Contributions Towards a Unified Concept of Information

Doctoral thesis

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ABSTRACT

The present thesis is to be a contribution towards a unified concept of information. Its aim is to achieve, within the framework of a new and interdisciplinary information theory, a coherent treatment of issues such as the ultimate information carrier, the information element, the appropriate unit of measurement or the general characterisation of information, which have so far been treated in contradictory ways. Two ideas form the basis of this theory. First of all, the various requirements for an information carrier can only be met by the very general concept of the thing as a unit in perceptual and conceptual reality, and not, as often suggested, by the concept of the sign as proposed by the semiotician Charles W. Morris. This entails a new interpretation of the semiotic terms syntax, semantics and pragmatics. In the new framework that I want to propose, these no longer stand for fundamentally separate relations between things, but designate only the context-dependent features which any directed relation has. The second idea is based on the insight provided by modern neurobiology that 'things' are merely the constructs of an organism's brain. After this discovery, similarities between the neuronal structure of the brain, the structure of knowledge and the structure of perceived reality no longer come as a surprise. Thus the foundations for a new formal information theory can be laid, enabling me to postulate, in conclusion, a 'law of information theory' that shows marked similarities with the second law of thermodynamics.

PREFACE

Computer science has existed as an independent discipline dealing with the systematic processing of information for more than three decades. Nevertheless, a universally valid definition of the concept of 'information' is still lacking. Although various attempts to define information have been made, no one has ever succeeded in deriving a satisfactory universal definition from those concepts of information developed in individual disciplines. Opinions about the basic issues such as the question of the information element or a suitable unit of measurement for information have sometimes diverged so much that a unification of the concepts has come to seem impossible. This fact may have contributed to computer scientists avoiding one of the most basic questions of the field in favour of issues concerning the development and the use of electronic devices suitable for processing 'information.' The question of the characteristics of information has been bracketed or confidently taken for granted. This illusory certainty is so deep-rooted today that most information theories have been forgotten, with the exception of Claude E. Shannon's mathematical theory of communication, which interprets information from a mathematico-technical point of view.

With the present thesis I venture to reactivate the discussion about the concept of information, at the same time as I attempt to define the term across disciplinary boundaries. Certain recent philosophical reflections about semantics on the one hand and the results of modern neurobiology on the other hand, which have not been taken into account yet, are to be introduced into the debate, thus helping to base the definition of the concept more broadly.

The thesis was written while I was working as a free-lance specialist for data modelling, at the same time teaching some lessons in computer science at the college of engineering in Bern (HTL). Neither activity interfered with my certainly rather more theoretical thesis; on the contrary, situations I encountered in my practice repeatedly provided examples that helped me clarify many of the thoughts of this study.

I thank Prof. Dr. Hansjürg Mey for the excellent support he gave me during the writing of my thesis. When the quest for solutions threatened to take me off-course, Prof. Mey would always be there with competent advice. What I appreciated in particular was the fact that I was able to realise my thesis independently and without external pressure. I would like to give special thanks to Dr. Stefan Hottinger who gave me generous help with the philosophical part of my thesis and often made useful suggestions to improve the other parts of my text. It is also a pleasant duty to thank Prof. Dr. Jürg Schmid and Prof. Dr. Hans-Rudolf Lüscher as well as my friend Ueli Gysel for their valuable contributions towards the completion of the thesis.

Finally, I would like to thank with all my heart my wife Eveline, who, despite her increased workload due to the delightful arrival of two healthy children, always stood by me and my work and immensely furthered my thesis by offering competent advice and suggestions.

Bern, 12th January 1995

Federico Flückiger

1. INTRODUCTION

In the 19th and 20th centuries the natural sciences have developed with breathtaking speed, and their products are used by us every day without further thought. The scientific process of discovery has its own dynamic which is fed by a constant stream of new discoveries. New facts lead to modified models, working hypotheses and experimental approaches, and the latter again lead to new discoveries. However, the assumptions, norms and definitions on which these activities are based remain mostly implicit and rely on an unspoken consensus. One example of this consensus is provided by the definitions of three basic concepts in the natural sciences: energy, matter and information. Consulting [Knaurs 1974] we find the following definitions:

> "Energy is the capacity to do work. Energy exists in many guises and is usually divided into: mechanical energy (...), heat energy (...), field energy of a gravitational field, of electrical, magnetic and electromagnetic fields (...), radiation energy of particles (...), chemical energy (...)."
>
> "Matter is the name for all substances as opposed to energy and the vacuum. Mass is an intrinsic quality of matter (...)."
>
> "Information = message, report, instruction." (1)

What is striking is that all three terms are explained by other, undefined terms which can again only be explained by terms that are undefined. In spite of the precariousness of these foundations important natural laws are based on those three concepts, and the conclusions drawn from those laws often allow impressive advances to be made. Yet, while energy and matter can at least be qualitatively delimited from other concepts, it seems that information can still merely be illustrated, by a list of synonyms, and remains to be clarified.

Etymologically the term information is a noun formed from the verb 'to inform,' which was borrowed in the 15th century from the Latin 'informare.' While the original Latin word means 'to give form to, to shape, to form,' the German word was always used figuratively. While during the Renaissance to inform was synonymous with 'to instruct,' by the 20th century its meaning had extended to include 'sending a message, giving intelligence.' Recently, by virtue of its application in the natural sciences in general and in biology in particular (genetic information), the term has reverted from its figurative German back to its original Latin meaning.

There is no lack of theories about the problem. While Norbert Wiener set up information as a separate category of the natural sciences by stating, in 1948, that 'information is information, neither matter or energy' (see [Wiener 1961, p. 132]), Claude E. Shannon, in the same year, provided the most important contribution to information theory so far with his book The Mathematical Theory of Communication (see also: [Shannon 1969]). Starting from the question how information content can be maximised while minimising message length, Shannon's theory defines in particular a measure for the average information content that can be transmitted using a given code. However, Shannon confines himself to the communication engineering aspect of the concept of information and deliberately ignores the aspects of semantics and pragmatics, which he considers to be irrelevant.

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(1) Author's own translation of the original which follows: "Energie ist die Fähigkeit Arbeit zu leisten. Energie existiert in zahlreichen Erscheinungsformen, man unterscheidet meist: Mechanische Energie (...), Wärme-Energie (...), Feld-Energie des Gravitationsfeldes, des elektrischen, magnetischen und elektromagnetischen Feldes (...), Strahlungsenergie von Teilchen (...), chemische Energie (...)." [Knaurs 1974, vol. 5, p. 1541 f.]
"Materie ist die Bezeichnung für alle Stoffe, im Gegensatz zur Energie und zum Vakuum. Die Eigenschaft der Masse ist mit der Materie untrennbar verbunden. (...)." [Knaurs 1974, vol. 12, p. 3907]
"Information = Mitteilung, Auskunft, Belehrung." [Knaurs 1974, vol. 8, p. 2816]

In the 1950s and 1960s Shannon's concept of information infiltrated various disciplines. Apart from the natural sciences, it was mainly in the humanities, in particular psychology, that specialised definitions of information were elaborated (cf. [Seiffert 1968] and [Attneave 1974]). In addition, increasing efforts were made to arrive at a unified definition that would integrate all aspects of the problem that had already been investigated in individual disciplines. Important impulses for the development of a definition came from semiotics, cybernetics and philosophy (cf. [Nauta 1970] and [Titze 1971]). But apart from a variety of verbal definitions and vague hints for the development of new information theories, these efforts have yielded little and have certainly not led to a generally recognised definition.

Not everybody understands the same thing by information. In modern information theory a distinction is made between structural-attributive and functional-cybernetic types of theories. While representatives of the former approach conceive information as structure, variety, order, and so on, members of the latter understand information as functionality, functional meaning or as a property of organised systems.

For philosophers like Hans Titze information takes place exclusively at the level of the mind, through the accumulation of messages, while psychologists like Helmut Seiffert would also like to include material elements like the outlines of a drawing, which can carry and transmit information by their mere presence. Other researchers, such as Jon Barwise and John Perry, subscribe to a contrary view of information. For them information is situated in the world as information about structured reality. Language can function as a carrier of information, but according to them information itself is non-linguistic. The cyberneticist Doede Nauta jr. sees the solution of the problem not in a general definition of information, but in the cybernetic re-interpretation of basic semiotic concepts (sign, syntax, semantics and pragmatics). At the centre of his reflections is the sign-processing individual which receives syntactical, semantic and pragmatic information via the sign. As a consequence, Nauta requires an independent information theory for each individual semiotic aspect, with a general framework provided by the semiotic paradigms.

The proposal advanced by Wiener whereby information was to become a new world principle like energy and matter has not been welcomed everywhere. Carl Friedrich von Weizsäcker, for one, argues that since modern physics considers matter as a special form of energy, energy may well be information. In that case information would even be a principle of all possible realities. Johannes Peters goes further when he claims that the statement in the Bible 'in the beginning was the word' would have to be translated as 'in the beginning was information.' And Fred Irving Dretske makes everything clear when he writes: 'In the beginning there was information. The word came later' [Dretske 1981, p. vii]. Finally, Hansjürg Mey considers matter, energy and information as a triad 'which in their interaction (...) constitute those features of (an) object which can be perceived by us' [Mey 1986, p. 84]. The opposite standpoint is represented by Hans Titze. The relation between information and entropy proposed by Shannon seems to him to indicate that information, energy and matter have something in common rather than their being distinct. In [Titze 1971] he claims to have proved that information is not a new world principle, but merely the causal aspect of the causality principle.

Some fundamental problems remain unsolved. For example, the choice of information unit depends on the observer's point of view. If a message taken as a combination of signs forms the object of investigation, the sign is the ultimate carrier of information (see [Flechtner 1968]). But if, on the other hand, the information source which produces signs is analysed, information consists in the selection of a sign from a pool of signs. In that case, the binary subdivision of the selection space has been shown to be the simplest way of reducing uncertainty concerning the selection of a sign. So the so-called bit ('basic indissoluble information unit') suggests itself as the information unit. Since any large finite sign pool can be represented in binary form according to an appropriate coding rule, certain schools hold that the binary number as the re-presentative of a bit and not the sign is the ultimate carrier of information. That neither of those views can be right is shown by the following example: On a very windy day a man is walking through a street. Chance has it that a tile falls from a roof directly towards the man's head. If the man notices the tile he will be taken by surprise; he will be informed neither through binary selection, nor through a sign, but only through the situation of the tile falling towards him. The existence of such 'unaddressed' information is well known, but, except for some tentative efforts (example in [Nauta 1970]), this kind of information is neglected in the current conception.

A further point to be debated is the persistence of information. Peter Heyderhoff and Theodor Hildebrand, for example, write in [Heyderhoff/Hildebrand 1973, p. 2] that information loses its value after it has been interpreted; according to them a particular piece of information is needed for a particular decision and is used up in that decision. Similarly, Yehoshua Bar-Hillel says in [Bar-Hillel 1964, p. 305] that the sentence 'Jonny is hungry' contains no information for someone who already knows that Jonny is hungry. Information would therefore merely influence the cognition process, in the sense of a reduction of uncertainty, and would be limited in its effect to the reduction of a relative difference in knowledge between two individuals. However, it has to be pointed out that there are instances of persistent information. One example is provided by genetic information. It is permanently stored and available for use in the genes and allows the cells that contain it to reproduce species-specific cells in the organism. The argument that this is a completely different kind of information can be countered by referring to the fact that before the beginning of cell formation there is also an 'information deficit' which is balanced when genetic information is duplicated during mitosis. The result are two new cells with exactly the same genetic information as in the mother cell, if we leave aside the occurrence of spontaneous mutations. Were one to apply this principle to mental processes, knowledge would be persistently stored information which could be transmitted ad libitum by means of information processes. Information would then be a superordinate concept for knowledge and not just a tool of cognition.

Finally another problem has to be addressed. Most information theorists postulate that 'truth' is a necessary requirement of information. Fred I. Dretske in [Dretske 1981, p. 45] can represent this view: 'Information is what is capable of yielding knowledge, and since knowledge requires truth, information requires it also.' But how do we interpret the situation when individuals unconsciously base their 'knowledge' on false premises and start to 'inform' people around them with that 'knowledge'? Don't the same rules apply to transmission, reception and storage as when they inform their neighbours on the basis of factually correct knowledge? To answer this question in the affirmative leads to the inevitable conclusion that truth, however desirable it may be, is not a necessary requirement of information. Thus deliberate misinformation could be accommodated in the same theory, which would be in the interest of a broad-based information theory.

The present thesis is to be understood as a contribution towards a unified concept of information. The main aim of this study is therefore the elaboration of a concept by which the results of previous information theories are taken into account, attempts are made to eliminate their shortcomings and, moreover, those aspects are integrated which, although well-known among researchers in the field, have yet not made it into information theory. Because this necessarily entails an interdisciplinary approach, those disciplines I draw on will first have to be introduced briefly. Accordingly, chapter 2 will give a comprehensive survey of the state of the art by summarising and critically assessing selected information theories.

Chapter 3 contains a reworking of the basic terms necessary for the sought-for information theory. First, the basic semiotic terms are examined as to their applicability to all aspects of information listed in chapter 2. This necessitates the substitution of a more general concept of the thing for the concept of the sign and thus a new view of the three semiotic dimensions of syntax, semantics and pragmatics. This view is based on a simple assumption, which must be understood as one of the most important theses of the present study, namely that syntax, semantics and pragmatics do not represent fundamentally distinct concepts of relations between real or conceptual things, but designate only the context-specific features which any directed relation has. In other words, I reject the autonomy of syntactical, semantic and pragmatic relations as proposed in semiotics and replace it by the view that each directed relation between two things can be interpreted syntactically, semantically or pragmatically depending on the thing that is analysed and its situation.

This concept is first of all situated within the humanities with reference to Willard van Orman Quine's theoretical reflections on semantics and Jon Barwise and John Perry's theory of situation semantics. The subsequent presentation of various theories about learning and knowledge, in particular the presentation of insights into learning and knowledge gained in modern neurobiology, will illustrate that my thesis is compatible with modern epistemological and scientific evidence. What is more, evidence found in neurobiology that everything that can be perceived or thought must be understood as a thinking subject's mental construction will be an important pillar of the information theory I propose. In addition, thanks to this insight, similarities between the neuronal structure of the brain, the structure of knowledge and the structure of perceptual reality will become clear.

In chapter 4, finally, it will be possible to design a new formal information theory on the basis of the results sketched in chapter 3 and to postulate in conclusion a 'law of information theory' which shows a clear affinity with the second law of thermodynamics. Thus Carl Friedrich von Weizsäcker's hypothesis that information is the superordinate term for energy will be confirmed.

The theses of the present study are based on arguments from different disciplines so that the reader has to be introduced to each discipline separately before he or she can be confronted with those statements that will be useful for the present study. Thus chapters 2 and 3 in particular contain sections that can be read on their own. In order for the reader to be able to follow the thread of the thesis, it has been necessary to insert cross references in some places. This could involve the reader in a lot of laborious page turning. In order to counteract this disagreeable side effect the most important results from previous chapters are recapitulated wherever suitable. Thus chapters 3 and 4 can be considered as independent units which, with certain exceptions, can be read on their own. Moreover, both chapters end in detailed summaries (cf. chapters 3.4 and 4.5 respectively). The resulting high redundancy may irritate those readers who read the study as a whole, but it will help those readers who are only interested in selected sections of the text.

2. HISTORICAL SURVEY

In the introduction I have briefly outlined the development of the concept of information. But a universal conception of information must be based on an in-depth understanding of the present state of the art. That is why the present chapter will summarise some interesting theses concerning information.

The chapter begins with a survey of the most important elements of the definition developed in communication engineering. It is true that, apart from communication engineers, it was mainly journalists who contributed to the historical foundations of a scientific definition of information in the 1920s, but their attempts only yielded phenomenological descriptions. The results achieved by communication engineers were much more concrete (thanks to their mathematical precision), leading as they did to Ronald A. Fisher's first simple statistical model (cf. [Fisher 1922] and [Fisher 1935]). At the end of the 1940s, with Claude E. Shannon's contribution as part of his mathematical theory of communication, a generally accepted definition of information was developed for the first time; it was made accessible to a non-mathematical readership by Warren Weaver. Shannon's theory is based on Norbert Wiener's groundbreaking reflections, but does not agree with them in every detail.

A wide-ranging debate about the new theory ensued. It was especially Shannon's deliberate exclusion of semantic aspects from his theory that led authors like Donald M. MacKay and Doede Nauta jr. to elaborate alternative information theories. They were based on interesting and promising premises, but were not generally accepted because of a lack of formalisation and have been practically forgotten.

Apart from authors who made their own attempts at a definition, there were also those who did not further question Shannon's theory, but refined it or enriched it with alternative interpretations. With the work of Helmut Seiffert, Hans Titze and Fred I. Dretske, three interesting contributions from this area will be presented at the end of this historical survey.

2.1 Definition in communication engineering

2.1.1 Norbert Wiener's pioneering work

Norbert Wiener is considered as one of the founders of cybernetics as a scientific discipline. In [Wiener 1961, p. 11] he calls cybernetics the 'entire field of control and communication theory, whether in the machine or the animal' (2). By establishing cybernetics as a science, Wiener hopes to bring together similar research efforts in communication engineering, psychology, sociology, biology and medicine. The automaton is at the centre of his investigations. Yet the precise nature of the automaton is of no concern since the most important prerequisite for two systems to be able to communicate with each other is that they move in the same temporal direction:

> "Thus the modern automaton exists in the same sort of Bergsonian time (3) as the living organism; and hence there is no reason in Bergson's considerations why the essential mode of functioning of

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(2) This phrase is not from the original edition (1948), but from the revised edition published in 1961.

(3) Bergson lays special emphasis on the distinction between the reversible time of physics, in which nothing new happens, and the irreversible time of evolution and biology, in which there is always something new.

> the living organism should not be the same as that of the automaton of this type." [Wiener 1961, p. 44]

From the point of view of communication engineering, it is above all the quantity of information which, apart from message, amount of interference (noise) and coding technique, is to be accounted for. According to Wiener the transmission of information is only possible as a transmission of alternatives, for if only one possible state is to be transmitted it is most easily done by not transmitting any message at all. Therefore he calls for the development of a statistical theory of the amount of information, a quantity that has natural affinities to entropy in statistical mechanics. While the amount of information of a system is a measure of the degree of order, the entropy of a system is a measure of the degree of disorder.

Nevertheless Wiener claims that amount of information and entropy stand for different situations and illustrates the fact by means of the thought experiment of the Maxwell demon (cf. [Wiener 1961, p. 57 f.]). The question is how entropy can be reduced in a closed container containing ideal gas. If we assume that the container has an opening that can be closed by means of a gate, a 'demon' acting as doorman would have to open this gate in those moments when a particle approaches the gate from within the container at higher than average velocity. Otherwise the 'demon' would have to close the gate. The demon can decide which action to take only if it knows the average velocity of all particles in the gas on the one hand and the velocity of the approaching particle on the other. It can only act on the basis of information received. Wiener deduces from this that the amount of information as a measure for 'knowledge about something' must be a quantity distinct from entropy, which is one index of gas in a closed system. He claims to be able to deduce the amount of information as negative entropy mathematically in [Wiener 1961, p. 61 ff.].

This still does not solve the question of a concept of information proper. Throughout his life Wiener attached special importance to finding an answer to this question. To this purpose he made use of the results of a long-term collaboration with medical scientists. Wiener was struck by the fact that doctors, in the grip of an instinctive materialism, could not cope with psychopathology and the fact that the causes of mental disorders are neither physiological nor anatomical. There was no way of identifying the brain of a schizophrenic, of a manic-depressive or of a paranoid patient. Wiener proposed that these functional disturbances of the mind be considered as fundamental disorders of the mind and the information circulating within it.

Thus information is not matter. Otherwise one would see a physical difference between the brains of a mentally ill and a sane person. Nor, on the other hand, is information energy, for the blood leaving the brain is only a fraction of a degree warmer than that entering it. These considerations led Wiener to make the famous statement:

> "Information is information, not matter or energy. No materialism which does not admit this can survive at the present day." [Wiener 1961, p. 132]

Thus he demands that information be established as an independent quantity of the natural sciences. Wiener is not sparing with illustrations of this thought. Among other examples he mentions that:

> "(...) musk, civet, castoreum, and the like sexually attractive substances in the mammals may be regarded as communal, exterior hormones, indispensable, especially in solitary animals, for the bringing the sexes together at the proper time, and serve for the continuation of the race." [Wiener 1961, p. 156]

Wiener concludes that a community can only expand as far as information can be transmitted efficiently. He even goes so far as to claim that every organism is held together by, in this order, the possession of the means for the acquisition, use, retention and transmission of information. In a society which is too big for its members to be in direct contact with each other those means are the press, radio, the telephone system, etc.

Norbert Wiener dedicates a lot of space in [Wiener 1961] to the idea that the living organism and the modern automaton basically work in the same way. Since both exist in Bergsonian time there is no reason to assume the opposite. In order to be functionally equal to the living organism, the modern automaton only has to have an ability to learn and to reproduce, two characteristics which according to Wiener are closely related, or, indeed, mutually dependent (cf. [Wiener 1961, p. 169 ff.]). Therefore he considers a canonical form of the representation of non-linear transducers, apart from the existence of machines capable to learn, as fundamental to a theory of self-reproducing machines. Wiener concludes:

> "In short, the newer study of automata, whether in the metal or in the flesh, is a branch of communication engineering, and its cardinal notions are those of message, amount of disturbance or 'noise,' (...), quantity of information, coding technique, and so on." [Wiener 1961, p. 42]

In this way Wiener prepares the merging of the disciplines of automaton theory and communication engineering which were then just emerging. The concept of information played a central role in the new science and became essential for the further development of information theory. It is Norbert Wiener's greatest distinction to have created, thanks to his willingness to work across disciplinary boundaries, a solid basis on which information can be convincingly distinguished from other concepts. Nevertheless he did not succeed in defining the concept perfectly.

2.1.2 Claude E. Shannon's statistical model

Wiener's idea of a statistical theory about the amount of information was realised by Claude E. Shannon in [Shannon 1969] (4). The basic problem that needed to be solved according to Shannon was the reproduction at one point of a message produced at another point. He deliberately excluded from his investigation the question of the meaning of a message (5), arguing that:

> "Frequently the messages have meaning; that is they refer to or are correlated according to some system with physical or conceptual entities. These semantic aspects of communication are irrelevant to the engineering problem. The significant aspect is that the actual message is one selected from a set of possible messages. The system must be designed to operate for each possible selection, not just the one which will actually be chosen since this is unknown at the time of design." [Shannon 1969, p. 31]

According to Shannon, in order for messages to be transmitted, we need a communication system. By this he means an arrangement such as is represented in Figure 1.

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(4) [Shannon 1969] is the fourth edition of the work first published in 1948.

(5) In chapter 2 'meaning' designates the extension of a message, i.e. the reference of the message to the things of the real world. An exception to this is chapter 2.3.3, where the deviation from this usage is explicitly noted. A detailed analysis of the concept of meaning in particular and the theory of semantics in general with reference to our concept of information will follow in chapter 3.

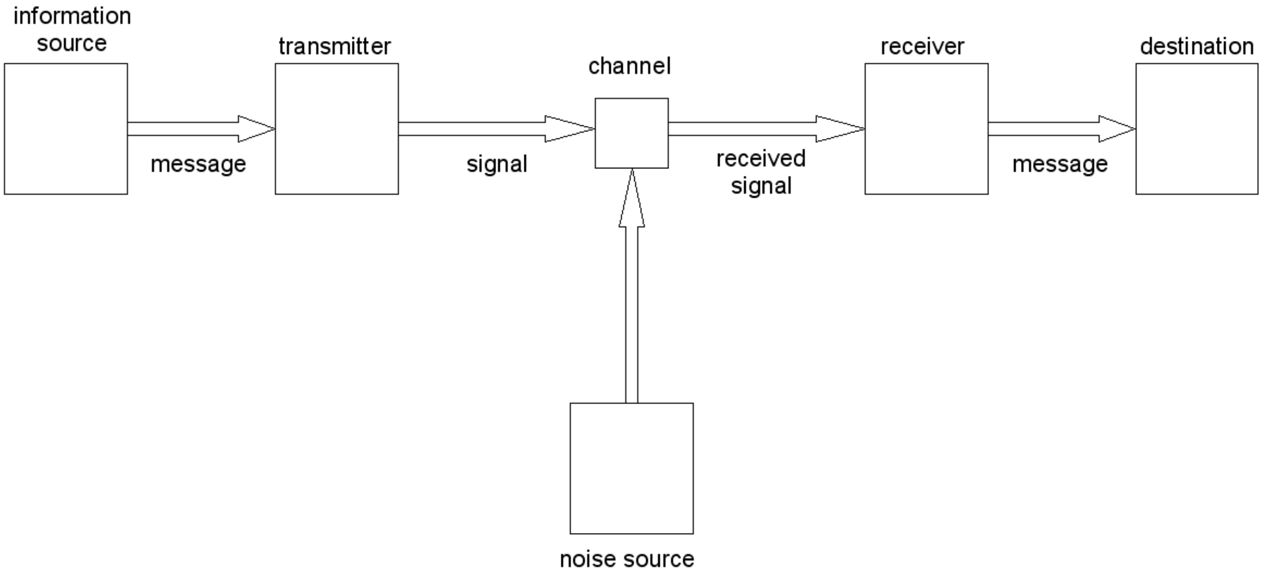

Figure 1: Schematic diagram of a general communication system (cf. [Shannon 1969, p. 34])

Shannon describes the components of the communication system as follows:
1) The information source (or message source) produces messages or parts of messages intended for a particular destination.
2) On the basis of the message, the transmitter produces a sequence of signals such that they can be transmitted over a channel.
3) The channel is merely the medium used to transmit the signal from transmitter to receiver. During transmission the signals may be perturbed and distorted by a so-called noise source.
4) The receiver usually performs the reverse operation to the transmitter, reconstructing if possible the original message from the signals.
5) The destination is the addressee of the message and can be either a person or a thing. It requires a priori knowledge about the information source which enables it to understand the message transmitted. In any case, the destination must know the set of signs available to the information source.

On the basis of his communication system, Shannon defines statistical quantities such as channel capacity and amount of information for discrete and continuous, noisy and noiseless systems. For the purpose of the present thesis, only the derivation of the amount of information for discrete noiseless information sources is relevant:
- Channel capacity is irrelevant for a definition of information. It is not of interest how much information per time unit can be sent over a channel, but only the fact that information has been sent and what it consisted of.
- Except for degenerated cases, continuous behaviour can be simulated to any desired degree of precision by means of discrete models.
- The noise source can be represented as an additional source of information which informs (or misinforms) the channel and thereby the information transmitted.

Shannon assumes that the set of messages which a discrete information source can produce consists of a finite number of elements N_1, N_2, ..., N_n (the elementary messages or signs), with a probability of occurrence of p_1, p_2, ..., p_n respectively. Since under very general conditions an information source combines the messages from sign sequences produced in a non-deterministic way, the information source can be interpreted as a stochastic process (6). In many cases, such as the transmission of a text in a natural language, the probabilities moreover depend on the preceding states. Thus in English the letter 'd' is more likely to be followed by the letter 'e' than the letter 'z'. In such cases the information source operates as a discrete Markov process (a special case of a stochastic process) or Markov chain respectively. Where transition probabilities converge on a particular probability distribution independently of the starting probability, such as is typically the case with information sources that produce texts in a given language, it is usual to talk of an ergodic Markov chain.

The ergodicity of transition probabilities can be illustrated by imagining that an information source can be brought to produce texts automatically and without human input [Shannon 1969, p. 43 ff.]. If digrams (7) are used, the resulting sequence will already differ greatly from a sequence produced using only normal probabilities of occurrence. If trigrams or indeed tetragrams (8) are used for generating text, it is possible to produce almost meaningful text.

