions about the 'real' world. Following the model of this thesis, propositions are representations, 'generated' by the process of sign recognition. This relation between perceptual judgments and the model of cognitive activity introduced in sect. 2.3 can be made more explicit by establishing a link between the above mentioned properties of perceptual judgments, and the interpretation moments of the processing schema. The interesting events are $(\mathsf{q}_1,\mathsf{C})$ and $(\mathsf{q}_2,\mathsf{C})$, representing the input state and effect in context, as an actual existent (subject) and a conventional property (predicate), respectively. In the model of perception, in sect. 4.3, $(\mathsf{q}_1,\mathsf{C})$ and $(\mathsf{q}_2,\mathsf{C})$ are represented by (a,a') and (b,b'), respectively, expressing the input qualia as instances of prototypical memory signs. For example, (a,a') is interpreted as an instance of a' triggered by a, arising from a_{-} (rheme), through complementation by a' (index). Although a' itself is thought, the complementation operation may only link a subset of the prototypical properties of a' to a, in the sense of agreement. Furthermore, as a may contain qualia that do not match the information stored in memory (such input qualia may indicate a novel value of a sort of quale, for example), (a,a') may only represent an input meaning that is imagined or 'thought-of'.

For example, if the input a consists of the qualia obtained through the observation of an oak tree, then a' may represent the prototypical concept of oak trees (an average value of their known qualia). The complementation of a with this a' enables the interpretation of this input as an actually existing instance of an oak, independently from the specific properties of the observed tree, for example, whether it has leaves, or is a sapling, or an old tree. The dicent sign of perception, (a,a'), is a representation of such an input meaning.

The interpretation of (b,b') is completely different. Similarly to a', also prototypical b' memory signs are 'thought'. However, due to the representation of stored effect qualia in a dense domain (see sect. 6.2.3), the input b always can be interpreted as a measure or a subset of b'. As b' is thought and b is a subset of b', (b,b') too must be a representation which is '*thought*'.

7.2.1 Sign interactions and inferences

By looking more closely at the process of perception, in particular at the interactions that generate (a,a') and (b,b'), meaning aspects of inferences can be discovered. This may be explained as follows.

By recognizing a as an instance of a', two goals can be achieved. First, known (combinatory) properties of a can be deduced from a'; second, novel properties of a can be used for extending the meaning of a', by means of memorization.

Either way, a representation of an entity satisfying certain properties can be deductively derived. Such a process has the element of deduction.

Similarly, by recognizing b as a measure of b', two goals may be attained. First, b can be tested for the property indicated by b', that is, whether b can be a measure of b'. Second, the property indicated b' can be generalized for b, that is, the domain b' can be adjusted by b, as a potentially new element. Such a process strongly resembles to induction.

Due to the aspect of generalization included in the meaning of the dense domain representation of effect qualia, the potential for inductive generalization is possessed by the sign recognition process by definition. This means that the testing of b may not involve the aspect of a genuine generalization, but may be a product of the recognition of a meaning that is potentially general by definition.

Deduction and induction, interpreted as meaning aspects, can be shown to be present in the *complementation* sign interactions generating the dicent and symbol signs of cognition as a process. Since the qualisigns of that process are defined as a re-presentation of the final signs of perception, A ($\neg A$) and B ($\neg B$) naturally inherit the meaning of a value and a measure, respectively, and this meaning of the qualisigns is also present in all other signs brought about by cognitive processing. For example, the index sign ($\neg A$+$\neg B$, $\neg A$∗$\neg B$) may be interpreted as a compatible pair of a measure of an effect ($\neg B$) and a (scale) value of a state ($\neg A$). The legisign (A∗$\neg B$+$\neg A$∗B) may be interpreted analogously. The interaction between the index sign and the legisign may be interpreted as an adjustment (cf. complementation) of the measure (and domain) included in the meaning of the legisign, by the (scale) value indicated by the index sign. Such an ‘intensional’ enrichment of a domain, introducing new values of an effect, has the aspect of induction. Similarly, the interaction between the rheme sign and the index sign may be interpreted as an adjustment (cf. modification) of the value included in the meaning of the rheme (A∗$\neg B$, $\neg A$∗B), by new values indicated by the index sign. More specifically, the value represented by A∗$\neg B$ may be extended by the value indicated by $\neg A$∗$\neg B$, and the value of the measure represented by $\neg A$∗B, by the value indicated by $\neg A$+$\neg B$. Such an ‘extensional’ modification of a domain, introducing new values of a state, has the aspect of deduction.

Finally *predication*, the interaction between the dicent (A+$\neg B$, $\neg A$+B) and the symbol sign (A∗B+$\neg A$∗$\neg B$), interpreted as a proposition which is a hypothesis, has the aspect of abduction. Also *sorting* and *abstraction* (via inheritence), eventually representing the input as an abstract state (rheme) and effect (legisign) or, as premises of a later ‘naive’ deductive and inductive inference, respectively, have the aspect of abduction (degenerately, in the logical sense).

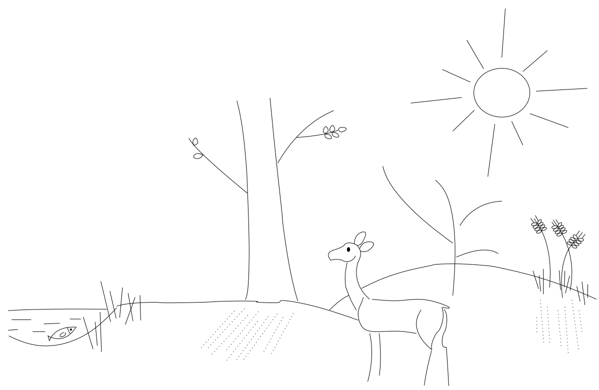

Figure 7.1: Bambi is staring at his marking tree. On the basis of the shadow casted by the tree, he decides to turn to the right, branch towards his grazing land.

7.3 An extended example

Cognitive activity as a 'naive' reasoning process is illustrated in this section by means of an analysis of an extended example. The aim of this analysis is an attempt to show that also 'naive' reasoning can be modeled as a kind of sign recognition process, in which, the arising signs exhibit the aspects of a minor, and a major premise, as well as the conclusion of a logical inference.

The example introduced in this section is about the deer Bambi (see fig. 7.1). More specifically, the focus will be on the phenomenon, in which, Bambi, walking in the forest, arrives at a certain location of his path. This location is marked by a tree, indicating a branch of the path in two directions: one, leading to Bambi's grazing land, and another, to his watering place, a lake. Every day, Bambi follows his path, and every time he branches to the pasture, if the sun has not yet reached its zenith, and to the lake otherwise. In the example it will be assumed that the marking tree is the only information about the location of branching and, that the tree looks naturally. The deer arrives at this branching point before noon where, following his habit, he turns right, to the east, towards his grazing land.

This section contains an analysis of the recognition of the marking tree, from Bambi's point of view. In addition, it will be assumed that the observed phenomenon is embedded in another one, which only differs from the nested phenomenon in a single quality: Bambi feels hungry. The focus will be on the interpretation moments of the process of cognition. The specification of the perception process is restricted to a definition of its initial and final signs (and the latter only as the qualisigns of the process of cognition). In the example below, interpretation moments can be indicated by their 'naive' logical expressions. Synonymous signs can be referred to by means of identical symbols. In the specification of the input of perception only the qualia appearing in Bambi's focus are defined, a definition of the complementary input qualia is omitted. Like in the previous chapter, the explanations of the sign interactions capitalize on the reader's knowledge about the input qualia, including their combinatory properties.

The qualisigns of perception are:

a	=	**tree-at-branching**
a'	=	marking-tree-prototype
b	=	**shadow-on-the-left**
b'	=	branching-state-prototype

The qualisigns of cognition are:

A	=	$a{*}a$'=	*tree*
$\neg A$	=	$a{+}a$'=	*other-tree*
B	=	$b{*}b$'=	*to-branch*
$\neg B$	=	$b{+}b$'=	*not-to-branch*

Here, A=*tree* stands for a tree where branching may occur; B=*to-branch* represents the need for branching, as an appearing property.

Although the specification of the complementary qualia of perception is beyond the goal of the current analysis, an example of such a memory sign may be a'=tree-prototype, indicating the prototypical meaning of marking-trees, as a possible interpretation of a=**tree-at-branching**. An example of a complementary input sign can be a= **tree-not-at-branching**, referring to a tree in the surroundings where any action (including branching) may possibly take place.

The qualisigns of cognition may be explained as follows. The deer is looking at the marking tree, rising at a certain location of his path (A). He may also see other trees and shadows, but those are not in his focus ($\neg A$). Suddenly he observes the appearing shadow of his marking tree, indicating the potential need for branching (B). He may also notice the appearance of other objects, that he is not concentrating on and do not compel him to branch anywhere ($\neg B$). In the current example it will be assumed that B contains the qualia of the characteristic shadow casted by the marking tree, and $\neg B$ contains mem-

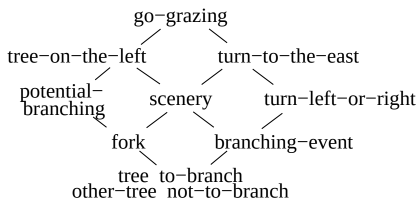

Figure 7.2: The signs of the sample branching phenomenon

ory information about the possible directions of branching, in relation to the presence of the shadow of the marking tree.

The above qualisigns only represent a potential meaning of the input. At this stage of information processing, Bambi may not 'know' that the tree he is looking at is the tree where branching may occur and, more importantly, he may not be aware of the direction he should turn to. That level of understanding may arise later as a result of the recognition process, briefly explained below. The signs generated are recapitulated in fig. 7.2.

$A{+}B{=}$ *tree+to-branch= fork*: the expression of the observed tree and branching need, as constituents of the input phenomenon.

$A{*}B{=}$ *tree∗to-branch= branching-event*: the expression of the simultaneous occurrence of the observed tree and branching need, as an event that occurs now.

$\neg A{+}\neg B$, $\neg A{*}\neg B{=}$ *scenery*: the expression of the complementary qualia as the context of the observed phenomenon. Information about the context can be necessary for the identification of the input as a marking tree. This may include information about those properties of the observed tree that make it different from any other tree ($\neg A{+}\neg B$), as well as information about the properties of the appearing branching need, such as the direction the tree is indicating and branching may follow ($\neg A{*}\neg B$).

$A{*}\neg B{=}$ *tree∗not-to-branch*, $\neg A{*}B{=}$ *other-tree∗to-branch*: the expression of the input as an abstract marking tree and branching need, indicating a range of possibilities, synonymously called *potential-branching*.

$\neg A{*}B{+}A{*}\neg B{=}$ *turn-left-or-right*: the expression of the compatibility relation between the abstract signs, $A{*}\neg B$ and $\neg A{*}B$, representing the habitual meaning of 'branching-at-a-marking tree', as a rule-like property of the observed bifurcating path.

$\neg A{+}B$, $A{+}\neg B{=}$ *tree-on-the-left*: the expression of the input meaning, as an act of branching somewhere ($\neg A{+}B$) or branching in the direction implied by the actual marking tree ($A{\rightarrow}B$); the other expression, $A{+}\neg B$, can be explained analogously. The synonymous interpretation of the two signs immediately above amounts to a representation of the input as the subject of the observed phenomenon.

$A{*}B{+}\neg A{*}\neg B=$ *turn-to-the-east*: the expression of the input as a conventional property such as 'turning-to-the-grazing land' ($A{*}B$) 'at-a-certain-location' ($\neg A{*}\neg B$). In the current analysis, the expressions 'to the east', 'to the pasture', and 'to the grazing land' are used interchangeably.

A *is* $B=$ *go-grazing*: the expression of the relation between the observed tree (A) and branching need (B), as a proposition which is a hypothesis.

Bambi may validate his hypothesis about the marking tree (*go-grazing*), by considering it in the context of the nesting phenomenon marked by the new quale: Bambi feels hungry. To this end, he may degenerately represent his final sign (*go-grazing*) as an effect quale, affecting the state represented by the quale (the feeling of) 'hungry'. By skipping the details of the corresponding preception process, the qualisigns of cognition can be defined as follows:

$$\begin{array}{lcl} A & = & \textit{hungry} \\ B & = & \textit{go-grazing} \end{array}$$

Bambi may find his hypothesis correct, if he is able to establish a true relation between the above qualisigns, for example, that he can abductively conclude that grazing may appease his hunger in all likelihood. A syllogistic representation of that inference can be the following (quantifiers are omitted):

$$\begin{array}{llll} & \textit{go-grazing} & \text{IS} & \textit{disappear-hunger} \\ & \textit{hungry} & \text{IS} & \textit{go-grazing} \\ \Rightarrow & \textit{hungry} & \text{IS} & \textit{disappear-hunger} \end{array}$$

A true conclusion can make the deer go towards his grazing field, but only if according to Bambi's knowledge, the reaction *disappear-hunger* can diminish the 'feeling of hunger'. In that scenario, *hungry* and *disappear-hunger* are considered as state and effect qualia, respectively. Establishing a meanigful relation between these qualia may represent a neutralization of the input stimulus (*hungry*). If Bambi's conclusion is in conformity with his knowledge about the world, the final sign of his 'marking tree' phenomenon will not introduce more interactions and changes, indicating that input processing may terminate. Bambi's conclusion may *not* satisfy him however, if during input processing the input stimulus somehow had changed and contains qualia that are not included in Bambi's latest conclusion. The difference induced from those qualia may reveal

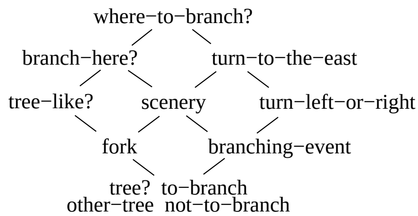

Figure 7.3: The signs of the sample damaged tree phenomenon

as a change, initiating further information processing. That possibility is not considered in the current example.

7.3.1 The need for abduction

While Bambi was away, his marking tree has been seriously injured by another deer. What happens, if Bambi arrives at his tree as usual?

Let us assume that the damaged tree *cannot* be interpreted as a potential marking tree (A), but the perception of a branching need (B) is still possible (if even that is not possible, no 'branching' would occur and Bambi would proceed without noticing anything). Given these conditions, the input qualisigns can be defined as follows:

($Perception$)

a	=	**damaged-tree-at-branching**
a'	=	tree-prototype
b	=	**shadow-on-the-left**
b'	=	branching-state-prototype

($Cognition$)

A	=	$a*a$'=	*tree?*
$\neg A$	=	$a+a$'=	*other-tree*
B	=	$b*b$'=	*to-branch*
$\neg B$	=	$b+b$'=	*not-to-branch*

The signs of the current phenomenon are illustrated in fig. 7.3. It is assumed that the damaged marking tree still qualifies as a tree. This means that, also now, the input may be recognized as a possible co-occurrence of constituents (*fork*). However, the injury of the tree hinders the recognition of a suitable rheme sign (*tree-like?*), as the current input cannot be interpreted as a 'tree-marked-branching-of-a-path' (*potential-branching*).

Although the event signs of the input impel Bambi to move ahead (go to the pasture, branch according to the position of the sun), the representation of the input as something 'tree-like' is inadequate. As a consequence, Bambi may not be able to recognize the location of branching (*branch-here?*) and his final argument sign (*where-to-branch?*) may not activate the necessary decision to branch. Bambi is vacantly staring at the tree. This is what Peirce formulated as "the surprising fact C is observed" (see sect. 7.1.1).

Bambi has now two options. Either he does not care about anything and pursues his course in the direction he followed so far, or he is waiting until the bark of the tree is sufficiently healed, thereby risking starvation.

7.4 Towards a process model of abduction

But let us help Bambi in this desperate situation. For us, his problem is almost trivial: The observed tree does not match the information about marking trees. But if we assume that the observed entity could be a marking tree, we may prove our conjecture by abductively deriving how the injury of the observed tree could have occurred. By conceptually removing any damage from the observed tree, we may be able to recognize it as a marking tree.

How can we make the above strategy work? The current input does not contain the qualia of a marking tree. Let us assume that the daily growth of the observed tree, the natural increase or decrease of its leafs does not hinder its recognition as a marking tree. As the bark of the tree is seriously damaged, Bambi is unable to link the input qualia with his memory information about marking trees. The problematic sign is the rheme ($A{*}\neg B$, $\neg A{*}B$), as it cannot be complemented by the information of the index ($A{*}B$, $\neg A{*}\neg B$). This is because the input (*tree-like?*) does not contain information enabling its interpretation as a possible location of branching. Either the observed tree is not a marking tree, or something has happened while he has been away, that deprived it from its potential to function as a marking tree.

As the input effect (B) is assumed to be correct, the interpretation of the input as an abstract state (rheme) may be improved by means of introducing new input qualia (A), via abduction. The reader may remember the assumption taken by the process model of perception (see sect. 3.1), that input as well as memory qualia can be distinguished in a pair of subsets of focused (f) and complementary qualia (c): $a{=}a_f{+}a_c$; $a'{=}a'_f+a'_c$.

For the model of 'naive' abductive reasoning, the most important are the state type memory signs (a'). In the current phenomenon, an example for a focused memory sign may be a'_f =tree-prototype. As the observed damaged marking tree qualifies as a tree, following the assumption above, there must exist complementary memory response qualia representing information about marking trees.[1] An example of such a memory sign may be a'_c =marking-tree-prototype. An illustration of the two subsets of input qualia, a_f and a_c, will be given in sect. 7.5.

7.4.1 A revised model of perception

Abduction can be modeled by means of interpreting the difference between a' and a, as an effect conceptually transforming a to a'. This understanding of abduction involves a 'shift' of focus from a to its relative difference with a': we take a different look at the input phenomenon. Here is an illustrative example.

If we know what marking trees generally look like, and what the difference between the input qualia (a_f) and their prototypical concept (a'_c) is, then we may obtain the qualia of a marking tree by removing or *abstracting* that difference ($a'_c \setminus a_f$) from the input.

The reader may remember that, according to the model of cognitive activity presented in sect. 2.3, the input qualia arise from the input percepts through a comparison operation. For example, the input effect qualia are defined as a relative difference of current and previous percepts, represented as sets. Most importantly, it is the previous percept that is 'subtracted' from the current one, indicating that the current percept is interpreted by cognitive activity as a 'goal' that the previous percept is conceptually transformed to, by the current interaction. The above example shows that this principle can be naturally generalized to the abduction of novel input qualia.

The generation of a relative difference between a' and a can be accomplished analogously to the generation of the input qualia of the perception process: a- and a'-type qualia that are related to each other in the sense of agreement may generate a new state (*new-a*), those related to each other in the sense of possibility, a new effect (*new-b*).[2] In the definition below, '$*$' and '$+$' denote a relation in the sense of agreement and possibility, respectively. '$\setminus$' stands for the operation 'relative difference'. For example, $a'_c \setminus a_f$ is an expression of qualia

[1] It must be so, because Bambi does have knowledge about marking trees, according to the analysis of sect. 7.3.1.

[2] This generation of new qualia capitalizes on the assumption of a homogeneous representation of memory information by the brain (see sect. 6.2).

that are elements of a'_c, but are not included in a_f. Notice that a relation in the sense of agreement is only possible between qualia that are in the focus (a'_f and a_f); a relation in the sense of possibility may exist between all other combinations of the qualia, such as, a'_c and a_f, a'_f and a_c, and a'_c and a_c.

$$\begin{aligned} \textit{new-a} &:= a'_f * a_f \\ \textit{new-b} &:= a'_c \setminus a_f + a'_f \setminus a_c + a'_c \setminus a_c \end{aligned}$$

In the revised model of perception it is assumed that abducted new qualia are type-wise merged with the original input. The rationale behind this step is that it enables the entire input to be recognized as a state (a) undergoing the abducted new effect (*new-b*), transforming it to another state (a').

The potential analogy of this model with the model of apparent motion perception may be used for an explanation of the importance of relative difference in the definition of *new-b*. By considering the input (a_f) and the memory response qualia (a'_c) as subsequent pictures of a film, their difference can be interpreted as an effect, transforming the previous picture into the next one. Another illustration of abduction can be the following example taken from natural language. Consider the 'naive' semantic language phenomenon defined by the qualia: a_f=**girl**, a'_c=beauty. The difference between beauty and **girl** can be interpreted as an effect: *new-b*:=beautiful, transforming **girl** to a beauty, thereby enabling the recognition of **girl** as a beautiful girl (*new-a*). Notice that *new-a* always forms a subset of the input a, due to the agreement relation (subsectively) between a_f and a'_f.

Abduction can be modeled by considering a and a' as input percepts, in the generation of the input qualia of perception by means of a comparison. A similar feedback of b and b' cannot be effective, since b' is a dense domain and a meaningful difference between b and b' cannot be defined (remember that b is interpreted as a measure representing a sub-domain of b').

In the revised model of perception, depicted in fig. 7.4, the current percept is copied to the previous percept, after some delay following input sampling. A control signal (ctrl) is used to enable either the qualia of the feedback, or those of the external stimulus, for generating the input state (a) and effect qualia (b), by means of comparison. The two modes correspond to 'abduction' and 'normal' mode operation, respectively. Abduction mode operation may be activated, if normal mode processing eventually fails. Following this realization of abduction, the definition of the abducted new qualia can be simplified.

$$\begin{aligned} \textit{new-a} &:= a' * a \\ \textit{new-b} &:= a' \setminus a \end{aligned}$$

This may be explained as follows. According to sect. 7.4, a=a_f+a_c and

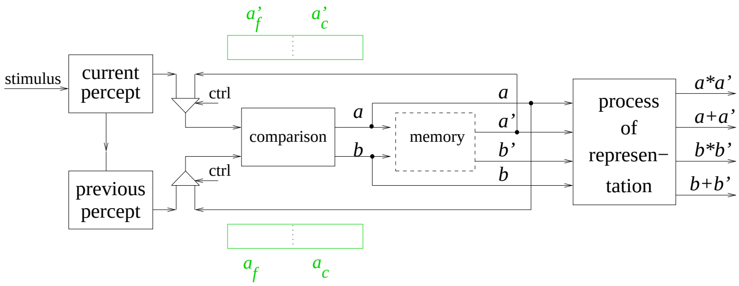

Figure 7.4: The revised model of perception. The difference with the model of fig. 3.1 consists in the existence of a controled feedback (ctrl) of a and a' to the comparison unit. The relative difference of a and a' is used for the abduction of new qualia, triggering potentially new interpretations of the input. A similarly meaningful feedback of b and b' is not possible.

$a' {=} a'_f + a'_c$. From this, it follows that

$$\begin{aligned} \textit{new-a} \quad &:= \quad a'{*}a \\ &= \quad (a'_f + a'_c){*}(a_f{+}a_c) \\ &= \quad a'_f * a_f {+} a'_f * a_c \; + a'_c * a_f {+} a'_c * a_c \\ &= \quad a'_f * a_f \end{aligned}$$

because a relation in the sense of agreement ($*$) may only exist between qualia that are in the focus; the other three term above are representing the emptyset. Similarly,

$$\begin{aligned} \textit{new-b} \quad &:= \quad a' \backslash a \\ &= \quad (a'_f + a'_c) \backslash (a_f{+}a_c) \\ &= \quad (a'_f + a'_c)^{*}(\neg a_f {+} \neg a_c) \\ &= \quad a'_f * \neg a_f {+} a'_f * \neg a_c \; + a'_c * \neg a_f {+} a'_c * \neg a_c \\ &= \quad a'_f \backslash a_c \; + a'_c \backslash a_f {+} a'_c \backslash a_c \end{aligned}$$

because now it is $a'_f * a_f$ that is representing the emptyset. Notice the elementwise negation ($\neg$) involved in the relative difference operation established by the comparison unit in fig. 7.4

Through abduction, new qualia may be introduced and merged with the already existing ones, in order to recognize their entire collection as a (meaningful) sign. This potential of the brain could be due to its capacity for maintaining the activation of its input for a longer time, thereby enabling the signs generated to modify the input and initiate further processing, instead of using those signs to generate signals for the motor sub-system. This way the brain may control the activation of its effectors and possibly even block them. For example, if we hear shouting 'Fire!' we will not run away, if we are able to abductively derive that the sound comes from a motion picture that we are watching.

7.5 Sample abduction

Following the revised model of perception, the relative difference between the qualia, a_f=**damaged-tree-at-branching** and a'_c=marking-tree-prototype can be interpreted as a new effect, transforming the observed damaged tree to a marking tree. In other words, it is $a'_c \backslash a_f$ in terms of which a'_c can be potentially more meaningful than a_f. By 'applying' this difference to a_f, as an effect, the injury can be conceptually removed from the input state.

$$\begin{aligned} a'_c \backslash a_f &= \textsf{marking-tree-prototype}\backslash\textbf{damaged-tree-at-branching} \\ &= \textit{tree-at-branching} \end{aligned}$$

This value of *new-b* has the potential for transforming the qualia of the damaged to the prototypical qualia of a marking tree. The abducted new effect qualia may trigger new memory response, for example, b'=marking-tree-prototype, representing the potential of the revised input for exhibiting the properties of a marking tree. As the input tree is damaged, there must be complementary qualia indicating that status, for example, a_c=**injury**. Also this quale may contribute to the abduction of a new effect:

$$\begin{aligned} a'_f \backslash a_c &= \textsf{tree-prototype}\backslash\textbf{injury} \\ &= \textit{tree-injury} \end{aligned}$$

This value of *new-b* has the potential for transforming the prototypical qualia of a genuine tree to the qualia of an injured tree. The abducted new effect may trigger new memory response, for instance, b'=tree-injury-prototype. In the current example it will be assumed that the final term of *new-b* ($a'_c \backslash a_c$) cannot contribute to the definition of a new effect:

$$\begin{aligned} a'_c \backslash a_c &= \textsf{marking-tree-prototype}\backslash\textbf{injury} \\ &= \textit{tree-injury} \end{aligned}$$

Besides new effect qualia, new state qualia can be generated by means of abduction:

$$\begin{aligned} \textit{new-a}: &= a'_f * a_f \\ &= \textsf{tree-prototype}*\textbf{damaged-tree-at-branching} \\ &= \textit{tree-at-branching} \end{aligned}$$

The representation of a new state must be possible (this time *tree-at-branching* is used as a reference to an a-type quale), for the memory sign a'_f =tree-prototype may contain information about branching, but is unlikely to contain information about tree injuries (originally this was the reason why Bambi could not recognize the observed damaged tree as an injured genuine tree).

Conform the revised model of perception, the abducted new qualia are typewise merged with the qualia of the original input, enabling the following definition of the input signs of perception (abducted new qualia are indicated by the subscript "new"; comments are preceded by a percent sign). Although some of the symbols, such as *tree-at-branching* and marking-tree-prototype, are used ambiguously as a state or an effect, the meaning of those symbols is always clear from the context.

a	=	**damaged-tree-at-branching**, *tree-at-branching*$_{new}$,	% a_f
		injury	% a_c
a'	=	tree-prototype,	% a'_f
		marking-tree-prototype	% a'_c
b	=	**shadow-on-the-left**,	
		tree-at-branching$_{new}$,	
		tree-injury$_{new}$	
b'	=	branching-state-prototype,	
		marking-tree-prototype$_{new}$,	
		tree-injury-prototype$_{new}$	

The qualisigns of cognition are defined as follows:

A	=	*tree?*,	% **damaged-tree-at-branching**$*$tree-prototype
		tree	% **tree-at-branching**$*$tree-prototype
$\neg A$	=	*other-tree*	
B	=	*injury*,	% **tree-injury**$*$tree-injury-prototype
		to-branch	% **shadow-on-the-left**$*$branching-state-prototype
$\neg B$	=	*not-to-branch*	

Although this input still contains the qualia of a damaged tree, the important good news is that the revised representation of the input as a state (A) contains the meaning of a genuine tree. The new qualisigns enable the generation of a new icon and sinsign:

A+B	=	*tree?*+*injury*, *tree?*+*to-branch*, *tree*+*injury*, *tree*+*to-branch*
	=	*some-tree*
$A*B$	=	*wounding*

as well as the generation of a new rheme (details are omitted):

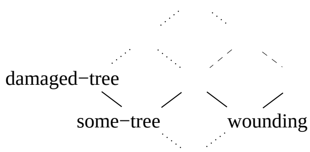

Figure 7.5: The generation of a new rheme sign

$$\begin{aligned} A{*}\neg B &= \textit{tree?}{*}\textit{not-to-branch},\ \textit{tree}{*}\textit{not-to-branch} \\ \neg A{*}B &= \textit{other-tree}{*}\textit{to-branch},\ \textit{other-tree}{*}\textit{injury} \end{aligned}$$

The first term ($A{*}\neg B$) is an expression of the input as a potential tree or 'tree-like' entity, remotely related to 'branching'. The second term ($\neg A{*}B$) is an expression of the input as a potential branching event, in relation to some injured 'tree-like' entity. A synonymous interpretation of the two rheme signs can be represented as 'a-tree-which-has-been-damaged-though-has-the-potential-for-in--dicating-the-branching-of-a-path', in short, *damaged-tree*. The signs generated so far are recapitulated in fig. 7.5. As $\neg A{*}B$ contains the meaning of a branching, and therefore also the meaning of a potential marking tree, and $A{*}\neg B$ the meaning of a genuine tree, Bambi's earlier signs may arise again (see fig. 7.2), he can go grazing at last.

Such a process, generating a potentially more adequate interpretation of a phenomenon through introducing new qualia by means of memory knowledge, is called in this thesis 'naive' abduction. If the abductively generated proposition can be evaluated true, the input qualia can be used for adjusting existing habits by means of learning. The potential of abduction for learning (including learning from negative examples) is beyond the scope of this research, however. According to this thesis, information processing and learning may be viewed as orthogonal 'dimensions' of information processing, indicating that the model of cognitive activity of sect. 2.3 can be combined with any strategy for learning.

Although Bambi can be satisfied by now, information processing may not yet be finished, as the abducted new qualia may allow further sign processing, recursively. This is illustrated with the earlier index sign (*scenery*) and the newly generated sinsign (*wounding*) which may be used for the generation of a more complete representation of the complementary qualia of the observed phenomenon, as follows.

In conformity with their complementary meaning, the abducted complementary memory signs (a_c', b_c') are not involved in the representation of the input qualia that are in the focus. By extending the observer's attention, by means

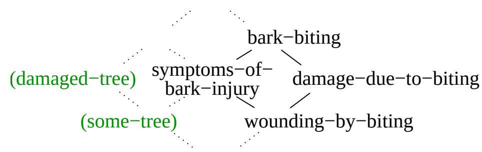

Figure 7.6: The new signs implicated by the abducted event of *wounding* (by an animal). Signs that are unchanged are indicated in parentheses.

of abduction, new complementary signs ($\neg A$, $\neg B$) and novel index signs can be generated, possibly recursively. In this process, the revised sinsign (*wounding*) is mediating between the revised input qualisigns and the index sign (preceding abduction), as a consequence of the processing schema, requiring that the input qualia are first represented as an actual event ($A{*}B$), before their representation as an index sign. The revised sinsign may indirectly contribute to the generation of a revised index sign (due to the coordination function of the index), for example, *symptoms-of-bark-injury*, representing such an event ($\neg A{*}\neg B$) and a state ($\neg A{+}\neg B$).

The modification of the index sign (context) may trigger a further revision of the representation of input as an actual event (sinsign). This may include the incorporation in the meaning of the sinsign the possible events of bark injury, as well as, the abduction of new effect qualia and memory signs. By adjusting the sinsign, new qualia can be introduced that may not be directly related to the original input. This may enable the recognition of events, different from those indicated by the observed phenomenon, such as the event of stripping, carving, or biting (by an animal). There may be many such events, but only those will be considered for interpretation that are compatible with the meaning of the existing rheme sign (*damaged-tree*). An example of such an event is the act of biting (by an animal). The incorporation of this event, and the corresponding effect qualia may as well trigger the revision of the legisign (*damage-due-to-biting*) and the index sign (*symptoms-of-bark-injury*), the latter due to its reference to the bark of the tree. The signs generated by this process are depicted in fig. 7.6.

7.6 Sign recognition as a 'game'

An important result of abductive sign recognition is that Bambi's final sign (*go-grazing*) may arise again, allowing him to proceed as usual. But this is not the only possible benefit of this process. By focusing on the abductively generated new qualia, new memory response signs can be introduced, both focused and complementary. In virtue of the brain's assumed potential for shifting its focus, for example, triggered by a high intensity memory response or an internally generated change (e.g. a saccadic movement of the eyes), new memory signs may arise and trigger further abduction recursively. Such a process is like a 'game', in which, signs are repeatedly generated and revised, as long as a consistent set of representations is obtained. The 'goal' of 'naive' reasoning, including abduction, is the generation of such a collection of signs.

This is illustrated above by the generation of the revised sinsign (*wounding-by-biting*) which may be summarized as follows. The input qualia as qualisigns are the first approximation of the meaning of the observed phenomenon. By abductively extending the collection of input qualia, we may broaden our focus. If the entire collection of input and abducted new qualia can be interpreted as a (meaningful) sign, the process of sign recognition terminates. As for the sinsign this means that, by 'freezing' its event meaning, new qualia extending the observer's focus can be looked for. The condition for abduction is such that the generated new qualia must be be compatible with, and enable the existing ('frozen') interpretation of sinsign. The abduction of new qualia may also introduce new complementary qualia (as A and $\neg A$, but also B and $\neg B$ arise due to the same input stimulus), but only those that enable to keep the existing sinsign invariantly meaningful.

For the generation of a revised legisign, that sinsign is selected from the possible event interpretations of the input, which is compatible with the meaning of the existing index sign. To this end, the event meaning of biting (sinsign) has to be removed from the interpretation of the input as *some-tree* (icon). As a result, the representation of the input can be generated, as the abstract meaning of 'biting' ($\neg A{*}B$), as well as, the expression of the input as an entity capable of enduring such an effect ($A{*}\neg B$). The revised legisign is called *damage-due-to-biting*. By complementing this sign with the information of the index (*symptoms-of-bark-injury*), the rule-like meaning of the legisign can be inductively generalized in the predicate: *bark-biting*. A similar complementation of the rheme (*damaged-tree*), by the index sign (*symptoms-of-bark-injury*) may deductively generalize the rheme in the representation of the subject: *bark-bitten-tree* (see also fig. 7.7).

7.6.1 The effects of 'naive' abduction

What may happen, if we put together the above signs yielded by deductive and inductive generalization? It turns out that their combination can be interpreted

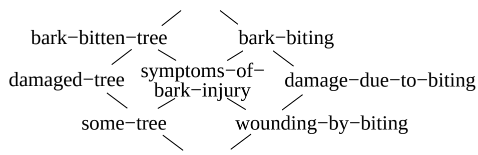

Figure 7.7: The signs of the sample nested phenomenon

as a proposition about the *nested* phenomenon: 'causation-of-damage-to-a-tree'. This sign, characterizing the conditions of our original predicate (*turn-to-the-east*), can be degenerately represented as a quale and recognized as a state undergoing the effect of the nesting phenomenon. In the domain of 'naive' semantic symbols, such an entity is usually called the *theme* or the *patient* of the observed phenomenon.

The example of the previous section illustrates how complementary qualia can be recognized by means of nesting. Natural language processing makes beneficial use of this potential of cognitive activity, by introducing transitive forms for certain verbs. For example, if experience shows that 'damaged-tree-phenomena' frequently occur, this may motivate the introduction of a transitive form for the verb 'branch' (representing *turn-left-or-right*) such as 'branch+<location>'.

Because the input qualia and the prototypical memory response may not precisely match, perceptual judgments or the first or immediate interpretations of the input may not adequately represent its meaning. One may improve on this shortcoming, by offering an abductive analysis to the observed qualia. This may include the generation of an extended set of qualisigns, enabling potentially more meaningful interpretations of the input. The generated (new) signs, representing the observer's reaction to the input as a stimulus, or his/her solution for the input as a 'problem', may be memorized or learned as habits. New memory information may be derived from those meaningful 'solutions', that are hypotheses, through degenerately representing them as qualia.

In the view of this thesis, it is the diversity of such qualia that makes an adequate explanation of prototypical memory signs so difficult or even impossible. In sum, the 'core business' of abduction is the generation of suitable memory qualia, thereby exploring the extension (a') and comprehension (b') of the potential concepts of the brain.

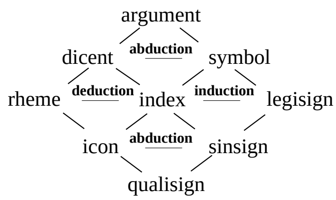

Figure 7.8: The classification of the three modes of 'naive' reasoning

7.6.2 Naive reasoning recapitulated

The process of sign recognition has the element of deduction in the interaction between the rheme and the index, and the element of induction in the interaction between the index and the legisign. This relationship of the three modes of 'naive' inferences is illustrated in fig. 7.8. Because the abduction of new qualia may entail a revised analysis of the entire input, abduction must contain the element of deduction and induction, both. As the sign recognition process includes the element of abduction in the predication sign interaction, and this element is also included in the introduction of the input qualia, and their abstract representations (cf. rheme and legisign), sign recognition, and so, 'naive' reasoning as a process is basically abductive and, within that framework, it is deductive and inductive. The last two types of 'naive' inferences are coordinated by the index sign, mediating the premises of the rheme and the legisign to their interpretation in a conclusion.