Apart from the requirement that abstraction be made from form and content of the information, the measure for the amount of information — called $H(p_1, p_2, ..., p_n)$ by Shannon — should have the following properties:

1) H is continuous in p_i.
2) If all p_i are equal ($p_i = 1/n$), then H must increase monotonically with n.
3) If a choice is broken down into two successive choices, the original H should be the weighted sum of the two new values of H.

In the form of a theorem, Shannon postulates in [Shannon 1969, p. 49 f.] that the only function satisfying the three criteria above is of the following form:

$$H = -K\sum_{i=1}^{n} p_i \log p_i \qquad \text{Formula 1}$$

where K is a normalising positive constant. Shannon shows in [Shannon 1969, p. 87 ff.] that Formula 1 is also valid for the more general case of real p_i.

With this formula Shannon created a direct equivalent to entropy as defined in statistical mechanics and thus contradicted Wiener's assertion that the amount of information was the same as negative entropy. The debate about the minus sign continued for quite a while until Shannon's formula was generally adopted, probably because it was sufficiently formalised so that it could be applied to practical cases immediately.

The amount of information H from Formula 1 is a quantity which allows us to calculate the average number of signs (from a set of signs x_1, x_2, ..., x_n) needed for coding a message. Since the resulting value is not always an integer, Shannon talks about the measure of information H* of the coding operation where: $H^* \geq H$. The resulting superfluous information, redundancy r, is calculated as follows:

$$r = 1 - \frac{H}{H^*} \qquad \text{Formula 2}$$

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(6) More detailed descriptions of stochastic processes and their special cases will be found in [Heller et al. 1978], [Ehrenstrasser 1974] or [Beyer et al. 1978].

(7) By a digram one understands the fact that the occurrence of a sign depends not only on its own probability of occurrence but also on the sign preceding it.

(8) For trigrams the two preceding signs and for tetragrams the three preceding signs determine the occurrence of a sign.

Shannon's theory of the amount of information was dismissed by many later authors as merely a theory of syntactical information, because it excluded the semantic and pragmatic levels. In particular, Yehoshua Bar-Hillel and authors drawing on his work, such as Doede Nauta jr., vehemently attacked Shannon's theory. They said that, except for the theory about the amount of information of an information source, considered irrelevant by this school of thought, information as a notion was not defined by Shannon at all (cf. [Bar-Hillel 1964, p. 301). Moreover, they claimed that physical entropy as a purely empirical concept was unsuitable for a definition of semantic information, which for them was a logical concept (cf. [Bar-Hillel 1964, p. 309). Any attempt to develop Shannon's theory into a universal theory of information would necessarily reach an impasse. To this day, though, there is no quantity in information theory which is as well-supported and as generally accepted as Shannon's amount of information. On the other hand, Shannon's work is rightly seen as lacking indications for a conceptual clarification of information.

2.1.3 Warren Weaver's comments

Shannon's information theory would probably have remained unknown to many less mathematically minded researchers if Warren Weaver had not reformulated it in a more accessible style and situated it in a wider scientific context in [Weaver 1969]. He uses the term 'communication' in an extended sense:

> "The word communication will be used here in a very broad sense to include all of the procedures by which one mind may affect another. This, of course, involves not only written and oral speech, but also music, the pictorial arts, the theatre, the ballet, and in fact all human behavior." [Weaver 1969, p. 3]

According to Weaver the problem of communication has three elements:
1) The technical problem: How accurately can communication symbols be transmitted?
2) The semantic problem: How precisely do the transmitted symbols retain the meaning that the sender intended?
3) The effectiveness problem: How precisely do desired and actual effect produced by the received signal correspond?

Like many of his contemporaries, Weaver believes that Shannon provides a solution to the first element of the problem. Unlike Bar-Hillel he sees no reason why Shannon's results should not be applied to other elements of the problem. Thus he has no difficulties in imagining a diagram similar to Figure 1 as a model for the transmission of semantic information. In that diagram, symbols would be produced by a semantic information source and translated by a transmitter into signals capable of transmission. These signals, their meaning distorted by a semantic noise source on the way, would be retranslated into semantic symbols by the receiver and conveyed to their semantic destination.

Weaver further supports this idea by stating that the theory of Markov chains deals with the most important and at the same time the most difficult aspect of meaning, namely the influence of context. From this he derives the following hypothesis:

> "One has a vague feeling that information and meaning may prove to be something like a pair of canonically conjugate variables in quantum theory (...). Or perhaps meaning may be shown to be analogous to one of the quantities on which the entropy of a thermodynamic ensemble depends." [Weaver 1969, S. 28]

This amounts to assuming that thermodynamic entropy and meaning are strongly interdependent, a thought that was unfortunately not followed up in the scientific debate about information, but one which should urgently receive serious consideration.

In his account, Warren Weaver — like Shannon and Wiener — poses the question of the smallest unit of information. Since for him information manifests itself as the choice of an element from a set of elements, he agrees with the other two authors that the unit of information is the choice between alternatives. This is supported by the insight that any selection can be reduced to a sequence of binary decisions [(9)]. Thus information theory received a generally accepted basis, which could moreover be implemented elegantly on electronic machines.

2.2 Alternative attempts at definition

2.2.1 Donald M. MacKay's descriptive information theory

Donald M. MacKay is one of those forgotten authors who tried to define information independently of Shannon. The basis for his so-called descriptive information theory is the assumption that information is linked to an increase in knowledge:

> "Suppose we begin by asking ourselves what we mean by information. Roughly speaking, we say that we have gained information when we know something now that we didn't know before; when 'what we know' has changed." [MacKay 1969, p. 10]

According to MacKay, knowledge must be understood as a coherent representation [(10)] in which the information element comes to be embedded. This information element can therefore not be understood as a shapeless isolated thing, but has to have a minimum of structure so that the meaning of the information intended by the sender can be inferred by the receiver [(11)]. In his view the receiver will find it all the easier to integrate a piece of information in what s/he knows, the more familiar s/he is with all or parts of it. In other words: If we receive the same message several times, it will each time become more familiar and seem more plausible. This effect is by no means limited to verbal communication. Thus, the result of a scientific experiment gains in evidence the more often it can be reproduced under similar conditions.

MacKay believes that this fact cannot be expressed using Shannon's amount of information, which he calls 'selective information-content.' Information should not be reduced to a choice between isolated messages, but should take into account the following two aspects:

1) the inner structure of the information element as a 'logical a priori' aspect (structural information) and
2) the so-called 'weight of evidence' of the individual structural elements as an 'empirical a posteriori' aspect (metrical information).

MacKay covers the first, logical a priori aspect by introducing his concept of so-called logons. It seems obvious to MacKay that the information element can be divided into structural elements, or logons. Accordingly he proposes logon content, an integer for the number of structural features of an information element, as a measure for structural content:

> "Logon-content is a convenient term for the structural information-content or number of logons (number of independently variable features) in a representation (e. g. the number of independent

(9) Incidentally, this is how the term bit ('basic indissoluble information unit') was developed. For the same reason, the amount of information H is usually not calculated using the logarithm to the base 10 as in Formula 1, but by means of the logarithm to the base 2. Consequently the constant K has to be set at a different value.

(10) By representation MacKay understands any structure (pattern, picture, model) whether abstract or concrete which, by virtue of its features, can symbolise some other structure.

(11) MacKay illustrates this thought with the following example: One single word rarely makes sense. Usually it takes a group of words or even several sentences acting together to clarify the role of a single word within a sentence.

> coefficients required to specify a given waveform over a given period of time)." [MacKay 1969, p. 165]

The empirical a posteriori aspect, a measure for the plausibility of a structural element, is accounted for by MacKay's metron concept. He defines the corresponding unit, the metron, as follows:

> "The unit of metrical information, one metron, is defined as that which supplies one element for a pattern. Each element may be considered to represent one unit of evidence. Thus the amount of metrical information in a pattern measures the weight of evidence to which it is equivalent." [MacKay 1969, p. 166]

The corresponding metron content is usually given as metron per logon, and contains as an integer the number of indistinguishable units of evidence for the logon, or as MacKay puts it:

> "Thus the amount of metrical information in a single logon, or its metron-content, can be thought of as the number of elementary events which have been subsumed under one head or 'condensed' to form it." [MacKay 1969, p. 166]

MacKay claims that if the logon content of a representation and the metron content of each individual logon are known, the descriptive information of the representation can be represented as an information vector in an information space. Each logon is assigned a dimension. The value of the corresponding vector component is the square root of the appropriate metron content. Thus the square of the absolute length of the information vector corresponds to the total metron content of the representation.

It should be mentioned that all the measures discussed above, both logon and metron content, are necessarily non-dimensional positive integers.

With his theory of descriptive information, MacKay provided a convincing and temptingly simple definition of information, which also takes into account certain semantic aspects. Nevertheless, it was barely developed further, and today it is almost forgotten. There are of course good reasons for that:

1) The logon concept is doomed to failure because of the differing perspectives of the various information sources on the information element. Certainly, one will easily find the minimum number of parameters necessary to characterise physical oscillation. But if one examines a purely verbal description of an event, it is highly unlikely that one will succeed in establishing a broad consensus about the number and kind of logons present.
2) With the concept of the metron, MacKay aims to describe in discrete mathematical terms a state of affairs which clearly also has psychological aspects. The concept of a gradual increase of the weight of evidence by a summand 1 with each repetition of the information seems too simple. The situation where what is said remains unclear and no apparent gain in plausibility is made, even though a statement has been repeated ten times, will be well-known. Furthermore it cannot be ruled out that, on the eleventh repetition, in a sudden explosion of understanding, the facts of the matter will miraculously become clear. The weight of evidence may also shoot up in this 'process of illumination,' since other statements which were previously not understood will suddenly appear crystal clear.

Yet although MacKay's descriptive information theory may have serious flaws, the ideas on which it is based are certainly sound and should be taken into account in any discussion about a universal concept of information.

2.2.2 Semiotics and information according to Doede Nauta jr.

Another author with his own comprehensive conception of information is the cyberneticist Doede Nauta jr. In contrast to MacKay, he does not want to oppose a new information theory to existing theories, but develops a conceptual framework for existing and future information theories. Like Wiener, Nauta considers information as a link between the humanities and the natural sciences. A comprehensive framework would therefore have to combine ideas from both sides. Since information concerns communication, Nauta seeks a solution to the problem in a cybernetic interpretation of the conceptual tools of semiotics (the theory of signs). Apart from the usual semiotic concepts in Morris' sense, such as syntax, semantics and pragmatics [(12)], the concept of semiosis is particularly important to Nauta. By semiosis or sign process semioticians understand the fact that a sign, perceived by an individual, will prompt this individual to react, a reaction which will often take the form of a specific behavioural pattern. The cybernetic interpretation of semiosis that Nauta proposes (Figure 2) forms the basic model of his theory.

In contrast to Shannon's communication model (Figure 1) in which a transmitter is opposed to a receiver and both are linked by the channel, the system which receives, processes and emits information (the so-called i-system; cf. Figure 2) is viewed as a whole. Semiosis takes place in the i-system as follows: An information carrier is received by the receptor and is passed on to a filter, which recognises it as a sign. This changes the interior state of the i-system (P) and in turn stimulates the next filter to prepare a goal-directed behavioural pattern. This is output to the environment via the emittor. A sign, whatever its type, will therefore have to possess:

1) an elaborate internal structure (syntactic component), otherwise it would not be recognisable as a sign,
2) a meaning for the i-system (semantic component), otherwise the internal state P will not change, and
3) a stimulus that activates the i-system (pragmatic component), otherwise no behavioural pattern will be produced and triggered.

According to Nauta, information theories that do not take these considerations into account are incomplete.

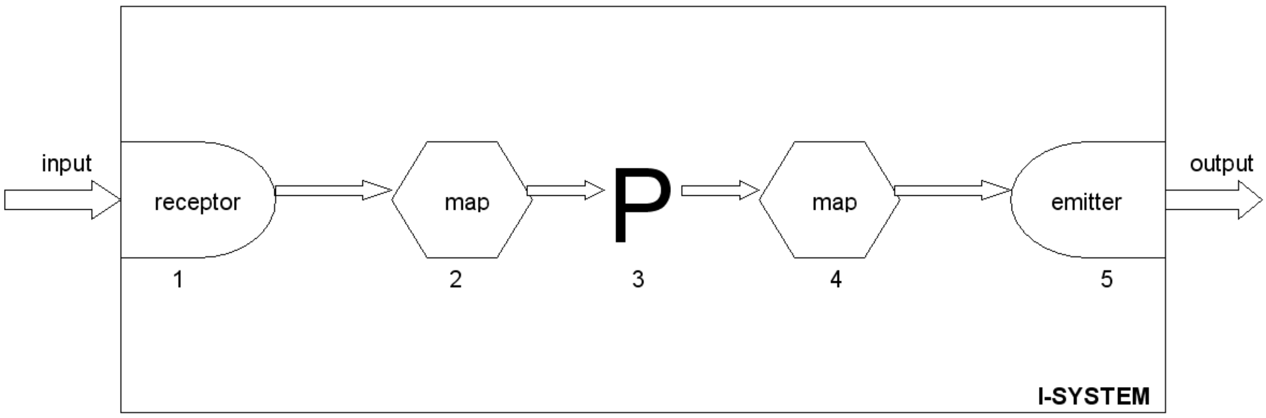

Figure 2: The i-system. A cybernetic model of semiosis (cf. [Nauta 1970, p. 61])

Phenomenologically, Nauta establishes a close relation between information and improbability when he says:

> "Information is news: what is known already is no information. So, something is information to the extent that it is unknown, unexpected, surprising, or: improbable." [Nauta 1970, p. 16]

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(12) The semiotic terms mentioned here will be treated in depth in chapter 3.1.

Since according to Nauta information is discrete, Nauta, quoting [Khinchin 1957], requires for all information theories that they have a finite scheme, indicated by a so-called 'universe A' and its appropriate probability distribution p:

$$\{A, p\} = \begin{Bmatrix} A_1, & A_2, & \ldots & A_N \\ p_1, & p_2, & \ldots & p_N \end{Bmatrix}, \textit{where } 0 \le p_i \le 1 \textit{ for } i = 1, 2, \ldots N$$

The corresponding improbability function H then has to take the following form:

$$H = -\sum_i p_i \log p_i \qquad \text{Formula 3}$$

According to Nauta, he has thus provided the basis for the division of information theories into three basic types:

1) the 'zero-semiotic' information theory: By this Nauta understands Shannon's communication theory, which only takes into account communication engineering or signalling aspects, but makes abstraction from semiosis (13). 'A' represents an alphabet of signals or potential messages from a communication source, 'p_i' the frequency of a signal 'A_i,' and 'H' the potential information of an information source.
2) the 'semiotic' information theory, which embraces the analysis of signal, sign and symbol semiosis (14): Here 'A' represents a set of signals, signs or symbols which can be used in messages within a given i-system, 'p_i' the subjective probability of message 'A_i' relative to the i-system, and 'H' the amounts of psychological or physiological information.
3) the 'meta-semiotic' information theory, which can be divided into the three disciplines of syntax, semantics and pragmatics: In this case 'A' represents a universe of statements formulated in an object language which can be analysed from a meta-semiotic point of view; 'p' represents logical probabilities, and 'H' amounts of syntactic, semantic or pragmatic information.

In his study Nauta focused particularly on the third type, the 'meta-semiotic' information theory, and defined the necessary framework for the formulation of a theory for the three fields, as far as the state of the respective disciplines at the time would allow it.

According to Nauta, syntactic information theory is the most advanced of the three disciplines, given that MacKay's descriptive information theory has already established essential structural aspects. Nauta sees a relationship between universe 'A' and the ensemble of logons on the one hand and the probability distribution 'p' and metron content on the other hand. Thus MacKay's descriptive information content would be an adequate analogue for the H value in Khinchin's theory of finite schemes, though it would have to be adapted.

The situation in semantic information theory is seen as less promising because it provides hardly anything beyond a phenomenological description. Quoting [Popper 1965], [Hintikka 1968], [Bar-Hillel 1964] and [Cherry 1963], Nauta claims that there is a relation between semantic information and improbability. A sentence carries the more semantic information the more precisely it expresses a situation, and this makes it more improbable (15).

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(13) Here Nauta contradicts other authors who call Shannon's information theory syntactical. In Nauta's view, Shannon even makes abstraction from the syntactical aspects.

(14) 'Semiotic' information theories sometimes provide a framework for the description of genetic and unaddressed information (example for the latter: the lion that suddenly appeared in front of me).

(15) Nauta illustrates this by the following example: The sentence 'A train will leave from London to Edinburgh today' is more probable, but has less semantic content, than the sentence 'A train will leave from King's Cross for Ed. at 10 a. m. today.'

Pragmatic information causes Nauta the most difficulties since up to that date there was no satisfactory scientific measure for it. According to him, pragmatic aspects are closely related to the situational context in which the i-system finds itself when information is passed on. Individual aspects such as need for information and motivation play an important part. Nauta suggests that under certain circumstances the monetary value that an individual (i-system) is ready to pay for a piece of information may provide a measure for pragmatic information.

Doede Nauta jr.'s work, an interesting contribution to the topic, certainly marks an important stage in the history of information theory. He presents a convincing model with which the various contradictory approaches can be brought together in a single comprehensive framework. By his own account, he has sketched a conception in which observed as well as communicative, addressed as well as unaddressed information can be represented. His information theory therefore also takes into account phylogenetic and ontogenetic learning. But like MacKay's descriptive information theory, Nauta's semiotic framework for information has today all but disappeared from the scientific debate. The reasons are obvious:

- In many parts, especially on the subject of meta-semiotics, Nauta's formulations are imprecise. There is no satisfying taxonomical concept, in particular for semantics and pragmatics; this could hardly be provided in a semiotic framework, anyway.
- The mostly uncritical way in which he accepts the semiotic terminology is questionable, to say the least. Semiotics, closely related to behaviourist psychology, is based on a rigorous stimulus-response paradigm and has difficulty in explaining cognitive phenomena. Modern neurobiology has recognised, however, that ontogenetic learning in animals is by no means exclusively based on learning by experience and thus semiosis (cf. [Singer et al. 1990]).
- Certain defects of the system, of which Nauta himself is aware, are eliminated by questionable means: When, for example, he includes unaddressed information in his considerations he proposes for lack of alternatives that the internal representation of a perception be considered as the sign of the perceived object. This, to say the least, is a bold extension of Morris' concept of the sign (cf. chapter 3.1).

Notwithstanding these criticisms, insights from semiotics will have to play their part in future attempts at defining information, for the categories of semiotics allow a structural classification of all sign systems (gestures, language, writing, and others). But an uncritical adoption of the paradigms will evidently not achieve its purpose.

2.3 Refinements

2.3.1 Redundancy and information according to Helmut Seiffert

MacKay and Nauta, Shannon's declared opponents, attempted their own definitions of information. But apart from them there are many authors who have adopted Shannon's theory and enriched it with their own ideas. With Helmut Seiffert, I want to present a representative of the humanities who has integrated Shannon's theory in a psychological and sociological framework. Among other things he has wrestled with the concept of redundancy (16) and has come to very interesting conclusions.

Seiffert notes that in communication engineering redundancy denotes superfluous information in a message. But this excess is not always useless; rather redundancy is often deliberately built into a system so that errors can be spotted or that messages that have been garbled in transmission can be reconstructed. According to Seiffert there is an analogous phenomenon in psychology. He writes:

(16) The word redundancy, like the word information, was already used in classical Latin. Etymologically it comes from the Latin 'unda' = wave and literally means 'overflow.'

> "The psychologists call a figure that insists on being seen as a whole a 'gestalt.' (...) A gestalt or a text whose elements can be reconstructed even though they have been partly mutilated can be called 'redundant.'" [Seiffert 1968, p. 67 f.; trans. from German]

From this he concludes:

> "Redundancy is (...) quite independently of any problems with 'disturbance' the ordered completely unsurprising way in which parts or elements of a whole are related to each other. In that sense, 'redundancy' is the probability with which certain elements appear within a certain context. The more probable this appearance, the greater the redundancy and the orderedness of the individual elements." [Seiffert 1968, p. 69; trans. from German]

Seiffert thus demands implicitly that a new system boundary be drawn when considering redundancy. While Shannon, relying on linguistic tradition, limits the system to the information source (for him redundancy is superfluous information generated by the sender), Seiffert also wants to include the receiver, or rather the whole communication system from Figure 1, in his investigation. For him, it is not only coded redundancy but also those transmitted elements that are already known to the receiver that in a given communication system are redundant. Therefore Seiffert interprets what Shannon considers as the a priori knowledge of the destination about the information source as the redundancy of the communication system itself. The information process could therefore also be interpreted as the receiver's redundancy process, in the course of which the total store of information increases and the necessary growth rate of information decreases gradually. Thus an object would consist of:
1) objective information (everything that a receiver can know about an object) and
2) subjective information (what the receiver does not know about the object yet).

The receiver's store of information about an object (the difference between objective and subjective information) would be equivalent to the redundancy relative to the object.

According to Seiffert, the redundancy process does make the world 'deficient in information,' but it also allows one to establish new relations. Thus social life would be impossible if we only met new faces all the time. In this sense redundancy creates relations of familiarity. Today the music of masters such as Handel and Mozart and pop songs produced according to a well-worn formula are particularly redundant. Where the musical style is historically unfamiliar, on the other hand, such redundancy will have to be established gradually.

With these reflections Helmut Seiffert shows the concept of redundancy in a new light. Where communication theorists believe that redundancy is an annoying side effect of inefficient coding, communication according to Seiffert is only possible through the presence of redundancy. In that sense the language spoken in a society is redundantly present in each member of that society. Such an approach engenders further questions such as:
- Can a computer learn anything at all that is not redundant from the start?
- Is it our ability to grasp non-redundant facts which distinguishes human intelligence from the capabilities of a computer?

The answers to these questions are not self-evident, for what is at stake is the as yet unanswered question whether artificial intelligence is possible. The present study does not aim to explore this problem and will at most speculate about it.

2.3.2 Hans Titze's reflections on information as a principle

While information theories as such already drew a lot of attention, it was in particular the idea of information as a new world principle which met with great interest in the general public and gave philosophers like Hans Titze food for critical thought. If information really were a principle, then a new way of thinking philosophically would have to be found. Hans Titze tried to invalidate this thesis in [Titze 1971].

Drawing on the phenomenological method developed by Husserl, Titze attempts to get a clear idea of information. Like Seiffert, he stays within Shannon's communication model as presented in Figure 1. He notes that transmitter and receiver can be either human or machines. The 'channel' as an acoustic, optical or electrical conduit, on the other hand, always represents something physical.

In the information process, according to Titze, it is the receiver's situation which is especially interesting. Phenomenologically, there are three possibilities:

1) One did not know the piece of information before one was informed.
2) One knew the piece of information already, but receives it again.
3) Up to now one knew something that is in direct contradiction to the new piece of information, and one has to recognise that the piece of information which one already had is false.

In each of the three cases a process of ordering takes place in the receiver. By 'ordering' (Ordnen) Titze understands the transition from a more probable to a less probable (rarer) state. This ordering is effected by the information source, the sender, when s/he intends a piece of information. There is thus a relation between information and causality, for in both cases one finds the same features: temporality, direction, continuity (in the classical sense), facticity, and a difference between initial and final states. Apart from the causal event itself, one determinant of a causal event is always its final state. Thus information is an event that produces a state with a higher degree of order and can trigger further events. Titze concludes that without information there would be no causal events. Information is therefore only another term for the concept of cause:

> "In discovering information one has found nothing really new. (...). Information is nothing but cause. (...). In this sense it can also be the cause for an event failing to take place or, which is also conceivable, the omission of a determinant." [Titze 1971, p. 135; trans. from German]

> "Information (...) is merely (...) the reason for an event taking place, which can also be a thought process. At the end there will be a message to inform a thinking being. The end is the effect, which (...) can again cause a further event." [Titze 1971, p. 138 f.; trans. from German]

Accordingly for Titze information as cause is only part of a causal operation on matter (receiver) involving a transfer of energy (channel). Information is thus not possible without matter and energy and cannot be a new principle in addition to matter and energy.

Titze introduces a new aspect into the debate about the concept of information which should be followed up. On the other hand, the idea that information and cause are identical should not be integrated into our definition of information without further examination. It seems obvious that the principle of causality can be represented with Shannon's communication system; Titze's line of reasoning bears out this intuition. But the inversion of his argument, namely that information is a sufficient criterion for cause must not be accepted uncritically, if the aim is a comprehensive definition of the concept. It would mean that MacKay's logon concept and Seiffert's objective information would not be considered as information because neither triggers causal processes; they merely describe the structural properties of so-called information elements. This loss of inclusiveness cannot be accepted.

2.3.3 Knowledge and flow of information according to Fred I. Dretske

Many contributions to the concept of information point out the connection between knowledge and information, but none analyses the nexus in such depth as Fred I. Dretske's work Knowledge and the Flow of Information. Dretske, using Shannon's concept of communication, attempts to explain how knowledge is gained. He consistently endeavours to demarcate information from other concepts such as causality or meaning. This sometimes leads him to other conclusions than the authors quoted above.

According to Dretske confusion may first of all arise when information and causality are not kept apart. Although in most cases the flow of information depends on causal processes [17], the informational and the causal relations between sender and receiver are of a fundamentally different kind. The main difference can be explained using Figure 3. Let there be a sender and a receiver which, among others, can assume states s_2 and r_2 respectively. If the rule applies that state s_2 in the sender always causes state r_2 in the receiver we are dealing with a causal relation. But the information that is communicated cannot thereby be given. It would entail knowledge of the other possible states of the sender with their respective probabilities of occurrence. Therefore Dretske, unlike Titze, refuses to equate information with cause. Rather he conjectures that there are properly informational relations between sender and receiver in addition to their causal relations (cf. [Dretske 1981, p. 26 ff.]).

sending station receiving station

s_2 -----------------------------> r_2

Figure 3: Causal relation between sender and receiver

According to Dretske, a further problem is caused by an insufficient demarcation of information from meaning. Past attempts to establish a semantic theory of information failed mainly when they attempted to assimilate information to meaning. For Dretske information and meaning represent independent semantic concepts, so that the information conveyed in a signal does not necessarily have to be related to the meaning of the same signal (cf. [Dretske 1981, p. 42 ff.]) [18].

Yet the difference between information and meaning only becomes clear when Dretske introduces knowledge into his information-based theory. Like MacKay (cf. chapter 2.2.1) he thinks that information increases knowledge. Knowledge is therefore defined as follows:

> "K knows that s is F = K's belief that s is F is caused (or causally sustained) by the information that s is F." [Dretske 1981, p. 86]

Thus knowledge is considered as a completed act of information. Because knowledge (and equally belief) are represented by cognitive and therefore, according to Dretske, digital structures, while information may consist of analogue sense data and digital structures, such an act of information is usually accompanied by a digitalisation of analogue structures (cf. [Dretske 1981, p. 135 ff.]). This automatically creates the possibility of producing semantic content, for semantic structures according to Dretske can only exist in digital form. This insight is crucial for the distinction between meaning and information: While Dretske considers meaning as a cognitive category, which only appears in digital form, he defines information, whose cognitivity he denies, as follows:

> "Structure S has the fact that t is F as its semantic content = S carries the information that t is F in digital form." [Dretske 1981, p. 177]

According to Dretske, knowledge can be called 'justified true belief' (cf. [Dretske 1981, p. 85]). Thus knowledge is composed of factual and therefore true elements, while belief can also be based on falsities. Since verification is achieved via a process of information, this information, too, will have to satisfy this limitation: Dretske only accepts true statements as information.