7.7 Logica Docens

The logica docens stems from our logica utens. Though a full account of this relation is beyond the goals of this thesis, in this section an attempt is made to illustrate the above dependency for syllogistic logic, which is at the heart of any formal theory of reasoning. It will be suggested that syllogistic reasoning can be modeled as a sequential version of sign recognition, similar to 'naive' language processing, except that now input qualia are interpreted as premises. The main result of this section is that the three syllogistic schemes or figures, introduced by Aristotle (see fig. 7.9) can be interpreted as a 'syntactic' structure underlying the three modes of 'naive' reasoning. Insofar as syllogistic reasoning is basically deductive, the three schemes are characterized as subtypes of deductive inferencing.

scheme−1	*scheme−2*	*scheme−3*
$\dfrac{\begin{array}{cc} X & B \\ A & X \end{array}}{\begin{array}{cc} A & B \end{array}}$	$\dfrac{\begin{array}{cc} X & C \\ A & C \end{array}}{\begin{array}{cc} A & X \end{array}}$	$\dfrac{\begin{array}{cc} C & B \\ C & X \end{array}}{\begin{array}{cc} X & B \end{array}}$

Figure 7.9: The three syllogistic schemes of figures of Aristotle

On the basis of the term structure of the inference modes it can be concluded that scheme-2 and scheme-3 have the elements of abduction and induction, respectively, due to the medium term functioning as the predicate (scheme-2) and the subject (scheme-3). The two schemes above can be interpreted as a process. Scheme-2: 'In the beginning we know *A is C*. From *X is C* we abductively conclude that *A* and *X* must have something in common, that is, *A is X*, too'; scheme-3: 'Initially we know *C is X*. From *C is B* we conclude that *B* can be inductively generalized in *X*, that is, *X is B*' too (*X* is more general than *B*). Scheme-1 has the element of deduction, due to its potential for propagating the properties of the predicate (*B*) to the subject (*A*), through the mediating term *X*.

7.7.1 Structural analysis

Syllogistic inferences consist of three propositions, functioning as case, rule and result. In this section the idea is proposed that it is possible to assign these functions to the meaning of a minor, and a major premise, and the conclusion of a syllogistic scheme, respectively.

In deductive inferencing, the conclusion (result) is a consequence of the major and minor premises, which are rule and case, respectively. The mechanism of induction is fundamentally different. According to Peirce, the key to induction is that

> *by taking the conclusion so reached as major premiss of a syllogism, and the proposition stating that such and such objects are taken from the class in question as the minor premiss, the other premiss of the induction will follow from them deductively (CP 5.274).*

This means that induction must be an inference of the major premise of a syllogism, from the minor premise and the conclusion. Following this analysis, the three schemes of syllogistic reasoning can be characterized as indicated in fig. 7.10.

	deduction	*abduction*	*induction*
major	rule	rule	result
minor	case	result	case
concl.	result	case	rule

Figure 7.10: A functional characterization of the three inference schemes

From the point of view of its characteristic meaning, a premise can be 'general' or 'experienced'. This may be explained by means of scheme-1, as follows. Aristotle proved (Bochenski, 1961) that from Barbara (scheme-1) any other syllogism can be generated by means of two transformations, *conversio*[3] and *reductio ad impossibile*[4] (the explanation of this section is restricted to the structure of the three figures, the aspects of quantification and negation are left out of consideration). Aristotle additionally assumed that any conclusion must be derived from a major and a minor premise. But what are the origins of these premises? According to Peirce, some may come from experience, but since Barbara requires a universal premise and experience without cognition (and learning) cannot be universal, the original major premise cannot be derived from experience alone. Thus, Peirce concluded, only minor premises can come from experience, major premises exist and have their truth in the brain (Fann, 1970). The model of 'naive' reasoning presented in this chapter assumes that such general premises correspond to rules, representing habits and abstractions.

7.7.2 A classification of the sign of reasoning

On the basis of the above considerations, a classification of syllogistic concepts can be defined as a nonadic hierarchy. This is displayed in fig. 7.11 (argument signs, representing a hypothesis, are assumed to function as a case, in a later syllogistic inference). The definition of the mapping of premises to their function as case, rule, or result, makes use of Aristotle's assumption that syllogistic terms represented by formal variables can be subject to renaming and, furthermore, that in a syllogistic inference the order of the premises is free.

The relation between the Aristotelian modes, the schemes of inference, and the Peircean signs, as meaning aspects, can be summarized as follows. Qualisigns, as well as the signs generated by *sorting* (cf. icon and sinsign) are experienced, indicating that these signs must be representations of a minor premise.

[3]SOME S is P $\Leftrightarrow$ SOME P is S.

[4]X,Y$\rightarrow$ Z $\Leftrightarrow$ NOT Z,X$\rightarrow$ NOT Y.

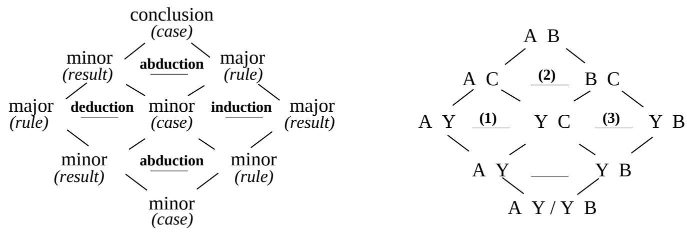

Figure 7.11: The syllogistic meaning of signs and sign interactions. 'Naive' reasoning is modeled as a sequential process. The expression in the qualisign position indicates a premise having the form either of $A\ Y$, or $Y\ B$.

Because, in the process of sign recognition, the complementary qualia representing the background of the observation, are experienced too,[5] the index sign of the input too must represent a minor premise (in accordance with their logical meaning, index signs can have two representations that are each other's converses). The signs obtained through *abstraction* represent the input as the minor and major premise of deductive and inductive inferences. In line with the similarity between 'naive' logical inferencing and 'naive' language processing, sorting and abstraction may correspond to degenerate sign interactions (in the model of language processing, in sect. 5.1.1, such interactions were called a coercion).

The rheme and the legisign represent the input, as a possible for an actual existent (subject), and a law-like property (predicate), respectively. From the syllogistic point of view, such a general meaning agrees with a major premise. The dicent sign signifies the input as an actual existent, arising as an instance of the range of possible entities indicated by the rheme. As such an instance is directly related to the input qualia, that are experienced, the dicent sign must be include the meaning of a minor premise. The symbol sign, finally, is the expression of the law-like property of the legisign in context, and as such, must include the meaning of a major premise.

The above classification holds for the process of cognition. In the perception process, the 'naive' reasoning interpretation of the signs is slightly different. This is due to the different 'goal' of perception, which is the recognition of the individual meaning of the input qualia. In this process, it is the index sign (memory) that is a representation of a general meaning (major premise). This

[5] This view is supported by the interpretation of the index ($\neg A + \neg B$, $\neg A * \neg B$) as a sorting-like representation of the complementary qualia ($\neg A$, $\neg B$).

is opposed to the rheme and the legisign of this process, which refer to perceived qualia, that are experienced (minor premise). This difference between the two processes, perception and cognition, does not affect the relation between the syllogistic schemes and their process interpretations, however.

Finally, it should be mentioned that the meaning of an average or 'discrete' value, and the meaning of a 'continuous' domain included in $A(\neg A)$ and $B(\neg B)$, respectively, could be used for the definition of the interpretation of these terms, as quantified expressions. $A(\neg A)$ could be associated with the meaning aspect of 'SOME' ($\exists$), and $B(\neg B)$ with the meaning aspect of 'ALL' ($\forall$).

This closes the analysis of 'naive' reasoning, in this chapter. The three types of inferences, deduction, induction and abduction, as the major methods of reasoning, are beyond the possibilities of this research. However, 'naive' induction will be subject to further study in the next chapter, in which, its function in mathematical induction will be analyzed.

Chapter 8

Mathematical signs

The obvious or 'naive' concepts of mathematics are due to our innate capacity for interpreting 'real' world phenomena as numbers. The premise of this chapter is that 'naive' mathematics can be modeled as a kind of sign recognition process, similarly to the symbols of 'naive' logic and natural language. The results of this chapter indicate that the concepts of 'naive' mathematics, for example, mathematical types, may function as mediating elements between the concepts of 'naive' logic and those of 'naive' or natural language. The importance of this close relationship between 'naive' mathematics and sign recognition is due to the potential of (naive) mathematics to be interpreted as a representation of 'real' world phenomena, indicating the possibility of a 'real' mathematical universe. As the focus of this chapter is on 'naive' mathematical signs, the 'naive' prefix can be omitted.

8.1 Introduction

The aim of this chapter is to show that the representation introduced in this thesis can be applied to the mathematical domain as well. Similarly to the model of reasoning signs, the focus is restricted to the 'naive' or obvious meaning of observed phenomena. What makes the 'naive' mathematical domain especially important is that its concepts underlie the complex meaning of abstract mathematical notions. This relation will be illustrated by the definition of a 'naive' mathematical interpretation of the concept of infinity. In traditional computational models of knowledge representation, for example, in programming languages, the notorious problem of infinite numbers is usually 'solved' by introducing a maximum value (e.g. '`max_int`'). Clearly, such a value cannot capture the full meaning of infinity. This chapter will foster the idea that the representation of infinity can be more adequately solved by making use of the prototypical meaning of memory signs. Besides the concept of infinity, attention will be paid to the questions why in the mathematical domain we need types, how 'naive' mathematics is related to 'naive' logic and natural language, and why mathematical induction requires three steps.

8.2 Cardinality as a sign

The theory of 'naive' mathematical signs proposed in this chapter is based on the possible interpretation of cardinality as a sign. The first part of this section is devoted to an overview of the neuro-physiological grounds for the perception of cardinality. In the second part, it will be shown how this ability of the brain may contribute to the interpretation of cardinality as a number.

8.2.1 Counting abilities

A recent neuro-physiological research, by (Nieder, Freedman, & Miller, 2002), experimentally proved the existence of number-encoding neurons in the brain. Such neurons fire maximally in response to a specific preferred number, correctly signifying a wide variety of displays in which the cues are not confounded. For instance, one such neuron might respond maximally to displays of four items, somewhat less to displays of three or five items, and none at all to displays of one or two items. It does not matter whether the displays are equalized according to perimeter, area, shape, linear arrangement, or density, such neurons attend only to number.

The number-encoding neurons are able to recognize the number of similar[1] items from 1 up to 5, but the representation of numbers gets increasingly fuzzy for larger and larger numbers. Many neurons fire selectively 120 ms after display onset, whatever the number on the screen, indicating that the neurons 'count' without counting (i.e. without enumerating items one by one).

The evolution of number-encoding neurons may entail superiority of a species, as information about the number of preys or predators can be crucial in certain situations. An exotic example of a possible counter evaluation may be the

[1]Similarity is assumed to hold trivially for single entities.

striped skin of zebras. The intertwining stripes of a group of zebras can make the recognition of their number most troublesome.

The experimental results suggest that the primary meaning of the signals produced by the number-encoding neurons is *iconic*. This is opposed to the mathematical interpretation of cardinality, which is *symbolic*. The intermediate *indexical* concept, linking the iconic and the symbolic interpretations, is the concept of ordering. The hidden agenda of this chapter is an attempt to show that, although those three interpretations of number signs are different, they can be modeled in a uniform manner.

According to (Nieder et al., 2002), the signal of the number-encoding neurons is vague already for low numbers, contradicting the common experience that the brain is able to accurately stipulate cardinality (up to a limit) without symbolic counting. In this chapter the hypothesis is raised that the number-encoding neurons could function analogously to the color receptors of the eye. An interesting property of color perception is that it is independent from the number of the receptors simultaneously discharged.

The perception of cardinality is modeled as follows. Following (Nieder et al., 2002), input entities that are similar to each other are assumed to be represented by the brain as cardinality qualia, enabling the interpretation of the entire input, as a number. Because cardinality, as a quale, arises in the brain and not in the senses, the perception of a phenomenon as a number must be accounted for by a higher level process, interpreting cardinality as a *memory* sign. Notice the ambiguous use of 'cardinality', as a quale arising for each similar input item (state), and a (cardinal) number representing their collection as a whole.

In line with the results of the neuro-physiological study mentioned above, it will be assumed that the brain is capable of distinguishing the collection of input state qualia in three types:

- no_num
  The entire input is recognized as a single entity. The number-encoding neurons are not active. Cardinality does not arise as a quale.

- one_or_more
  The input is represented as a small multitude of similar items. Some of the number-encoding neurons are active. Cardinality arises as a quale; its value can be recognized as a number.

- many
  The input is interpreted as a large multitude of similar items. The number-

encoding neurons are all active. Although cardinality does arise as a quale, its value is too vague to be recognized as a number.

The boundary between no_num and one_or_more is usually marked by collections consisting of one or two similar entities. Linguistic evidence for the latter, in English, is found in the distinction between singular, two, and plural, such as one, both, but all three, all four, or a trouser, a pair of trousers, but many trousers. Singular, but also two always refer to a small multitude, representing a minimal value of some sort. The boundary between one_or_more and many is usually less sharp, but it could be between 5 and 9, in accordance with the capacity of the brain for a simultaneous storage of signs in the so-called 'working memory' (Miller, 1956), (Broadbent, 1975).

The next section contains as analysis of the important case of one_or_more. An analysis of the case of many is postponed until sect. 8.5.

8.3 The concept of finite numbers

Because cardinality as a memory sign is independent from the input effect, it must be an a'-type memory sign. And because it is not representing the primary meaning of the input, it must be a complementary type memory sign (a'_c). The interpretation of phenomena, as a number, may proceed as follows. If, for any reason, the primary meaning of the input is found unsatisfactory, the brain may seek for a more suitable interpretation, by means of abduction. The modeling issues of such a process have been the subject of the previous chapter. This chapter is concerned with the idea that abduction could also underlie the 'naive' mathematical interpretation of phenomena as a number.

8.3.1 Iconic number signs

The first level in the mathematical recognition of phenomena is based on an *iconic* interpretation of cardinality qualia. This may be illustrated with the cognition of a multitude of similar cubic bodies as a number. In the example below, the existence of the following input and memory response qualia are assumed:[2]

[2]As in earlier chapters, Peirce's nine signs and 'naive' logical expressions are used as references to the status of a sign in the process of sign recognition.

(*Perception*)

a	=	**cube**
a'	=	memory-sign-of-cube, memory-sign-of-cardinality
b	=	**cubic-form, size**
b'	=	memory-sign-of-cubic-form, memory-sign-of-size

(*Cognition*)

A	=	$a{*}a'$=	*cube*	% **cube**$*$memory-sign-of-cube
$\neg A$	=	$a{+}a'$=	*cardinality*	% **cube**$+$memory-sign-of-cardinality
B	=	$b{*}b'$=	*form*	% **cubic form**$*$memory-sign-of-cubic-form
$\neg B$	=	$b{+}b'$=	*size*	% **size**$+$memory-sign-of-size

The primary meaning of the input is '*cube* IS *form*', that may be paraphrased as the proposition 'some cubic entities are there'. If, for any reason, this proposition is found to be unsatisfactory, new input qualia may be introduced by means of abduction. As pointed out earlier (see sect. 7.4.1), the abducted *new-a* qualia are always included in the original collection of *a*-type input qualia. However, the abducted *new-b* qualia may represent an effect, 'transforming' the observed cubic entity (a) to a cardinality (a'). As usual, the abducted new qualia may trigger new memory response signs.

The current example restricts itself to a definition of the abducted new qualia in relation to their memory response, as the qualisigns of a cognitive process:

A	=	*cube*	% a cubic multitude;
$\neg A$	=	*unit-value*	% the increment value of counting;
B	=	*cardinality*	% cardinality as an property;
$\neg B$	=	*growth*	% incrementation as a property;

The interpretation of the above input signs, as a number, proceeds as follows (see also fig. 8.1). The icon ($A{+}B$) and sinsign ($A{*}B$) are an expression of the simultaneously present similar entities and cardinality qualia, as a possible co-existence (*similar-items*), and an actual event (*number-event*), respectively. As cardinality qualia may arise for any countable phenomenon, the sinsign may represent the input as a number, independently from the *sort* of similar entities simultaneously present.

The rheme ($A{*}\neg B$, $\neg A{*}B$) is an expression of the abstract meaning of the observed cubic bodies and cardinalities, as the primary entities of counting (*number-base*). The legisign ($A{*}\neg B{+}\neg A{*}B$) represents the rule-like meaning of counting such abstract entities (*rule-of-counting*), by means of *accumulating* the input cardinality qualia on a stack. The accumulated value is interpreted as a measure, iconically representing the input as a number.

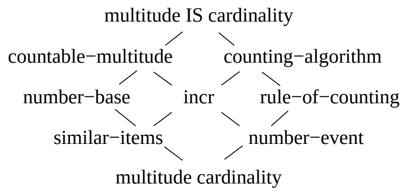

Figure 8.1: Iconic representation of number-phenomena

An essential component of any procedure for counting is the unit value of that operation. Such a value can be interpreted both as a increment (value), and as an act of incrementation (property). For example, small cubes may be counted in steps of $1/10$, if a collection of ten pieces of small cubes is equivalent to a large cube. According to the theory of this chapter, such a value and property, as a type (*incr*), is the meaning of the complementary information or the *context* of observed number phenomena, captured by the index sign ($\neg A{+}\neg B$, $\neg A{*}\neg B$).

The complementation of the abstract rheme sign with information provided by the context (index sign) is represented as an actually existent multitude ($A{+}\neg B$) and cardinality value ($\neg A{+}B$). The synonymous interpretation of these dicent signs is an expression of the input as a computable entity, or the *subject* of the observed number-phenomenon. The analogous complementation of the legisign obtains the symbol sign, representing the input as a conventional (cardinality) property, or the *predicate* ($A{*}B{+}\neg A{*}\neg B$). It is this property in terms of which the subject can be interpreted as a number. In a computational setting, the predicate sign of iconic number phenomena may be called the 'algorithm for counting B-number of A-entities by means of accumulation'. The predicate (symbol sign) may use type information provided by the complementary qualia via the mediation of the index sign.

The final step in the recognition of the input as a number consists in the interaction between the subject and the predicate of the input phenomenon. This is represented by the argument sign, expressing the input a measure of similar entities, which is iconic knowledge (*multitude* IS *cardinality*).

Evidence for counting by means of accumulation is found in a recent experimental study by (Wittlinger, Wehner, & Wolf, 2006), proving that desert ants measure distances by means of some kind of step integrator, or "step counter". In the experiment, the legs, and hence the stride length of freely walking ants were manipulated. Animals with elongated or shortened legs took larger or shorter strides, respectively. Travel distance is overestimated by ants walking on elongated legs, and underestimated by ants walking on shortened legs.

8.3.2 Inclusion ordering

Indexical interpretation of number-phenomena is the brain's potential for *ordering* multitudes, without symbolical counting. This ability can be shown to be present in children already at the age of two (Bullock & Gelman, 1977).

A sample ordering phenomenon may be defined as follows. Assume there are two collections of cubes, one on the left- and another on the right-hand side of a separating line, and that the task is the recognition of the relation between those collections, as an *ordering relation.* Additionally assume that the cardinality of the left-hand side collection is already available as a memory sign, and the task is concerned with the recognition of the cardinality of the collection on the right-hand side (n_r), in the light of the cardinality of the collection on the left-hand side (n_l). The recognition of an ordering relation defined by the two multitudes, which is indexical knowledge, may proceed as follows.

The argument sign of the recognition of the left-hand side collection (n_l), as an iconic number-phenomenon, is degenerately represented as a complementary quale: a_c:=n_l, a'_c:=n_l (a_c and a'_c are a representation of n_l as a cardinality and a number, respectively; such a twofold interpretation of n_l is possible, as cardinality arises in a memory sign, and, in an abduction (cf. sect. 7.4.1), memory signs can be interpreted as input qualia). In addition, it will be assumed that the subsequently recognized number sign of the right-hand side collection (n_r) is represented analogously, this time, as a quale which is in the focus: a_f:=n_r; a'_f:=n_r.

These signs can be used for the recognition of the input, as an ordering-phenomenon, as follows. By interpreting *a'* and *a*, as the previous and current percepts, respectively, new qualia can be generated through abduction, as depicted in fig. 8.2. Remember that a=a_f+a_c and a'=a'_f+a'_c (cf. sect. 7.4) and, that a relation in the sense of agreement ('$*$') is only possible between qualia that are in the focus (a'_f and a_f). A relation in the sense of possibility ('+') may exist between all other combinations of focused and complementary qualia, such as a'_c and a_f, a'_f and a_c, and a'_c and a_c (cf. sect. 7.4.1).

$$\begin{aligned} \textit{new-a} \;&:=\; a' * a \\ &=\; a'_f * a_f \\ &=\; n_r \end{aligned}$$

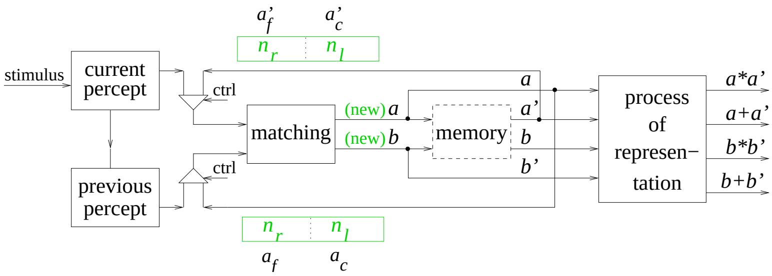

Figure 8.2: The recognition of ordering-phenomena

$$
\begin{array}{lcl}
\textit{new-b} & := & a\text{'}\backslash a \\
 & = & a\text{'}_c \backslash a_f + a\text{'}_f \backslash a_c + a\text{'}_c \backslash a_c \\
 & = & n_l \backslash n_r + n_r \backslash n_l
\end{array}
$$

The relative difference operation is used for the implementation of subtraction of (iconic) numbers represented as sets. This operation may not always be meaningful. For example, $n_r \backslash n_l$ can only be interpreted as an ordering relation (‘$<$’), only if $n_l < n_r$. In conformity with the model of perception (sect. 3.1), the difference of the previous and current percepts can only represent qualia which were not there, but are there now. Similarly, $n_l \backslash n_r$ can only be interpreted as an ordering relation (‘$>$’), only if $n_l > n_r$. Put differently, the relative difference of iconic numbers (substraction) can be interpreted as an ordering sign, if the accumulated cardinality of the subtrahend is not less than the accumulated cardinality of the subtracter. If both ordering relations can be recognized, then n_l and n_r must be equal (‘$=$’).

The abductively generated new qualisigns may contribute to the recognition of the input as an ordering-phenomenon, representing the *inclusion relation* of the right-hand side collection (r), with respect to the one on the left-hand side one (l). This relation can be expressed as a proposition: ‘$r\ R\ l$’, where $R \in \{<,=,>\}$.

8.3.3 Symbolic number signs

What makes the indexical representation of cardinality especially important is that it underlies the symbolic interpretation of phenomena as a number. This potential of ordering signs may be illustrated by the rheme sign (number-base), and how its meaning is involved in the symbolic signs of number phenomena.

The basic concepts of symbolic counting are the primary symbolic numbers (cf. cardinal numbers), representing cardinalities that we are able to recognize 'naively'. As the properties of symbolic counting are well known, the focus of this section is restricted to an analysis of the relation between the symbolic and the indexical interpretation of number-phenomena. To this end, the earlier example of the cubes is revisited and in this section the problem is considered how the collections on the left- and the right-hand side of the separating line may be rearranged such that, eventually there are equally many cubes on both sides.

Children not possessing the concept of symbolic counting tend to solve this problem by first collecting all cubes on one side of the separating line and then, by moving cubes one-by-one, they iconically 'count' their number on the two sides, in order to indexically determine equality. Those familiar with symbolic numbers may attain the same goal simply by means of symbolic calculation.

If solving the above problem is supervised, and the act of moving a cube is repeatedly followed by the articulation of "one cube", the ordering operation as well as the referencing to a cube may become rule-like associated with the numeral "one". By executing the operation for different number of cubes and other entities, the prototypical meaning of "one", representing 'anything countable', may arise through abstraction. In general, a finite number of numerals can be learned analogously.

The prototypical meaning of symbolic numbers emerges from entities found to be similar in earlier observations, by means of averaging and domain formation. An example is the symbolic meaning of "one", as the value '1' (state), and as the operation 'incrementation by 1' (effect), amongst others. Large multitudes can be recognized recursively by focusing on contiguous segments of the input qualia, and recognizing them as nested number-phenomena. But large multitudes may be more conveniently counted by making use of symbolic numbers. As the rules of symbolic counting are syntactical, similarly to the rules of language processing, the definition of a model for the recognition of symbolic numbers is omitted.

8.4 A 'real world' of mathematics

From the assumption that 'naive' mathematical signs arise from the observation of 'real' world phenomena, it follows that a 'real' mathematical universe may exist. That 'world' too must consist of phenomena that are interactions between states and (cardinality) effects, except that such effects are of a special kind: they have the potential to interact with *any* state. This is a consequence of the earlier assumption, that cardinality as a quale may arise for any countable multitude. 'Real' world phenomena can be commonly interpreted as 'existence-events'. This is opposed to the phenomena of the mathematical 'universe' which can be commonly characterized as 'cardinality-events'. Because, in the mathematical 'world', states are inherently related to cardinality effects, all state (a) can be interpreted as a number: an 'a-number'. For example, in the recognition of a multitude of cubic objects as a number, initially it has been assumed that each similar cubic entity is marked by a cardinality quality. The interpretation of those cubic entities as a number can be generalized in the concept of 'cube-type-cardinality-sign', or simply, '*cube*-number', which may be used as a unit value in an algorithm for counting cubic entities.

Number signs, or simply, numbers can be degenerately represented as a state and such qualia can be considered *similar* hence countable, in a recursive process. An illustrating example is be the number-phenomenon: $sin^2(x)$. In this expression, the function $sin(\_)$ is representing an effect, interacting with the function parameter x, which is interpreted as a state. In addition, $sin(\_)$ itself is functioning as a state too, in the interaction with the function $\uparrow^2$, which is an effect.

Such a flexibility of symbol use is not characteristic for natural language, in which symbols representing a state or an effect are not interpreted interchangeably. An example is the verb run, interpreted as a syntactic effect. If we are about to use the same symbol as a syntactic state, the verbal relational properties have to be removed, and run has to be interpreted as a noun. Mathematical signification is free from this rigidity of re-presentation. The meaning of $sin(\_)$, as an effect, is invariantly present in the interpretation of $sin^2(x)$, the second power of $sin(x)$. This is witnessed by the potential of $sin^2(x)$ to map its parameter x, which is a state, to its image $sin(x)$, which is another state in the function $\uparrow^2$. The rigidity of natural language signs might be a consequence of the concreteness of language signs, as opposed to the mathematical signs which are more abstract.

Inasmuch as in the mathematical world all states may interact with all cardinality effects, the representation of symbol interactions is free from any constraints. However, following the assumption that mathematical signs are about 'real' world phenomena (possibly through a sequence of re-presentation steps), the mathematical 'universe' must be part of the 'real' world, in which interactions *are* subject to constraints. This roughly means that an entity may interact with certain other entities, but that it may not interact with *all* kinds of entities.

In order to avoid the danger of chaos, mathematical symbol interactions are checked for correctness, for example, by verifying the 'well-formedness' of the state and effect qualia of an interaction. To this end, mathematics introduced the concept of a *type*. In the next section, it will be advocated that mathematical types may arise, through refinement and generalization, from the indexical level concept of the increment (*incr*).

8.4.1 Mathematical types

The correctness of mathematical operations included in the meaning of number-phenomena may be affirmed by making use of complementary information about the input state and effect, mediated by the context. A mathematical operation shall be called *well-formed*, if the underlying number-phenomenon can be recognized as an index sign. The dicent and symbol signs of a mathematical phenomenon, which arise from the rheme and legisign through complementation by the index sign, contain all information necessary for a meaningful interpretation of the input operation. As the complementary qualia of a phenomenon may signify the relation between the input and memory in the sense of possibility, the mathematical index sign may only represent the observed operation in a general sense, through a reference to the rule-like meaning of a *type*.

The model introduced in this chapter assumes that the mathematical index sign is expressive of the type compatibility of the input qualia, as the constituents of the observed operation ($\neg A + \neg B$). In addition, the index sign is also an expression of the type of the entire input phenomenon, as a mathematical operation ($\neg A * \neg B$). This type checking by the index sign enables the sign recognition process to 'find out' whether the input phenomenon is a meaningful combination of qualia, or is due to a malfunction, e.g. a hallucination.

According to this thesis, the index sign is the *key* to mathematical sign recognition. As mentioned above, in the mathematical 'universe', (cardinality) effects can also be interpreted as a state, which brings about the need for a special treatment of number-phenomena. Because a mathematical function, as a state, preserves its meaning as an effect, the well-formedness of mathematical expressions requires that the sign interactions are properly typed. The expression of such a type is the meaning of mathematical index signs. In sum, if the input can be recognized in a type (index sign), this indicates that the observed mathematical operation can be meaningful.

The basic type of cardinality, 'natural' numbers, arises through generalization, from the obvious meaning of mathematical index signs (*incr*), which is enumeration. By applying this type to the input entities recognized as an abstract state (*number-base*) and effect (*rule-of-counting*), the representation of the input as a natural number may be obtained. For example, the 'naive' mathematical meaning of a collection of cubes may arise through the interpretation of each cube as an abstract entity ("one"), and the accumulation of their cardinality on a stack ("counting one by one"). Formal mathematical types, such as natural ($\mathcal{N}$), rational ($\mathcal{Q}$), and real ($\mathcal{R}$), arise from the 'naive' mathematical concept of a number, through an iconic, indexical, and symbolic representation of the meaning of '*incr*', respectively, as a constant, a quotient, and a process, and a generalization of these concepts in the habitual, rule-like meaning of a type. In sum, $\mathcal{N}$ can be interpreted as the abstraction of (natural) numbers, $\mathcal{Q}$ as that of an infinite sequence of natural numbers, and $\mathcal{R}$ as an abstraction of an infinite sequence of rationals.

8.5 The concept of infinite numbers

Infinity is perhaps the most controversial concept of mathematics. This section proposes the idea that the prototypical meaning of memory signs could be used as a vehicle for a 'naive' representation of infinite multitudes.

According to the theory of sect. 6.2, memory signs are prototypical representations of *all* memorized qualia responding to the input as a stimulus. This implementation of memory signs allows for a twofold interpretation of the relation between the input and memory. According to the first, A=a∗a' is an expression of a as a value complemented by a'; and B=b∗b' an expression of b as a measure (value) of b'. In both cases, the interpreting sign contains the meaning of a reference to an *individual* quale, as value. Following the second interpretation, A=a∗a' and B=b∗b' are a representation of *all* qualia, that are included in the definition of the average value (a') and the dense domain (b'), triggered by the input a and b, respectively. In this interpretation, A and B have the meaning of a reference to a collection as a whole, but no reference to the individual elements. In the proposed model, such signs are used for the representation of the 'naive' mathematical meaning of infinite numbers.

How can we recognize the 'naive' mathematical meaning of phenomena, as infinite numbers? Following the results of the neuro-physiological study by (Nieder et al., 2002), in this thesis earlier it has been assumed that the brain is capable of distinguishing the input state in three types: no_num, one_or_more, and many. The last one, many, refers to a multitude possessing cardinality, as a quality, but without an increment (neither as a unit value, nor as a property). In this section it will be suggested that such multitudes may be recognized as the 'naive' concept of an infinite number. Because the 'infinite' interpretation of memory qualia includes the meaning of a reference to a collection, but no reference to the elements contained, such an interpretation does not possess the concept of an increment, indicating that the collection in question may not be countable.

The suggested relation between the 'naive' mathematical interpretation of phenomena and the ambiguous interpretation of memory signs is also supported by linguistic analogy. For example, in the mathematical interpretation of the utterance, the police are going to lunch, the syntactic subject is ambiguously interpreted as a whole, and as individual persons. This analysis is underpinning the conclusion that the 'naive' interpretation of infinite numbers and the prototypical meaning of memory signs, such as nouns, are related, tacitly implicating that all memory signs contain the meaning of infinity as a possibility.

Returning to the domain of mathematical signs, finally it should be mentioned that the 'naive' mathematical meaning of formal variables too can be explained on the basis of the concept of abstract states (*number-base*). The representation of the input as an abstract state contains the meaning of a collection of possible values as a whole, without access to the individual elements. A reference to such a 'container' of possible values, is what is considered in the proposed model to be the 'naive' meaning of a formal variable.

8.6 The concept of naught

Cardinality as a quality may arise if there are similar entities in the input. As a consequence, naught cannot be perceived as a cardinality, except through inferencing. Such a process may be illustrated with the observation of a phenomenon in which there is no cardinality, as a quale ('no_num'), but that nevertheless is interpreted as a number. In this case, as the input is not perceived as a cardinality, one may abductively infer that earlier there must have been 'something', that has disappeared. If that entity can be interpreted as a countable state, its cardinality can be represented in the current observation as naught or zero. In sum, the 'naive' concept of zero can be defined as a hypothetical number sign, not including the meaning of cardinality, nor the meaning of increment (*incr*).

8.7 The secondness of mathematics

From a categorical point of view, 'naive' logic is a 1st, 'naive' mathematics a 2nd, and 'naive' or natural language a 3rd of meaningful representation. The goal of this section is a justification of this hypothesis.

'Naive' *logic* is concerned with the types of relations existing between the dual qualities of 'real' world phenomena. Such a relation may exhibit the category of

- 1stness, if it is interpreted as a quale independent from other qualia; a logical relation as a quale may be a state or an effect, focused or complementary (a, a', b, b');
- 2ndness, if it is interpreted as a link connecting two qualia; a logical relation as a link may exist between focused and complementary qualia, that are a representation of a state or an effect (A, $\neg A$, B, $\neg B$);
- 3rdness, if it is interpreted as a logically meaningful relation between state and effect qualia (A+B, A∗B, A∗¬B, ..., A *is* B).

'Naive' *mathematics* is re-presenting the logical relations of the input, as numbers. In addition, 'naive' mathematics introduces common types for the incomparable (dual) input qualia of the input phenomenon. By defining common types, 'naive' mathematics lays the foundation for the primary concept of natural language, which is the relational need of symbols.

The 'naive' mathematical concept of a type enables the derivation of an induced ordering of (consecutive) numbers. This is due to the brain's potential for classifying the simultaneously present input entities in collections of similar entities, thereby tacitly introducing a 'boundary' between them (notice that 'separation' is less meaningful than 'identification', which contains the element of differentiation as well). The introduction of a boundary between the input entities is crucial for language recognition, as information about potentially different entities may be necessary for determining the referential meaning of language symbols, for example, in syntactic modification phenomena.

Natural *language* is 'lifting' the three types of logical relations, mediated by the concepts of 'naive' mathematics, to the concepts of a potentially existing or 'neutral' (n), a lexically defined possible or 'passive' (p), and an actual or 'active' relational need (a), representing the types of combinatory properties of language symbols.

8.7.1 Mathematical sign recognition revisited

There are some interesting properties of 'naive' mathematical signs, as well as of the relation between mathematical and linguistic signification that may deserve attention (see also fig. 8.3).

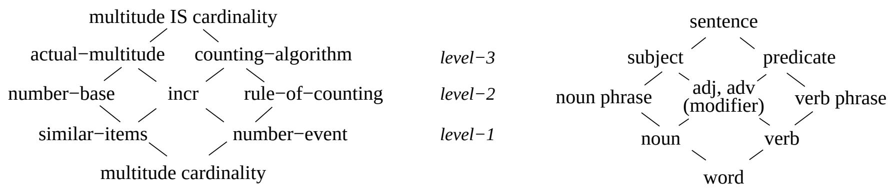

Figure 8.3: A comparison of mathematical and language concepts

On the first 'level', in the recognition of number-phenomena (level-1) we find the mathematical icon and sinsign, which are a representation of the input as a constituency relation and an actual event, respectively. These signs, which arise by sorting the input qualia in two types, are an expression of a logical relation. As the icon and sinsign do not yet contain the meaning of the input as a number, this level of representation can be called a *logical* level. In language, the icon and sinsign may represent a morphological root (which may be subject to affixation) and an affix (which requires a root), respectively.

The second 'level' (level-2) introduces the abstract concept of numbers. The mathematical rheme and legisign represent the input as a countable abstract entity or a '*number-base*' (it makes no difference if houses or cats are counted) and a '*rule-of-counting*', respectively. The mathematical index sign represents the concept of increment(ation), through a reference to a type. This follows from the potential of the index sign for completing the meaning of the '*number-base*' and the '*rule-of-counting*', without changing their conventional meaning. This level can be called a *mathematical* level, because the rheme, index, and legisign only refer to the mathematical operation included in the input phenomenon, as a structure. The language analogue of the two types of index signs is the adjective and the adverb; the rheme and legisign are implemented by noun and verb phrases, respectively.

On the third 'level' of the recognition of number-phenomena (level-3) we find the concepts of a countable multitude (subject) and a counting algorithm (predicate). This level can be called a *language* level, due to its potential for representing the relation between the mathematical subject and predicate as a proposition. The corresponding concepts of natural language are the syntactic subject and predicate, and the sentence.