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(17) In [Dretske 1981, p. 32ff.] Dretske constructs examples where the transmission of information does not depend on causal processes.

(18) Dretske encapsulates this in the statement that a signal has meaning, but carries information. Later in the book he defines the new concept of 'carrying' information as follows: "The signal carries as much information about s as would be generated by s's being F" [Dretske 1981, p. 63], where s is the variable for the state of the sender and F is a possible value of this variable.

In his work Dretske also comments on the question briefly raised above whether artificial intelligence, i.e. intelligence based on a system of formal logic suitable for information processing, is possible. Such a system, if it qualifies for cognitive attributes at all, has to possess so-called 'high-order intentionality' (cf. [Dretske 1981, p. 172 f.]). Only thus can cognitive status such as belief, meaning, etc. arise. Information and therefore systems of formal logic also have intentionality, but only low-order intentionality (cf. [Dretske 1981, p. 75 f. and 171 f.]) (19). Thus for Dretske the impossibility of artificial intelligence is sufficiently demonstrated.

It is Dretske's achievement to have demarcated the concept of information from other concepts and to have embedded it in the context of cognitive theory. In so doing, though, he has limited the semantic space of the concept of information so much that not all phenomena previously considered informational fit in. Thus unaddressed information cannot be represented in Dretske's conception because it is not unequivocally transferred from a sender to a receiver. Furthermore, the limitation of information to mental phenomena — a limitation which is never explicitly stated, but nevertheless runs through his work — raises the question whether a phenomenon which is as important as genetic information can be dealt with by Dretske's system.

An additional flaw in Dretske's theory is finally the requirement that information be true. This excludes a considerable part of everyday use of the term information from scientific discussion. More than that: Anything that turns out to be false will lose the attribute of informationality retroactively. Such an approach would lead to the paradoxon that, for example, a physics student who is acquainted with Newtonian physics at primary school would realise on studying the theory of relativity that he was never informed about physics in the past because Newton's theory only gives an approximate, but never an accurate account of physical phenomena. The same thing would happen to the same student if ever the theory of relativity turned out to be wrong. But such an approach cannot be reconciled with the concept of information I am looking for in the present study. What is needed is a value-free concept of information as such, independent of the way in which information presents itself or which attributes it shows. The truth, which in this context can be considered as a purely accidental property, is therefore a very desirable but not at all necessary property of information. Any other approach, as the example above shows, would lead to a grey zone of barely plausible cases.

2.4 Concluding remarks

With the exception of a few contributions such as Dretske's, the debate about the concept of information died down in the mid-seventies and shows no signs of a resurgence. The profession has apparently accepted that the problems with the definition will remain unsolved and makes do with the results achieved on the basis of Shannon's concept of information. Among certain engineers one can even discern something like a siege mentality such that any attempt to extend the concept of information to areas other than pure communication engineering is dismissed as sterile speculation:

> "The term 'information' as used in information theory (...) was (...) very popular in the fifties and sixties, and non-specialists applied it to areas to which it must not be applied under any

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(19) In [Dretske 1981, p. 172f.] Dretske distinguishes between three grades of intentionality, which he identifies as follows:
- First order of intentionality: All Fs are G. (...).
- Second order of intentionality: It is a natural law that Fs are G. (...).
- Third order of intentionality: It is analytically necessary that Fs are G. (...).

Information then is of the first order of intentionality, while cognitive status such as meaning and belief are of the second or even the third order of intentionality.

circumstances. Attempts to explain and interpret the totality of human thinking as a transfer of information and as data storage in the sense in which it is used in information theory is at least as funny as the serious attempts of someone like Christian Kramp (...) at the beginning of the nineteenth century to explain the human cardiovascular system and its disorders by means of differential equations." [Heise/Quattrocchi 1983, p. 92; trans. from German]

Werner Heise and Pasquale Quattrocchi here overlook that it is precisely models of human cognition that played a crucial part in the original statistical definition of information by Shannon (cf. [Wiener 1961, p. 120 ff.]). But the reason why attempts to apply this concept of information to other areas have only met with modest success most probably lies in the fact that too many fundamental questions have not been solved satisfactorily:

1) The question of the characterisation of information: Is information to be equated with the process that increases knowledge, or is information knowledge itself as a structured object?

2) The question of the information carrier: Is the bit, representative of the smallest element that can be chosen, the ultimate carrier of information, or is it the sign as the smallest unit of perception?

3) The question of the appropriate measure for information: Is Shannon's entropy as the measure of possible successive states or MacKay's descriptive information content as the measure for the structural cardinality of an information element the correct quantity for measuring information? Or are there several, mutually independent information theories with their own measures which remain to be defined, as Nauta suggests?

The three questions represent nothing but the conflict between a functional-cybernetic and a structural-attributive approach to information. It seems that the reconciliation of these apparently irreconcilable points of view is a prerequisite for a comprehensive definition of information where material information such as genetic information as well as the phenomenon of unaddressed information will all find their place.

3. BASIC CONCEPTS

The historical survey above has shown that many basic questions concerning the concept of information have not yet been answered. What is particularly unsatisfactory is the fact that with Shannon's mathematical theory of communication and MacKay's theory of descriptive information we have two seemingly incompatible concepts of information. True, for the time being Shannon's concept has won the day in the technical sphere, but the debate cannot be considered closed, for Shannon's theory owes its success primarily to the fact that the formulas Shannon provides can immediately be applied to practical problems, and less to a general recognition that it is superior as a theory. Only very grudgingly do many information theorists accept the fact that information theory has to make do with a concept of information that leaves semantic aspects out of consideration as irrelevant. In many areas of modern computer science such as data base technology, artificial intelligence, the theory of neural networks and so on, the call for a clarification of the semantic aspects is growing louder. It is precisely with this point that MacKay's theory of descriptive information begins. Unfortunately it is based on a tenuous concept of semantics and takes little account of psychological concepts such as 'learning,' 'knowledge' and so on. Thus it is imperative to re-examine the foundations on which the information theories of the past were built and to propose alternative definitions where possible. Only in this way can a basis be created on which a universal concept of information can be founded.

3.1 Semiotic concepts

Semiotics is the science of signs, of their structure and their communicative function. Its founders, Charles S. S. Peirce and Charles W. Morris, defined it very broadly, in the hope that it would influence as many disciplines as possible:

> "The sciences must look to semiotic for the concepts and general principles relevant to their own problems of sign analysis. Semiotic is not merely a science among other sciences but an organon or instrument to all sciences." [Morris 1938, p. 56]

Indeed, today semiotics is an important tool in communication research, linguistics and the fine arts as well as psychology. Yet, although other disciplines - information theory among them - recognise the potential importance of semiotic paradigms for their fields, they have not yet found a satisfying way of integrating them in their domain.

The analysis of the sign, in particular its syntactic, semantic and pragmatic aspects, forms the main field of research for semioticians. But other questions, too, such as that of the origin and the addressee of a sign are discussed in semiotics. Mindful of the principle that the methods of semiotics should be applied widely, it is not only organisms such as plants, animals or humans which are accepted as senders or receivers of signs, but also inorganic objects such as machines or computers. Thus man-machine interaction becomes a semiotic issue.

3.1.1 The sign

The key concept of semiotics is the sign. For Peirce it is an essential function of the sign that it stands in for an object. Since, according to Peirce, only the sign, but not the object can have meaning (cf. chapter 3.1.2), the sign becomes a prerequisite for cultural life as such; this is emphasised when he writes: "We have no power of thinking without signs" [Peirce 1984, p. 213]. Thus Peirce believes that the highest degree of faithfulness to reality can only be achieved by means of signs.

Peirce distinguishes three kinds of signs according to their relation to objects:

1) the index, which refers to something more general (another index, a badge)
2) the icon, which gives the pictorial equivalent of an object (suitcase and umbrella in the sign for the left-luggage office)
3) the symbol, which represents an area of meaning without pictorial equivalent (numbers, the colour red for love).

Thus Peirce defined a categorial system for signs which has hardly been challenged.

In contrast to Peirce, Morris is less concerned with the nature of the sign than with its behavioural aspect. For him the sign is an integrated part of a stimulus-response scheme. The sign is something that directs behaviour with respect to something that is not a stimulus at that moment. Thus a sign can only be recognised as such when it stimulates in the interpreter a process which Morris calls semiosis, and defines as follows:

> "Semiosis (or sign process) is regarded as a five-term relation - v, w, x, y, z - in which v sets up in w the disposition to react in a certain kind of way, x, to a certain kind of object, y (not then acting as a stimulus), under certain conditions, z. The v's, in the cases where this relation obtains, are <u>signs</u>, the w's are <u>interpreters</u>, the x's are <u>interpretants</u>, the y's are <u>significations</u>, and the z's are the <u>contexts</u> in which the signs occur." [Morris 1964, p. 2]

Thus the sign according to Morris necessarily implies behaviour, without which it is not a sign at all. What is also necessary for the existence of a sign is a reference of the sign to an object at a specific time, and an identifiable subject, the interpreter. Unlike Peirce, Morris does not postulate a close relation between sign, object and interpreter; rather, the relation is formed ad hoc when these three meet:

> "S is a sign of D for I to the degree that I takes account of D in virtue of the presence of S." [Morris 1938, p. 4]

With this very general definition Morris does much more than gather letters, numbers or hieroglyphics under the concept of the sign. A sign can be a word, a sentence, a message, or even a picture. Since Morris by no means limits the interpreter's receptivity to visual perception, smells, sounds or even behavioural patterns and many other things besides can function as signs.

3.1.2 The three dimensions of the sign

However much Morris' and Peirce's views about the question what can be called a sign diverge, their theories can be said to share certain features. Thus both authors agree that the structure of the sign includes various relations that can be divided into three disjoint sets:
1) relations to other signs, forming the structure of the sign,
2) relations to objects, which determine the references of signs to things of the external world, and
3) relations to subjects or interpreters, where the communicative effect of the sign is manifested.

These three kinds of relations each represent one of the three dimensions proper to the sign, namely the syntactic, the semantic and the pragmatic. For Morris the three dimensions are canonically conjugate since none can be derived from the other two, but all three together make semiosis possible and thus constitute the sign as such. Thus in his work Morris mainly discusses the concepts of syntax (or 'syntactics,' as Morris terms it), semantics and pragmatics:

- Syntax:
  Syntax is the dimension of the sign in which the sign indicates that it is a sign, but not what it stands for nor the behaviour it can trigger at a specific place and time. In that sense it is the question of the sign itself and its relation to other signs that is examined. According to Morris syntax can also be called the theory of the relations between signs. These relations obey syntactic rules which are not defined in detail and enable compound signs to be formed. Thus complete messages or even complexes of messages, which may in turn become signs, may be formed.

- Semantics:
  A sign may be formed correctly in terms of syntax. But without semantics, which deals with the question of the relation of signs to their designata [(20)] it is merely a meaningless conglomerate of signs. In this sense, a sign only has a semantic dimension when it refers to an object or a situation. Just as for syntax, Morris requires from semantics that it have rules. These semantic rules determine the conditions under which a sign can be used for an object or a situation.

- Pragmatics:
  By pragmatics Morris understands a relation between a sign and its interpreter, which can be characterised by the fact that a sign calls an interpreter to action and, in the framework of semiosis, does issue in action or, more generally, in a reaction. Pragmatic relations must obey pragmatic rules which indicate under which circumstances a sign vehicle functions as a sign in the interpreter and thus triggers a semiosis.

Thus Morris has established a framework for the structural definition of the sign which has also found acceptance outside the ranks of behaviourism. The reason for this probably lies in the comprehensive definition of the concepts of syntax, semantics and pragmatics. All that is required is the existence of syntactic, semantic and pragmatic rules, the formulation of which is left to the individual disciplines.

3.1.3 Conflict situation

3.1.3.1 Problematic aspects of the concept of the sign

In defining the sign and its structure in such a comprehensive manner, Morris has undoubtedly left a remarkable oeuvre. In particular, the emancipation of the terms syntax and semantics from a rigidly linguistic definition as theories of the sentence and of meaning respectively enables the concept of the sign to be used outside the narrow confines of linguistics. But sooner or later the strict linkage between the new definitions and the paradigms of behaviourism was bound to give rise to problems.

Among behaviourists all behaviour, even language and thought, is explained with reference to the stimulus-response model. The direction of individual development is mainly attributed to environmental influences, while other developmental constraints such as genetic dispositions are assigned a subordinate role. Also, behaviourism completely dispenses with self-observation and its analysis, since precise observations and descriptions of animal and human behaviour provide it with enough data to support its statements. According to Gordon H. Bower and Ernest R. Hilgard this only allows an accumulation of procedural knowledge (i.e. knowledge about habitual skills), but does not lead to well-founded factual knowledge (cf. [Bower/Hilgard 1975, p. 23 ff.]). Thus, cognitive phenomena such as purely mental reasoning from previous knowledge to a new state of affairs or the occurrence of insight in problem solving can only be explained by behaviourists if they have recourse to an interpretation of cognitive structures as complex habits. So, many important aspects of information would lack a firm foundation if the basic concepts were only justified in behaviourist terms.

Therefore the sign as a necessary part of semiosis such as Morris requires it cannot be the information element in every informational event as Nauta claims. But this does not imply that the information theorist has to reject the semioticians' ideas and results out of hand. On the contrary, they represent the basis for an adaptation of the basic concepts of semiotics to the needs of information theory.

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(20) By designata semiotics understands objects to which reference is made by means of the semantic relation of a sign.

When Nauta's information theory was discussed it was already mentioned that unaddressed information cannot be integrated satisfactorily in a theory that is based on Morris' concept of the sign. Let me just remind you that, for this case, Nauta proposes considering the internal representation of the object in the subject as a sign; the relation between this internal representation of the object and the object itself would be considered as the semantic relation. Since in a behaviourist framework it is never a cognitive structure, but always a thing outside the mind that functions as a stimulus in the stimulus-response scheme, the object would have to stand in for the internal representation in the subject, which would mean that the same thing would play the parts of both sign and object and the semantic relation would become self-referential: The thing would refer to itself. This would violate Morris' requirement that sign and object be distinct. Moreover, stating that "The functioning of signs is (...) a way in which certain existences take account of other existences through an intermediate class of existences" (cf. [Morris 1938, p. 7/8]), Morris requires that the interpreter himself exist in his own right, distinct from signs and objects, the other entities involved in semiosis. Thus the question of self-referential relations among the three sign dimensions is invalidated. The semiotic model in its present form cannot deal with the case of unaddressed information and similar phenomena.

A refinement could conceivably be achieved by admitting that the same thing could indeed play several parts in the same semiosis. The fact of being a sign, an object or an interpreter would no longer be the unique temporally specific function of a thing, but would have to be considered as one of several possible roles that a thing can fill simultaneously. But this would blur the clear distinctions between sign, object and interpreter that Morris makes, and some semiotic definitions and conclusions would have to be reworked. For an information theorist who sees in Morris' and Nauta's concepts only partial realisations of functional-cybernetic information (21) it becomes even more difficult to accept the sign as the unit of information. Moreover, if structural-attributive aspects (information as order and structure) are to be included in the definition of the concept of information, a re-examination of the basic concepts becomes inevitable. In a structural-attributive perspective it is not the question of the trigger of a cybernetic process that needs to be answered, but the question of the features and structure of a passive element, which is only selected and evaluated by coincidence. Such features belong more properly to Morris' object than to his sign. If the aim is to define a unit of information which takes into account the aspects that have emerged so far, then this unit must be something that sign and object have in common, namely the fact that both only represent possible roles of a thing (22). Thus the information element is not the thing as sign or object, but should be sought in the thing itself as a 'carrier of information,' regardless of the semiotic roles the thing may play (cf. chapter 4.1). But such a proposal must not be advanced before the consequences for other definitions, in particular those for Morris' sign dimensions, have been discussed.

3.1.3.2 Problematic aspects of the distinction between the three sign dimensions

Apart from the concept of the sign, the three dimensions of the sign, namely syntax, semantics and pragmatics, are the most important elements of a semiotic theory. Of course, Morris uses those dimensions to distinguish between the interrelation of signs on the one hand and sign, object or interpreter on the other hand. He can only keep the three types of relations separate because he can clearly distinguish sign, object and interpreter. But since this distinction can now no longer be upheld, it will be difficult to keep the three sign dimensions separate and new criteria for a demarcation will have to be sought.

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(21) According to Nauta, Morris' semiosis can be interpreted as a cybernetic process where the sign in the role of the stimulus always functions as the trigger of the process (cf. [Nauta 1970, p. 60ff.]).

(22) For the time being, the term of the 'thing' shall subsume all of Morris' uses of the terms sign, object and interpreter. A detailed definition follows further down.

Let us first focus on the difference between semantics and syntax. In traditional linguistic terminology, semantics denotes the theory of the meaning of the contents of language or more generally the theory of meaning, where meaning means the relation mediating between the linguistic elements of a sentence and extra-linguistic things. An instance of such relations has to be conceived as a directed relation aiming away from the linguistic element at an object of the external world. If semantics, as is the case in linguistics, is restricted to the field of language, the individual element of meaning will rarely be unambiguous. A general verbal statement is precisely characterised by the fact that it can be used in different situations. Jon Barwise and John Perry call this phenomenon in [Barwise/Perry 1983, p. 32 ff.] the 'efficiency of language.' Linguistic objects such as words, phrases, sentences and so on seem to be embedded in a zone of semantic relations. For reasons which will emerge in chapter 4, I shall call this zone the 'relations closure' of a thing. The relations refer on the one hand to the object designated by the statement at the time of utterance and on the other hand to other objects that will be or have been designated by the same statement in other utterance events.

On close analysis, a similar statement can be made concerning the sign in a general semiotic scenario in Morris' sense. If one makes abstraction from individual instances of semiosis and examines the thing as to its ability to assume the function of a sign in different ways, in different contexts and at different times, then the appropriate semantic relations of the thing as a sign in individual semioses will usually refer to different objects. Therefore there will be several relations pointing away from the thing and, depending on the situation, satisfying Morris' criteria of a semantic relation. This clearly amounts to a generalisation of the linguistic situation described above.

Syntax, on the other hand, is conventionally understood as, literally, 'putting together,' and is the linguistic term for the correct linking of words in a sentence, the theory of sentence structure. While syntax stands for a set of syntactic rules governing the composition of a sentence, the individual syntactic element may be considered as a unique relation of a word to a resulting sentence. The syntax of a sentence therefore consists in the 'putting together' of individual syntactic elements, that is, in the relations of all the words used in the sentence to the sentence itself. As in the case of semantics we can assume that linguistic objects such as sentences, statements, even words insofar as the ordering of characters can be considered as a syntactic problem, are embedded in a syntactic relations closure. Unlike the semantic relation, the individual syntactic relation does not point from the linguistic object to a designated object, but on the contrary from a (linguistic) object to the analysed (linguistic) object, in the constitution of which it participates.

According to this argument, the direction of the relation with respect to the object under examination would be a sufficient criterion for the distinction of semantic from syntactic relations. But we thereby clearly contradict Morris' definitions, in particular that of syntax. Syntax according to Morris is of course the study of the relations of signs to each other (cf. [Morris 1938, p. 13 ff.]), but the question of the direction of these relations does not arise in Morris' system. Morris automatically assumes that generally a sign can consist of several individual signs, or as he puts it:

> "(Syntax is) that branch of semiotic that studies the way in which signs of various classes are combined to form compound signs." [Morris 1946, p. 355]

Morris correctly concludes that viewed from the point of view of the more general sign S_1 the relations with the other more particular signs have to be considered as syntactic relations because they determine the structure of the former. But if the same situation is viewed from the point of view of a more particular sign S_2, then the same relation $R(S_2,S_1)$, identified as syntactic when viewed from S_1, can be interpreted differently. $R(S_2,S_1)$ is only one among several conceivable relations pointing away from S_2, and $R(S_2,S_1)$ is only examined because it happens to participate in the semiosis under examination. Thus we are confronted with a comparable constellation to the one we face when discussing semantic relations: At the centre is a thing that is surrounded by accidental relations pointing away from it, which, depending on situational context, refer to a thing. The question arises whether $R(S_2,S_1)$ can be interpreted as a semantic relation from the point of view of S_2. One answer to this could be Fred I. Dretske's suggestion that apart from meaning, a cognitive semantic concept, there are other, non-cognitive semantic concepts, such as information. Now, the relation that makes a sign a part of a more general whole can very well be called an informational relation, because on the one hand it participates in the 'shaping' of the generalised whole and on the other hand is capable of revealing this part-whole relation to an observer.

This line of argument - where the same relation appears as syntactic or semantic depending on point of view - makes it even more difficult to keep Morris' sign dimensions apart. The differences only emerge when the attention is directed to an individual sign, or rather, an individual thing. In that sense the relations pointing from another thing to the thing under consideration would be the syntactic relations, while those relations pointing away from the thing under consideration towards other things would be the semantic relations [(23).]

Assuming that the hypotheses above are correct and that the linguistic understanding of syntax and semantics can be applied to situations in general, every directed relation between two things could become a semantic or a syntactic relation depending on which of the things linked by the relation is the focus of investigation. The thing itself, which can be examined in isolation, but is always embedded in a situational context, is therefore surrounded by a set of relations which may be syntactic (pointing towards the thing) or semantic (pointing away from the thing).

The model sketched above reduces the problem of recognising a relation as syntactic or semantic to that of determining the direction of that relation. But this creates two new problems, which will have to be solved. First of all, the model deviates so much from the original semiotic definition of the terms syntax and semantics that it seems indicated to assign special terms to the new concepts in order to avoid misunderstandings. Thus syntactic is to be replaced by d_syntactic and semantic by d_semantic wherever the property refers to the direction of the relation. A second problem arises because a relation can only have one of two directions so that only two of the three semiotic sign dimensions can be represented. The third dimension, namely the pragmatic one, cannot for the moment be accommodated, and the question arises how this category of relations which is so important for communication can be integrated into the model.

According to Morris the pragmatic dimension of the sign process is the relation of the sign to the interpreter. It can be recognised by the nature of the interpreter's reaction to the sign in semiosis, but not on the basis of the properties of the sign itself. Certainly, the sign is always at the beginning of semiosis, but semiosis is always initiated by the subject which perceives the sign and represents it mentally according to her own rules (cf. chapter 3.3). This representation is then responsible for any reaction by the subject after she has recognised the sign. In this sense, there is nothing in the sign that would actively incite the interpreter to act, something that could be taken as the third dimension of the sign. Rather, the pragmatic dimension of a sign lies in the fact that each interpreter of the sign will recognise it in his own way and will assign meaning to it according to his a priori knowledge and to the situational context at the time when the sign is perceived. But this aspect is already taken into account in the new model, in that it is not the sign as a participant in individual semioses, but the thing that is analysed as to its capacity to play the part of a sign in spatiotemporally specific semioses.

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(23) In this connection the fact that among semioticians the relation $R(S_2,S_1)$ is interpreted as a syntactic relation even if it is viewed from S_2 could be explained by the exclusive focus on the semiosis under scrutiny.

Therefore one difficulty that comes up again and again in the discussion of the concept of pragmatics is the fact that the process of individual cognition covers two different phenomena, namely a thing which is perceived, and a representation of that thing in the subject's mind, which is the result of a cognitive process. The difference between those two entities is emphasised by the fact that the thing is often only perceived and memorised in fragments. Moreover, in the individual perception process details concerning location, time and social environment as well as the perceiving subject's dispositions are memorised, in addition to information about the thing itself. Thus the collection of thing-specific relations that make up the representation will be supplemented by further d_syntactic and d_semantic relations that cover the situational context of the perception process. Of course the subject may misinterpret the situation if the selection of perceived relations of the thing at its disposal does not suffice to activate an adequate representation in the brain, or if context-specific relations crowd out the thing-specific relations for the representation, so that the subject can no longer recognise the thing itself.

Thus the term pragmatics also expresses the variability of the interpretations of a thing by a subject which may range from a clear perception of the thing to a complete misinterpretation. This variability of interpretations depends on the number and the quality of the relations perceived with respect to the thing, as well as on their correlation with the relations concerning the thing that are represented in the subject's mind. Instead of the question of pragmatic relations, one should ask how the relations closure of the thing can be divided into relations that are needed to adequately perceive a thing in a particular situation and those which, in the same situation, can be dispensed with if it is purely a matter of perceiving the thing. This division obviously applies to the set of d_syntactic relations, for a thing can be recognised correctly even if its structure has only been perceived in fragments. In this case the correct classification of the perceived fragment of the structure depends on the subject's a priori knowledge about the thing. But even the d_semantic relations, which point away from the thing, can be divided according to the same criterion. According to the interpretation of semantics proposed here, the contextual relations that mark the appurtenance of a thing to a particular space and time belong to the d_semantic closure of a thing just as much as the relations of meaning. These complementary d_semantic relations are always needed to demarcate a thing from its environment, although usually, as in the case of d_syntactic relations, only a fragmentary recognition of the relations is needed to make a correct demarcation.

As a consequence the relations closure surrounding a thing has to be divided into an essential and an accidental closure, depending on whether the relations are necessary for the recognition of a thing in a particular situation or not. The essential closure contains the relations which are necessary for the recognition of a thing in a specific situation depending on the subject's a priori knowledge, while the accidental closure comprehends all other relations. This subdivision always depends on the context in which the perceiving subject finds herself.

The ideas argued above are summarised in Figure 4. At the centre is the thing as the 'carrier of information,' as outlined in chapter 3.1.3.1. It is surrounded by a relations closure, the probable 'elements of information.' The thing has a range formed by the union of the ranges of Morris' terms sign, object and interpreter. Since Morris' concept of the sign in particular admits as possible values both linguistic and non-linguistic things, the information theory to be established here, based on the model of Figure 4, can be applied to linguistic and extra-linguistic problems. In the model which I propose the question is not what kind of a thing something is, but only whether it can carry information. A relation between two such things may therefore, for example, link a sentence, the original entity, with a fact, the target entity. Thus the relation stands for the actual linguistic meaning, which relates the sentence to an extra-linguistic thing. Similarly, the model does not exclude the possibility of a relation linking two extra-linguistic things. In this way, what Jon Barwise and John Perry in [Barwise/Perry 1983] call situation semantics can be integrated into the model. Finally, the conception of Figure 4 also allows mutual relations between two linguistic elements. Thus words that treat of words, those words which trigger the so-called stimulations of 'second intention' (see [Quine 1960, p. 48]), are on a level with other possible relations.

All kinds of relations discussed above can thus be disjointly grouped according to two criteria: Depending on the direction of the relation with respect to the thing, they are divided into a d_syntactic and a d_semantic closure, and, depending on whether the relation is necessary or dispensable for recognition at the time of perception, into an essential and an accidental closure.