As the mathematical subject and predicate signs of a number-phenomenon may only arise, if a suitable index sign exists, input phenomena that are not well-formed, cannot be recognized (their recognition process fails). An example

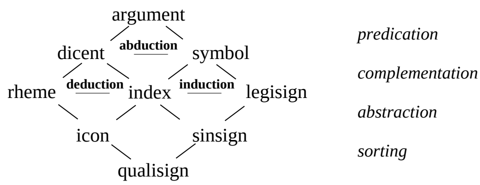

Figure 8.4: Logical inferences as symbol interactions (recap.)

for a not well-formed (symbolic) number-phenomenon is '2/1.5', assuming '/' stands for integer division. A semantically not well-formed (nonsensical) language utterance is Chomsky's famous example: 'colorless green ideas sleep furiously' (Chomsky, 1957).

8.8 Meta-mathematical signs

Mathematical induction is an instantiation of inductive reasoning.[3] The goal of this section is a justification of the claim that the process model of reasoning introduced in chapter 7 is applicable to 'naive' mathematical signs too, indicating that the two domains could be merged in a meaningful way. In turn, the close relationship between the two knowledge domains may provide an explanation why mathematical induction requires three steps.

The classification of the logical inferences as symbol interactions (fig. 7.8) is recapitulated in fig. 8.4 (as the qualisign, icon, and sinsign are less important for a model of 'naive' mathematical induction, the abduction meaning associated with the operation abstraction (cf. sect. 7.2.1) is omitted.

8.8.1 Mathematical induction as sign recognition

The first principle of mathematical induction says: If for a property P, $P(0)$ holds and, for $k>0$, from $P(k)$ it follows that $P(k+1)$ holds too, then P is true for all natural number. From this definition the second principle of induction can be derived (which is more suitable for the purposes of this section): If for an arbitrary n, from the statement that, $P(k)$ holds for all $k<n$, $P(n)$ follows, then $P(n)$ is true for any n. Formally, if $\forall n \forall k.(k<n \rightarrow P(k)) \rightarrow P(n)$, then $\forall n.P(n)$ can be concluded. Here, $\forall k.(k<n \rightarrow P(k))$ is a formal representation of the

[3]This section is based on a theory by J.J. Sarbo, presented in (Sarbo & Farkas, 2005).

induction hypothesis. In the rest of this section an attempt is made to prove that the meaning of the second principle of mathematical induction is included in the 'naive' mathematical interpretation of number-phenomena.

Following the above definition of mathematical induction, initially we know that $P(k)$ holds for all $k<n$. Assuming each $P(k)$ ($k<n$) arises from the 'naive' mathematical interpretation of a phenomenon, initially we have k states satisfying the property P. This is alternatively represented as a collection of states $P(0),\ldots,P(k)$, for $k<n$. In order to prove that $P(n)$ holds too, the next state satisfying P has to be considered. To this end, the change brought about by the effect of incrementation (*succ*) to the state $P(0),\ldots,P(k)$, is interpreted in the context of P.

The qualisigns of this induction-phenomenon may be defined as follows. Braces are used for indicating set formation, and square brackets for domain formation (in later definitions). P is tacitly 'lifted' from elements to sets and domains; $P(0),\ldots,P(k)$ is abbreviated as $P\{0,\ldots,k\}$.

$$\begin{array}{lllllll} A & = & P\{0,\ldots,k\} & \quad & \neg A & = & P \\ B & = & succ & & \neg B & = & P \end{array}$$

The above specification may be explained as follows. The initial condition for induction requires that P holds for all $k<n$. This indicates the existence of earlier observation of $k+1$ phenomena as deductive inferences $P(0),\ldots,P(k)$, depicted in fig. 8.5. The above definition of A is obtained by merging the proposition signs of the individual observations $P(0),\ldots,P(k)$ in a single sign through coordination, and by degenerately representing that sign as a state.[4] In order to prove the inductive statement about P, it has to be shown that P holds for the next element satisfying P or the successor of $P(k)$. This can be modeled by applying incrementation (*succ*) as an effect on P-type entities. This explains the definition of B. The complementary signs, $\neg A$ and $\neg B$, are defined by P, as a state and an effect, indicating the context in which the interaction between A and B has to be interpreted.

Sign recognition proceeds as usual. In this section, the focus will be on the process of cognition (see fig. 8.6). The first interesting sign is the rheme, abstracting the meaning of $P\{0,\ldots,k\}$ and *succ* in the concept of a 'P-number' (number-base). The rheme sign contains the prototypical meaning of memorized P-type entities as an average value. That meaning is now extended with the meaning of *succ*, representing the subsequent P-type element as a possible.

The legisign is an expression of the compatibility of the abstract meaning of

[4] The resulting state-type quale contains the meaning of P,0,…,k, and that of $P(0),\ldots,P(k)$.

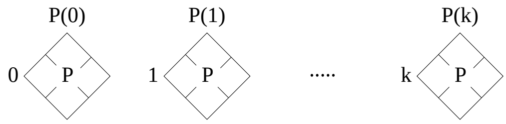

Figure 8.5: Earlier observations as deductive inferences

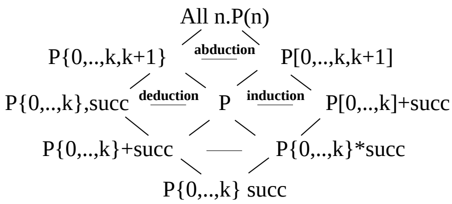

Figure 8.6: The logical relations of mathematical induction as a cognition process (complementary qualia are not indicated, except in the index position)

$P\{0,\ldots,k\}$ and *succ*, according to which the collection of P-type input entities may be rule-like extended with a subsequent next element. This interpretation of the legisign makes use of the dense domain meaning of $P\{0,\ldots,k\}$, in short: $P[0,\ldots,k]$. The fact that this domain exists and can be extended with a next element indicates the existence of a property shared by all elements in this domain.

The interpretation of the rheme sign in the context of P (complementation) obtains the representation of the input as an existing collection of P-type cardinalities. In the context of P, *succ* can be interpreted as "k+1", referring to such an element ($P(k{+}1)$) and such an incrementation event, ambiguously. The information deduced from the context is used in the complementation of the rheme in the meaning of the dicent sign, representing $P\{0,\ldots,k\}$ and $P\{k{+}1\}$ as actually existent entities, in short: $P\{0,\ldots,k{+}1\}$. This interpretation moment, in which, P is applied to the next possible element indicated by "k+1" or, alternatively, the collection of $P\{0,\ldots,k\}$ is extended by the next element, has the aspect of a deductive inference.

An analogous complementation of the legisign amounts to testing the new element of the extended domain for compatibility under P (the legisign is only an expression of the rule-like compatibility of $P[0,\ldots,k]$ and the operation *succ*). This requires the hypothesis that $P[0,\ldots,k]$ can be inductively generalized to

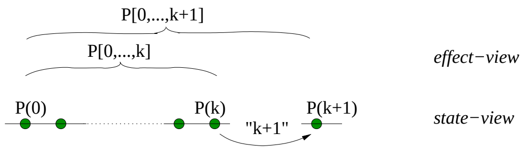

Figure 8.7: Sample mathematical induction. Initially we have knowledge of $P(0),\ldots,P(k)$. These elements are deductively generalized as a collection by deriving their next element, and inductively generalized as a dense domain by testing that element for P. In the two operations, "k+1" is used as a value and a measure, respectively. The essence of 'naive' mathematical induction is the hypothesis that the results of deductive and inductive generalization are equal.

the next element (k+1) in the context of P. If testing is successful, it means that $P(0),\ldots,P(k)$ and $P(k+1)$ are related to each other in the sense of agreement. This is expressed by $P[0,\ldots,k]*P(k+1)$ or briefly $P[0,\ldots,k,k+1]$, representing the conventional property included in the meaning of the observed number-phenomenon (cf. symbol sign).

In the final step, the interaction between the dicent and symbol sign is interpreted as a proposition which is a hypothesis, postulating that the input as a collection of P-type entities (*state-view*), or alternatively, as a P-type event (*event-view*); see also fig 8.7. The 'naive' mathematical meaning of this relation is expressed by the formula: ALL $n.P(n)$, where n is a formal variable representing a collection of P-type entities as a whole, and 'ALL' is used as a shorthand for generalization on the basis of 'all' entities that we have knowledge of. In the proposed model, such entities are represented as a domain and interpreted as an infinite number, providing the meaning of 'ALL' included in the meaning of the argument sign of mathematical induction phenomena.

The reader may have noticed the secondary role of P. What really matters in 'naive' mathematical induction is the testing of the next element of some domain. The concept of infinity arises as a tacit 'ingredient' in this process.

8.8.2 Example

Assume, the task is to prove that $P(n)=0+1+2+\ldots=(n^2+n)/2$, for all $n\geq 0$. The interesting interpretation moment is the re-presentation of the input, as a conventional property (symbol sign). This requires some preparatory calculations, recognized as nested phenomena:

$$\begin{aligned} P(k{+}1) &= ((k{+}1)^2{+}k{+}1)/2 \\ &= (k^2{+}k)/2{+}(k{+}1) \\ &= P(k){+}(k{+}1). \end{aligned}$$

The meaning of this calculation is degenerately represented as a complementary quale which, then, is recognized as an index sign accumulating with the indexical meaning of P as the context ("$k{+}1$" is interpreted as a representation of the increment induced by P). This index sign is used for the generation of the dicent and symbol signs. By establishing the correspondence between the deductively and inductively generated expressions, represented by the dicent and symbols signs of the input, respectively (cf. fig. 8.7), the final meaning of the input is presented as a proposition: ALL $n.P(n)$. The meaning of 'ALL' is due to the continuous domain interpretation of $P[0,\ldots,k,k{+}1]$.

8.9 Summary

According to an earlier assumption of this thesis, knowledge arises from the observation of 'real' world phenomena, which are interactions between dual qualities represented as qualia. This duality is captured by 'naive' logic, representing it as a relation or fact. The generalization of the independent qualia of logical relations in types is the main contribution of 'naive' mathematics. Language abstracts from the mathematical concept of types, by lifting them to the meaning of relational needs. This indicates that 'naive' logic, mathematics, and language, may be interpreted as increasingly more meaningful levels of human knowledge representation. An interesting 'feature' of mathematical sign recognition is that, to some extent, it includes the whole of this knowledge representation potential of the brain/mind. Although mathematical sign recognition, as a process, is about mathematical signs only, its interpretation moments show strong affinity with 'naive' logical and linguistic information processing.

Chapter 9

Text summarization

Natural language as a knowledge representation is frequently redundant. Words, phrases, and even larger units can sometimes be removed without changing the essential meaning of a text. This feature is used by text summarization, which is a technique for generating a concise summary of a text typically by means of syntactic parsing and statistical analysis (Jones, 1993), (Endres-Niggemeyer, 1998), (Hovy, 2005) (Mani, 2001). These techniques may not be sufficient for the generation of meaningful summaries however. According to this thesis, the limitations of traditional text summarization are due to two factors. One of them is the formal ontology underlying traditional language modeling, because it is not based on a model of cognitive activity and, therefore, does not support the generation of semantically meaningful concepts. The other factor is the lack of a uniform representation, that may be necessary for merging knowledge obtained in different domains.

The premise of this chapter is that, on the basis of the theory introduced in this thesis, an alternative method for text summarization can be introduced that does not suffer from those limitations. The essential constituents of that method are a uniform representation of knowledge, including a trichotomic specification of qualia, and a process interpretation of summarization. The focus of this chapter is on an illustration of the theoretical potential of the proposed method for the generation of summaries.

9.1 Introduction

The approach suggested in this chapter is based on the idea that a pair of subsequent sentences (previous and current sentence) may be interpreted as a *transition*, transforming the state represented by the previous sentence, to the next state indicated by the current sentence. Text summarization, as a process, combines transitions induced from consecutive sentences of a text, in a summarizing single transition, representing the meaning of the text as a whole. By removing signs not contributing to the unifying single transition induced by the entire text, a summary may be generated and represented as a sentence.[1] A sign may be superfluous for various reasons. For example, a syntactic modification may be unimportant, if there is no reference to the modifier elsewhere in the text; a verb phrase may be redundant, if it is an expression of a semantically neutral effect.

What is in the focus of summarization, may depend on the interest of the observer (the reader of the text). For example, it may be one of the characters or one of the occurring events. Text summarization, therefore, may have many different outcomes in general.

The idea behind the interpretation of sentences as 'transitions' may be illustrated by the metaphor of apparent motion perception. What makes this phenomenon especially interesting, is the fact that, although we observe steady pictures that may be meaningful in themselves, we are able to perceive their series as motion. According to the hypothesis of this chapter, the summarized meaning of a text may arise from an analogous process of interpretation. A single picture may correspond to the individual state and effect represented by a clause or a sentence, and the experience of motion to the meaning of the entire text as a summarizing state *transition*. The goal of text summarization, as a process, is the generation of such concise representations.

There is an important difference between motion perception and text summarization, however. Motion perception is successful if the subsequently displayed pictures are not 'too' different from each other. This is opposed to text summarization, in which subsequent sentences may refer to semantically 'distant' phenomena. That we are be able to combine a series of sentences comprising a text in a summarizing single sentence, indicates that we mentally 'bridge' the gap between their individual meanings. Text summarization capitalizes on the interpretation of the input symbols in different domains. For example, two sentences may be summarized in a single sign, if they are related to each other

[1] A tacit assumption of this chapter is that such a sentence may exist.

by means of a syntactic or a semantic state transition. As a side effect of such a process, new signs may be introduced, enabling further summarization recursively.

Text summarization is a hard problem. This may explain why the method presented in this chapter is illustrated by the summarization of a non-trivial text, but is not defined as an algorithm. The sample text of this chapter, which is a version of the fairy tale "Snow White" (Grimm & Grimm, 1988), contains a number of difficult sentences. The hidden agenda of this chapter is an attempt to show the potential of the language model, introduced in chapter 5, for the analysis of complex utterances characterizing actual language use.

9.2 Language model revisited

An important element of the process model of cognitive activity (see sect. 2.3) is the assumption that input recognition can be established by means of processing contiguous segments (disjoint collections) of qualia. In natural language, an example for such collections are the contiguous strings of input symbols corresponding to phrases, clauses, and sentences. Another important element of the model of cognitive activity is the trichotomic specification of qualia. An example of such a classification is the trichotomy of verbs as legisigns (cf. sect. 6.3.2), defined by the divisions: an act of existence(1), modification(2), and transformation(3), or alternatively, by the ordering existence<modification<transformation, which represents a phenomenon as a semantically neutral action (e.g. there is a book), a modification of a state (e.g. she has a book), and a state transformation (e.g. John begun running), respectively. These three classes of verbs correspond to increasingly more meaningful semantic phenomena.

The summarization of the sample text of this chapter makes use of a morpho-syntactic analysis of article symbols. As the parsing of such phenomena has not been discussed earlier (in sect. 5.2), it has to be specified now. An illustrative example may be the expression 'the beautiful Queen'. Following the classification of morpho-syntactic symbols, recapitulated in fig. 9.1, the above string may be analyzed as: (beautiful)(the Queen). This analysis, which is depicted in fig. 9.2, illustrates how article symbols may become immediate neighbors of their references, as a result of morpho-syntactic sign recognition, according to the model introduced in this thesis.

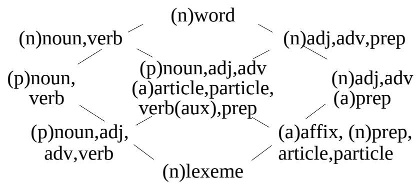

Figure 9.1: The classification of morpho-syntactic symbols (n=neutral, p=passive, a=active relational need)

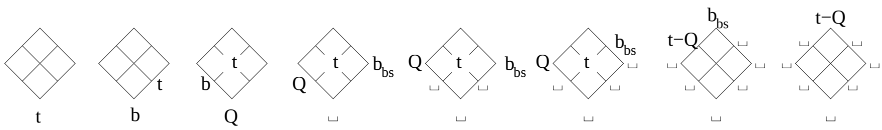

Figure 9.2: The morpho-syntactic analysis of 'the(t) $\mathsf{beautiful}$(b) Queen(Q)' (bs='base-degree'; the treatment of inter-word space symbols is omitted)

9.3 Towards a theory of text summarization

The input qualia of the summarization process are the input sentences and clauses, that will be commonly referred to as *sentences*. A sentence is interpreted as a state transition, representing the change occurring to the input state (subject), as a 'modulation' due to the input effect (predicate). The modulated state shall be called the *next state*; the act of 'modulation' itself, a *state-transition*. The reader may have noticed the analogy of the above model with the process model of cognitive activity (sect. 2.3), in which qualia representing the observer as a state (q_1) are affected by qualia representing the stimulus as an effect (q_2). In this chapter, the summarized meaning of a text is defined as the cumulative effect of individual sentences, transforming the initial state of the first sentence, to the final state indicated by the last sentence. This is illustrated by fig. 9.3.

A pair of subsequent sentences can be summarized, if a *transition* from the previous sentence to the next or current sentence exists. A transition is viable, if the states (subjects) and the effects (predicates) of the two sentences can be pairwise unified and, furthermore, a common context shared by the two unifications can be defined. Such a *unification* is an operation generating a synonymous interpretation of signs exhibiting different meaning aspects (notice the difference with the sign interaction, accumulation, which is restricted to

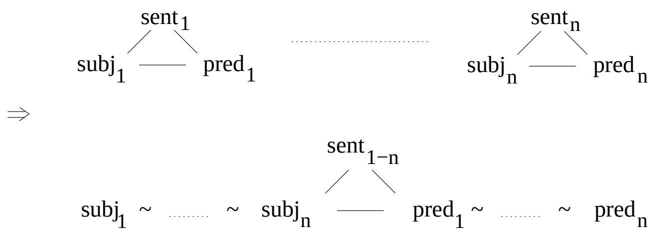

Figure 9.3: The generation of the summary of a text consisting of n sentences ($\mathsf{sent}_1, \ldots, \mathsf{sent}_n$); the summary itself is represented by sent_{1-n}. The symbols subj, pred, and sent are short for subject, predicate and sentence, respectively; a '$\sim$' symbol denotes a unification operation.

signs having identical meaning aspects, according to its definition in sect. 5.1.1). In a state transition, the subjects and the predicates, their unification, and the common context, are typically a result of a 'naive' syntactic, semantic syntactic, and reasoning interpretation of the input symbols, demonstrating the benefits of the uniform knowledge representation provided by the model of this research.