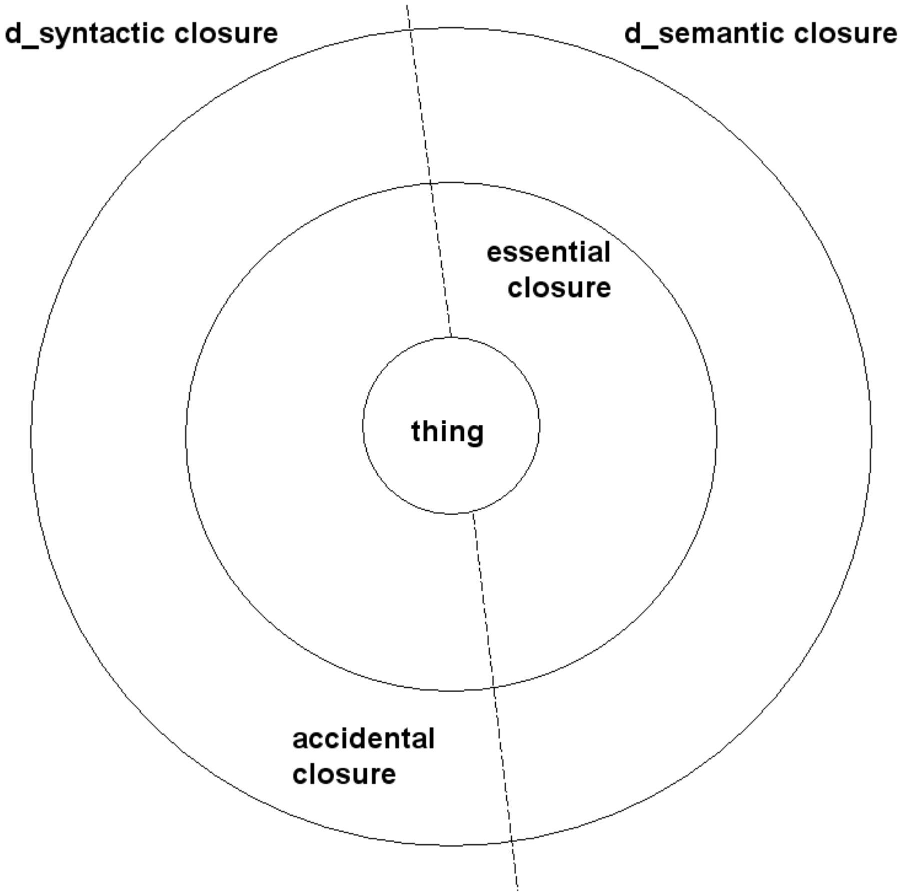

Figure 4: The thing with its relations closure at the time of its perception

3.1.3.3 Postscript

The structure of the thing proposed above, i.e. a relations closure consisting of directed relations, as well as the conclusion that syntax and semantics are not fundamentally different are, as far as the author can judge, without precedent in the literature. It is the aim of the present study to provide a firm basis for these theses. Nevertheless it should be mentioned that ideas quite similar to the author's can already be found in earlier publications. Helmut Seiffert, for example, points out that the border between syntactic and semantic dimension can be drawn in different ways. He argues, although without giving criteria for differentiating between the two dimensions, that the location of the border depends on how much the observer wants to assign to the syntactic and how much to the semantic dimensions (cf. [Seiffert 1968, p. 91]).

A more formal treatment of this issue is provided by Douglas R. Hofstadter in his book Gödel, Escher, Bach: An Endless Golden Braid. It is a highly original work, although it does not everywhere meet rigorous scientific standards:

> "Thus, another way of characterizing the difference between 'syntactic' and 'semantic' properties (...) is that the syntactic ones reside unambiguously inside the object under consideration, whereas semantic properties depend on its relations with a potentially infinite class of other objects, and therefore are not completely localizable. There is nothing cryptic or hidden, in principle, in syntactic properties, whereas hiddenness is of the essence in semantic properties. That is the reason for my suggested distinction between 'syntactic' and 'semantic' aspects of visual form." [Hofstadter 1979, p. 583]

Thus Hofstadter reduces the difference between syntax and semantics to a qualitative difference between relations. When Hofstadter insists that syntactic relations have no cryptic content, he is probably referring to the fact that the syntactic relations of a thing (or of an object, according to Hofstadter's nomenclature) will have to be present as a matter of principle for the thing to be recognisable as such. This is what may have led Hofstadter to say that the syntactic relations are located in the thing. But it is a necessary condition that the thing and its syntactic relations be recognised by the subject before the question of the relations pointing away from the thing can be asked. Which of these semantic relations manifest themselves to the subject depends on the moment of perception or is, to put it in Morris' terms, a question of semiosis [(24).] Under no circumstances, though, can it be assumed that all the semantic relations of a thing will necessarily manifest themselves to a subject. This obvious non-determinacy of the semantic relation at the moment of perception is probably the reason why Hofstadter calls it cryptic and hidden.

Certainly, at the moment, the new definitions of semiotic terms proposed here rest on very vague notions and will have to be analysed further in the following chapters. But they seem to offer an alternative to previous theories where the concept of information could not be defined satisfactorily.

3.2 Reflections on semantics

In chapter 3.1 we discovered certain flaws in Morris' conception of semiotics which have prevented important aspects of the concept of information from being integrated into the theory of signs. By rethinking certain semiotic concepts it has been possible to create a provisional context where such an integration becomes possible. The basic idea that ultimately syntax and semantics are merely the attributes indicating the direction of the relation between two entities and are not defined by the type of the entity (object or sign) which the relation is targeting is without precedent in the literature, and it must be the aim of the present study to provide further support for this thought. For this purpose the works of other authors interested in the concept of semantics, e.g. of the analytical philosopher Willard Van Orman Quine or of the two representatives of ecological realism, Jon Barwise and John Perry, are to be consulted.

3.2.1 Willard Van Orman Quine's ideas

Willard Van Orman Quine is one of the most important philosophers of this century. As an empiricist he took an interest in issues of ontology, epistemology and the philosophy of language. One thread running through all of Quine's reflections is the fact that only an analysis of language allows one to tackle philosophical questions, for language is not only the medium in which the questions are asked, but is itself the reason why these questions arise. For him a theory is not much more than a special formulation for the stimuli that humans receive via their senses, which, although it is suitable for logical inference, is always incomplete. Questions raised by a theory always refer to these formulations and not to the stimuli. Thus an ontology, for example, can only be determined with respect to a particular language, by analysing which objects the language assumes as existent. Epistemology, too, is inconceivable for Quine without the philosophy of language. Very young children, to give an example, learn primarily by learning to speak about objects (cf. chapter 3.3.1). The words and sentences learnt in this way are then not only linked to the relevant non-verbal stimuli, but also to other words and sentences. Therefore both memory and the capacity of a non-verbal stimulus to evoke a specific sentence can hardly ever be ascribed to earlier sensations, but are mainly due to earlier conceptualisations and an earlier linking of sentences with sentences.

[(24)] Morris himself, incidentally, does not exclude the possibility that a sign vehicle may have different semantic relations in different situations.

The same can be said about scientific discovery. According to Quine a theory consists of sentences that are on the one hand linked to non-verbal stimuli in various ways and on the other embedded in the sum total of a society's sentences. Quine therefore considers theory defined in this way as an integral part of a language and not as something outside language. Thus theory and language are as it were inextricably intertwined. In spite of the fundamental qualitative differences between a child's sentences such as 'Papa sleep well?' and a theory-based scientific proposition such as 'e = m*c^2,' language as a whole forms a genuine totality, and individual language components can usually only be understood in the context of this totality or at least parts thereof.

Of course these statements are also valid for those disciplines which Quine classes with linguistics, for example those theories that concern themselves with semantic problems [(25).] If, for example, the question of the meaning of a sentence is examined, regardless of whether the utterance to be analysed comes from theoretical science or ordinary language, the aim cannot be the establishment of an objective meaning. The sentence can only be meaningful within the total context of a language, i.e. in terms of the "socially inculcated set of dispositions" of a community (cf. [Quine 1960, p. 45]). Henri Lauener calls this view in [Lauener 1982, p. 27] 'semantic holism.'

Quine rejects the common view that the 'meaning' of linguistic elements has a mental existence. In accordance with his holistic approach Quine is of the opinion that meaning, like knowledge and mind, is part of the world to which it refers. So it should be investigated in the same empiricist spirit as natural phenomena are investigated in the sciences. In that sense, meaning is primarily a behavioural feature and should always be understood as a response to sensory stimuli. Quine illustrates this connection of meaning to behaviour by introducing the notion of 'radical translation' [(26):] If a native, whenever a rabbit or a very life-like fake rabbit appears, assents to the expression 'Gavagai,' one is justified in translating this expression tentatively as 'There's a rabbit.' In a similar way and with the same justification one could also accept the translations 'There we have a rabbit' or 'Lo, a rabbit!'

There are two ways in which this example exhibits what Quine calls the 'indeterminacy of meaning': First, the meaning of 'Gavagai' cannot be equated with its referential relation to rabbits, for otherwise the natives would not assent to this expression when they are shown a mere imitation rabbit. Secondly, the scope of the situational context designated by 'Gavagai' is indeterminate, so that the translation of the expression into English cannot completely succeed without further knowledge of the native language. The only thing about this radical translation that is certain is that the native will always assent to the expression 'Gavagai' whenever there is a certain kind of non-verbal sensory stimulus. This insight leads Quine in [Quine 1960, p. 31 ff.] to call this phenomenon 'stimulus meaning' and to define it as follows:

> "(...) a stimulation σ belongs to the affirmative stimulus meaning of a sentence S for a given speaker if and only if there is a stimulation σ' such that if the speaker were given σ', then were asked S, then were given σ, and then were asked S again, he would dissent the first time and assent the second. We may define the negative stimulus meaning similarly with 'assent' and 'dissent' interchanged, and then define the stimulus meaning as the ordered pair of the two. [Quine 1960, p. 32 f.]

Thus stimulus meaning must be understood as the stimulus meaning of a sentence (S) for a speaker (a) at a given time (t). Further, Quine counts as relevant for the definition of stimulus meaning the so-called stimulus modulus, i.e. the maximum duration recognised for a stimulation (modulo n seconds). The stimulus modulus is of particular importance because the stimulus meaning could be changed by certain stimuli that last longer than the time span allowed by the stimulus modulus.

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(25) According to Quine there is no special theory of semantics, although there are disciplines that deal with semantic problems.

(26) By 'radical translation' Quine understands translation from a remote language on behavioural evidence alone, without the assistance of existing dictionaries. Stating that 'radical translation begins at home,' Quine points out that infantile language acquisition works on the same principle (cf. [Quine 1969 b, p. 45 f.]).

One problem with stimulus meanings is that not all stimulus meanings are susceptible to the influences of so-called 'intrusive information' in the same way [(27).] In that sense the word 'rabbit' allows a much wider range of interpretations than the word 'red.' One reason for this may be that stimulus meaning is relative to stimulus modulus, for 'rabbit' represents an expression for a passing sense datum, while 'red' is to be understood as an enduring objective trait of a physical object. Nevertheless this 'observationality' [(28)] of the stimulus meaning of 'red' is again relative for several reasons. First of all, it can vary from one time to the next because of collateral information about lighting. Then, it is particularly vulnerable to so-called intersubjective variability where it merges into other colours. This is due to the fact that the division of the colour spectrum into the colours defined by a language community is a question of individual linguistic development.

If a sentence is more likely to be learnt through connections with other sentences than through reference to objects of the external world, the intersubjective variability of its stimulus meanings will be increased. Quine's example here is the phrase 'bachelor.' There is no object in reality which can permanently serve as the stimulus meaning for this sentence. On the contrary, 'bachelor' is usually merely a temporary trait of a male person that can change any time. An individual's stimulus meaning of 'bachelor' is therefore provided by previously acquired paraphrases, such as 'unmarried man.'

The greatest difficulty Quine has is in assigning an unambiguous stimulus meaning to so-called stimulations of 'second intention,' i.e. to words about words. Here the variability of stimulus meaning is no longer just intersubjective, but also intrasubjective, for the search for second-intention stimulations that would prompt a subject to assent to the questions 'bachelor?' or 'unmarried man?' can lead to different solutions. For example, a stimulation showing how to spell 'bachelor' or a stimulation offering the words "rhymes with 'harried man'" could prompt affirmative responses to these questions.

Ambiguities of that kind are especially disturbing to Quine when they affect scientific statements. By definition the scientific method is designed for the 'elaboration of a system of methodically safe, objective sentences about a field' and therefore needs sentences with unambiguous stimulus meanings. Quine requires behaviour-related criteria to remove such ambiguities, but realises that they are not easy to formulate. One reason for this quandary is the notion of similarity, which Quine denounces as dubious. On the one hand, this notion is fundamental for learning, knowledge and thought, for only our sense of similarity allows us to order things into kinds so that these can function as stimulus meanings for sentences. Moreover, every reasonable expectation depends on the similarity of circumstances and on our tendency to expect that similar causes will have similar effects. On the other hand, Quine feels there is something logically repugnant about the notion of similarity because its application ultimately leads to paradoxa, as he demonstrates in [Quine 1969 c, p. 114 ff.]. Any attempt to relate the notion of similarity to the terms of logic in a meaningful way must therefore fail. Even the proposal that things be called similar if they have all or most of their 'properties' in common or the attempt to consider similarity as simply a matter of yes-or-no without gradations do not achieve Quine's declared aim of making similarity an applicable term in mathematics and logic (cf. [Quine 1969 c, p. 125 ff.]). In the former case one would have to tackle the daunting task of defining what counts as a 'property,' and in the latter one would forfeit the possibility of identifying a kind as contained in a larger kind. Moreover, according to Quine the attempt to derive the notion of similarity from related concepts such as that of kind is bound to fail because these concepts are themselves dubious.

Thus man in his role as a scientist is in a permanent dilemma, for as a researcher he has to strive to eliminate ambiguities and vagueness, while he has to rely on his innate measure of similarity in order to arrive at the necessary scientific insights. It is therefore, according to Quine, a particularly clear sign that a scientific discipline is mature when it no longer uses an irreducible notion of similarity.

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(27) Quine speaks of 'intrusive information' when a stimulus is only vaguely related to an original stimulus evoking the stimulus meaning in question, but can nevertheless evoke the same stimulus meaning.

(28) A stimulus meaning is called observational when it is not likely to change under the influence of collateral information.

In this spirit Quine requires criteria for language that facilitate such a process of scientific maturation. He sees one possible approach in the classification of the sentences of a language according to their duration of validity into 'occasion sentences' and 'standing sentences.' Thus an occasion sentence such as 'His face is dirty' is characterised by the fact that it will prompt assent or dissent immediately after a suitable stimulation of the receptors, while a standing sentence such as the sentence 'The paper has come,' uttered daily at a certain time, can also prompt assent or dissent later on [(29).]

Among the occasion sentences Quine draws special attention to the observation sentences, which are characterised by the fact that their stimulus meaning is not subject to the usual variability of occasion sentences. Observation sentences are less susceptible to intrusive collateral information and can always be supported by evidence in the shape of an observable object in the external world. According to Henri Lauener, observation sentences are thus characterised by the fact that alone among the occasion sentences they have a meaning in isolation, i.e. an unambiguous and invariable stimulus meaning (cf. [Lauener 1982, p. 67]).

Standing sentences, like occasion sentences, give rise to doubts concerning their scientific applicability. True, standing sentences are characterised by the fact that their stimulus meanings remain stable over longer intervals, but even that kind of sentence offers no guarantee that its stimulus meaning will remain invariable. There can only be assent to the sentence 'The paper has come,' quoted above, if the paper has really come, a paper being defined as 'having come' if the postman has already left it at the door of the future owner of the paper on the same day. Assent to this sentence can be repeated daily, but it is not independent of the time of the stimulus, for the same sentence will by definition prompt dissent <u>before</u> the postman's daily appearance. As a consequence, if the stimulus modulus is extended too far, the sentence 'The paper has come' will become an occasion sentence which will only prompt assent or dissent depending on the stimulation preceding the utterance event.

This temporal relativity does not apply to all standing sentences, though. Sentences such as 'Copper oxide is green' or 'On 6th August 1993, at 3 o'clock p.m., the sun was shining in Berne' have a constant stimulus meaning even if the stimulus modulus is considerably extended. Quine calls this kind of sentences 'eternal sentences.' An important trait of eternal sentences is the fact, on which Quine lays particular emphasis, that they have a constant truth value, i.e. a truth value that will remain the same over time and from one speaker to another. Quine uses the eternal sentences as the real vehicles of truth. For this reason the use of eternal sentences is appropriate mainly in those cases where statements are meant to be made on the basis of fixed truth values.

Ordinary language allows the same state of affairs to be described by several adequate eternal sentences. For example the two sentences 'On 6th August 1993, at 3 o'clock p.m., the sun was shining in Berne' and 'In Berne, on 6th August 1993, at 3 o'clock p.m., the sun was shining' are only distinguished by their word order; stimulus meaning and truth value are identical in both cases. In order to achieve unambiguous formulations also for eternal sentences, Quine proposes paraphrasing them in so-called canonical notation [(30).] Quine's notation has the merit of showing up the structure of an eternal sentence because it is no longer burdened with the quirks of ordinary usage. Moreover the use of canonical notation prevents the occurrence of truth value gaps, that is, of cases where the question of truth value does not arise. Because canonical notation is a language on the basis of first-order predicate logic with identity, its propositions are produced by the substitution of bound variables with elements of sets of individuals. Thus sentences that stand for truth value gaps such as 'Pegasus flies' are counted as false, because terms such as 'Pegasus,' rephrased with predicates, do not refer to a real object and thus cannot be elements of a set of individuals.

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(29) Note that the period of validity of both terms is relative to the stimulus modulus, i.e. the interval elapsed between stimulus and assent or dissent.

(30) Canonical notation is an artificial, rigorously regimented language without names on the basis of first-order predicate logic with identity.

Quine recommends that in formulating scientific theories one should use eternal sentences rewritten in canonical form. In this way the occurrence of verbal ambiguities and avoidable complications in the formulation of a theory can be prevented without the theory losing its explanatory force. Quine believes that all features of reality can be formulated in canonical notation, if they can be formulated at all. Thus Quine has at his disposal tools for formulating the abstract bases of theories in the form of propositions with a constant truth value.

A further problem which empirical theories have to face is the question of their anchoring in reality. For it is one of the main requirements of scientific theories that their statements be made to agree with mankind's past, present and even future sensory impressions. But this is not a trivial endeavour, for according to Quine there is no obvious correspondence between non-verbal stimuli and natural languages. Here, observation sentences seem the obvious choice, since, as mentioned above, they alone among the occasion sentences are characterised by unambiguous stimulus meanings. In that sense observation sentences form the anchors of empirical theories in reality, for they alone are capable of providing a link between a scientific theory and the observations supporting it.

With his painstakingly argued introduction of the concept of stimulus meaning Quine has developed a semantic concept which, despite its limitation to language, seems more useful for the development of a concept of information than the semantic relation in Morris' conception of semiosis. Of course, Quine, like Morris, is a proponent of the behaviourist approach, and Quine's stimulus meaning of an individual utterance can be interpreted as a semantic relation of a suitably chosen Morrisian semiosis. But it is its holistic approach that renders Quine's concept superior to Morris': While Morris makes his statements on the basis of a hypothetical individual semiosis, Quine can only make his investigations in the context of a comprehensive theory. Thus the analysis of a stimulus meaning does not only concern an ephemeral event, semiosis, but a sentence whose stimulus meaning is examined as to its persistence or variability over time. If we look at a stimulation, the question is not only the semiotic one of its mere existence, but of further traits such as the stimulus modulus, the choice of which may influence stimulus meaning.

The consequence of this insight, namely the fact that most sentences do not have a unique stimulus meaning, agrees well with the findings of chapter 3.1, represented in Figure 4. Remember that the 'thing' introduced there can always refer to other things via several d_semantic relations. If the sentences of a language are understood as things [31] and the stimulus meanings as d_semantic relations, Quine's findings in terms of the philosophy of language find their obvious correspondence in that model. What is more problematic with respect to a comprehensive information theory is Quine's requirement that ambiguous sentences, because they are unanalysable, be rejected and therefore excluded from scientific discussion. It is certainly desirable that only sentences with a fixed truth value be used when formulating empirical-scientific theories. Mostly this will also be the case in the sought-for information theory. But sentences with ambiguous stimulus meanings may sometimes have to be accepted as objects of such a theory because information theory is interested in the authentic information content of an event of utterance.

Quine himself provides the best argument against the requirement that ambiguous sentences be paraphrased in canonical notation for theoretical analysis: Because according to Quine it is not possible to form synonyms, that is to form phrases that have the same stimulus meaning as the original phrase, rewriting a phrase will never yield an object of analysis that is truly identical with the original phrase. Any information theory deserving of the name will always have to attempt to analyse without distortion all possible sentences of a language as to their information content (cf. chapter 4).

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(31) Since the range of values of the 'thing' in Figure 4 results from the union of the ranges of the semiotic concepts of 'sign,' 'object' and 'interpreter,' one can very well agree to this assumption.

The difficulty this engenders is obvious: Any information thus conceived cannot be completely formulated in terms of first-order predicate logic with identity. This violates one of Quine's basic requirements for an empirical theory. But ever since the formalisation of thermodynamics by means of statistical methods, if not earlier, it has been generally known and accepted that mathematical methods other than predicate logic can be used to develop scientific and therefore empirical theories. The enormous variety of particles which usually form the objects of enquiry in this branch of physics no longer allows exact mathematical treatment of every detail; rather it forces the scientist to limit himself to condensed general features subject to statistical laws. Such a procedure is justified since only a few properties, such as gas pressure - and not the shocks of individual gas molecules that cause the pressure - can be observed and influenced from outside at all. Consider also the attempt to find the next probable state of a gas at a certain time in a certain container with a certain volume. This is not a determined quantity either, but always a choice from possible alternatives, whose real validity can only be ascertained when the next probable state has really come about. Therefore prediction cannot rely on precise calculations, but only on approximations on the basis of statistically determined probabilities.

The last example shows obvious parallels to the discussion about the stimulus meaning of a sentence, which will have to be examined. If the sentence examined is not an observation sentence or an eternal sentence, its stimulus meaning will be different depending on when it is analysed. If a stimulus meaning is understood as a d_semantic relation that simply links two things (here the sentence uttered, there the object referred to by the stimulus meaning), and if moreover we take into account that the event of utterance of the sentence always precedes the stimulus meaning instantiated in interpretation, the perceived utterance of the sentence can be taken as an analogue to the state of gas and, similarly, the object referred to as akin to the next probable state of the gas. Finally, in this model, stimulus meaning would be equivalent to the relation between gas state and next probable state. Not only does this pave the way for the integration of the linguistic theory of meaning into Shannon's mathematical communication theory. For the first time, describing a functional-cybernetic problem (transition of a gas state into the next probable state) and a structural-attributive problem (stimulus meaning of a sentence) in the same way has become a distinct possibility. If we take this thought to its logical conclusion, the information theorist would have to endeavour to deduce the various stimulus meanings of a sentence in function of the diverse possible kinds of utterance events, and if possible to furnish them with probabilities of occurrence. This would certainly not be a simple, but neither would it be an impossible task.

3.2.2 Situation semantics according to Jon Barwise and John Perry

Quine's system of analytical philosophy is mainly supported by one pillar, namely the insight that a theory is inseparable from the language in which it is set out. Thus his consideration of semantic problems is largely kept going by an examination of language. But the example mentioned in the introduction, of the tile falling towards a man, describes a possible case of extra-linguistic 'meaning,' since the accidental discovery of the tile and its stimulus meaning as a potential danger cannot possibly be based on earlier conceptualisations of similar constellations, but only on the situation as perceived by the senses. Therefore one is justified in asking whether such an everyday situation can really 'mean' anything and how such a 'meaning' could be characterised, if at all. Questions of this kind and possible answers to them have been discussed at length by Jon Barwise and John Perry in [Barwise/Perry 1983].

Like Quine, Barwise and Perry do not consider semantics as a purely mental matter. But while Quine views semantics as determined by the observable behaviour of human beings alone, Barwise and Perry see it as determined by the interaction of living beings, be they human or animals, with their environment. In this approach, which is known as ecological realism, it is not only the elements of language that function as carriers of meaning, but, as in semiotics, the real things of the world in general, which they call situations. Thus meaning does not only denote the meaning of a word or a sentence, but also the non-linguistic meaning of a situation, such as a loved one's raised eyebrows.

For Barwise and Perry, situations are 'individuals having properties and standing in relations at various spatiotemporal locations' [Barwise/Perry 1983, p. 7]. Situations can consist of other situations, be contained in other situations or overlap. Every situation is unique and singular. The four basic building blocks of a theory of situations, namely individuals, properties, relations and space-time locations have to be thought of as invariants or uniformities across real situations. By individuals one understands real things, which may in turn consist of parts that may again be understood as individuals. The space-time locations are extended yet connected regions in the four-dimensional space-time continuum, which may be linked with each other. Finally an n-ary relation ($n \geq 0$) mutually relates n different objects (for example individuals, space-time locations, relations, but also situations etc.), where the unary relation is considered as a property and the 0-ary relation as a situational state. Thus situations stand for real constellations and events, but also for cognitive states and so on.

Situations can be grouped into situation-types. These are partial constructions and convey only incomplete information about the objects that can act as instances of a situation-type. The main purpose of situation-types is therefore the characterisation of situations independent of the 'where' and 'when,' i.e. independent of spatiotemporal aspects. A special kind of situation-types are the courses of events which encompass possible sequences of events. They are constructed as partial functions from space-time locations to situation-types. All the entities mentioned just now are abstract set-theoretic objects for Barwise and Perry, built up from real situations by abstraction. They always consist of individuals, properties, relations and space-time locations. Barwise and Perry also call them abstract situations because they do not occur in nature, in contrast to real situations which are parts of reality. Thus abstract situations can be considered as sets whose function it is to classify real situations accurately.

Among the situation-types, a special role is played by the so-called event-types, not to be confused with the courses of events mentioned above. Unlike other situation-types, event-types are not condensations of events of the same type, but each event e is itself already an event-type, namely the event-type of which e is a part. Because two different events cannot contain each other as parts, there is no possibility of both being of the same type. Event-types that describe similar processes can then be grouped into something like types of event-types, the so-called schemata. As possible realisations of event-types Barwise and Perry mention object-types in which the procedure for the classification of an object is indicated. Complex properties, complex relations, roles, contexts and a large part of the situations classed as abstract fall under the heading of object-types (cf. [Barwise/Perry 1983, p. 75 ff.]).

One very interesting aspect of Barwise and Perry's theory is the fact that words as elements of a language constitute themselves objects in the sense described above. Sentences and statements are to be considered as abstract situations, among other things because they turn out to be uniform across utterances. Moreover, linguistic objects are characterised by specific properties, which Barwise and Perry call semantic universals and which are defined as follows:

1) The external significance of language, which emphasises the linkage of language with the represented world.
2) The productivity of language, i.e. the obvious capability of the human being of using and understanding expressions which have never been used before.
3) The efficiency of language, whereby is understood its unlimited recyclability.
4) The perspectival relativity of language, or the fact that language always has to be seen as relative to our contextual environment at a particular time.
5) The ambiguity of language.
6) The mental significance of language, i.e. its connection with the speaker's state of mind.

In this list, item 3, the efficiency of language, deserves special attention. The concentration of semantics on formal languages and the eternal validity of sentences, so strongly advocated by Quine, entails precisely that little attention is paid to the efficiency of language. But if we examine the detailed explanation of this point by Barwise and Perry we see a profile of linguistic elements which, together with their readiness to accept that utterances are ambiguous, comes very close to meeting the requirements of the present study:

> "By the efficiency of language we mean this: expressions used by different people, in different space-time locations, with different connections to the world around them, can have different interpretations, even though they retain the same linguistic meaning." [Barwise/Perry 1983, p. 5]

This concept of efficiency is in keeping with the concept of pragmatics outlined in chapter 3.1. But efficiency also covers part of what Quine designates with the supposedly dubious concept of similarity, namely the ever-present possibility of reapplying an uttered sentence of a language to similar situations, without an assurance of the determinacy of its stimulus meaning. It is therefore obvious that Quine's eternal sentences fall under Barwise and Perry's non-efficient sentences. But these have to be considered as merely special cases of general sentences, which is why the eternal sentences and their utterance events easily find their place in the theory of situations.

One crucial aspect of the efficiency of language lies in the fact that linguistic elements can be recycled. A successful analysis of efficiency therefore entails an examination of the context in which the utterances are used, namely the three factors of discourse situation, speaker connection and resource situation. The concept of the discourse situation takes account of the fact that for each utterance there must be someone who makes this utterance at a certain place and at a certain time. The speaker connection stands for the fact that the speaker, on the basis of past and present perceptual experiences, sets up connections to objects, properties, places and times, which he can exploit by referring to them. If a speaker says for example 'Franz is eating,' he informs someone about a very specific person known to the speaker, called Franz. The resource situation finally stands for the speaker's ability to exploit a particular state of affairs to convey information about another state of affairs. If for example someone says 'the child running past the window has just eaten,' meaning that Franz has just eaten, this is a resource situation.

According to Barwise and Perry, the concept of the situation allows the formulation of what the two authors call the relation theory of meaning. Starting from four observable examples, namely:

- Smoke means fire,
- kissing means touching,
- the ringing of the bell means that the lesson is finished, and
- cookie means cookie [(32),]

which shall be mentioned as representative of innumerable other examples, we see that a situation S_1 only conveys information about another situation S_2 if there is a systematic relation between a situation pair (S_1,S_2) which shares some configuration of uniformities with S_1 and S_2 respectively. In other words, it is suggested here that 'meaning' can only be understood as a relation between different situation-types. The corresponding relations between individual situations are therefore called constituent relations of meaning. Thus what becomes clear is that meaning, like language in general, is characterised by efficiency. This is not only true of linguistic meaning, but of any kind of meaning, thus also of the meaning of cognitive states or the meaning of events. Barwise and Perry illustrate the latter with the following, very plausible example:

> "Similarly, that smoke pouring out of the window over there means that that particular building is on fire. Now the specific situation, smoke pouring out of that very building at that very time, will never be repeated. The next time we see smoke pouring out of a building, it will be a new situation, and so will in one sense mean something else. It will mean that the building in the new situation is on fire at the new time. Each of these specific smoky situations means something, that the building then and there is on fire." [Barwise/Perry 1983, p. 14]

The two situations share the fact that smoke emerges from a building, so they are of the same type, a type meaning fire. Both events thus have the same event-type meaning. But they happened at different places and times; this constitutes the difference and the uniqueness of the individual events and therefore of the individual meaning.

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(32) Meaning of course: The word 'cookie' denotes the pastry called cookie.

This insight leads Barwise and Perry to the conclusion that the meanings of non-linguistic situations also have to be sought outside language, that is in systematic and constant relations between situations, such as natural laws. The two researchers call such relations 'constraints.' The fact that a situation may contain information about another situation and can therefore mean something is due to such constraints, although this information can only be recognised as such by a person when she is attuned to such constraints. Barwise and Perry go so far as to say that only attunement to constraints makes life possible, for reality is highly structured by such constraints, and it is only this structuring which allows intelligent life to arise and to be maintained (cf. [Barwise/Perry 1983, p. 94]).

Situation theory basically distinguishes three kinds of constraints:

1) Necessary constraints: Necessary are those constraints that arise from necessary relations, such as the fact that every woman is a human being or that every kiss means touching. But necessary constraints also occur when object-types are individuated.
2) Nomic constraints: These designate the inviolable patterns in nature, the so-called natural laws.
3) Conventional constraints are constraints that arise out of the explicit or implicit conventions that a community has imposed on itself. Such constraints are neither necessary nor nomic, since conventions can always be violated. For example, the ringing of a school bell does not always mean that the lesson is finished.

Apart from this categorisation, Barwise and Perry distinguish between unconditional constraints which hold in every space-time location - the so-called facts - and conditional constraints which only hold in certain conditions. This distinction does not only cut across conventional, but also across necessary and nomic constraints. Examples for this are given in [Barwise/Perry 1983, p. 100 ff.].

In situation theory, the concept of constraint is central: A situation can only mean something if there is a constraint between the situation and this something, which may also be a situation. A scientific theory of semantics should thus mainly endeavour to make explicit the constraints between situations. Because generally both unconditional and conditional constraints shape a situation, it will seldom be possible to completely reveal all constraints. It is always a question of context of use which of the conditional constraints are recognised as such. If a semantic relation can be reduced to a conditional constraint, it has at the same time the pragmatic feature of context dependency. Thus in situation theory there is evidence for the assertion that pragmatics and semantics cannot be examined independently of each other.

Barwise and Perry consider language as a subset in the set of situations. Therefore linguistic meanings are also governed by constraints. This kind of constraint is always conventional since it has been determined by a language community. Thus linguistic constraints function as relations between utterances and other aspects of objective reality such as individuals, space-time locations, situations, as well as other utterances and so on. It comes as no surprise that the six semantic universals affecting language are part of the constraints of language.

One problem that has already been mentioned is the question of the connection between linguistic meaning and the truth of propositions. For Barwise and Perry there is a plausible answer to that: Truth is only one of many constraints imposed on speakers by meaning. If one only ever said what was really the case, truth would never be perceived as a property that can only be ascribed to certain utterances. A sentence is therefore neither true nor false as such, but truth always has to be seen in relation between the meaning of the sentence and the interpretation of the utterance of the sentence:

> "The interpretation of an utterance depends on the meaning of the expressions used and on various additional facts about the utterance. The truth of an utterance depends, in turn, on whether its interpretation fits the facts." [Barwise/Perry 1983, p. 6]

A sentence is true according to Barwise and Perry if there is a real situation in its interpretation, or, to put it differently, if external and mental significance - or point 1 and 6 of the semantic universals of a sentence - agree. Because depending on context a sentence may be true at one time and false at another (cf. [Barwise/Perry 1983, p. 159 ff.]), a relative concept of truth is required: An utterance u with an interpretation P shall be true relative to an actual situation e if e is in P. Thus the possibility of utterances with interpretations that conflict with reality is acknowledged and integrated into the theory of situations.

With their theory of situations and semantics Barwise and Perry have produced an account that seems to satisfy many of the requirements for a comprehensive information theory mentioned in chapter 2. Not only real constellations or the elements of the language, but also events, cognitive states, even 'untrue' utterances, i.e. utterances that are not true to fact, are recognised as ultimately, at an abstract level, objects of the same kind: as situations. Because events can moreover be examined independently of their effects, the phenomenon of unaddressed information also finds its place in the theory of situations. Thus the domain of what may count as a building block for a situation becomes so open that at the moment no gaps with respect to the sought-for information theory can be discerned. Situations can enter relations of the most diverse kind with other situations in almost any way so that, like the thing in Figure 4, they are embedded in a relations closure.

A further point that deserves attention is the introduction of the concept of efficiency which, according to Barwise and Perry, can be applied not only to linguistic situations, but also to situation-types such as meanings or cognitive states. This concerns the capability of a situation-type to be recycled so that, depending on the situation, different interpretations are possible. Together with the acceptance of ambiguity in language this breaks the taboo that the determinacy of meaning has to be assured, which runs through both Quine's work and most other information theories published so far.

In addition, Barwise and Perry indirectly provide arguments to support the idea that syntax and semantics are only distinguished by the direction of the corresponding relation. The basis for this argument is the insight that meaning always corresponds to a constant a priori relation, or constraint. A constraint, be it necessary, nomic or conventional, inextricably links two situations S_1 and S_2, although the direction of the constraint need not be determined in advance. If a constraint between S_1 and S_2 is interpreted as 'S_1 means S_2,' this on the one hand determines the direction of the relation (namely from S_1 to S_2) and on the other hand sets the starting point of the analysis at S_1. Thus the constraint between S_1 and S_2 appears as a d_semantic relation pointing from S_1 to S_2. Conversely, the focus of the analysis could equally well be S_2. The interpretation of the same constraint would then no longer be 'S_1 means S_2,' but 'S_2 implies S_1.' Thus the same relation does not appear to the analysing individual to be pointing away, but to be approaching, and is therefore a d_syntactic relation implicated in the structure of S_2.

Let us consider the example that smoke means fire from [Barwise/Perry 1983, p. 12 ff.]. With this example Barwise and Perry describe an extra-linguistic constraint between the two situation-types smoke and fire in such a way that one can interpret it as 'smoke means fire.' This assumption is certainly plausible. If an individual sees smoke rise somewhere in the vicinity, he may assume with good reason that there is a fire on that spot. The obviously d_semantic relation 'smoke means fire' which the individual recognises because of previous experiences helps him to achieve this insight. If, on the other hand, a person is sitting at home in front of the fireplace and watches the fire burn, she will conclude, because of the same constraint which has been interpreted elsewhere as 'smoke means fire,' that smoke will be escaping from the chimney of the house. The reason for this is simple: This person knows, again from personal experience, that a fire is a flame feeding on combustibles which produces smoke. The interpretation of the constraint, which is now d_syntactic, thus means 'fire produces smoke.' Under the situation-theoretical assumption that a constraint permanently connects two situation-types, this can also be paraphrased as 'fire implies smoke.' Thus it seems to be a question of the interpretation of the constraint whether the relation derived from it shall be considered as d_syntactic or d_semantic (according to the model in chapter 3.1).

The concept of 'pragmatics' as interpreted in chapter 3.1 can also be integrated into situation theory. The phenomenon of efficiency, the third semantic universal, already seems to indicate the presence of pragmatics in situation theory without this ever becoming explicit. Indeed, certain hints can already be found in [Barwise/Perry 1983, p. 32]. But the pragmatic flavour of their approach becomes much more obvious when one analyses the three types of constraints. The exploitation of conventional constraints is most clearly a matter of pragmatics, since these constraints are established by a community and can be violated at any time depending on the situation. But the deployment of nomic and even necessary constraints may also depend on situational context. Both categories, as we know, are divided by Barwise and Perry into the two disjoint subsets of unconditional and conditional constraints It is self-evident that the latter subset can only be accidental. If we assume that constraints can be interpreted d_semantically as well as d_syntactically - and there are indications to that effect - then both the d_syntactic and the d_semantic side of the relations closure, as indicated in Figure 4, could be further divided into an essential and an accidental subset.

Barwise and Perry's situation theory forms a good basis for the definition of information since it agrees with the model in Figure 4 in many points. Moreover, compared to Quine's theory, situation theory offers the advantage that it is not limited to the analysis of language, but may also investigate extra-linguistic circumstances. Thus the linguistic elements and the extra-linguistic constellations are put side by side as equal objects of research, namely as situations.

Nevertheless, situation theory is not without its flaws. Thus the fact that situation theory sees those constraints responsible for the complex structure of reality as part of that reality cannot be reconciled with the neurobiological assumption that the world perceived by us, and thus the constraints on this world, are constructed by our own brains. This problem will be discussed in chapter 3.3.4. A further shortcoming of Barwise and Perry's situation theory is the way in which their findings are formalised. The two authors have developed a new formal-logical notation in the shape of an algebra on the basis of finite objects, which in itself fits well with the assumptions of situation theory as summarised above. But the fact that a Barwise-Perry sentence, like propositions in predicate logic, is always based on either/or statements of existence, rather than statements of possible existence, may lead situation theory into the same impasse that Quine reached when he asked for an assurance of determinacy of sentences. The semantic relations of a situation cannot always be determined with certainty, and it is doubtful whether the efficiency of all situations and relations can ever be grasped in all their diversity. As in thermodynamics, a formalism that allows quantitative statements would be more suitable here. The details of this problem will concern us later on, in chapter 4.

3.3 Learning and knowledge

The discussion has so far focused on the definition of the terms syntax, semantics and pragmatics and their re-interpretation in terms of the needs of a yet-to-be-elaborated information theory. In this connection an important aspect has been neglected, namely the question of the relation between the concepts of information and knowledge. The comments in the introduction and the historical survey have shown, though, that this problem is the object of intensive reflection in several information theories. In [Heyderhoff/Hildebrand 1973] for example, but also in [Bar-Hillel 1964], the information process is described as a process of knowledge acquisition understood as the reduction of uncertainty, the information being used up by the end of the process. Donald MacKay, too, sees in the information process the cornerstone for an increase in knowledge; only here information is not used up: The information element is embedded by the information process into knowledge, which is understood by MacKay as a coherent representation. Therefore knowledge and information are not conceived by MacKay as completely different concepts; rather, knowledge itself turns out to be a special kind of information. Fred I. Dretske, finally, notes that the knowledge that s is F is preceded by the information that s is F. For that reason information is a semantic concept like meaning, and the connection between knowledge and information consists in the above-mentioned causal relation.

The arguments in the present study clearly favour the direction taken by MacKay. A unified definition of the concept of information which should embrace the functional-cybernetic as well as the structural-attributive forms of information will therefore support the suggestion made by Johannes Peters and Carl Friedrich von Weizsäcker that knowledge is a special case of information. But reasons for such an assumption can only be given after an examination of the concept of knowledge.

3.3.1 Preliminary remarks

Among the authors quoted so far there are several who have thought about the concept of knowledge and knowledge acquisition or learning. The various theories do not present a uniform picture. This is not very surprising given that even in psychology and philosophy a clear concept of learning and knowledge remains to be established. In order to introduce the reader to the field some theories will be summarised briefly.

For Hans Titze, for example, knowledge in its most general form consists of a set of messages composed of sentences, ideas, concepts and personal experiences. These messages are unconscious as long as they 'lie dormant' in memory, but they can become conscious any time. Therefore learning can be explained as the gradual accumulation of messages according to Shannon's communication model.

Barwise and Perry have also commented on knowledge and learning. As in their theory of meaning, epistemological ideas are part of the theory of situations. An organism (33) is part of a reality consisting of situations in which it participates (real situations) or which are proper to it (mental states). Since Barwise and Perry consider mental states as epistemic attitudes like knowledge and belief, it is not surprising that they conceive of learning as a process or course of event which maps general situations onto such attitudes. This process is mostly triggered by the senses, but non-perceptual knowledge acquisition is not excluded by their theory.

According to Barwise and Perry, knowledge itself, as a mental state, must have a factual correspondence in reality, otherwise the same attitude is counted as a belief. Nevertheless, knowledge and belief are not clearly distinguished in [Barwise/Perry 1983]. Thus knowledge is also a form of belief based on the degree of reality of the knowledge. Moreover each of the two mental states may turn into the other when the situational context changes in the course of evolution. In that sense belief is failed knowledge when what is known no longer has a factual correspondence in the new situation but is still recognised as correct by the organism. Conversely, knowledge is successful belief in the sense that a formerly unsupported conviction may have found its confirmation in a corresponding fact in reality.

Quine is much more explicit in his epistemological comments. As in his investigation of semantics he focuses on aspects of the philosophy of language. Empirical knowledge, which is ultimately based on sensory experience, primarily on observation, can only be realised in the so-called 'speaking of objects.' Thus the units of perception are the epistemological building blocks, but they lack all epistemological value if they are not integrated into a natural language environment. Therefore for Quine learning has to consist in an acquisition of verbal behaviour. Knowledge about a state affairs becomes equivalent to the ability to describe this state of affairs.

According to Quine, the process of learning is to a high degree determined by the human ability to perceive similarities between different things. Only thus can general, abstract ideas be formed. If a child wants to learn the colour 'yellow,' for example, it has to determine the scope of the term on the basis of several samples. This entails a process of trial and error, where the child will examine several instances of an object in order to establish how reddish, brownish or greenish a thing can be and still be counted as yellow. When it finds that it has applied the word too far out it can use this example as a counter-sample (cf. [Quine 1969 c, p. 121 f.].

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(33) By organism Barwise and Perry understand those parts of reality that are capable of perception and action.

Quine distinguishes six phases of language learning according to the kind of terms learnt:

1) Bulk terms such as 'water' and 'mama' stand for a primitive phase of learning because the distinction between singular and general does not apply, yet. Certain bulk terms such as 'mama' will at a later stage in the learning process develop into names for observable spatiotemporal objects.
2) Individuative terms are learnt in the second phase. Quine understands by individuative terms general terms such as 'apple' which apply to each of many objects.
3) The third phase is characterised by the acquisition of demonstrative singular terms such as 'this apple.' At that point a seriously used singular term may for the first time, through error, fail to name because the object referred to by 'this apple' might also be a fake.
4) The attributive joining of general terms with each other marks the fourth phase in language acquisition. Now we get general terms such as 'blue apple' which are not true of anything.
5) In the fifth phase, comparative terms are applied to singular terms: 'smaller than that speck.' Here terms can be formed that can admittedly never be observed, yet cannot be rejected as non-existent, unlike blue apples.
6) The sixth phase, finally, is characterised by the occurrence of abstract singular terms such as 'redness,' 'roundness' or 'mankind' which purport to be the names of qualities and classes.

With these six phases of learning Quine not only describes the stages which a child learning a language has to pass through in order to recognise the ontology accepted by a language community, but he illustrates at the same time the dilemma of a philosophy based on a concept of truth: The necessary and indeed desirable increase in knowledge can only be bought at the price of an irritating and to Quine unacceptable side-effect, namely a concomitant increase in the possibilities for misuse of the growing number of concepts.

Each of the views on knowledge and learning briefly summarised here serves as a building block for more general theories. The summaries therefore do not provide a comprehensive state of the art overview of the discipline. What is missing are important aspects of a psychology of learning and in particular modern neurobiological research. The latter has already yielded interesting and convincing findings concerning knowledge representation and the inference process as it takes place in the brain. It is precisely these two issues that will concern us in chapters 3.3.2 and 3.3.3.

3.3.2 Learning from a psychological point of view

3.3.2.1 Alternative theories of cognition

Among scientific disciplines, psychology is distinguished by the fact that from its inception it has been concerned with the question of how knowledge is acquired. Therefore it seems appropriate to summarise here some of its main theses concerning knowledge acquisition. The main source for the following survey has been the work Theories of Learning by Gordon H. Bower and Ernest R. Hilgard.

Psychology does not rely on a single theory of learning and knowledge; rather there are different, in parts widely divergent approaches to the issue of knowledge acquisition. According to Bower and Hilgard the various theories can basically be grouped into two diametrically opposed groups, namely the behaviourist theories of learning, which can be traced back to the philosophical school of empiricism, and cognitive psychology, which is based on rationalism. Apart from those two movements, there are several psychological schools that try to reconcile the views of the two sides on many important issues.

Drawing on the paradigms of empiricism, behaviourism holds that all knowledge can be derived from experience, i.e. from sensory impressions. Thus complex ideas would have to be combined from a basic stock of simple ideas to which the former can be reduced (reductionism). The simple ideas or mental elements themselves are created by association of contiguous experiences. Thus the mind, like a machine, has nothing mysterious about it and is composed of simple elements. With this approach the behaviourists relegate the mind to the role of a more or less passive store of a succession of sensory impressions. What contradicts this view is the obvious ability of the mind to gain insights by abstraction. In order to explain this mental activity the behaviourists introduce the concept of reflection. With this term they designate the ability of the mind to "call up from memory several ideas, compare them, arrange them in some logical order, and thence remember that 'imaginary' conclusion" [Bower/Hilgard 1975, p. 5]. Thus, for the behaviourists, it is sensory perception which is the ultimate source of knowledge even in this case.

It is exactly the opposite with those theories of learning that draw on the philosophical tenets of rationalism. Cognitive psychologists claim that it is thought, and not sensory impressions or intuition, that is the main source of knowledge. For them sensory impressions are "unstructured, undifferentiated chaos that only provide raw material to an interpretive mechanism that considers these raw data as clues regarding their probable source and meaning" [Bower/Hilgard 1975, p. 7]. Individual perceptual unities are not simply composed of elementary sense points, but mainly consist of relations between these sense points. Furthermore, as an explanation for the capacity of organisms to organise sense data, the rationalist will only accept the existence of a priori restrictions such as innate dispositions. Taking the example of a well-known piece of music one will quickly realise that it is not a sequence of sounds, but a whole melody that is perceived.

It is commonly thought that the rationalist claims, in particular the thesis of an innate structuring of stimulus processing, find their confirmation in the phenomenon of language acquisition in early infancy. Regardless of the language acquired, the linguistic competence of all children develops more or less in the same way and at the same age. Considering that in this process an extremely complicated and abstract diversity of rules for the transformation of strings of sounds into 'meaning' and vice versa is acquired, a purely behaviourist explanation cannot satisfy the rationalists. Peter D. Eimas, for example, writes on the evidence of speech perception experiments that very young children, like adults, perceive differences in voice-onset time as categories, and this at an age when this form of perception can hardly be due to a learning process (cf. [Eimas 1985, p. 34]). Thus Noam Chomsky's idea that every child is provided with an innate set of linguistic universals, which seemed superseded, receives fresh impetus. On the other hand, one has to note in objection that the language which is actually learnt is a product of sensory impressions, as the great differences in the phonetic systems of the human languages, although learnable by any child independently of its origins, make clear.

Obviously both views, the empiricist as well as the rationalist one, contribute to a psychological explanation of some aspects of knowledge acquisition, yet neither can claim to be complete, and it is far from clear which view should be privileged.

3.3.2.2 Learning

In presenting the most current epistemological approaches, we have discussed issues of knowledge and its representation in the subject, but not the issue of knowledge acquisition or learning. It is this aspect of psychology which is of the greatest interest for a new definition of the concept of information, particularly if we consider the issue of knowledge extension. In encyclopaedias, learning is described as the

> "general term for those processes that enable or prompt an individual to change her or his behaviour, if the change in behaviour is not caused by organic maturation, fatigue, sensory adaptation or external influences (e.g. injuries, drugs), but only by a previous acquaintance with the situation." [Knaurs 1974, vol. 11, p. 3650; trans. from German]

Thus learning is only considered to have occurred if no other explanation such as maturation, fatigue or adaptation is available.

Time	Inferred states and events	Psychological labels
0	S's prior state of knowledge	Pretest
1 2 3	E presents event X to S S experiences event X New state of knowledge	Trace formation (acquisition)
. . .		Trace retention (repetition of the trace-forming process)
n n+1 n+2	S's 'altered' state of knowledge E cues S to test S's knowledge S answers or responds	 Trace retrieval Trace utilization

Figure 5: Synopsis of the most important events in a learning episode (S stands for subject and E for environment)

For Bower and Hilgard the simplest type of knowledge is merely a biographical 'event record' (cf. [Bower/Hilgard 1975, p. 13 f.]). Even if these events are not profound items of wisdom they are nevertheless components of the organism's knowledge about the world. Bower and Hilgard represent a learning episode, the so-called learning trial, as in Figure 5. The subject's prior state of knowledge is analysed using a pretest. Then the formation of a memory trace is prompted in the subject by means of a confrontation with an event and reinforced by several repetitions of the same event. 'Learning' now designates the total difference in knowledge between the time 0 (before the first pass) and the time n (after the trace has been retained). What has been learnt in this way can be ascertained in 'trace retrieval,' by means of retrieval cues that test what the subject knows about the target item.

While there is relative agreement among psychologists about the definition of learning as such, there are several points of disagreement between the different theories of learning about the forms that learning can take. To exemplify the differing approaches let me mention the questions of what it is that is actually learnt and how problems are solved. According to Bower and Hilgard the question as to what is learnt is answered by the stimulus-response theoretician with 'habits' and by the cognitive theoretician with 'cognitive structures.' Yet both rely on everyday observations: If for example a local inhabitant L finds the way to her community centre the behaviourist will explain this by the fact that L has learnt the route by the repeated experience of taking the route, while the cognitive psychologist will claim that L knows where the community centre is, which in turn allows her to home in on it successfully from different points. The answers to the question of how novel problems are solved diverge in a similar way. The stimulus-response theoretician will see the grounds for the solution in the past which allows a subject to match past experiences to a new situation by trial and error, while the cognitive theoretician will pay more attention to the actual structuring of the problem, which can be solved, if not on the basis of experience, then on the basis of insight.

The differences described above do not by any means represent all the differences of opinion that exist between the psychological schools. But they show clearly how far the various psychological approaches have diverged, to a point where they no longer seem reconcilable. Nevertheless, the fact that most of these theories spring from everyday observations allows one to hope that the creation of a common framework for the different views is not completely precluded. Moreover, the findings of modern neurobiology summarised in the following pages seem to indicate that what cognitive psychologists call 'cognitive structures' have to have a correspondence in the different regions of the brain. This would mean that the results of cognitive psychology become analysable in a reductionist way, allowing their integration in behaviourist theories.

3.3.3 Biological correspondences

Apart from psychology and philosophy it is neurobiology that has recently concerned itself most with the issues of learning and knowledge, in particular dealing with their physical representation in the brain. Although many conclusions of this discipline are based on relatively speculative assumptions, the findings of neurobiology as a whole convey a unified and reliable picture because the experiments on which their findings are based can be reproduced and because the same effects can be produced in different ways.

In biology a basic distinction is made between two kinds of learning, namely phylogenetic and ontogenetic learning. By phylogenesis biologists understand the evolution of plant and animal species, while ontogenesis describes the evolution of individual animals. Although these types of learning differ greatly in their nature and the time they take, they mutually influence each other. The capacity for ontogenetic learning is decisively influenced by the phylogenetic size and complexity of the brain. On the other hand, according to the latest theories, phylogenesis is not only influenced by changing environmental conditions, but also by an organism's capacity to learn. Allan C. Wilson, for example, claims that:

> "(...) the high rate of evolution for mammals with respect to that for frogs may be due to the large brain of mammals. A large brain generates an internal pressure to evolve that frogs lack." [Wilson 1985, p. 155]

While phylogenetic learning is encoded in DNA sequences (34), the physiological basis of ontogenetic learning cannot be determined so easily. Although knowledge about this area is growing all the time, the way the brain functions from a neurobiological point of view has basically remained a mystery. Only for a few behavioural patterns has science been able to discover basic neuronal processes (cf. [Crick 1979, p. 181] and [Singer et al 1990, p. 9]). Nevertheless neurobiology can boast some interesting and promising results, as can be seen from the following remarks.

3.3.3.1 The neuron and its functional morphology

The nerve cell or neuron is the main constituent of the brain. In order to understand the workings of the brain one has to examine the workings of the neuron. The structure of this cell type differs from most other cells by its high degree of ramification. Starting from the cell body one distinguishes the dendrites, which receive incoming signals from other neurons, and the nerve fibre, the so-called axon, which enables the neuron to emit signals. The end of the axon divides into many branches which all end in so-called terminal buttons or terminals in contiguity to the dendritic synapses of other neurons (cf. [Iversen 1979, p. 121] and [Stevens 1979, p. 49 ff.]). The synapses, functioning as switch points between neurons, have a key role in the transmission of signals in the brain. In the course of intercellular communication, complex chemical processes, described in detail in [Stevens 1979, p. 58] and [Kandel 1979, p. 64], take place in the synapses. Depending on the type of signal transmission they support one distinguishes between excitatory (depolarising) and inhibitory (hyperpolarising) synapses.

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(34) The phenomenon of genetic information, of its storage and retrieval on a molecular basis, is described in detail in [Sitte et al. 1988].

According to Günther Palm a neuron receives signals from other neurons via approximately 10^5 afferent channels and can again transmit outgoing signals to other neurons via 10^5 synapses. Since the human brain consists of around 10^{10} neurons, the brain consists of a total of about 10^{15} neuronal connections which according to Palm can all be used to store memories. According to [Alkon 1983, p. 84] it is generally recognised that a certain basic wiring diagram is genetically given, but this wiring diagram does not of itself ensure the effortless functioning of the brain. According to Wolf Singer it is generally accepted that the human brain can only develop its numerous skills by interacting with the environment. In [Singer 1990, p. 50 ff.] he supports this thesis with observations gained when working with children whose corneas and lenses were so clouded by infections and injuries that they completely lost their capacity to see. While it is possible today to restore the purely optical part of the eye with microsurgery to the satisfaction of the patient, these operations did not restore vision to children where the clouding had existed from birth or from the first weeks of life and where patients had only been operated on when they had reached school age. Not one of those patients succeeded in using his eyes at first. Only a few laboriously learnt to recognise simple patterns and to find their way around by sight. Many broke off rehabilitative treatment and opted for life as blind people (cf. [Singer 1990, p. 50]. It seems that the neurons of the visual cortex develop their functionality only under the influence of visual experiences, and this in a critical phase, which, according to Singer, only lasts till about school age. Thus the hypothesis that experiences in early infancy simply stabilise innate capabilities can be discarded since experiential deprivation will bring the developmental process to a standstill at an immature stage.