If a transition is possible, the previous and the current sentence are merged in a summarizing single sentence, called the *summary*. Otherwise, the current sentence is interpreted as a nested phenomenon or an 'episode', later intertwining with the nesting phenomenon, marked by the previous sentence.[2]

The interpretation of sentences as 'transitions' is also supported by the process model of language, introduced in chapter 5. According to that model, the subject and the predicate of a sentence arise from the rheme and the legisign, respectively, through complementation by the index sign[3]. The rheme is interpreted as 'a possible for the subject', and the legisign as a representation of 'the rule-like meaning included in the predicate'. Besides providing the context, in the generation of the subject and the predicate, the essential function of the index sign is coordination between the complementation events of the rheme and the legisign (see fig. 9.4).

Text summarization may proceed as follows. Preceding summarization, the input sentences are analyzed individually. A pair of previous and current sen-

[2]This is a consequence of the tacit assumption that the entire text can be summarized in a single sign.

[3]In this chapter too, the Peircean signs are only used as pointers to the status of a sign in the process of sign recognition.

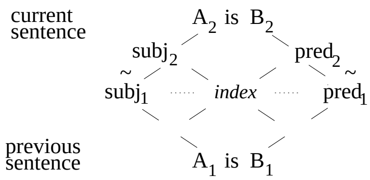

Figure 9.4: Coordinated unification. The previous sentence (A_1 is B_1) and the current sentence (A_2 is B_2) are represented as an argument sign and a qualisign, respectively. The typewise unification of the subjects and predicates of the two sentences is coordinated by the index sign. Unification is denoted by a '$\sim$' symbol.

tences are re-presented as a qualisign and an argument sign, respectively. This is followed by a re-generation of the syntactic rheme, index, and legisign of the previous sentence, and the syntactic dicent, index, and symbol sign of the current sentence. In this preparatory phase, the signs derived from the two sentences may not be representations of a single phenomenon. In fact, the generation of such a consistent set of signs is the essential goal of the text summarization process. The unification of the rheme and the dicent sign on the one hand, and the legisign and the symbol sign on the other, may obtain the definition of the subject and the predicate of the summarizing sentence, as well as of the qualia of the underlying phenomenon.

The above procedure of text summarization complies with the earlier requirement set for the processing schema of cognitive activity. The existence of a successful unification of the signs obtained from a re-analysis of a pair of subsequent sentences indicates that a transition from the previous to the current sentence is possible. This may be illustrated by the summarization of the sample text: 'John left the house. The door closed'. In the two sentences, the subjects are John and the door (in short door); the predicates are left the house (in short left)[4] and closed (see fig. 9.5). By making use of the model of 'naive' reasoning, introduced in chapter 7, the summarization of the two sentences may be explained as follows (in the syllogistic inferences below, the aspect of quantification is omitted; unification is denoted by a '$\sim$' symbol).

The unification of John and door is possible (John$\sim$door), if there is (semantic) memory information about John's ability to open something. As the same ability may be characteristic for door too (doors may be opened), John and door can be

[4] The complement of left, the house, may be represented as an index sign.

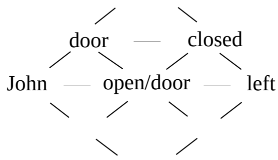

Figure 9.5: Sample summarization (accumulation is denoted by a '/' symbol)

unified as participants of an 'open' event.

open *IS* door	% the door is opened
John *IS* open	% John opened something
⇒ John *IS* door	% it is John who opened the door

Similarly, the unification of left and closed is possible (left∼closed), if it can be derived that left and closed may both refer to door as a constituent state.

door *IS* left	% somebody left (the house) through the door
door *IS* closed	% now the door is closed
⇒ closed *IS* left	% (the door which is) closed (is the door)
	% through which somebody left (the house)

The two unification operations above reveal the existence of a common property (open) possessed by the two subjects (cf. deduction), as well as the existence of a common state (door), compatible with the rule-like meaning included in the predicates (cf. induction). Summarization is possible, if this property and this state can be interpreted as dual representations of a common context (open/door). If this condition holds, a summarizing single sentence can be generated, for example: 'John, who opened the door, left the house behind the closing door', or briefly, 'John left (the house)'. Notice that the above summary of the original text is generated from John's (actor) point of view.

In order to prove that John and left can be used as the subject and predicate, respectively, of a sentence representing the summary of the input text, summarization needs semantic memory information. In the current analysis it will be assumed that, through their 'naive' semantic syntactic meaning, John and door can be unified by the symbol John, as John and door may be the agent and patient of an open event, respectively, and, from the semantic point of view, patient(2)<agent(3) (a specification of thematic roles will be given later in this chapter). John (unifier) is interpreted as 'John, who opened the door'. Similarly, the unification of left and closed may obtain the symbol left, representing

the property 'left behind a closing door'. Unification is possible again, because close (a door) may indicate a measure in the dense domain of 'leave'-events. The meaning of open and door, as converse symbols, is included in the unification of John and door, expressing door as the patient of the act indicated by open. Put differently, if we observe an open event to occur, then there may be a door, undergoing that event. Given these unifications, the summarizing sentence, John left (the house), can be used to replace the original two sentences and can as well be summarized with another sentence, if the sample text is part of a larger discourse.

A potential benefit of an intertwined 'naive' syntactic, syllogistic, and semantic syntactic analysis is the introduction of new signs, enabling further summarization recursively (this aspect is not illustrated by the above example). The generation of new signs may entail the definition of new qualia that, together with the original input qualia, may be used as a definition of a summarizing single phenomenon.

Efficient combination of knowledge obtained in different domains is possible due to the uniform character of the proposed representation. By applying text summarization to a series of sentences, recursively, the effect induced by the individual sentences may be combined in a single effect, changing the initial state represented by the first sentence, to the final state indicated by the last sentence. It should be mentioned that text summarization may put a great burden on the lexical specification of the input qualia. This aspect falls outside the focus of this thesis however.

9.4 An extended example

The proposed method of text summarization is illustrated in this section, by the summarization of the non-trivial text of the fairy tale "Snow White". The sample text is displayed in fig. 9.6. Dialogs, not affecting the development of the story, are removed.

As mentioned before, the summary of a text depends on the focus taken, as well as on the degree of conciseness required. In this section it will be assumed that the focus is on the main character, Snow White, and that the goal of summarization is the derivation of a single catchy sentence describing the events occurring to her. The price that has to be paid for requiring such a summary is that other important aspects, such as the narrative structure of the text, may not be respected by the final result.

In the presentation of the analysis below, individual summarization steps

"SNOW WHITE"

($\mathbf{s}_0$) In a far off land, there lived a very beautiful Queen who had a stepdaughter called Snow White. ($\mathbf{s}_1$) The wicked Queen ordered a servant to take Snow White to the forest and put her to death, but the poor man had not the heart to do it, and told her to hide in the forest. ($\mathbf{s}_2$) Snow White ran into the thickest part of the forest and walked for many long days, until she came upon a tiny little house. ($\mathbf{s}_3$) The Princess thought that in such a lovely place as that, there must live kind people who would give her shelter. ($\mathbf{s}_4$) The house, which at that moment was empty, was in a state of complete disorder. ($\mathbf{s}_5$) The furniture and everything inside was small. ($\mathbf{s}_6$) Snow White cleaned and tidied the little house until it shone. ($\mathbf{s}_7$) Then she lay down exhausted on one of the little beds and fell asleep. ($\mathbf{s}_8$) When she woke up, she found herself surrounded by seven little dwarfs who, on hearing what had happened to her, promised to protect her from her stepmother. ($\mathbf{s}_9$) They were all very happy and contented. ($\mathbf{s}_A$) One day, the Queen, who had heard that Snow White was still alive, disguised herself as an old woman and invited her to try an apple which she had poisoned. ($\mathbf{s}_B$) The Princess was tempted by the lovely apple the old woman was offering her. ($\mathbf{s}_C$) The old woman insisted, assuring her that she had nothing to fear, until at last, she accepted. ($\mathbf{s}_D$) But ... when she bit into the apple, Snow White fell senseless on the ground, and how those dwarfs cried and cried. ($\mathbf{s}_E$) A Prince who was passing by saw the beauty of Snow White and kissed her on the forehead, whereupon she wakened from that bad dream and the dwarfs were happy again. ($\mathbf{s}_F$) Snow White and the Prince married and were happy ever after.

Figure 9.6: Sample input text for summarization. The individual sentences are marked by a letter '**s**', followed by a sequence number (in hexadecimal).

are simplified as follows. In a symbol interaction, less meaningful symbols are omitted in favor of symbols that are more meaningful. This holds for index signs representing complementary information too. For example, in an adjectival modification of a noun, the adjective may be omitted (for instance, if there is no other reference to that entity). This is opposed to a lexically defined complement of a verb which always has to be represented (remember that in a 'naive' syntactic analysis, adjectives and verb complements are uniformly represented as index signs). Index signs may complement the meaning of rheme signs and legisigns. In the analysis below, the reference of an index sign is represented by a '$\leftarrow$' and a '$\rightarrow$' symbol, indicating the rheme and the legisign, respectively. In virtue of the differences between their references (which can be the rheme or

nouns (rheme):
  possible existence < actual reference < conventional function
actual reference:
  general < indefinite < definite

adjectives (index):
  intersective < subsective compatible < subsective incompatible

verbs (legisign):
  existence < modification < transformation
transformation:
  neutral < modulation < change

nouns (dicent):
  theme < patient < agent
nouns (dicent):
  unnamed < episodic < title

Figure 9.7: An overview of the semantic trichotomies used in the example. A classification is expressed as an ordering, for instance, general<indefinite<definite is short for general(1), indefinite(2), definite(3). Recursive definitions are given in italics.

the legisign position), index signs can be accumulated typewise.[5] Temporal aspects of verbs are left out of consideration. It will be assumed that the order of appearance of the input sentences and the temporal order of their effects are isomorphic, from which it follows that 'neighboring' sentences may be summarized in any order (summarized sentences may be replaced by their summary). The analysis below makes use of thematic relations in the interpretation of semantic relations between verbs and complements (Fillmore, 1968). Semantic syntactic information is specified by means of trichotomies. Some of the trichotomies have been introduced earlier, in sect. 6, others are defined 'on the fly'. The semantic trichotomies used in the example are recapitulated in fig. 9.7.

The syntactic analysis of a sentence is presented in the tabular form, introduced earlier in section 5.4 (a column corresponds to a sign class, a row to the recognition of an input symbol). The signs generated by 'sorting' (icon and sinsign) and 'predication' (argument sign) are omitted. The following abbreviations are used: input(i), accumulation(a), coercion(c), binding(b), degenerate representation(d). A pair of accumulated signs are separated by a '/' symbol; coordination is uniformly denoted by an '&', subscripted by the actual coordi-

[5] In sect. 5.1.1, this potential of the language model has been used for a uniform representation of syntactic modification and complementation phenomena.

nator symbol, for example, '$\&_{but}$'; a sign interaction is indicated by a '-' symbol. Coinciding semantic and syntactic sign interactions are merged in a single (isomorphic) representation. In a syntactic analysis, signs that play a role in a summarization step are displayed in bold face.

s$_0$ (In)(far off)(a land)(there)(lived)(very beautiful)(a Queen)(who)(had)
(a stepdaughter)(called)(Snow White).

s$_1$ (Wicked)(the Queen)(ordered)(a servant)(to take)(Snow White)(to the forest)
$\&_{\text{and}}$ (put)(her)(to death) $\&_{\text{but}}$ (poor)(the man)(had not)(the heart)(to do)(it)
$\&_{\text{and}}$ (told)(her)(to hide)(in the forest).

Figure 9.8: The morpho-syntactically finished symbols (in parentheses) of the sentences s_0 and s_1. Coordinator symbols are uniformly denoted by an '&', subscripted by the actual coordinator.

The signs generated by a morpho-syntactic and a syntactic analysis of s_0 are shown in fig 9.8 and table 9.1, respectively. This sentence contains (nested) syntactic language phenomena, that are represented degenerately as complementary qualia, and are recognized as index signs. These are: in a far off land (inffl), a stepdaughter called Snow White (stcsw), who had a stepdaughter called Snow White (hadst). The syntactic signs of s_0 that play a role in the summarization process are recapitulated in fig. 9.9.

The first clause of the syntactic analysis of s_1 is depicted in table 9.2, the second clause in table 9.3. The syntactic signs of the first clause that are involved in a summarization step are displayed in fig. 9.10. As the predicate complement in this clause itself is a clause, its summarization is postponed. For the time being it will be assumed that the predicate of this clause is the verb ordered (this analysis makes use of the lexical interpretation of this symbol as an intransitive verb). The coordination structure, 'take Snow White to the forest and put her to

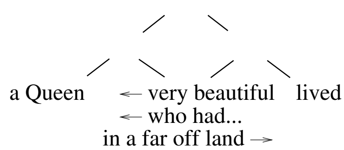

Figure 9.9: The syntactic symbols of s_0 as the signs of the previous sentence, in the summarization with s_1

input	rhme	indx	legi	dcnt	symb	action
in						
far off(foff)			in			c
a land(alnd)		foff	in			c
	alnd	foff	in			c,b
		foff-alnd	in			b
there(t)		infl→				d
lived(lvd)	t	infl→				c
very beautiful(vb)		infl→	lvd	t		c,c
a Queen(aQ)		←vb,infl→	lvd	t		c,a
	aQ	←vb,infl→	lvd	t		c
recursion(1)						
who(wh)						
had	wh					c
	wh		had			c
recursion(2)						
a stepdaughter(st)						
called(ca)	st					c
Snow White(SW)	st		ca			c
	st	SW	ca			c
	st	ca-SW				b
				st-ca-SW		
return(2)						
	wh	stcsw	had			d,c
		stcsw	had	wh		b
				wh	had-stcsw	b
return(1)						
	aQ	**←vb/hadst**, **infl→**	**lvd**	t		d,b
...						
				t/aQ-hadst...	lvd-infl	b

Table 9.1: The syntactic analysis of s_0. The analysis of this complex sentence needs recursion, for example, the subordinate clause starting with who is parsed recursively. A recursive call(return) of the parsing algorithm is denoted by the symbol *recursion*(*return*). Recursion depth is indicated by an integer given in parentheses. Whether the syntactic analysis of a sentence is recursive or not, has no effect on the summarization process.

death' is represented by the short term 'take&put'.

Is a transition from s_0 to s_1 possible and, if so, what may be the summarized

input	rhme	indx	legi	dcnt	symb	action
wicked(wk)						
the Queen(tQ)		wk				c
ordered(ord)	tQ	wk				c,b
			ord	**wk-tQ**		
recursion						
a servant(se)						
to take(ta)	se					c
Snow White(SW)	se		ta			c
to the forest(tf)		SW	ta	se		c,c
		tf	ta-SW	se		b
				se	ta-SW-tf	b
coordination						
put(pu)						
her(he)			pu			c
to death(td)		he	pu			c,b
		td	pu-he			b
					pu-he-td	
restore						
				se	**take&put**	
return						
		se-take&put	ord	wk-tQ		d,b
				wk-tQ	ord-se-take&put	b

Table 9.2: The syntactic analysis of the first clause of s_1

meaning of these two sentences? In order to answer these questions, the relation between s_0 and s1 is established by analyzing the relation between the rheme, index, and legisign of s_0 on the one hand, and the dicent, index, and symbol signs of s_1 on the other (see fig. 9.11, on the left-hand side).

The unification of the subjects may proceed as follows. The two symbols, a Queen (rheme) and the wicked Queen (dicent) may be unified by the symbol the Queen. Following the trichotomy of referential rhematic signs,[6] a(2)<the(3), implicating that the indefinite article (a) may be removed. According to the trichotomic classification of adjectives (cf. sect. 6.3.1), wicked(1) and very beautiful(1) are semantically less meaningful than who had a stepdaughter called Snow White(2) (in short who had...), indicating that those two adjectives may be ignored.[7]

[6]The trichotomy general(1), indefinite(2), definite(3), introduced in sect. 6.3.2.
[7]As part of the re-analysis of s_0, wicked is represented as an index sign.

input	rhme	indx	legi	dcnt	symb	action
coordination						
poor(po)						
the man(tm)		po				c
	tm	po				c
				po-tm		b
recursion(1)						
had not(hn)						
the heart(th)						
			hn			c
		th	hn			c
			hn-th			b
recursion(2)						
to do(td)						
it			td			c
		it	td			c
		td-it				b,d
return(2)						
		td-it	hn-th			
					hn-th-td-it	b
return(1)						
				po-tm	**hn-th-td-it**	
coordination(2)						
told(td)						
her(hr)			td			c
		hr	td			c
			td-hr			b,d
recursion						
to hide(hi)						
in the forest(tf)		tf	hi			c
					hi-tf	bd
return						
		hi-tf	td-hr			b
					td-hr-hi-tf	
restore(2)						
				po-tm	hd...&td...	
restore(1)						

Table 9.3: The syntactic analysis of the second clause of s_1

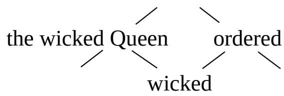

Figure 9.10: The syntactic symbols of the first clause of s_1 as the signs of the current sentence, in the summarization with s_0

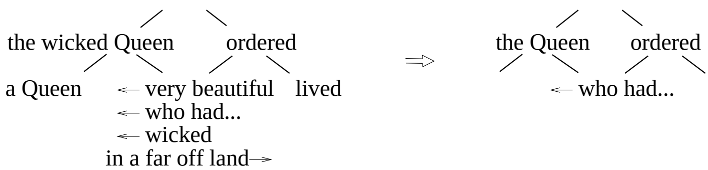

Figure 9.11: The summarization of s0 and s1

The unification of the predicates obtains the symbol 'ordered', because lived(1) may be classified as an act of existence, and ordered(2) as a modification of a state,[8] according to the semantic trichotomy of verbs as legisigns[9] (notice that in both events, the actor is the Queen). Summarization is possible, based on the index sign (who had...) which coordinates the unifications of the subjects and the predicates. This is depicted in fig. 9.11, on the right-hand side (the indexical sign in a far off land is removed, as it does not change the interpretation of lived as an existence(1) event).

The complement of ordered contains embedded clauses, enabling further summarization. To this end, the process makes use of a semantic specification of verbs as legisigns, in particular of their meaning as an act of transformation(3) recursively defined as: neutral(1), modulation(2), and change(3), representing a neutral (told her), a reversible (take her to the forest), and an irreversible transformation (put her to death), respectively. The analysis below tacitly assumes the existence of a trichotomy of prep–complement symbols (cf. sect. 5.1.3) as index signs, that may be specified analogously to the above classification of verbs as transformation acts.

The summarization of the complement of ordered, which is the clause to

[8] Here, ordered is considered to be an intransitive verb. This is opposed to the interpretation of the same symbol as a transitive verb in table 9.2 (which also explains its representation as a legisign (ord), instead of a symbol sign).