Certainly, visual impressions are not the only source of knowledge, yet there is no indication that the brain develops its capacity for the processing of signals received from the non-optical organs in any way differently. One clue is the fact mentioned by Fernando Nottebohm in [Nottebohm 1989, p. 56 ff.] that chaffinches bred in soundproofed chambers only learnt very simple patterns of song and did not enlarge their repertoire even if they were exposed to the songs of their fellows after they had reached sexual maturity. But young birds that were played taped chaffinch songs over loudspeakers under similar circumstances learnt to imitate songs easily.

These findings show clearly that the conflict represented in chapter 3.3.2 between the learning theories subscribing to behaviourism and those of cognitive psychology is probably based on an unjustified bias towards certain observations. Both approaches have yielded valuable hypotheses about areas of learning and knowledge: The brain does have innate dispositions without which learning would be impossible as cognitive psychology assumes, but the same brain is incapable of correctly processing the signals communicated by the senses without experience, a finding that supports the behaviourist approach. In this sense the two psychological schools are not competing theories about learning, but approaches that complement each other.

3.3.3.2 Learning from a biological point of view

In chapter 3.3.3.1 we briefly alluded to the fact that signals are transmitted from one neuron to the next by a chemical chain reaction. It is therefore highly probable that an ontogenetic process of learning reinforces (or inhibits) the tendency of neurons to communicate with each other. In other words, the biochemical composition of a cell would have to be modified in a learning process in order for the cell to be able to react more strongly (or more weakly) than normally to an incoming signal.

Daniel L. Alkon has shown experimentally using the marine snail Hermissenda that such chemical changes do occur during learning processes and can be detected by chemical methods (cf. [Alkon 1983, p. 70 ff.]). The experiment consisted of a source of light that would light up and would quickly be followed by simulated ocean turbulence; the turbulence became weaker the closer the animal was to the source of light. If the animal wanted to escape the turbulence it had to move towards the source of light. Alkon succeeded in showing that Hermissenda did in fact learn, according to the paradigm of classical conditioning, to associate the two stimuli. After the training period, the snail would move towards the source of light even if no turbulence was simulated. The biochemical analysis of the animal showed that conditioning over several days modified the pattern of ion flow across cell membranes permanently. According to Alkon the capacity of Hermissenda for associative learning is comparable to that of a dog or even a human. Alkon counters the objection that the great differences between the brains make such a statement meaningless by saying:

> "Lower species can learn to associate only a narrow range of stimuli; human beings can associate whatever they perceive. Human consciousness makes possible willful forgetting or repression; it places perceptions in a rich emotional context, with gradations of positive and negative feelings that invest associations with value and meaning. For all of that, much of the biophysics and biochemistry of learning may be quite similar in snails and in human beings. It may be the neural circuitry that makes the difference." [Alkon 1983, p. 84]

The behaviour of neurons described by Alkon is called long-term potentiation (LTP) in [Kandel et al. 1991, p. 1019 ff.] and [Rahmann/Rahmann 1992, p. 208 ff.]. LTP refers to the phenomenon that rapidly repeated electrical stimulations of brain regions, e.g. of sections of the hippocampus studied in vitro, demonstrably lead to an amplification, lasting up to several hours, in the neuronal response behaviour of those cells that were excited by the stimulated fibre cells. Brief LTP stimulation suffices to produce long-term morphological changes in the nerve endings concerned, evidenced by a significant increase in the number of stabilised synapses. According to Hinrich and Mathilde Rahmann this confirms Donald O. Hebb's speculation in 1949 that potentiation of a synapsis triggered by a simultaneous activation of pre- and postsynaptic neurons is the basis of memory storage.

According to the LTP concept outlined above, a complex learning process - the trace formation already familiar from psychology - would have to cause certain modifications in the ion flow along a considerable length of the neural pathway. At the moment, this claim cannot be proved beyond a doubt with biochemical methods, but Mortimer Mishkin and Timothy Appenzeller have found interesting evidence to support the thesis. They concentrated on the processing of visual information in the brain (cf. [Mishkin/Appenzeller 1987, p. 62 ff.]). Working on the neural pathway that is responsible for visual perception, the visual pathway and using case histories of patients in which certain brain regions had been damaged by illness or injury as well as experimental research into macaques (so-called old-world monkeys which are related to baboons), the two researchers realised that visual information is processed sequentially along the visual pathway, the degree of complexity increasing with each additional neuron:

> "The cells respond to progressively more of an object's physical properties - including its size, shape, color and texture - until, in the final stations of the inferior temporal cortex, they synthesize a complete representation of the object. (...) Along the visual pathway, then, the brain integrates sensory data into a perceptual experience." [Mishkin/Appenzeller 1987, p. 64]

This is confirmed by Anne Treisman in [Treisman 1986, p. 106 ff.] who found that complex objects are not recognised a priori, but only after an analysis of their properties and parts and their subsequent synthesis. Using a sophisticated experimental arrangement she demonstrated that the colour of a red triangle is not incorporated in an analogue of the triangle that also encodes size and shape of the object, but has to be seen as something like an abstract code for red which is then associated with the triangle.

While Anne Treisman arrived at her conclusions by interpreting psychological tests, Semir M. Zeki recently succeeded in localising brain regions in macaques that participate actively in the construction of a perceptual experience, yet only respond to partial aspects of the total picture, such as colour, form, depth or spatial relations (cf. [Zeki 1992, p. 45 ff.]). He claims that specific functions in object recognition are clearly assigned to specialised areas of the visual cortex. Zeki also showed that individual cerebral regions work separately and that the total failure of one cerebral region may impair object recognition, but does not make it impossible. Thus the failure of the colour centre still allows the construction of an adequate representation of an object, although its colours are replaced by shades of grey.

According to Luc Ciompi, processes of learning and thought in all higher species, but particularly in humans, cannot be dissociated from moods, feelings, emotions and affects. In his theory of affect logic (35) Ciompi postulates that the complexity of structures and processes of the mind results from the interplay of two basic functions which are complementary in their effects: a qualifying affective system that operates with a small number of basic affective states such as rage, joy, anger, sadness and fear, and a quantifying abstractive thought system (cf. [Ciompi 1993, p. 76 ff.]). The affective system has a fundamental, organisational and integrating function. The affects or rather their neurobiological correlates, which Ciompi locates in the hippocampus and the amygdala, two important structures on the inside of the temporal lobes, link cognitive contents that belong together to context-dependent affective, cognitive and behavioural programmes. Thus the capacity to learn and remember depends to a large extent on the individual's affective context. A person in love, a happy or a euphoric person will register completely different aspects of the same environment to a sad, an angry or a frightened person.

According to Ciompi, all human beings are always in a certain mood. Not only joy and sadness, but also relaxation, harmony and soberness, even indifference, are moods accompanied by certain physical and bodily symptoms. Such affective states are not random impulses; rather they have their neurological correlates in the brain. In [Ciompi 1993, p. 83 f.] Ciompi quotes the findings of other research groups which, on the basis of experiments with animals and observations of brain-injured patients, located an anger-rage system, a fear-anxiety system and a panic-sadness system. This means that neurobiology is close to furnishing physiological proof of one aspect of the concept of pragmatics from chapter 3.1.3, namely the fact that when a thing is perceived the perceiving subject's psychological disposition is stored in the brain together with the structural features of the thing.

Ciompi's findings agree well with Mishkin and Appenzeller's views on perceptual processes. A perceptual experience takes place when sensory impressions are associated in hippocampus and amygdala, those brain regions where affective states are formed, in such a way that they can be recognised as complete pictures. It seems that this process corresponds to the process of trace formation in a psychological learning episode (as represented in Figure 5). The memory trace itself, which in biological terms is not only a linear sequence of memory addresses in the brain but a tree-like pathway through various brain regions, very probably occupies the same regions of the brain in which sensory impressions take shape, since damage to the inferior temporal cortex may greatly impair visual learning, while old memories will be preserved. Mishkin and Appenzeller suspect that the synapses between the neurons participating in the trace are modified in such a way that the connectional patterns are strengthened and transformed into a permanent memory content, or, to put it in terms of cognitive psychology, into cognitive structures. Object recognition would then occur when a particular neuronal assembly is reactivated by a similar sensory event (cf. [Mishkin/Appenzeller 1987, p. 67]). In the paper quoted above only the processing of visual signals was examined, but according to the two neurobiologists other sense data are processed in a similar way.

(35) Affect logic defines affects, emotions, moods or feelings such as rage, joy, anger, sadness and fear as comprehensive qualitative affects that may last from a few seconds (emotions in a physiological sense) to several hours, even days and weeks (dispositions in the psychological sense) (cf. [Ciompi 1993, p. 76]; see also [Ciompi 1988]).

One further, very interesting insight from Mishkin and Appenzeller's research is based on the observation that humans with a damaged hippocampus, which are no longer capable of many types of cognitive learning, are nevertheless able to acquire complex habits such as freehand drawing or other skills. Since their achievements can hardly be distinguished from those of healthy humans, Mishkin and Appenzeller suggest that learning is built on two completely different and apparently independent systems (cf. [Mishkin/Appenzeller 1987, p. 70 f.]): One system is capable of learning non-cognitive habits according to the paradigm of classical conditioning. This process, which is often called implicit learning, is relatively slow, since the sequence of stimuli which have to be associated is only memorised after many repetitions of a particular situation. The other system is the basis of cognitive memory. There, learning happens explicitly and quickly, and it may often only take a single try in an experimental situation. The stimuli associated thereby often arrive simultaneously and may have different sources. They are processed in several brain regions at the same time and undergo their final fusion into a perceptual experience in the associative cortex.

Thus anatomical correlates for both habitual and cognitive learning have been found. The theses of behaviourists and cognitive psychologists on learning seem at first sight to complement each other as explanatory systems for different kinds of learning. Nevertheless, a careful re-examination of the cognitive approach leads to a different conclusion. In the light of the neurobiological findings above one pillar of this theory, namely the idea that it is thought and not sensory impressions that form the main source of knowledge, loses its strength. The findings presented above demonstrate that innate structures such as the basic circuitry of the brain can only develop fully if they have repeatedly been stimulated with sensory data. Thus the ontogenetic development of cognitive memory can now be explained empirically, with the stimulus-response theory. The mind has nothing mysterious about it, just as the empiricists have been saying all along, and the reductionist thesis according to which complex ideas can be reduced to simple ideas becomes a plausible explanation for cognitive phenomena. But this will have to remain a mere hypothesis pending definite proof from a further analysis of neuronal processes.

3.3.4 Model of the brain and knowledge

3.3.4.1 Model of the brain

Certainly the theories and findings outlined above do not allow any definite conclusions about the structure of the brain and the way it functions, but there are enough data to propose a simple model of the brain as a store of knowledge. As has become clear in chapter 3.3.3 it is advisable to base such a model on the findings of empirical theories of learning. Therefore it will have to be presupposed that an object of the external world confronts the perceiving organism as the ultimate source of the learning process and thus of knowledge.

An object of the external world can, as we have seen, be perceived by the sensory organs of an organism and converted into an internal representation, a memory trace, by the brain. Thus the senses function as mediators between the object and the organism, transmitting the signals of the external world to the brain via neurons. But object recognition cannot be explained merely by the sustained bombardment of the senses by stimuli produced by the external world and the subsequent transmission of these signals to the brain. Before they are evaluated these data are unstructured and meaningless. Thus the question arises how an object can be discovered in such a wealth of unstructured elements. According to Wolf Singer this is possible because the object is distinct from its environment in a way that can be apprehended by the brain:

> "Objects can only be recognised as such because their properties make it possible to distinguish them as unities from other unities. At the beginning of all pattern recognition processes stands the basic operation performed to demarcate the object to be identified from surrounding contours that do not belong to the object." [Singer 1990, S. 61 f.; trans. from German]

In this sense, colour, texture, brightness and contours, for example, are features that allow one to distinguish an object from its surroundings in visual perception. But the other senses also furnish criteria for object demarcation. Thus pitch or timbre in acoustic perception or the texture of surfaces when a subject explores an object by touch can offer such distinctive features.

Accordingly the association of such features in memory could be the basis of memory trace formation. Because individual features are usually processed in different regions of the brain, the question arises how individual impressions are connected to form an ensemble. This so-called binding problem is exacerbated, according to Andreas K. Engel, Peter König and Wolf Singer, by the fact that outside the laboratory an object never presents itself alone (cf. [Engel/König/Singer 1993, p. 42]). One possible way of accounting for our ability to distinguish objects from their surroundings is the synchrony model proposed in the same paper according to which widely dispersed neurons are combined into assemblies through synchronisation of their firings. The representation of an object of the external world in the brain and thus the formation of a trace would then be achieved through the simultaneity of neuronal firing.

Because according to the synchrony model simultaneity is the only way of accounting for the binding problem, the mind may be able during a learning episode to form associations with completely extraneous memory contents, not only between components that constitute an a priori sensory unit, if they are activated at the same time. Thus it would be possible to explain the phenomenon of imagination or the non-factual association of facts. Memory formation seems to take place through molecular modifications at specific locations in a neural system which have their correlate in a modification of the synaptic ion flow (cf. [Alkon 1989, p. 26]). According to certain remarks in [Alkon 1983, p. 83] and [Crick 1979] these changes take place progressively and cannot be described as two distinct states. The representation thus formed is therefore not at all fixed; rather it has to be seen as a prototype which can always be adjusted to its perceptual correspondence in reality.

Anatomically such a learning phase is localised in the hippocampus and the amygdala (cf. chapter 3.3.3.2). However, according to Valentin Braitenberg and Almut Schütz, cognitive functions such as planning and thinking, which are widely thought to distinguish humans from animals, take place in the cortex cerebri which covers most of the human brain. The reason for this must be sought in the enormously dense and sophisticated wiring of this part of the brain. Below the cerebral cortex lies the central medullary layer which consists mainly of fibres linking the cells of the cerebral cortex. These so-called cortico-cortical circuits practically neutralise the relations of contiguity that exist between cells in the cortex, which, as we know, play an important part in the processing of perceptual stimuli. Thus the mutual likelihood of a connection between two brain cells no longer depends primarily on their physical distance, but on the simultaneity of their activation (cf. [Braitenberg/Schütz 1990, p. 184]). It is obvious that these and future findings will make it possible to explain the enormous flexibility of human associative memory.

There are no absolute correspondences between individual neuron chains and the components of a series of properties of a perceived object represented by them. Although individual cortical regions evidently specialise in processing certain perceptual properties, there seems to be no predetermination as to which neuron will be activated to deal with a specific perceptual datum. Nevertheless an interesting parallel between the two perspectives can be established. In both cases a larger totality is composed by relating things, which in turn relate two other things to each other. On the one hand, the memory trace is composed, as we know, of neuronal connections [36], the probable storage units of the brain. Thus the elementary unit of the trace can be viewed as a relation between two neurons. On the other hand, an object of the external world is perceived through the senses as a series of features distinguishing it from its environment. Yet each distinctive feature is characterised by the fact that it marks a particular difference between the perceived object and its immediate surroundings which is specific to the feature in question. Thus the distinctive feature can also be interpreted as the relation of an object to its immediate surroundings. If the learning process is examined from this point of view it can also be interpreted as a process in which relations are, as it were, mapped onto relations, or, as Günther Palm succinctly puts it: "Correlations in the external world become connections between neurons" [Palm 1990, p. 168; trans. from German].

Assuming that this hypothesis is correct, perception and understanding can be interpreted as the result of synchronous nerve activity. Semir M. Zeki, to quote a representative of this neurobiological view, concludes that the world perceived by us is actively constructed by the brain (cf. [Zeki 1992, p. 43]). A structural concept of the so-called external world, but also of knowledge, language, etc., must therefore reflect the neural structure of the brain. According to Günther Palm this structure consists of the neurons that are the primary components of the brain on the one hand and of reciprocal connections between neurons, represented by the synapses, the probable storage units of the brain, on the other. Thus the structure of the brain can conceptually be reduced to two types of elements, namely to so-called basic elements which correspond to the neuron, and the relational elements which have their correlates in the neural connections. The preferred direction of the relational elements is defined in advance since neuronal impulses usually spread from the axon terminal of the pre-synaptic neuron to the dendrite of the post-synaptic neuron, independently of the kind and the cortical location of the neurons involved. The data perceived in a scene, which are originally direction-neutral, acquire a direction through the neural perception process which is responsible for the transmission of the perceived data from the sensors to the temporal lobe.

This shows clear parallels with the conclusions of chapter 3.1. The state of a neuron, which is reflected in the chemical composition of the cell interior, is determined by electro-chemical signals from other cells coming in via the dendrites. This is why the relations with other neurons which a neuron establishes via the dendrites can be interpreted as d_syntactic relations, since the ions flowing through the post-synaptic channel proteins will ultimately determine its internal state. On the other hand, the main task of the axon is to transmit neuronal signals to other cells. Thus the terminals of an axon stand for the d_semantic relations of a neuron. If, finally, the synapses are seen as representative of the relations between two associated neurons, the most important hypothesis of chapter 3.1 - the assumption that a relation may be d_syntactic or d_semantic depending on point of view - has its correlate in the current model of the brain. According to this view the synapsis stands for a d_semantic relation if it is considered as representative of the state of the axon of the preceding neuron. If the same synapsis stands for the effect of the signal received at the post-synaptic dendrite, it will stand for a d_syntactic relation.

3.3.4.2 Brain and computer

In all, the findings of chapter 3.3 so far provide a mechanistic picture of the brain so that one is bound to ask what are the similarities between brain and the computers available today. Braitenberg and Schütz see correspondences between the cortex and electronic processors in two areas:

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(36) A synapsis is frequently considered as representative of the corresponding neuronal connection because it links the axon terminal of one cell to the dendrite of another.

- uniformity of the probable storage units: In the cortex most synapses link neurons of the same kind so that the secret of their function is more likely to lie in their uniformity than in their complexity.

- huge storage capacity: Compared to the devices from which the cerebral cortex receives and to which it transmits data, it is very large, which would suggest that the cortex stores data rather than transmitting them.

In spite of these points of contact a comparison between computer and brain must be tackled with extreme care. Francis H. Crick in [Crick 1979] adduces several reasons why such a comparison lacks explanatory force:

- speed and sequence of signal processing: A computer processes incoming signals sequentially and at great speed, while the brain deals with the flood of information much more slowly, but using uncountable parallel channels.

- reliability: Unlike the neurons of the brain, the components of a modern computer function reliably. But if one removes one of them the machine will become useless, while even the failure of several neurons may not greatly impair the functioning of the brain. The brain seems to store information in a decentralised way, so that a number of the cells can be removed without a substantial loss of information.

- flexibility in message interpretation: A computer only understands messages encoded in binary code, while the brain can apparently also interpret signals that are more diffuse. Moreover, the brain is probably capable of adjusting the efficiency of its synapses in complex stages so that it can learn from experience (cf. [Crick 1979, p. 181]).

These differences are reflected in the fact that although a computer may be able to solve most arithmetical problems much more quickly than the human brain, the computer is vastly inferior to the brains of even very simple animals in many areas of pattern recognition, in particular if we think of the perceptual invariance of object recognition [37]. Gerald D. Fischbach explains this difference by pointing out that the brain, unlike the computer, has not been built for a well-defined purpose, but is a product of natural selection. Thus the structure of the human brain is less like a modern computer with its precision wiring than a network of dispersed connections which can be modified as a result of activity and in which the experiences an organism has made are stored as knowledge about something. Thus, although the neural network has been proven to have a genetically predetermined basic circuitry which may govern certain response properties of individual neurons, the connections that are effectively used are mainly determined through interaction with the environment, depending on the particular state in which the brain is at a particular moment.

3.3.4.3 A possible structure of knowledge

One of the hypotheses presented above which is crucial for the present study is that the world perceived by an organism is a brain construct. Assuming that this is correct, a possible structure of knowledge must agree with the neural structure of the brain, since knowledge as the object of a theoretical investigation is part of the same world as the one constructed by the brain. As we know, the conceptual structure of the brain is composed of elements that can be divided into two classes, namely the class of neurons as basic elements and the class of neuronal ensembles, the probable storage units of the brain. Furthermore, one has to take into account that the neuronal ensembles are directional relations because the synapses which represent neuronal connections usually have a preferred direction for the transmission of signals. Since signal transmission is never absolutely certain, but occurs with statistical likelihood, a transmission probability has to be assigned to each neuronal ensemble.

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(37) By perceptual invariance of object recognition psychologists understand the phenomenon that an object is identified as identical with itself even if it is reflected in different ways on the retina due to differences in distance, orientation and lighting (cf. [Delius 1990, p. 106]).

A tentative model of the knowledge of an organism O therefore consists of a set K_O which can be divided into the class KE_O of knowledge elements and the class KR_O of knowledge relations (with $KE_O \cup KR_O = K_O$). The knowledge elements $k \in KE_O$ as the basic elements stand for things that are to be considered as coherent totalities such as objects of the external world or the sentences of a language. On the other hand the knowledge relations $r(k_1,k_2,p) \in KR_O$ mutually relate two knowledge elements $k_1, k_2 \in KE_O$ to the probability p. A knowledge relation $r(k_1,k_2,p) \in KR_O$ always points from k_1 to k_2.

Thus the set K_O includes all elements that can be part of the knowledge of any organism O in some form or other. With knowledge elements of this construction one can furthermore speculatively form equivalences between the model of knowledge outlined above and the neural structure of the brain, although this should not lead one to conclude that there is in fact a bijection rule for mapping the set K_O into the neural structure of an organism. In such a thought experiment a knowledge element $k \in KE_O$ could be considered as the analogue of a neuron, and a knowledge relation $r(k_1,k_2,p) \in KR_O$ as the analogue of a synapsis, where k_1 would mark a reference to the pre-synaptic and k_2 a reference to the post-synaptic cell. Finally p would represent a measure for the transmission probability of a synapsis. The knowledge relation $r(k_1,k_2,p)$ could thus also be interpreted as d_semantic with reference to k_1 and d_syntactic with reference to k_2. In analogy to the wiring network of the brain the knowledge of an organism would thus have to be understood as a structure whose basic elements form a network of knowledge relations.

There is one point, though, where the structure of the model of knowledge seems to diverge from the conceptual structure of the brain. While neurons and neuronal ensembles always represent distinct things in the brain, it may not always be possible to clearly distinguish knowledge elements from knowledge relations. If we examine not only the knowledge elements, but the knowledge relations as to their structures - whether out of perfectly legitimate scientific or ordinary human curiosity - the knowledge relation suddenly appears in the role of the knowledge element, which can in turn be related to other knowledge elements. This would mean that the intersection $KE_O \cap KR_O$ is not empty, which would contradict the outcome of the thought experiment above where KE_O is the set of all neurons and KR_O is the set of all neuronal ensembles so that their intersection would logically have to be empty. A close examination of this paradox shows, though, that the cause of the problem lies in the implicit equation of two fundamentally different facts. Information about the structure of a knowledge relation is of course represented in a completely different region of the brain of an organism from the knowledge relation itself. Therefore if one is analysing a knowledge relation there will be at least one neuron that represents this relation and thus makes it possible to store further information about the knowledge relation. Thus the knowledge relation as a physically determined neuronal connection on the one hand is identical with its representation formed for the purpose of analysis on the other hand only on a conceptual, but not on a real level.

This simple model of the elementary parts of a possible structure of knowledge is characterised by its high degree of flexibility. It is capable of representing the structure of knowledge in terms of the neural model of the brain on the one hand, and of the psychological model of learning in Figure 5 on the other. The memory trace which is formed in the learning process as a temporally uni-directional relation between perceived elementary events can thus be understood as an alternating sequence of basic elements and knowledge relations. Moreover, Luc Ciompi's affect logic and thus important aspects of the concept of pragmatics from chapter 3.1.3 can easily be represented in this model of knowledge. Because the qualifying affective system of an organism is as much an integral part of the brain as the quantifying abstractive thought system, and because, moreover, the same type of neurons is responsible for the functioning of both systems, this 'category of knowledge' can be integrated in the model of knowledge above without conceptual modifications. Thus a potential affective bias of the cognitive-sensory stimuli produced by the affective system has its correlate in the model of knowledge proposed here.

The flexibility of the model can also be seen from the fact that aspects of the brain model which have not been clearly defined can be modelled regardless of the eventual solution. For example Gerald D. Fischbach's question as to how many neurons have to change their firing rate in order for individual features of a percept to be recognised as belonging to a coherent percept or gestalt is answered in various ways today. The most extreme view holds that there is only one final neuron for each gestalt. Yet according to recent experiments, knowledge that belongs together is stored in a decentralised way, and the cells react to gestalts of a similar shape and not to specific individual gestalts. According to Hanna and Antonio R. Damasio, on the other hand, the unity of complexes of knowledge is assured by means of separate records in a dedicated area of the brain. Because both hypotheses start from the same neural model, they can of course be represented by the same kind of elements from K_O.

Cognitive knowledge is not always associated with objects of the external world directly, for very often the object of knowledge is abstract. This kind of knowledge is due to the association of neurons in brain regions that are localised very far from the sensory organs in terms of circuitry. According to Fischbach neurons react to increasingly abstract aspects of complex stimuli the more synapses there are between them and the original point of stimulation. Because neurons, particularly in those areas, are enormously flexible they can enter into relations with almost any other cell. The possibility of erroneous or deliberately false associations between different items of knowledge increases in those regions. Thus non-factual, imaginary knowledge can also be integrated into the set K_O because 'false' knowledge and 'false' reasoning have their correspondence in the neurobiological model of the brain.

This hypothesis agrees well with Quine's observation that the possibility of misuse of acquired terms increases in line with the increase in abstraction. In contrast to Quine's claim that the origin of this phenomenon lies in the animal irrationality of our sense of similarity, it is postulated here that the potential misuse of terms is a logical by-product of highly intelligent behaviour. Mathematical logic, on the other hand, which has the highest scientific value for Quine, can be compared to the simple activation of a series of consecutive synapses.

3.4 Summary of findings

It has been the aim of chapter 3 to analyse concepts that were controversial or fragmentary in earlier information theories and to integrate them into our conception. Given the importance of the results of this survey for the proposed definition of the concept of information, the most important points will be recapitulated here.

We started with the concept of the sign in semiotics as defined by Charles W. Morris. Thanks to the comprehensiveness of his definitions they can be applied in many areas. Morris' concept of the sign includes not only characters or hieroglyphics, but also whole words or sentences, and even smells, noises or patterns of behaviour, in short, anything that can in some way be apprehended by an organism via the senses. According to the semiotic view a sign has three dimensions, syntax, semantics and pragmatics, which manifest themselves in the kind of relation that links a sign with other entities. Thus the relations between two signs are syntactic, between a sign and an object semantic, and, finally, those between sign and interpreter pragmatic. According to Morris a sign with an object designated by the sign and an interpreter who evaluates the sign form a necessary part of so-called semiosis, a behaviourist stimulus-response scheme.

Morris' concept of the sign can be used to explain many aspects of information, as Doede Nauta jr. has shown convincingly in [Nauta 1970]. However, certain problems that arise in information theories cannot be answered with the original semiotic definitions. Thus unaddressed information can only be integrated into a semiotic framework by reinterpreting the semiotic scheme in a very problematic way, such as interpreting the internal representation of an object in the subject as a sign. In this way one saves the structure of semiosis, but violates the empirical principle that all stimuli should arrive from outside. In order to avoid such inconsistencies, it was proposed that the same thing, contrary to Morris' assumption, could have different roles in a semiosis. This allowed a solution of the problems above, but other difficulties arose. The terms syntax, semantics and pragmatics - which could only be delimited from each other in semiotics because clearly defined roles were assigned to the things referred to - lost their distinctive features. In the new context the same relation could be called either syntactic or semantic, because the same thing could play both the part of a sign and the part of an object in the same semiosis.

In this quandary, the direction of a relation offered itself as the new criterion for the distinction of syntax and semantics. One consequence of this was that relations that describe the syntax of a thing, its structure, always point towards the thing. On the other hand it was realised that the semantic relation of a thing in its role as a sign establishes a reference to another thing, that is, it points away from the sign. Consequently it was postulated that all relations pointing towards a thing belong to its syntax and, conversely, all relations pointing away from the thing belong to its semantics. But because this definition deviates too much from previous uses of the terms of syntax and semantics, new terms had to be invented. Thus we called a relation d_syntactic (or d_semantic) if it was only assigned to syntax (or semantics) on the basis of the direction of the relation.

Within this alternative concept of syntax and semantics, a new problem arose when a place had to be found for the third semiotic dimension, pragmatics, since a relation only has two directions. One possible solution to this difficulty was found when it was realised that the call of the subject to action which is the main feature of a semiotic-pragmatic relation does not actually emanate from the thing as sign, but is initiated by the subject as interpreter herself. In this sense, the pragmatic moment of a thing can be identified by the ever individual way in which the subject recognises a thing and assigns her own meaning to it according to her a priori knowledge and the situational context. Thus this variability in interpretation ranges from a clear recognition of the thing by the subject to its misinterpretation depending on the number and quality of the relations taken into account, as well as their correlation with the corresponding relations represented in the subject's brain. Instead of the question of pragmatic relations we get the question of the subdivision of the relations closure enveloping the thing, a division into those relations that are necessary for an adequate recognition of the thing in a particular situation and those that are not necessary to mere recognition of the thing in the same situation.

In this way it was possible to free the theory of communicative relations from the semiotic yoke of an a-contextual disjoint division of relations into syntactic, semantic and pragmatic ones. The new subdivision of relations now refers to a thing to be analysed, where the individual relation counts as d_syntactic at one time and d_semantic at another, depending on point of view, but never as both at the same time. Therefore the structure of the thing can be represented according to the model in Figure 4. The relations closure surrounding a thing can be dichotomised according to two criteria: The criterion of the direction of the relation divides the bundle of relations into a d_syntactic and a d_semantic closure; the same relations closure is divided into an essential and an accidental closure according to whether a relation is necessary for recognition at the time of perception or not.

At this point, the definition, which can be considered as one of the most important theses of the present study, was still based on weak foundations, and it was the aim of chapter 3.2 to integrate these ideas into a broader theoretical context, in particular with reference to modern theories of semantics. For that purpose, works by Willard Van Orman Quine as well as Jon Barwise and John Perry, important contributions to the definition of the modern concept of semantics, were consulted.

Quine's theory of semantics starts by introducing the linguistic concept of stimulus meaning. Semantics is represented as a behaviouristic problem which can only be understood in terms of the behaviourist model of stimulus and response. According to this approach there is no a priori meaning, but the 'meaning' of a sentence is considered as the normative form of linguistic behaviour which arose through mutual attunement of the members of a language community. Stimulus meaning must then be understood as the reference by an individual to an intended object at a certain point in time in reaction to a temporally specific linguistic stimulus. Unlike semioticians, Quine in his semantic reflections does not merely seek for the meaning of an individual utterance event, but the variability of the stimulus meanings of words, statements and sentences across several utterance events. The indeterminacy of stimulus meaning found by Quine in most sentences runs counter to his endeavour to establish criteria for the formulation of scientific theories on the basis of sentences with a constant truth value which can be written down in so-called canonical notation (cf. [Quine 1960, p. 157 f.]). Therefore he reduces the range of scientifically acceptable sentences to 'observation sentences' and 'eternal sentences,' the stimulus meaning of which remains constant over time while other sentences are dismissed as not susceptible of a determination of their stimulus meanings.

Such a restriction may sound convincing from the point of view of formal logic, but from the point of view of information theory it cannot be accepted. A comprehensive information theory must be capable of encompassing the information content of imprecise sentences. Thus the question arose first of all which mathematical concept was suitable for a formal definition of this problem. The first-order predicate logic with identity favoured by Quine cannot be used since it is usually impossible to represent in canonical notation the full extent of the variability of sentence stimulus meaning which is rarely known completely. But according to the arguments put forward on p. 34 f., the problem of the variability of stimulus meaning has similarities with the thermodynamical question of the next probable state of a gas in a closed container, which is similarly indeterminate. Transposing the approach used in thermodynamics to the linguistic environment and tackling the problem with statistical methods seems the obvious route to take. This would endorse Shannon's idea that the thermodynamic concept of entropy should be applied to certain phenomena in communication theory and would extend it in an interesting way: In contrast to Shannon's intention of excluding meaning from a discussion of communication theory, entropy according to the present proposal would emerge as something like a measure for the 'meaning' content of a communication element (cf. chapters 4.2 & 4.3).

Quine's theory relies on an analysis of the language in which a science is formulated whenever scientific questions are treated, since to him any theory is inextricably entwined with the language in which it is formulated. Yet information theory provides examples such as unaddressed information which can only insufficiently be explained with Quine's methods (cf. chapter 3.2.2). Jon Barwise and John Perry's theory of situation semantics, on the other hand, succeeds in satisfying many of the requirements of a comprehensive information theory formulated in chapter 2. The concept of the situation includes real constellations of the external world, events and the cognitive states of organisms, as well as the elements of language. All situations, including the extra-linguistic ones, can mean something according to Barwise and Perry, the individual meaning corresponding to a systematic and constant relation between two situations, a so-called constraint. The two authors explicitly include the possibility of a meaning being interpreted differently by different individuals with a different approach to the world at different times, a phenomenon that Barwise and Perry term the 'efficiency of meaning.' This enables Barwise and Perry to make the variability of the (stimulus) meaning of sentences, which Quine dismisses as unscientific, susceptible of scientific discussion. Thus the concept of efficiency plays a crucial part in situation theory. It covers the fact that a thing may be interpreted differently by different subjects in different contexts and with a different stock of a priori knowledge. The definition of situation theory for the concept of efficiency broadly coincides with the definition of pragmatics in chapter 3.1.

Situation theory introduces a relative concept of truth - an utterance u with an interpretation P shall be true relative to an actual situation e if e is in P - so that truth is considered not as the necessary property of a sentence, but as one of several possible constraints on a sentence. Moreover, the situation-semantic concept of the constraint indirectly furnishes arguments to support the thesis that syntax and semantics are only distinguished by their direction. Because every constraint which relates a situation S_1 to another situation S_2 has a direction - from S_1 to S_2 - this constraint automatically becomes a d_semantic relation with respect to S_1. Since every constraint, according to Barwise and Perry, is moreover present a priori (that is, does not only emerge when it is discovered), it also has syntactic properties that contribute to the construction of the network that holds together the situations of the world. In that sense, the constraint, a relation from S_1 to S_2 constitutive of meaning, is an integral part of S_2 so that seen from S_2 it can also be considered as a d_syntactic relation.

Thus Barwise and Perry's situation theory is compatible with the theses advanced in chapter 3.1. In addition, the theory meets most requirements for a comprehensive information theory listed in chapter 2, since all types of entities mentioned there [(38)] are considered as objects of the same value and kind: as situations. Due to the conceptually equal treatment of time-bound things (events) on the one hand and things that remain invariant over time (objects) on the other, situation theory has finally succeeded in grouping things under one heading which, because they were supposedly so different, led to the distinction between structural-attributive and functional-cybernetic approaches to the concept of information in the first place. Because it is possible to examine an event as a situation regardless of its effect, unaddressed information can also be modelled in situation theory.

One important hypothesis of situation theory is that those constraints which are responsible for the complex structure of reality also have to be understood as parts of this reality. This claim conflicts with the assumption of modern neurobiology that the world perceived by us is a construct of our brain. Neurobiology has recently developed promising theses to clarify questions that arise in connection with the concept of information, such as learning as a process of knowledge acquisition or the question of knowledge representation in the brain. This made it necessary to discuss the differing approaches to the constructedness of reality in various theories of learning and knowledge in chapter 3.3.

Modern neurobiology starts from the assumption that the perceptual signals received from the environment are processed in stages according to different criteria along a neuronal pathway and then synthesised into a coherent representation. How this happens is determined by the structure of the neurons, which can receive signals from more than 10^5 other neurons via their dendrites and transmit their own signals via the axon to more than 10^5 other neurons. Learning is therefore understood as a process whereby biochemical changes in the synapses, the switchpoints between two neurons, increase the probability of interneuronal communication. Thus we get a coherent ensemble of several neurons that are always stimulated together. If this ensemble of neurons continues to react adequately after a longer period this structure can be viewed as part of the knowledge of an organism. The representation of knowledge in the brain would therefore consist of a network of neurons permanently linked through biochemical changes, and the knowledge element could be equated to a link between two neurons.

If representations composed in this way constitute our idea of the external world, the 'real world' must have the same conceptual structure as the brain constructing the world, a brain that as we know consists of a dense network of interrelated neurons. Indeed, several findings suggest that this assumption is correct. When Wolf Singer, for example, says that objects can only be recognised as such because their properties allow them to be distinguished from other objects, he implicitly assumes that the recognition of an object can only take place with reference to the relations it has with its surroundings. Günther Palm's hypothetical statement that correlations in the external world become connections between neurons (cf. [Palm 1990, p. 168]) points in the same direction. Both statements are confirmed by Semir Zeki's findings which show that seeing and understanding are the product of synchronous neuronal activity in different areas of the brain and are therefore inextricably entwined.

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(38) This includes constellations of reality, elements of language, utterance events regardless of their factual accuracy, as well as events and cognitive states.

Thus it makes sense to view such diverse phenomena as objects of the external world, events or thoughts as basically having the same structure. Like the structure of the neuron all entities recognised or invented by an organism have relations that point towards them and relations that point away from them. Thus the structure of the thing proposed in chapter 3.1 is confirmed by the findings of modern neurobiology. But Jon Barwise and John Perry's successful attempt to reduce the world and its parts, events, language as well as mental attitudes to the same simple structure of the situation also acquires plausibility here. Anything perceptible or intelligible, whether one calls it a sign, a situation or a thing, according to this view, is nothing but a brain construct and thus depends on situational context and thing-specific a priori knowledge. This applies equally to perceived 'real' things and to invented 'figments of the mind,' to linguistic structures as well as to patterns of behaviour, to stationary things and to experienced events: They are always pragmatic. Of course this thesis necessarily also applies to constraints which are assumed by Barwise and Perry to be part of the external world, but are in fact also constructed by the brain. All things basically have the same structure, which is always a reflection of the structure of the individual brain in general and the structure of its neurons in particular. Thus the division of the relations closure enveloping the thing into a d_syntactic and a d_semantic closure as well as the speculations about the concept of pragmatics here find a simple and plausible explanation.

In this world of neural constructs, language has of course a central part. It is one of the most important mediums with which an individual can reveal his ideas about the world to other individuals. This allows the various individual 'worlds' constructed by different individuals to be mutually attuned and adjusted. Language becomes something like the individual's gauge for the accuracy of her own world construct. So it cannot surprise that Quine equates the existence of objects and external processes with the existence of sentences about the same entities. Only in this way can a broad consensus about their existence be established. The concomitant requirement that scientific statements be made in unambiguous sentences paraphrased into canonical notation in order to avoid verbal ambiguity is a necessary consequence of this approach. In that sense a future formulation of information theory will have to be judged on the clarity of its statements. On the other hand, language as an object of analysis has no exceptional status in information theory, since, like the things referred to in its statements, it is a construct of our brains and as such to be treated like any other thing.

In sum, the findings of chapter 3 have produced a framework within which a formal concept of information can be developed independently of the context in which a particular information process takes place, but also without any sacrifices such as the elimination of the aspect of semantics from Claude E. Shannon's communication theory (cf. [Shannon 1969]).

4. INFORMATION, A NEW CONCEPT

In the preceding chapter we discussed concepts such as sign, syntax, semantics and pragmatics, the definitions of which were either unclear or inadequate so that in the traditional information theories they led to contradictory results. From the beginning, the aim was to find a comprehensive framework in which the seemingly incompatible aspects of the various information theories could be integrated. Such a framework was found when it became clear that the things perceived in the external world, like the thoughts of an organism, are constructed by the individual brain, so that the question of the structure of things can only be answered in a first abstract phase on the basis of the neuronal model of the brain. Of course this also applies to the concept of information which is a construction of the human brain. Thus the guiding lines for a new concept of information are now in place.

4.1 A universal communication system

Chapter 2 provided an overview of the different definitions of the concept of information in various communication and information theories. In the course of this survey it became clear that the different views can broadly be grouped into functional-cybernetic and structural-attributive theories. While the first of these streams views information as a communication process, the second considers information as an ordered multiplicity of entities which offer themselves as elements of communication. The models used to explain information differ accordingly. While Shannon's functional-cybernetic communication model (Figure 1) is an attempt to explain the transmission of signals from a transmitter through a channel to a receiver, Nauta, decisively influenced by MacKay's structural-attributive ideas, tries in his concept of the i-system (Figure 2) to examine the modifications of the internal state P caused by the information process. This means that the two theories answer questions about the concept of information, such as the question of the information unit, in different ways. Yet since, according to the insights gained in chapter 3, the structural differences between event and object no longer matter, one is justified in hoping that a reconciliation of the two seemingly incompatible types of information theories will be possible.

Shannon's communication system consists of six elements: information source, transmitter, channel, noise source, receiver and destination which are selectively linked by directed relations according to the direction of communication (cf. Figure 1 on p. 8). Communication takes place when a message produced by the information source is conveyed into the channel by the transmitter. In the channel the message may be distorted by signals from the noise source. At the other end of the communication system the receiver receives the signals from the channel, passing them on to the destination for final processing. With this description Shannon conceptually summarises those aspects of information that fall under the heading of functional-cybernetic information. Moreover, the accompanying mathematical-statistical formulation of the processes forms the formal basis for a technical realisation of communication systems and computers. Yet Shannon deliberately excluded important aspects of information such as semantics because they seemed irrelevant to the technical realisation of his concepts.

It is precisely this aspect of Shannon's approach that Nauta chooses as the starting point for his reflections on an alternative basic model for information. In his concept of the i-system he tries to abstract from the purely technical application and to take psychological and epistemological ideas into account. The i-system is designed to form the basis of an information theory that can be understood as a link between the humanities and the natural sciences. That is why Nauta does not only investigate the transmission of signals from an information source to a destination, but also the individual processing of information by the i-system and its effect on the environment. In that sense the i-system is not hermetic like Shannon's communication system, but open, capable of receiving, processing and sending information according to the framework provided by Morris' semiosis.

The i-system consists of emittor and receptor, two filters and an internal state P, which are linked pairwise according to the direction of processing (cf. Figure 2 on p. 13). According to Nauta, a semiosis takes place in such a way that an information carrier is accepted by the receptor and recognised by the following filter as a sign so that the internal state P of the i-system changes. This change causes the production of a purposeful behaviour pattern in the following filter, which pattern is emitted to the environment by the emittor. Thus in Nauta's account of information the structural-attributive issue of the changes in the internal structure of the i-system provoked by an information process and its effects on the environment are foregrounded.

This means that both authors only treat one of two important aspects of information in their theories, namely either the aspect of signal transmission (Shannon) or the aspect of information accumulation (Nauta). In order to reconcile the two concepts, one has to find possibilities for incorporating one of the two concepts into the other. For that purpose, we will first attempt to answer the questions of one author in terms of the other's system. Thus Shannon's main problem consists in the question how a message can be transmitted by an information source to a destination without distortions. That is why Shannon's representation of a communication system in Figure 1 focuses on the situation between two communication stations. If Nauta used the same model, on the other hand, he would ask for the reasons that motivate an information source to generate a message. Furthermore, the destination's reaction to the stimulation caused by the reception of the signal would be of prime importance to Nauta. The issue of signal transmission between information source and destination would be of secondary importance. That is why in his conception of the i-system Nauta focuses on the information-processing thing which receives, processes and emits signals in reaction to the incoming signal. He emphasises the analysis of the internal state of the i-system, which would be of secondary importance to Shannon since, if he were analysing the i-system, he would primarily be interested in those processes taking place after transmission and before reception of the message.

This brief comparison of the two approaches shows clearly that it makes little sense to play off one system against the other. Rather, they are complementary theories which, taken separately, only deal with certain aspects of information, but taken together can issue in a comprehensive model of information. Each author starts asking questions precisely at the point where the other ceases to see problems as relevant to his own model. Seen from this point of view a reconciliation of the two concepts seems a simple matter. It would only take the adjustment of one of the two systems in such a way that the other author's approach could be integrated. This would result in a universal communication system that would satisfy the requirements of both workers.

The adjustments are to be executed on Shannon's communication model without impairing its universality. From Nauta's point of view the information source and the destination in this model would have to be defined as i-systems. This cannot be achieved without conceptual modifications to the communication model. Because the i-system already provides for an emittor at the interface to the external world, the sender which in Shannon's model follows on the information source is superfluous in the new model. Similarly, the receiver preceding the destination becomes superfluous because the i-system already has a receptor at the input interface. Thus the schematic diagram of a universal communication system has a simplified structure compared to Shannon's original design because sender and receiver no longer need to appear explicitly. Such a universal communication system, which will form the object of further comments in this chapter, now consists only of an information source, a destination, a channel and a noise source (Figure 6).

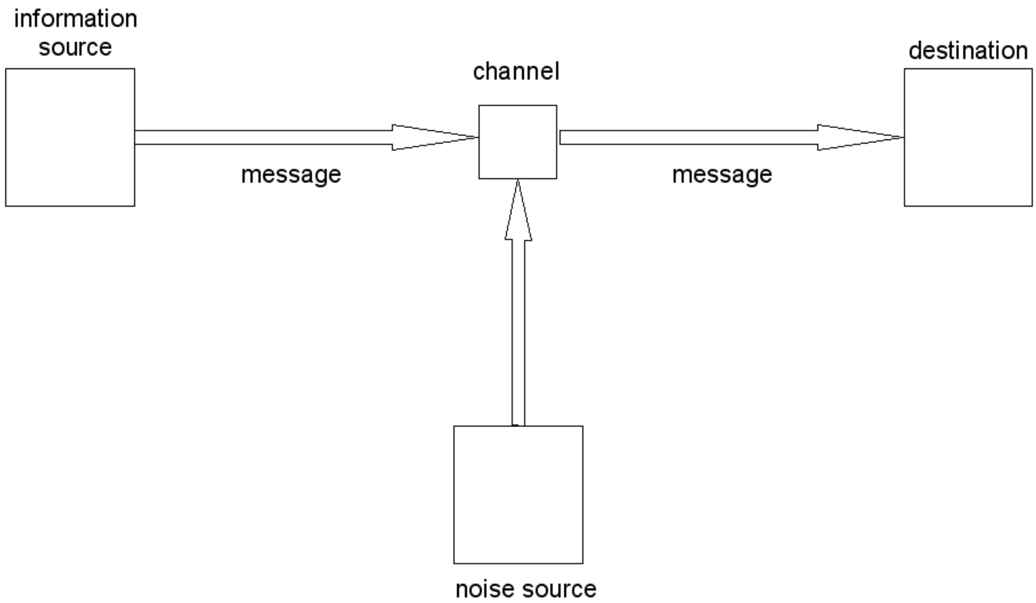

Figure 6: Schematic diagram of a universal communication system

One aspect that was not or only insufficiently taken into account in both Shannon's and Nauta's concepts was unaddressed information. In order to include this aspect a slight modification of the present outline of a universal communication model will have to be made. It is a feature of unaddressed information that the corresponding information source does not transmit its information to a well-defined destination, but simply emits it to its surroundings. Only when another i-system feels addressed as a destination by such information can a relation or channel be formed between information source and this destination. Of course, transmission over such a channel may again be impaired by a noise source. For that reason, the channel structure of Figure 6 which links information source and destination must not be understood as a fixed, ever-lasting link between those two components. Rather it must be viewed as an accidental, temporary relation between the two i-systems that are part of the model in Figure 6.

With these modifications, the universal communication model can be applied more widely than Shannon's communication model: All the informational phenomena mentioned in the preceding chapters can be accommodated. Because information source and destination are no longer considered as inscrutable black boxes, but as systems with a well-defined internal structure, the system is open to Nauta's range of meanings for information. As a consequence, communication between intelligent individuals, for example, explicitly falls under the concept of information and has to be discussed as such. Although Shannon did not explicitly exclude this possibility, his work shows a lack of interest in intelligent signal processing, unlike Nauta's concept of the i-system which is designed with a view to accounting for it. On the other hand, Nauta deliberately allows trivial i-systems so that simple machines or objects can be taken into account in his discussion of information. Finally, thanks to the proposal that channel and noise source be considered as accidental components of the universal communication system, unaddressed information, which was hitherto insufficiently integrated, can now be represented in this model. This allows us to design a system that eliminates the flaws of Shannon's communication model without discarding its advantages.

4.2 Information carrier and information element

One problem that runs through previous information theories like a red thread is the disagreement about how the two concepts of information carrier and information element should be distinguished. For Nauta, for example, the sign as the trigger of a semiosis in an i-system is the information carrier (or vehicle, as he terms it), since only the information immanent in a sign can change the internal state P of an i-system in the course of semiosis. The information elements which are carried by such a sign differ in character, according to Nauta. Depending on which of the three dimensions that determine the sign are discussed - syntax, semantics or pragmatics - a sign may contain syntactic, semantic or pragmatic information. Nauta proposes a separate information theory for each of the three types of information with their separate information units (cf. [Nauta 1970, p. 162 ff.]). According to Nauta, these information theories, differing widely as they do, can only be reconciled within the framework of a broadly defined semiotics.

There are other difficulties to be surmounted in those information theories drawing on Shannon's communication theory. They basically pose the question, already asked by Norbert Wiener, how information can be transmitted over a channel in the form of alternatives. The binary decision where one of only two options is chosen thus suggests itself as the element of information. This definition is also justified by referring to the fact that every n-ary decision can be reduced to a series of binary decisions, which cannot be further reduced. This conception of 'information unit' thus represents a selection from the smallest set that allows a genuine selection, namely a set with two elements. This information unit is often called bit and considered as an acronym of 'basic indissoluble information unit.'

Yet the term 'bit' is not always used in the same way in the literature. Apart from the version quoted above there is a second variant which considers bit to be the abbreviation of the two words 'binary digit.' In that case bit is considered as the smallest possible element for the binary representation of data. Usually the two digits '0' and '1', the character set of the dual system, are used as binary digits. The bit defined in this way is suitable both for a general representation of data and the solution of arithmetic problems.

Thus the term bit has two meanings, on the one hand a binary choice from a binary set, on the other hand a binary digit representing either the values '0' or '1', or adequate code alternatives. In order to distinguish the two definitions, we will call the first alternative bit1 and the second bit2. The root of the ambiguity between bit_1 and bit_2 lies in the fact that the alternatives represent different stages of the phenomenon of a binary decision. While bit_1 represents the existence of a binary decision which need not be made, bit_2 represents the result of such a decision in the shape of a fixed value from the set {0,1}. Thus bit_1 stands for something which may contain either of the two values of {0,1}, while bit_2 expresses the completed decision by means of one of the two values. Thus bit_1 stands for the carrier of a decision yet to be taken and to be expressed by an element of the type bit_2.

If bit_1 is viewed as a thing in the sense proposed in chapter 3, its d_semantic closure only contains two elements, namely the relations to those two things involved in the selection. In that sense the bit as a thing represents the elementary storage unit in a computer where the two things referred to by the d_semantic relations of bit_1 are represented by the values '0' and '1' or their electronic equivalent. If one of the two d_semantic relations is selected, for example as a value to be stored in a storage unit, this relation refers to a binary digit and thus to a thing of type bit_2.

From the preceding comments we can draw the following conclusions: In a binary decision things of type bit_1 play the part of information carriers offering themselves as storage options for a binary decision without preempting the result. On the other hand, relations referring to bit_2 are the relational elements in the case of a binary decision. They represent decisions that have already been made and thus in a way represent atomic entities. However, these conclusions only apply to binary decisions and not to other things of the world. Thus a thing of type bit_1 can never be the information carrier of a ternary decision, since it would have to have a d_semantic closure with three elements where bit_1 only contains two. The corresponding information elements cannot be relations that refer to bit_2 because they would have to represent a value from a set of three elements. All things and states of affair that can be formulated can certainly be represented in binary form, but these representations will always merely be paraphrases of statements in a particular language into a binary analogue. According to chapter 3.2.1 a paraphrase may approximate the original statement very closely, yet it is never identical with it.

We are justified in asking for a universally valid definition of the terms of information carrier and information element. Generalising from the hypotheses concerning binary decisions and combining them with the insights of chapter 3, we can hypothesise that the things constructed by the brain are the information carriers and the relations between these things the information elements. There are several indications that this assumption is plausible: First of all Nauta's claim that a sign in Morris' sense functions as the information carrier is in keeping with the generalisation of the concept of information carrier proposed just now, because according to chapter 3.1 a Morrissian sign is a special case of the thing. Moreover, Barwise and Perry's situation theory also supports this thesis: According to them information is always information about something and thus dependent on constraints between situations. Therefore there are situations that contain information about other situations, which is indicated by the constraint between them. Such a constraint always has a direction from the situation carrying the information to the situation referred to by the constraint or informational relation. The elementary information of situation theory is thus always an element of the d_semantic closure of that situation which functions as the information carrier. Because moreover the concept of the situation according to chapter 3.2.2 is only a variant of the more general concept of the thing, the situation-theoretical view of information is also covered by the definition proposed here.

The structure of things considered as brain constructs can now be understood as analogues of the neural structure of the brain constructing those things. Therefore the structure of information carrier and information element would have to be deducible from the brain model, which is consistent with the hypothesis made above. The neurons would then be the ultimate and atomic information carriers. According to the same model the ultimate information elements would have to be sought in the reciprocal relations between the neurons, which are in turn represented by their synapses.

These remarks may suffice to demonstrate that the bit, whether in the guise of bit_1 or bit_2, cannot be taken as the information element as such, but only represents the information carrier or the information element in the case of binary decisions. Nevertheless, bit_1 as a type of things differs from all other types of things in one important respect: It stands for that kind of thing with the smallest possible d_semantic closure from which one among many relations can be selected. Because any decision tree, however ramified, can be reduced to a binary structure, bit_1 will continue to play an important part especially in technical information processing, in particular since it is easy to simulate electronically. But it should be emphasised that information represented in binary form, insofar as it is not itself the object of information, is always a representation of information and thus not identical with that information.

The paraphrases of the concepts of information carrier and information element we have given so far might create the impression that we are dealing with concepts for fundamentally different matters. Yet the structural model of knowledge in chapter 3.3.4.3 has shown that relational elements can conceptually become basic elements if knowledge is gathered about them [(39)]. Because knowledge as the basis of the subjects' brain constructs forms an important issue in the discussion of the concept of information, this matter will have to influence the definition of the concepts of information carrier and information element. In that sense there may be cases where the information element assumes the role of information carrier, namely when information is given about a relation as information element. In those cases aspects of the structure of belongingness and meaning of the information element become important so that the relational element will itself be surrounded by a closure composed of d_syntactic and d_semantic relations. Thus this relational element meets the requirements for an information carrier. Seen from this point of view the information element as relation is no longer simply a link between two information carriers, but it can itself take centre stage and become an information element with a relations closure.