[9] The trichotomy: existence(1), modification(2), transformation(3), introduced in sect. 6.3.2.

take Snow White to the forest and put her to death, may proceed as follows. To take(2) and to put(2) are reversible transformation events. As the modifications of the two events, to the forest and to death, are semantically different (to the forest(2)$<$to death(3)), the first conjunct of the above clause (to take Snow White to the forest) may be removed. The resulting expression, (to) put her to death, may be summarized with the second conjunct of 'but'. This requires the unification of the subjects (servant and the man), and the predicates (to put her to death and had not the heart...). The first unification obtains the symbol the servant, because the current coordination does not affect the meaning of the subjects ('but'-coordination structures exhibit the aspects of a syntactic complementation). The indexical symbol, poor, which is not representing a lexically defined semantic relation of the servant, may be removed.

The unification of the predicates proceeds as follows. As told her... is a neutral transformation event, it may be safely removed. In the first conjunct (had not the heart to do it), the logical meaning of not can be abstracted in a negation operator ('neg') and represented as a prefix symbol: 'to put her to death, but (neg) had the heart to do it'. Next, the semantic trichotomy of verbs as transformation events (legisign) is used in order to derive that had the heart to do it(2)$<$put to death(3). Indeed, the first conjunct is an expression of an intention indicating a 'modulation' of a state (for example, the emotional state of the actor), but the second conjunct is a reference to an irreversible change. As put to death may be synonymously represented by the verb murder, her is a reference to Snow White, and it is anaphorically linked with the first conjunct, the summarization of the predicates eventually may obtain the expression: '(neg) to murder her'.

The complement of ordered, which is a non-finite clause with an explicit subject (syntactically), may be interpreted as an argument sign. The summarization of this clause with the earlier summary of s_0 and s_1 (see fig. 9.11, on the right-hand side), is illustrated by fig. 9.12 (the index sign, who had..., which is not representing a lexically defined relation of the Queen, is omitted). Summarization is possible, if the subjects (Queen and servant) and the predicates (ordered and murder her) can be pairwise unified and, most importantly, a common context coordinating the two unification operations exists. Queen and servant may be unified (Queen$\sim$servant), because the Queen may be the 'master of' the servant ('master of' is assumed to be a lexically defined potential relation of 'Queen'). As a result of this unification operation, 'master of' is defined as an index sign.

At this point the summarization process makes use of the classification of thematic roles, defined by the trichotomy: experiencer(1), patient(2), agent(3). Because, Queen is the agent, but servant is the patient of ordered (this time, order is syntactically interpreted as a transitive verb), and ordered transitively

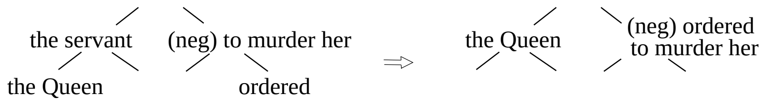

Figure 9.12: The summarization of s0 and s1 (cont.)

links the agent (Queen) with the theme of this verb ((neg)to murder her), through the mediation of the patient (servant), it is concluded that the servant (index sign) may be removed. Put differently, by acknowledging the Queen as the 'master mind' behind the murder event, her role as the real actor of that event is exposed. The above complementary meaning of order, as a mediation event, may be represented as an index sign too.

A summary may only exist, if the index signs introduced in the course of the unification of the subjects can also be used in the unification of the predicates. That this condition may be satisfied as well, is explained below.

The unification of the predicates makes use of the 'naive' induction meaning included in complementation sign interactions (cf. sect. 7.2.1). The interpretation of ordered, as a legisign, contains the meaning of a dense domain of 'order'-effects. A measure of this domain, indicated by 'to-make-somebody-do-something' (index sign), may be ordered to murder her. The summarization of the predicates, ordered and (neg)to murder her, is possible, because 'master of' and 'to-make-somebody-do-something' may be interpreted as semantic counterparts (converse symbols), and these signs together with the mediation meaning included in ordered (index) may be interpreted as synonymous signs. In the end, this enables the definition of the subject and the predicate signs of the summary generated so far, which are the Queen and (neg) ordered to murder her, respectively. Because ordered refers to a semantic transformation event and neg is an indication of the failure of that event, the predicate may be alternatively expressed by the converse of failure: failed. The above interpretation of neg can be merged with the meaning of ordered, by means of syntactic coordination: (s_{0-1}) The Queen ordered to murder her, but it failed (notice the use of it, as a reference to murder).

Further summarization is possible, by interpreting the title of the text as an incomplete clause, the predicate of which is defined by the tale itself (more precisely, by that part of the tale that has been considered for summarization so far). The unification of the Queen with Snow White needs a classification of the roles of a personage in a story. Such a trichotomy is: unnamed(1), episodic(2), title(3). Because the predicate of s_{0-1} can be interpreted as a measure of order events ((to) murder her), and to murder (event) is a counterpart of murder (noun), the final summary can be expressed by the catchy sentence:

Snow White: A murder failed.

Interestingly, this sentence may as well function as the summary of the whole story. The analysis of the rest of the tale proves that the remaining sentences do not change the meaning of the above summary (assuming the focus of summarization is on Snow White). Indeed, when the Queen discovers that the servant has not been loyal to her, she begins her 'apple project', but that eventually fails as well.

The summarization of the remaining sentences may proceed as follows. Below, the presentation of the analysis is restricted to an overview of the individual summarization steps. A transition act is denoted by a '$\Rightarrow$' symbol. Summaries are labeled such that the label recursively refers to the sentences involved. For example, the summary of s_2 and s_3 is labeled by s_{2-3}.

s_2: Snow white ran into the forest indicates the beginning of a new episode. This sentence may be summarized with s_4, assuming that Snow White and the Princess are identical persons. $s_2 \Rightarrow s_3$: (s_{2-3}) Snow White ran into the forest and thought.... Also s_4 is marking the beginning of a new episode. Because in the summarization of s_2, house (index sign) may be removed, the entire sentence s_4 can be ignored. As s_5 may be summarized with s_4, that sentence can be removed as well.

$s_{2-3} \Rightarrow s_6$: (s_{2-6}) Snow White ran into the forest and cleaned and tidied (some) house. s_7: She lay day and fell asleep. $s_{2-6} \Rightarrow s_7$: (s_{2-7}) Snow White ran...and lay down and fell asleep. s_8: She found herself.... $s_{2-7} \Rightarrow s_8$: (s_{2-8}) Snow White ran...and lay down...and fell asleep and found herself.... s_9: They were.... Because dwarfs, indicated by they, have been removed in s_8, the entire sentence of s_9 can be ignored.

s_A: The Queen disguised herself and invited her to try an apple. $s_{0-1} \Rightarrow s_A$: ($s_{0-1,A}$) The Queen ordered...but it failed, and disguised herself.... Assuming that her refers to Snow White, the stories of the Queen and Snow White can be merged by means of the linking element, the event 'invited'. As a result of merging, all events that only refer to one of the personages, such as ran and found herself, may be removed. $s_{0-1,A} \Rightarrow s_{2-8}$: ($s_{0-A}$) The Queen invited Snow White to try an apple (here, summarization tacitly assumes her to be a reference to Snow White).

s_B: The Princess was tempted.... This sentence can be summarized with s_{0-A}, but it does not modify its summarized meaning. s_C: The woman insisted. Also this sentence can be merged with s_{0-A} and, again, there will be no change in the summary. s_D: Snow White bit...and fell. As the dwarfs have been ignored in s_8, they can be omitted in this sentence too. $s_{0-A} \Rightarrow s_D$: (s_{0-D}) The Queen invited Snow White to try an apple and Snow White bit into the apple and fell.

s_E: A Prince saw Snow White and she wakened from (a) dream indicates the beginning of a new episode. s16: Snow White and Prince married. $s_E \Rightarrow s_F$: (s_{E-F}) A Prince saw Snow White and they married.

Finally we are left with two sentences, which are s_{0-D} and s_{E-F}. These sentences may be combined in a summarizing single sentence through logical inferencing. By taking the first part of s_{0-D} (Snow White bit into the apple and fell), as the first premise, and using earlier information about the apple (which she (Queen) had poisoned), as the second premise, it may be deduced that Snow White could have been poisoned. Inasmuch as a poisoned person (who fell) must be dead, it may be abductively inferred that Snow White must be dead too. However, according to s_{E-F}, which occurs later in time than s_{0-D}, Snow White gets married. From this, it may be deductively concluded that Snow White must be alive. Assuming poisoning is a lexically defined counterpart of murder, we get: (s_{0-F}) a murder failed.

9.5 Conclusion

This chapter introduces the blueprints of a method for the hard problem of text summarization. The proposed technique makes beneficial use of the potential of the process model introduced in this thesis for a uniform representation of knowledge in different domains. This includes a specification of such domains as nonadic classifications, and a recursive classification of their signs as trichotomies.

The sample text “Snow White” is commonly known and almost everybody is able to summarize its meaning in a few sentences. Such a summary may be different from the one derived above, because of the specific goal of this chapter which is the generation of a single catchy sentence. Another reason for obtaining a different summary may be the limited number of domains considered by the example, which are the ‘naive’ syntactic, semantic syntactic and reasoning domains, but also the lack of important other interpretations, such as a discourse analysis of the sample text. Nevertheless, the extended example of this chapter illustrates that, theoretically, the proposed method could be successfully applied for summarization. A practical realization of the underlying algorithm requires that trichotomic specifications of symbols in different domains are available.

Chapter 10

Recursive analysis

This thesis is engaged with the question how knowledge may arise from the observation of 'real' world phenomena. It assumes that in an observation the observer generates the meaning of the input phenomenon (stimulus) by means of (re)cognizing it as a sign. From the input meaning, knowledge may arise through learning, for example, by means of generalization. Sign recognition and learning may be considered to be independent processes. This thesis restricts itself to the introduction of a model for the first process, an analysis of the second one is beyond its goals.

Meaningful interpretation is a hard problem as has been shown by Searle in his famous Chinese room thought experiment. Searle maintained that, in virtue of its irreducible character, meaning must contain the element of qualitative change (Searle, 1992). This is opposed to the basically compositional 'knowledge' representation enabled by the current computer, that cannot capture the full complexity of human meaningful representation. Roughly, the world 'perceived' by the current (electronic) computer is more restricted than the world perceived by the human, enabling the latter to experience a richer variety of qualitative changes. In conformity with this limitation of knowledge representation, this research has set as its goal the introduction of a model for cognitive activity only as a process.

Due to the specific nature of the subject of this research, i.e. knowledge representation, a summary of this thesis may be given in a unique way. Since the presentation of this work itself may be perceived as a phenomenon, it is possible to apply the theory to itself, recursively. This is the goal of this final chapter, in which the different chapters of this thesis are interpreted as the events of a meaningful interpretation or understanding of the problem of knowledge representation, as a process.

10.1 A meta-theory of knowledge representation

In order to prove that the theory of this thesis can be recursively applied to itself, the chapters of this book are re-visited one by one, and characterized from the point of view of knowledge representation. The goal of this analysis is to show that the meaning aspects exhibited by the subjects discussed in the different chapters can be interpreted as interpretation moments of a sign recognition process. This is specified by means of a set of Peircean signs and suitable keywords. The results of this meta-level analysis of this chapter are displayed in fig. 10.1.

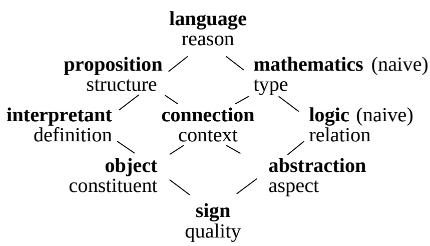

Figure 10.1: A meta-level analysis of knowledge representation introduced in this thesis. Keywords associated with identical Peircean signs (possibly in different chapters) are represented by a single expression; the imputed meaningful representation of a meaning aspect is denoted by a bold-face symbol.

10.1.1 Phenomena and signs

The initial assumption of this thesis, in chapter 1, states that meaningful interpretation is teleological by nature and, therefore, contains the element of completeness. Applications of the theory of knowledge modeling reveal the presence of this property of sign recognition in all domains. For example, the model of 'naive' logical signs indicates that cognitive activity, as a process, considers the meaning of input phenomena from all possible angles.

The appearance of completeness as a property indicates that an observed phenomenon is meaningful from some point of view. Because sign recognition is always related to some aspect(s) of interpretation, but not to all aspects, the meaning generated by that process may always be an approximation of the (full) meaning of the observed phenomenon.

The assumption that phenomena, appearing as qualities, have the potential of being interpreted as signs, is acknowledged in the proposed model by assuming that input qualities can be represented as qualisigns. For example, in qualisigns the qualities of the external stimulus are represented as qualia.

Qualisign = quality, **sign**

10.1.2 Signs and their recognition process

Meaningful interpretation is intimately tied up with signs and, therefore, this thesis is interested in the properties of signification. According to Peirce, a sign always stands for something else than itself. That what the sign is standing for, Peirce called the sign's object. Because phenomena are interactions and hence a duality, and, because all signs are re-presentations of phenomena, it follows that all signs must be a duality. This property of signs, in combination with the teleological nature of interpretation (i.e. the compelling need for completeness), enables sign interpretation to be modeled as a process of interaction events. The dual qualities comprising a sign are represented, in chapter 2, by a constituency relation of qualisigns, forming the (immediate) object of the observed phenomenon from the point of view of the recognition process.

Icon = constituent, **object**

10.1.3 Perception and cognition

Following the assumption about the organization of memory in the brain, in chapter 3, cognitive activity is defined as a combination of two processes that are isomorphic instances of a single schema. The goal of the first process, perception, is the analysis of the input qualia in themselves; the goal of the second process, cognition, is the establishment of a relation between the perceived qualia. As has been shown in this thesis these two processes may uniformly characterize information processing in different knowledge domains. What makes the domains different, is the point of view or aspect of interpretation. For example, phenomena can be interpreted from a 'naive' logical, a (morpho-)syntactic, or a semantic syntactic point of view. The meaning of an interpretation aspect contains the element of abstraction, as an event.

Sinsign = aspect, **abstraction**

The habitual character involved in the 'interpretation from a certain point of view' may be generalized in a rule or a rule-like meaning of which the most fundamental is the one captured by the (naive) logical interpretation, which has been shown to be a close relative of Boolean logic, in chapter 4.

Legisign	=	relation, 'naive' **logic**
Index	=	Boolean logic, process

Logical signs, capturing the relational meaning of observed phenomena, are an abstract account of the combinatory properties of their qualia, such as a lexical definition expressing the relational potential of a symbol as a range of possibilities. This is acknowledged in the proposed model by the generation of the (immediate) interpretant of the input phenomenon, as an expression of the abstract meaning of the constituent input qualia.

Rheme	=	definition, **interpretant**

According to a theory of Categorical Perception (CP) (Harnad, 1987), 'real' world phenomena as qualities are perceived by the senses as qualia. Qualia may characterize the higher level cognitive activity by the brain as well. This is acknowledged in this thesis by ambiguously using the term 'qualia' as a reference to the primary symbols of knowledge domains, as well as a reference to memory information. The input qualia may trigger memory, generating a response consisting of memorized qualia. This interaction is interpreted as a memory sign, representing the relation between the input and the memory response, in the sense of agreement or possibility.

Index	=	CP, qualia, memory model

10.1.4 Syntactic signs

An adequate definition of the combinatory properties of input qualia is complex. The impact of this problem may be reduced by considering knowledge domains that are more well-known. Such a domain is natural language. For example, in the domain of (morpho-)syntactic signs, a lexical definition of the combinatory potential of the primary symbols is available. However, language recognition introduces the problem of sequential processing. Chapter 5 shows that the processing schema of cognitive activity can easily be adapted to sequential processing by means of capitalizing on the model's potential for handling unfinished signs. The feasibility of the proposed language model is demonstrated by parsing non-trivial sentences taken from actual language use.

Legisign	=	(morpho-)syntactic language **rules**
Rheme	=	(morpho-)syntactic relational **needs**

10.1.5 Semantic syntactic signs

The close relationship between signs and categories is beneficially used, in chapter 6, for a systematic specification of signs on the basis of Peirce's categorical interpretation of phenomena. More specifically, it is shown by example that 'naive' semantic syntactic qualia can be specified by means trichotomies. Evidence for the use of semantic trichotomies in human language processing has been found in a psycholinguistic research on nomen-adjective combinations (Draskovic et al., 2001).

The analysis of 'naive' semantic syntactic signs reveals the need for the introduction of a more complete model of memory signs. To this end, memory signs are defined as a duality, consisting of an interpretation of memory qualia as average values and as dense domains of values.

Legisign	=	semantic syntactic **rules**
Rheme	=	semantic syntactic **relational needs**
Index	=	average, domain, trichotomy

10.1.6 Naive reasoning signs

The 'naive' logical interpretation of the model of cognitive activity opens the way for an analysis of the interpretation moments of this process, from a 'naive' reasoning's point of view. This analysis, in chapter 7, shows that also higher level knowledge can be modeled by means of the processing schema. Due to the complexity of this domain, a lexical definition of the combinatory properties of 'naive' reasoning signs may not be available. In the examples, a definition of the input qualia is taken for granted.

Legisign	=	'naive' **reasoning**
Index	=	deduction, induction, abduction

10.1.7 Naive mathematical signs

Another important knowledge domain, besides language and 'naive' logic, is 'naive' mathematics. The model of 'naive' mathematics is based on three types of cardinality, introduced in chapter 8. In conformity with the results of neurophysiological research by (Nieder et al., 2002), that cardinality arises in the brain, not in the senses, it is suggested that 'naive' mathematical signs are inherently related to abductive reasoning.

An analysis of non-trivial mathematical concepts, such as infinite and zero, reveal the hidden potential of memory signs as 'naive' interpretations of a type. It is suggested that this 'naive' concept is underlying the abstract mathematical notion of types. Because types may characterize the conventional property involved in the meaning of observed phenomena, they may as well be defined as law-like rules in context. The close relationship between 'naive' reasoning and 'naive' mathematics is illustrated by an analysis of sign recognition as 'naive' mathematical induction.

Symbol = 'naive' mathematics, **type**

10.1.8 Text summarization

The application of the process model of cognitive activity to different knowledge domains is motivated by the need for an illustration of the proposed theory, including the conjecture about its uniform representation potential. This boils down to a definition of models for different knowledge domains as isomorphic instances of the processing schema introduced in chapter 2, as well as a test confirming the hypothesis that the concepts generated by those models may also be meaningful in the 'naive' or obvious sense.

Encouraged by the successful test of the theory in the domain of 'naive' (morpho)-syntactic language signs, a blueprint for a systematic approach of text summarization is introduced in chapter 9. An important element of this model is the assumption that the cumulative effect of a series of sentences can be interpreted as a transition, transforming the initial state represented by the first sentence to the final state indicated by the last sentence. It is suggested that, from the individual clauses and sentences, interpreted as premises, a summary of the entire text can be generated as a conclusion. The summarizing conclusion or summary, which is a proposition, may be represented as a sentence as well. This result indicates that the key to efficient text summarization could be uniform knowledge representation, reducing the hard problem of merging complex signs to the less difficult problem of structural coordination. The proposed method, which is illustrated by a non-trivial example, makes extensive use of a trichotomic specification of signs as well as the interpretation of such trichotomies as order relations. The latter proves to be especially useful for the simplification of representations.

The suggested approach for text summarization capitalizes on the interpretation of a sentence (argument sign) as a relation between the subject (dicent sign) and the predicate (symbol sign). From the point of view of sign recognition, the essential meaning of the dicent sign is an expression of the input, as a proposition about the structural relation between the input qualia. This is opposed to the argument sign, which is an expression of the relation between the input qualia, as a proposition expressive of the aspect of reason. As all signs are in principle symbolic, representations including the aspect of reason or meaning are inherently related to language.

Text summarization is one of the fields in which the theory of this thesis might prove to be of practical. The potentially large number of knowledge domains, a systematic definition of the properties of their symbols and an efficient use of the definitions may require a uniform representation, which is at the heart of the approach of this thesis.

Dicent	=	structure, **proposition**
Argument	=	reason, **language**

10.2 Process interpretation

Finally, in the final chapter, an analysis is offered to the theory itself, recursively. In order to simplify the presentation of the results of this analysis (cf. fig. 10.2), collective names are introduced for some of the concepts identified. For example, all keywords indicated as index signs are collectively called *context*, in conformity with meaning of those concepts to establish a link between the qualia that are in the focus and those that are complementary. The corresponding meaning aspect is denoted by **connection**. The collective name for the keywords and the term for the meaning aspect of the legisign are *relation* and **logic**, respectively.

The classification of meaning aspects depicted in fig. 10.2 may be interpreted as a sign recognition process as follows.

Sorting is an operation representing the appearing qualities as constituents and as the view or aspect of interpretation. *Abstraction* has two interpretations that may be explained by means of their logical meaning, as relative difference operations.[1] The first, '$constituent \backslash aspect = definition$', is an abstract expression of the input constituents, independently from the actual aspect of interpretation, such as a (lexical) definition. The second, '$constituent / abstraction = relation$', is an expression of the logical dependency exhibited by the input, as a rule-like relation.

[1]A definition of these, 'naive' logical operations can be found in sect. 3.3.1.

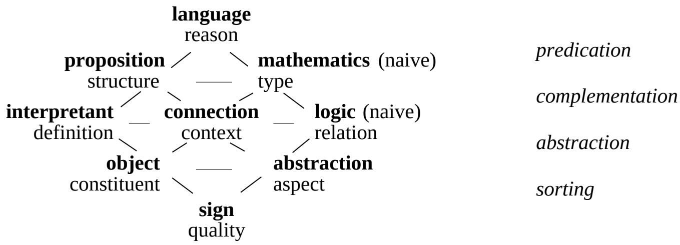

Figure 10.2: A meta-level analysis of knowledge representation as a process (cf. fig. 10.1). A horizontal line denotes a sign interaction, a diagonal one a representation relation. The four types of sign interactions are indicated on the right-hand side of the diagram.

Complementation has two instances. The first is an expression of the actual meaning of the input constituents, or the abstract or lexical definition of the input qualities in context (the interaction between *definition* and *connection*). The duality involved in the input is represented as a *structure*. The second is an expression of the logical relation of the legisign in context (the interaction between *relation* and *connection*), or the inductive generalization of the property involved in the input qualia, as a *type*.

Predication is an expression of the relation between the input qualia, which are arranged in a *structure*, and their conventional property which is a *type*. This is presented as a proposition, expressing the completeness of the input or, in other words, the *reason* why the input is found potentially meaningful. An example, in language, is the expression of the syntactic well-formedness of the input, for instance, a sentence.

Finally, the category related dependencies of the concepts of fig. 10.1 may be interpreted as polymorphic order relations (‘<’) in two different ways and in both cases as a trichotomy of orderings. In the first case or on the ‘phenomenological dimension’ (how signs appear in our experience):[2]

1st: sign < object < interpretant
2nd: abstraction < connection < structure
3rd: logic < mathematics < language.

In the second case or on the ‘ontological dimension’ (how signs function as a mediation of meaning):

[2]The ordering, logic<mathematics<language refers to a relation between the ‘naive’ models of these domains. According to Peirce, (full) mathematics precedes (full) logic.

1st: quality < aspect < relation
2nd: constituent < context < type
3rd: definition < structure < reason.

Peirce characterized his nonadic signs from the phenomenological and the ontological points of view.[3] Briefly, the phenomenological type can be firstness, secondness, or thirdness, depending on the category exhibited by a sign. The ontological type can be a 1st, a 2nd, or a 3rd depending on the signification function of a sign (Liszka, 1996).

10.3 Potential cognitive relevance

Throughout this thesis, serious effort has been made to clarify the potential relation between the proposed approach and certain evidences provided by cognitive research. Although it cannot be proved that the model introduced in this thesis could be used as a model for knowledge representation in the brain, one cannot withstand making a parallel between the process model of cognitive activity introduced in this work, and the 'working memory' suggested by cognitive theory.

In an early paper (Miller, 1956), George Miller reported about the capacity of the working memory of the brain. In his research, Miller considered the brain as a communication channel, and examined the effect of input variance on the output change. In one of the experiments, listeners were asked to identify tones between 100Hz and 8kHz, by assigning numerals to them. After each classification act, the test person was told the correct solution. This experiment showed that classification was precise when 2-3 different tones were presented. With 4 different tones the result was increasingly more erroneous and beyond 14 different tones identification was very bad. From this and a number of similar experiments, Miller concluded that the capacity of the brain as a communication channel could be 2.5 bit information, that is, 7 signs approximately. This capacity is invariant, whether the entities are simple (e.g. simple words) or complex (e.g. large numbers). Donald Broadbent, who repeated Miller's experiment fifteen years later, wrote (Broadbent, 1975):

> *Human processing is limited to handle a fixed number, say 7, independent units at one time. Each unit could nevertheless be divided into sub-units so that facts and actions of enormous complexity could*

[3] Van Breemen (pers. comm., 2007).

be handled by calling up a fresh ensemble of sub-units at each stage when it became necessary.

The hypothesis about the size of the working memory may speculatively be interpreted in the context of the theory of this thesis. The process model of cognitive activity acknowledges the existence of nine interpretation moments. The first (qualisign) is a representation of the input, as qualia. As qualisigns are not yet meaningful, their value may be stored outside the working memory, for example, in neurons generating the input for information processing. The last interpretation moment (argument sign) is a representation of the output of sign processing. This value too may fall outside the recognition process, and may be stored elsewhere (e.g. in neurons generating signals for motor control). In sum, the proposed model has 7 interpretation moments that have to be remembered during input processing, which is in conformity with the Miller–Broadbent conjecture. It should be mentioned that according to that conjecture the working memory may simultaneously contain 7 independent signs. In the model of sign recognition of this thesis all signs are a representation of the input qualia and, therefore, are not independent. This is not the case in text summarization, however, in which signs obtained from different sentences are combined in a single recognition process.

10.4 Conclusions

This chapter shows that the model introduced in this thesis can be used recursively. The recursive analysis reveals that the order of the chapters is not arbitrary, but is dictated by the dependencies between the interpretation moments of the process model of cognitive activity. The possibility of a recursive application of the theory also shows that the proposed knowledge representation must be generic indeed.

Appendix A

Towards a definition of a syntactic lexicon

This section introduces the blueprints of a lexicon for syntactic sign recognition, but the results trivially apply to the morpho-syntactic domain as well. Lexical definition of syntactic entities is simplified by assuming that the properties of syntactic (proto-)signs, illustrated by fig. 5.4, are available to the processing schema interpreted as a parser. For example, that in sequential sign recognition only coercion sign interactions (cf. sect. 5.1.1) may occur between symbols occurring in the icon and sinsign positions or, that passive relational needs are always optional, except in the dicent position (syntactic subject), in which they has to be realized in conformity with the SV(O) rule of English.

An important contributions of this chapter is an illustration of the possibility that, by making use of the above simplifications, a lexical definition of syntactic symbols may be given, which is close to their specification known from English grammar (Aarts & Aarts, 1982), (Quirk et al., 1985). The lexical definitions presented in this appendix are restricted to the syntactic symbols used in the examples of chapter 5. A specification of a full fledged lexicon is beyond the possibilities of this research.

A syntactic lexicon is defined as a set of entities. A single entity or a lexical entry of a symbol consists of two parts: a defining string, and a trichotome, recursive specification of relational properties, represented by tuples, defining the symbol's neutral, passive, and active relational need in a symbol interaction. A tuple is subdivided in three parts: (1) information about the relational properties of a symbol in itself, (2) about the relational needs the symbol may be affected by, and (3) about the relations the symbol itself may establish.

For example, the verb likes (1) may not be neutral ($n()$); (2) it may function as a verbal entity in a coercion symbol interaction, due to the neutral need of an appearing next symbol (the optional passive relational need of likes, which is not realized in a coercion, is ambiguously denoted by an n-need too) or, in an accumulation or a binding symbol interaction, for instance, due to the passive need of a syntactic modifier or a complement (p(verb,n/p,acc/bind)); finally, (3) it may function as a transitive verb in an accumulation symbol interaction with another verb or, actively trigger a complementation relation with a syntactic complement or a predication relation with the subject of the sentence (a(trans,compl/subj,acc/bind)). In sum:

likes[n(); p(verb,n/p,acc/bind); a(trans,compl/subj,acc/bind)]

Following the theory of this thesis, lexical definitions of morpho-syntactically finished or syntactic symbols can be dynamically generated from their morpho-syntactic constituents. A definition of such a process, for instance, the generation of a lexical definition of likes as a combination of morpho-syntactic relational properties due to like and -s, as well as their morpho-syntactic symbol interaction, is beyond the goal of this section.

A.1 A formal definition

A formal definition of a syntactic lexicon, as a context-free grammar extended by regular expressions is given below. In order to keep the size of the grammar small, nonterminals representing related concepts are unified in a single symbol (clearly, this may increase the size of the language generated by the specification). For example, the three nonterminal symbols occurring in the definition of “rel_needs”, specifying a neutral, passive, and an active relational tuple, are generalized in the nonterminal symbol “rel_tuple”. The definition below makes reference to grammatical notions, but no reference to model specific concepts such as interpretation moments or Peircean signs, except the categorically inspired three types of relational needs, indicating that a syntactic lexicon could be ‘naturally’ defined. Information about the language model is made available to the parser through the classification of syntactic entities depicted in fig. 5.4 (in fact, that classification can be used as a specification of the parser itself).

lexicon= {lex_entry}*
lex_entry= string, ”[”, rel_needs, ”]”.

rel_needs= n-needs, ";", p-needs, ";", a-needs.
n-needs= "n", "(", rel_tuple, ")".
p-needs= "p", "(", rel_tuple, ")".
a-needs= "a", "(", rel_tuple, ")".
rel_tuple= element_type, ",", implied_rels, ",", imputed_rels.
element_type= neutral_type; passive_type; active_type.
neutral_type= conjuction.
passive_type= {nominal_type; verbal_type; mod_type}$^+$.
nominal_type= common-noun; proper-noun; pro-noun.
verbal_type= copula; intransitive; transitive.
mod_type= adjective; adverb; preposition-compl.
active_type= {complement; subject}$^+$.
implied_rels= {n; p; a}$^+$.
imputed_rels= {coercion; accumulation; binding}$^+$.

Sample lexical specifications

This section contains an illustration of a lexical specification of the symbols occurring in the examples of chapter 5. In this presentation the convention is used that terminal symbols derived from a regular expression are separated by a "/" symbol. For example, "p/a" is a representation of two values, "p" and "a", generated from the nonterminal "implied_rels". Below, the following abbreviations are used: accumulation(acc), binding (bind), complement (compl), verbal (verb), transitive (trans), intransitive (intrans), subject (subj), conjunction (conj), adverb (adv), adjective (adj), preposition-compl (prep).

1. John likes Mary and Mary, John likes.

   John[n();p(proper-noun,n/p/a,acc); a()]
   likes[n(); p(verb,n/p/,acc/bind); a(trans,compl/subj,acc/bind)]
   Mary[n();p(proper-noun,n/p/a,acc); a()]

2. John likes Mary and Kim.

   John[n(); p(proper-noun,n/p/a,acc); a()]
   likes[n(); p(verb,n/p/,acc/bind); a(trans,comp/subj,acc/bind)]
   Mary[n();p(proper-noun,n/p/a,acc); a()]
   and[n(conj,(),()); p(); a()]
   Kim[n();passive(proper-noun,n/p/a,acc); a()]

3. Mary eats pizza with a fork.

    Mary[n();p(proper-noun,n/p/a,acc); a()]
    eats[n(); p(verb,n/p,acc/bind); a(trans,compl/subj,acc/bind)]
    pizza[n();p(common-noun,n/p/a,acc); a()]
    with_a_fork[n(); p(); a(prep;p/a;acc/bind)]

4. Mary is a democrat and proud of it.

    Mary[n();p(proper-noun,n/p/a,acc); a()]
    is[a(); p(); a(copula,bind,compl/sub)]
    a_democrat[n();p(proper-noun,n/p/a,acc); a()]
    and[n(conj,(),()); p(); a()]
    proud[n(); p(adj,n/p,acc); a(adj,p/a,acc/bind)]
    of_it[n(); p(prep,n/p/0,()); a(adj,p/a,bind)]

5. A man entered who was covered with mud.

    a_man[n();p(proper-noun,n/p/a,acc,); a()]
    entered[n(); p(verb,n/p/,acc/bind); a(trans,comp/subj,acc/bind)]
    was_covered[n();p(verb,p/a,acc,bind); a(trans,compl/subj,acc/bind)]
    with_mud[n(); p(); a(prep,p/a;acc/bind)]
    who[n(); p(pronoun,n/p/a,bind); a()]

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Index

Summary

This thesis introduces a model for knowledge representation as a sign recognition process, on the basis of an analysis of the properties of cognitive activity. By offering a logical account of this model, the existence of a 'naive' logic underlying human information processing is revealed, which in turn opens the way towards a Peircean semiotic characterization of the cognitive model. 'Naive' logic is a procedure generating relations between collections of qualia, in the sense of agreement, possibility, and (relative) difference. It is suggested that those relations have common meaning aspects shared with Boolean relations on two variables.

The close relationship between the process model of cognitive activity on the one hand, and the Peircean signs on the other enables the cognitive model to be interpreted as a *meaningful* process, and the Peircean classification of signs as a *process*, generating meaning aspects or parameters of (meaningful) interpretation.

In conformity with the fundamental nature of cognitive activity, it is suggested that the process model of cognitive activity may be *uniformly* applied for modeling different knowledge domains. This hypothesis is tested for the domain of 'naive' logical, (morpho-)syntactic, semantic syntactic, reasoning and mathematical symbols. Each of these models consists in a specification of a recognition process (parser) and a definition of combinatory properties of primary entities (lexicon). An advantage of the proposed theory is that adjustments of the model of a domain, for example, in order to cope with new phenomena, may only require an adjustment of the lexicon, not the parser, which can be invariantly used.

Besides a uniform representation of knowledge, also the possibility for a *systematic*, trichotomic specification of lexical entries is proposed by the thesis, on the basis of an analysis of Peirce's category theory. This hypothesis is only illustrated by means of a simple lexicon, specifying the syntactic symbols used

in the examples of the chapter on language modeling (sect. 5). A definition of a full fledged lexicon is far too complex and falls beyond the possibilities of this research, unfortunately.

An advantage of uniform knowledge representation is that it may reduce the hard problem of merging complex signs obtained in different domains to the more simple task of structural coordination. Such a representation of knowledge, in combination with a trichotomic specification of combinatory properties of lexical entities is used in this thesis for the definition of a technique for text summarization. This too is only illustrated by an example, however by a non-trivial one, which is the summarization of the fairy tale Snow White.

The paradigmatically new understanding of reality developed by Peirce is consequently present in the different applications considered in this thesis. A simple comparison of the theory introduced in this thesis, with traditional knowledge representation theory may not be possible, as a consequence of paradigmatical differences. As the traditional, and the semiotically inspired knowledge representation proposed by this thesis are expected to possess identical predictive potentials, by only focusing on a few examples one may not be able to prove the superiority of any one of these theories.

In my opinion, the importance of the Peircean approach will become more obvious in tasks, in which knowledge arising in different domains has to be merged in a single representation. Because of the need for translations between different representations, such a task can be too complex for traditional knowledge representation, that may become impractical. A solution necessarily must be found in a uniform representation, precisely what the Peircean approach can offer.

Evidence for a uniform representation by the brain is found in a research by (Hagoort et al., 2004), who experimentally proved that input stimuli are simultaneously analyzed by the brain in the syntactic and semantic domains. The (full) meaning of the input may contain its interpretation in both domains, but the temporal differences between a syntactic and a semantic analysis is small (there may not be time for a translation between the representations in the two domains), indicating the necessity of a uniform representation (in those domains at least).

According to this thesis, human information processing may be characterized as a certain type of process. This hypothetically implies that information generated by the computer could be more easily processed as knowledge by the human, if the computational process respects the properties of cognitive activity. An experimental validation of this conjecture has been provided by a recent research by (Couwenberg, 2007).

The practical value of the theory developed in this thesis is strongly depending on the practical value of Peircean semiotics. With respect to the latter let me refer to the abundant literature available in libraries and on the Web, proving the usefulness of Peirce's theory in various fields such as conceptual modeling, organizational semiotics, etc. With respect to the first, I must admit that the research presented in this thesis is restricted to an illustration of the proposed theory. Although the thesis contains a number of non-trivial problems and shows how they can be solved by means of the theory introduced, it does not contain a computational specification of the proposed knowledge representation. Such a specification (and a program), its use in requirement engineering as well as in medical text summarization is the subject of current research.

Curriculum vitae

József Farkas was born in Szeged, Hungary, on October 08, 1954. His secondary education took place in Ruzsa at the Radnoti M. Gimnazium. After graduation he studied at the József Attila University of Szeged, Hungary, where he received his MSc in chemistry and physics (1988).

Following his studies, he joined a research project on computer assisted instruction (CAI) systems at the József Attila University. In 1992-1993 he studied Intelligent Tutoring System and Neural Networks at the University of Utrecht, The Netherlands. Later he took part in the development of a speech analyzer and synthesizer as one of the leaders of the project at the Technical University of Budapest, Hungary. Since 1995 he has been guest researcher at the Radboud University in Nijmegen, The Netherlands, several times. Currently he is lecturer at the Szent György College, Budapest. József Farkas is married and has seven children.