Thus the field of what can count as information carrier and information element has been delimited. All brain-constructed entities can play the part of an information carrier. Not only things of the external world and the world of the mind, but also relations between such things, insofar as they are to be examined as objects, are to be considered as entities. The information elements on the other hand are the relations between the things functioning as information carriers. Note that anything capable of being constructed by a brain can take the part of information carrier. Other constraints such as the features of truth or factuality, which Dretske or Barwise and Perry consider as necessary properties of information, are relegated by the present information theory to the realm of mere properties of a thing taken as an information carrier, which only makes a qualitative statement about the thing. So the prerequisites for a more precise definition of the concept of information without any value judgements are now in place.

4.3 Phenomenological remarks about the concept of information

Building on the basic concepts clarified in chapter 3, it is now possible to reconcile the two fundamentally distinct models of information theories - the structural-attributive and the functional-cybernetic models - mentioned in the historical survey. But a unified theory of information has not been formulated yet. Because both models can be reduced to the same universal communication system (cf. Figure 6 on p. 60), there is nothing to prevent us from attempting to describe the phenomenological aspects of both approaches using the same elements, namely the concepts of information carrier and information element developed in chapter 4.2.

First of all let us analyse the structural-attributive version of information: Information as a structure is a thing as an information carrier together with the d_semantic relations which point away from the thing acting as information elements. It does not matter what are the type and the internal structure of the thing, since the thesis applies equally to physical and mental, to inert and changeable things. A thing constructed in this way can take the part of an i-system so that the thing in its guise as an information carrier can take the place of either information source or destination (cf. Figure 6).

(39) The neural equivalent of this supposedly special case is described in the same chapter.

If an information source is considered as a structure in this sense, an interesting fact emerges: The d_semantic closure of such an information source contains among others those relations that refer to the messages that it can generate. In the case of a technical information source in Shannon's sense, which only produces signs, these relations correspond exactly to the manifold of the various signs that can be produced by the information source, i.e. its character set. Note that concatenations of such signs are recognised as wholes by human interpreters, but cannot be 'recognised' as such by technical information sources, because for a machine any message it produces is merely a sequence of individual signs whose occurrence is at most distinguished statistically.

Matters are different if a living being capable of learning such as a human being is viewed as an information source. This kind of information source differs from the technical variant in one very important respect, namely in terms of the set of messages it can generate: Unlike a technical information source, it is capable of combining elementary messages into larger units, which may in turn be elements in a larger message, and so on. The resulting number of possible messages that can be produced by an organic information source is practically infinite, which means that its d_semantic closure attains a complexity whose whole extent can hardly be comprehended explicitly. This insight, sobering as it may seem, can easily be dealt with in the framework of an information theory whose main building block is the thing as a brain construct. Whatever the individual or the object that plays the part of an information source in a universal communication system, in information-theoretical reflections it will always appear as the brain construct of an individual who experiences the communication system as an external observer. Thus the extension of the d_semantic closure of any information source will be limited to the area that can be perceived by the observer.

Information as a functional-cybernetic process can now be understood as follows: Messages in coded form, corresponding to individual knowledge elements of an information source, are transmitted via a channel to a destination. The relation between message and knowledge element of the information source need not be direct. The sequence of sounds of a spoken message only very rarely stands in a direct relation to its content. But the correlates have to be selected in such a way that the destination can adequately reconstruct the state of affairs intended by the information source and integrate it into its own structures when decoding the message. In that sense the destination must at least know a priori the coding rule with which the intended state of affairs was transformed into a message.

A message that is sent by an information source in the constellation outlined above effects a change in the internal structure of a destination. Assuming that the destination is a technical device we can say without restricting the universality of our theory that its storage area has a binary organisation. Thus a certain number of bit_1 in the storage area, corresponding to the length of the message, is adjusted to the new situation after an information process has taken place. This does not increase the 'knowledge' of a machine, but only changes the state of some bit_1. The memory of the machine may contain something completely new for a possible user of the machine, but not for the machine itself. It is from the start geared towards storing a bit_2, i.e. one of two possible values, in every bit_1, and thus 'learns' nothing fundamentally new when it stores a message. The d_semantic closure of bit_1, namely the relations of bit_1 to the values 0 and 1, remains untouched by this process. The same applies when, instead of the d_semantic closure of an individual bit_1, one analyses the d_semantic closure of the whole storage area of a technical device. Here, too, nothing is changed by information except for the arrangement of binary digits.

Things are different if the destination represents a being capable of learning. Here new structural elements are generated by the integration of the message into the cognitive structures of the being if the following three conditions are met:

1) The destination is ready to receive a message and to analyse its contents.
2) The message is understood by the destination. For this, the organic destination needs a priori knowledge about the rules that govern the generation of the message: The organic destination knows at least the language in which the message has been produced. Only in this way does it become feasible to locate suitable cognitive structures for the integration of the content of the message.
3) The message contains something that is news to the destination, i.e. something that can modify the destination's knowledge. In that sense there are four kinds of news that can be conveyed by a message:

a) The destination learns something that she did not know before. Note that the destination's a priori knowledge must include specialist knowledge about its contents apart from the language of the message; otherwise the cognitive anchoring points for the integration of this message in the destination's memory are missing. (For example, there is no point in explaining quantum mechanics to an eight year old child because he lacks the necessary basic concepts in physics.)
b) The destination learns something that she knew vaguely, but without absolute certainty. In that case the message will contribute to the imprecise knowledge being better anchored in memory.
c) The destination learns something that contradicts what she knew previously. In that case the news conveyed by the message consists in the previous, supposed knowledge being revealed to be false and in new knowledge crowding out the falsehood.
d) The destination learns something that she already knew. In that situation the news conveyed by the message consists in the confirmation of something already known.

While the situation under point 3a unquestionably represents the reception of news by the destination, the three other points, but in particular point 3d, should all be treated with caution because the contents of the message analysed by the destination are already known to her (3d), are partly known to her (3b) or appear to be known to her (3c). A closer analysis of the situations shows that in all three cases additional cognitive structures result from the information process, which complement existing structures, but do not erase them. This phenomenon can be recognised in practice by the fact that an organic destination will usually remember long after a reorientation has taken place that he had known or partly known or thought he knew a certain fact. The information process proposed here thus not only changes the individual's certainty about the knowledge in question, but also introduces new relations in the structure.

It follows that the destination is not informed in a way that extends structures, i.e. does not form new structures, if the message generated by the information source only leads to a rearrangement of existing values, as is usual when two devices, particularly two computers, communicate. Because this kind of information does not change the structure of the destination at all, it can only contain news for a living organism using the machine, not for the automaton itself. On the other hand one can only talk of information that extends structures if new structural parts are actually integrated into the destination's existing structures. This increases the number of possible messages that the destination as an information source can transmit, which according to the insights of chapter 2.1 increases its amount of information.

4.4 Formal definitions

In all, the comments above provide the basis for a new information theory that reconciles the different previous approaches and remedies their flaws. Such a theory about information must present itself in formal logical form if it is not to remain marginal to modern information technology, but should rather contribute to its evolution. That is why the definitions which have hitherto remained verbal are to be formalised. But the author does not claim that such complex matters as knowledge, learning or thought can really be expressed in simple mathematical formulas. The definitions proposed in the following, whose form is based on the textbooks of [Halmos 1976] and [Wechler 1992], are purely meant as foundations for the model of a new information theory.

4.4.1 Basic definitions

The insights of chapter 3.3 suggest that the question whether there are any a priori things can probably not be decided by any individual, since all things of so-called reality and of the world of the mind are constructed by the brains of some individuals. The formal structure of an information theory based on the premises developed in the present study requires things as the basis of such a theory that are independent of individuals. In that sense the first problem will be how to outline the set of all possible a priori things.

We will first of all define a broad area of so-called a priori basic units from which the a priori things mentioned above are to be selected. The framework of these a priori basic units is begun with the definition of a set U_0 of a priori atoms that are axiomatic. According to the insights of chapter 4.3 this set has to be supplemented at once in two respects. First of all U_0 lacks reciprocal relations between the elements of U_0. Furthermore, finite subsets of U_0 have to be included as a priori basic units because only in this way can objects composed of other a priori basic units be considered as a priori basic units themselves. These supplements are taken into account in a set U_1 which is formed by the union of U_0 with the set of pairs of elements from U_0 and the finite power set of U_0. We have not reached our goal yet, though, because set U_1 does not contain all the required elements of a set of a priori basic units either. It still lacks the relations between the elements of U_1 as well as the finite subsets of U_1. Thus we have to construct, in an analogous way, a set U_2, which is again plagued by the same problems as the sets U_0 and U_1. In that way we construct a tower of sets U_n ($n \in \underline{N}$), where the set U_{n+1} always contains those elements that are still missing according to the previously outlined pattern in U_n. The set U of all 'a priori basic units' finally results from the union of all sets U_n constructed in this way. The formal structure of this set U is therefore as follows:

Def 1: $U_0 =$ set of all '**a priori atoms**'

$$U_1 = U_0 \cup U_0 \times U_0 \cup P_{fin}(U_0)$$
$$U_2 = U_1 \cup U_1 \times U_1 \cup P_{fin}(U_1)$$
:
:
$$U_{n+1} = U_n \cup U_n \times U_n \cup P_{fin}(U_n)$$

Thus we construct:

$$U = \bigcup_{n=0}^{\infty} U_n$$ the set of all '**a priori basic units**', and

$$U_R = U - U_0 - \bigcup_{n=0}^{\infty} P_{fin}(U_n)$$

the set of all '**directed relations between elements of U**' such that from $u \in U_R$ it follows that:
$u = (b,c) = \{b,\{b,c\}\}$ with $b, c \in U$.

Thus the set U already includes everything that can be an a priori thing. For example, it is possible with Definition 1 to define the material parts of a piano as a priori atoms and to reciprocally relate them in such a way that the piano can be described as a structure. This structure is then itself an element of set U and thus an a priori basic unit even if it has not been defined as an a priori atom.

However, set U contains many more elements than are necessary for the description of a priori things. We require not just any subset of U_n ($n \in \underline{N}$), but only those subsets whose elements represent a coherent structured unit. It is therefore the aim of the following definitions to describe structures from set U, which are themselves composed of elements of this set, mathematically. The term structure is defined in encyclopaedias as the 'way in which something is put together, system, organisation of a whole whose parts have spatial or mental relations with each other' (cf. [Knaurs 1974, vol. 17, p. 5795]). Therefore we will have to show in the following how coherent structures can be formed from basic and relational elements. Thus the next definition goes as follows:

Def 2: **Direct a priori relatedness**: Let the binary relation $E_\delta \subseteq U \times U$ be defined as:

$(a,b) \in E_\delta \Leftrightarrow (a,b) \in U_B$ or $(b,a) \in U_R$ for $a, b \in U$

We say that b is '**directly related a priori**' to a and vice versa if $(a,b) \in E_\delta$.

The analysis of a network of a priori basic units concerns not only the direct, but also the indirect a priori connections between elements of U. Remember for example the neurobiological theories of learning according to which impulses have to spread through more than one neuron in the memory trace from the perception of an object to its recognition. In order to capture this phenomenon in mathematical terms, we have to take one step further and describe the indirect relatedness of two a priori basic units which are linked via other a priori basic units:

Def 3: **Indirect a priori relatedness**: Let E_ι be the transitive closure of E_δ defined as:

$(a,b) \in E_\iota \Leftrightarrow \exists\ P = \{p_1, ..., p_n\}$ ($n \in \underline{N}$), $p_i \in U$, so that $(a,p_1), (p_1,p_2), ..., (p_{n-1},p_n), (p_n,b) \in E_\delta$ for a, b $\in$ U

If: $(a,b) \in E_\iota$, then b is '**indirectly related a priori**' to a, via the elements of P in the order indicated. In that case P is the path from a to b and vice versa.

So far only pairs of a priori basic units have been examined as to their reciprocal direct or indirect a priori connections. However, this does not yet exhaustively describe a structure forming a network of a priori basic units connected in pairs. Thus we have to propose the following definition:

Def 4: The set $CO \subset U$ is called '**a priori coherent**' if for each pair $co_1, co_2 \in CO$ it is the case that: $(co_1,co_2) \in E_\iota|_{CO} = E_\iota \cap CO \times CO$. Moreover, for the intervening path $P = \{p_1, ..., p_n\}$ ($n \in \underline{N}$) the rules are:

- $P \subset CO$
- $(co_1,p_1), (p_1,p_2), ..., (p_{n-1},p_n), (p_n,co_2) \in E_\delta|_{CO} = E_\delta \cap CO \times CO$
- $(co_1,p_1), (p_1,p_2), ..., (p_{n-1},p_n), (p_n,co_2) \in CO$

That is, each pair $co_1, co_2 \in CO$ must be indirectly related a priori, via the path, including the connections of relatedness, which lie in CO. We call any set CO which is a priori coherent an '**a priori structure**'.

With this definition, structured a priori objects can be formally described as entities: A structured a priori object CO can mathematically be viewed as a finite a priori coherent subset of U. Base on this insight, we can now construct the set of a priori things A. In analogy to the set U of all a priori basic units, A is based on the set $A_0 = U_0$ of all a priori atoms. Following the pattern of Definition 1 we construct, on the basis of A_0, a tower of sets A_{n+1} ($n \in \underline{N}$) of which each is composed of the union of set A_n with the set of pairs of elements of A_n and the set of all finite a priori coherent subsets of A_n. The set A of all a priori things then results from the union of all sets A_n. The formal definition of this set must be as follows:

Def 5: Let $\wp_{co}(X) = \{CO \in \wp_{fin}(X) \mid CO$ is a priori coherent$\}$, so that for the set A of all a priori things:

$A_0 = U_0 =$ set of all 'a priori atoms'

:

:

$$A_{n+1} = A_n \cup A_n \times A_n \cup P_{co}(A_n)$$

Thus we construct:

$$A = \bigcup_{n=0}^{\infty} A_n$$ set of all '**a priori things**', and

$$A_R = A - A_0 - \bigcup_{n=0}^{\infty} P_{co}(A_n)$$

set of all '**directed a priori relations between elements of A**' such that it follows from $a \in A_R$:

$a = (b,c) = \{b,\{b,c\}\}$ with $b, c \in A$.

Now the set A includes all elements that are eligible as a priori things: Apart from the a priori atoms, A also comprehends all directed a priori relations as well as all possible a priori structures. In chapter 3.1 we found that every non-atomic thing and thus every non-atomic a priori thing has an internal structure that is determined by so-called d_syntactic relations. Moreover, every thing has a meaning space which is delimited by d_semantic relations. This state of affairs can be represented in the following definition:

Def 6: Let $c = (a,b) \in A_R$ with $a, b \in A$, then we call c a '**d_semantic relation a priori**' with reference to a and a '**d_syntactic relation a priori**' with reference to b.

Furthermore let $DSEA(a) = \{c \in A_R \mid \exists\, b \in A$ with $c = (a,b)\}$ be the '**d_semantic closure a priori**' of $a \in A$ and $DSYA(b) = \{c \in A_R \mid \exists\, a \in A$ with $c = (a,b)\}$ the '**d_syntactic closure a priori**' of $b \in A$.

Definition 6 represents the thesis proposed in chapter 3.1 of the present study whereby a directed relation, depending on whether its beginning or its end is the centre of interest, can either be interpreted as d_semantic or as d_syntactic [40]. Thus we now have all we need to define the thing as the basis of a mathematically constituted definition of information.

4.4.2 Information as a structured object

Structural-attributive information theories describe information as a structured object which can transmit parts of its internal structure as information and whose structure can itself be modified by processes that are usually called information processes. The preceding chapters have shown that a description of information in general and of information as a structured object in particular can be reduced to the thing as outlined in chapter 3.1 and further elaborated in chapter 4.3. Such a thing, unlike the a priori thing postulated above, is individual and time-bound, since it can be understood as an individual's brain construct. Moreover this kind of thing has a value that quantifies the number of times an individual (cognitively) retrieves the thing understood as a brain construct in order to generate a message destined for its environment (cf. Definition 10). The set TH of such things therefore has the following profile:

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(40) Note that in mathematical logic the use of the terms syntax and semantics is different from the use in the present study.

Def 7: Let $I \subset A$ be a set which we can interpret as the set of all organic individuals capable of grasping, i.e. of constructing as such, the a priori things postulated in Definition 5. Further, let $\Re^+_0$ be the set of positive real numbers including 0 and $\underline{N}_0$ the set of all natural numbers including 0. The **'set TH of all things'** is then defined as:

$$TH = \{th \mid th \in A \times I \times \Re^+_0 \times \underline{N}_0\}$$

A thing $th \in TH$ is thus a 4-tuple (a, i, t, s), with:

a = the a priori thing corresponding to th,
i = the individual who constructs th,
t = the time when th is constructed, with the origin $t_0 = 0$ set arbitrarily to the origin of the universe, better known as the Big Bang, and
s = the selection counter with an initial value of 0, which indicates how often the thing th has been used to generate a message (cf. chapter 4.4.3).

Moreover for the set $TH_B \subset TH$ of all relations:

$$TH_B = \{th \mid th \in A_B \times I \times \Re^+_0 \times \underline{N}_0\} \quad \text{holds.}$$

Definition 7 defines TH as the set of all things th which can be constructed by an individual $i \in I$. It has to be noted that every individual can basically comprehend every a priori thing $a \in A$ as a thing, as is indicated by the first two components of th. The third component of th serves to represent the fact that the same a priori thing a can be comprehended by the same individual i at different points in time t. Every $th \in TH$ moreover possesses a so-called selection counter $s \in \underline{N}_0$ which is incremented by the value 1 every time that th is used in the generation of a message. With this structure it also becomes possible for two different things $d, e \in TH$ with d _ e, which can be constructed by the same individual, to refer to the same a priori thing, with $d = (a, i, t_d, s_d)$ and $e = (a, i, t_e, s_e)$. The difference between d and e lies in the difference between the construction times t_d and t_e and in the difference between the selection counters s_d and s_e.

It has become clear that the set TH consists of the union of the cognitions of all individuals $i \in I$. Yet the reflections in previous chapters have shown that an information theory can only be built up individually, i.e. it can only be based on a constellation of an individual $i \in I$ and the things TH(i) that can be constructed by it. This set, which will play an important part in the following definitions, is defined as follows:

Def 8: Let $i_0 \in I$, then the **'set TH(i_0) of all things that can be constructed by an individual i_0'** is defined as:

$$TH(i_0) = TH \cap A \times \{i_0\} \times \Re^+_0 \times \underline{N}_0$$

or in other terms:

$$TH(i_0) = \{th \in TH \mid th = (a, i_0, t, s) \text{ for suitable } a \in A, t \in \Re^+_0, s \in \underline{N}_0\}$$

Furthermore the set $TH_B(i_0) \subset TH(i_0)$ of all relations that can be constructed by i_0 is defined as:

$$TH_B(i_0) = TH \cap A_B \times \{i_0\} \times \Re^+_0 \times \underline{N}_0$$

Because the set TH(i) contains all things that can be constructed by the individual i, TH(i) in a way represents the knowledge of i. The set TH(i) can basically contain one or more things $th \in TH(i)$ for each a priori thing $a \in A$. Thus the existence of structures in TH(i) on the pattern of the a priori structures in Definition 4 becomes conceivable. Yet since TH(i) is more complex than A, Definitions 2-4 and Definition 6 have to be adapted to the new situation. First of all the direct relatedness between two things has to be redefined:

Def 2*: **Direct relatedness**: Let b, c $\in$ TH(i) with b = (a_b, i, t_b, s_b) and c = (a_c, i, t_c, s_c). Let the binary relation $E_\Delta(i) \subseteq TH(i) \times TH(i)$ with i $\in$ **I** be defined as:

$$(b,c) \in E_\Delta(i) \Leftrightarrow ((a_b,a_c), i, t, s) \in TH_B(i) \text{ or } ((a_c,a_b), i, t, s) \in TH_B(i)$$

We say that c is '**directly related**' to b and vice versa if (b,c) $\in E_\Delta(i)$.

In a similar way, we adapt the definition of indirect relatedness:

Def 3*: **Indirect relatedness**: Let $E_I(i)$ be the transitive closure of $E_\Delta(i)$ defined as:

$$(b,c) \in E_I(i) \Leftrightarrow \exists \quad P = \{p_1, ..., p_n\} \ (n \in \underline{N}),\ p_i \in TH(i) \text{ with } i \in \mathbf{I}, \text{ so that } (b,p_1), (p_1,p_2), ..., (p_{n-1},p_n), (p_n,c) \in E_\Delta(i) \text{ for } b, c \in TH(i)$$

If: (b,c) $\in E_I(i)$, then c is '**indirectly related**' to b via the elements of P in the order indicated and vice versa. In that case P is the path from b to c or from c to b respectively.

Thus the definition of an information structure follows almost naturally :

Def 4*: The set CO $\subset$ U is called '**coherent**', if for every pair co_1, co_2 $\in$ CO the following holds: $(co_1,co_2) \in E_I(i)|_{CO} = E_I(i) \cap CO \times CO$. Moreover for the intervening path P = $\{p_1, ..., p_n\}$ (n $\in \underline{N}$) it is true that:

- $P \subset CO$
- $(co_1,p_1), (p_1,p_2), ..., (p_{n-1},p_n), (p_n,co_2) \in E_\Delta(i)|_{CO}$
  $= E_\Delta(i) \cap CO \times CO$
- $(co_1,p_1), (p_1,p_2), ..., (p_{n-1},p_n), (p_n,co_2) \in CO$.

Thus every pair co_1, co_2 $\in$ CO has to be indirectly related and the path including the relations of relatedness has to lie in CO. We call every coherent set CO an '**information structure**'.

The knowledge of i represented by TH(i) is thus composed of structured things, the so-called information structures. We are now left with the adaptation of Definition 6 which describes the internal structure and the meaning space of a thing:

Def 6*: Let th = (a_{th}, i, t_{th}, s_{th}) $\in$ TH(i) with i $\in$ **I**, then

- DSE(th) = $\{e = (a_e, i, t_e, s_e) \in TH_B(i) \mid a_e \in DSEA\ (a_{th})\}$
  is the '**d_semantic closure**' of th.

- DSY(th) = $\{c = (a_c, i, t_c, s_c) \in TH_B(i) \mid a_c \in DSYA\ (a_{th})\}$
  is the '**d_syntactic closure**' of th.

It is self-evident that every e $\in$ DSE(th) is always a d_semantic relation pointing away from th towards another thing and every c $\in$ DSY(th) is a d_syntactic relation pointing from another thing towards th.

Definition 6* makes it possible to mathematically describe the thing in the way outlined in chapter 3.1 and represented in Figure 4: All things th ∈ TH(i) with i ∈ I thus have a d_syntactic and a d_semantic closure. Moreover the reflections on pragmatics in chapter 3.1 also have their mathematical correspondence in the series of definitions proposed here. The fact that according to Definition 7 every thing th ∈ TH(i) contains, apart from the reference to the a priori thing a_{th}, references to a constructing individual i and a construction time t_{th}, might - together with the selection counter s_{th} which in a way expresses a 'tendency of the individual i to make th known' - be taken to point to the pragmatic aspect of a thing. How far the four components of a thing can provide criteria for the subdivision of the relations closure surrounding th into an essential and an accidental closure as proposed in chapter 3.1 will not be discussed in the present study, but may become the object of later studies.

With Definitions 1-8 we have created a general framework to describe the structural-attributive view of information. Together with the theses in chapter 4.2 the new findings necessitate the following two notes:

Note 1: Every thing x ∈ TH which is an information structure according to Def 4* will be considered as an 'information carrier' if and only if DSE(x) ≠ ∅.

Note 2: If a thing x ∈ TH is an information carrier according to Note 1, then every relation c ∈ DSE(x) is an 'information element.'

Thus structural-attributive information can be called a non-trivial information structure whose d_semantic closure is not empty. In this way we can formalise both the structure of the external world and the structure of individual knowledge. The cardinality of such an information structure CO, i.e. the number of elements in CO, is expressed according to [Halmos 1976, p. 118] as CARD(CO) = | CO |.

4.4.3 Information as process

Functional-cybernetic information theories describe information as a process IP which over time modifies information structures in general and knowledge in particular. According to chapter 4.3, an information structure Y, for example, which has been transmitted at a time t_1 has a greater cardinality at the time $t_2 > t_1$ than at the time $t_0 < t_1$. This process IP is to be elucidated on the basis of the model of a universal communication system in Figure 6; it is to be understood as a process during which a message is produced by an information source and transmitted to a destination which then integrates the structure of this message in its own structure. All the components of this model - message, information source, channel and destination - are considered as reciprocally independent information structures according to Definition 4*, constructed by an individual i ∈ I in its role as an external observer of a situation. It is understood that both the information source and the destination can be living beings which are observed by individual i in their roles as parts of a universal communication system.

Of course, the successful completion of such an information process requires that the destination have a certain internal structure, since the destination must always have certain structural similarities to the message. It would, for example, be extremely difficult to inform an English-speaking individual by means of a message in Chinese. In other words, the question arises how the qualities of any two information structures can be compared so that differences and similarities become visible:

Def 9: Let X, Y ∈ TH(i) with i ∈ I be two information structures, and let further $x = (a_x,i,t_x,s_x) \in X$ and $y = (a_y,i,t_y,s_y) \in Y$, then:

- The two things x and y are called '**equivalent**', if $a_x = a_y$, that is if x and y refer to the same a priori thing. We note this fact with x ~ y.

- The set $SC_{X,Y} \subset X$ is called the '**structural community**' of X relative to Y, if it is true that: $SC_{X,Y} = \{x \in X \mid \exists\, y \in Y \text{ with } x \sim y\}$.

- Finally the set $SD_{X,Y} = X - SC_{X,Y}$ is called the '**structural difference**' of X relative to Y.

Of course, the statements of Definition 9 apply to all information structures in TH. Now, if the two information structures X and Y represent intelligent beings, this definition can be interpreted as follows: The set $SC_{X,Y}$ stands for the a priori knowledge of X with respect to Y and $SD_{X,Y}$ for the difference in knowledge of X relative to Y. On the other hand, $SC_{Y,X}$ designates the a priori knowledge of Y relative to X and $SD_{Y,X}$ the difference in knowledge of Y relative to X.

In the course of the information process, the message M plays a central part. It transmits a structural part S of an information source X to a destination Y in coded form. Such a message need not correspond directly to S, but there must be an unambiguous translation rule from S into M and vice versa which must be known both to the information source and the destination. Thus there is no reason why the sound waves of a spoken word should correspond to its intended meaning. A correspondence will only emerge if one knows the language, which entails a translation rule from sequences of sound waves into words and vice versa. Further, the message M must not differ structurally from S, since M cannot in any case contain more than the information source X knows about the fact S to which M refers. Moreover each instance of the generation of a message M increments the selection counter s_S of information structure S by the value of 1. Finally, M as a product of information structure X is always linked to S by a directed relation $r \in TH_B(i)$. Thus we get the following definition of a message:

Def 10: Let $M, S \in TH(i)$ with $i \in I$, where both M and S are information structures. We call M a '**message**' of S, if it is true that:

- There is a relation $r \in TH_B(i)$ with $r \in DSE(S) \wedge r \in DSY(M)$.
- $SD_{M,S} = \emptyset$.
- The selection counter s_S of information structure S is incremented by the value 1.

Further let $MA(S) = \{M \in TH(i) \mid M \text{ is a message of } S\}$ be the set of all messages of S and further let $MB(S) = \{r \in TH_B(i) \mid r \in DSE(S) \wedge r \in DSY(M) \ \forall \ M \in MA(S)\} \subseteq DSE(S)$ be the set of all relations of S to its messages.

Definition 10 only stipulates formal conditions for a message, not conditions that concern its content. In fact, it is conceivable to interpret both a knowledge element coded in a suitable medium by an organic information source <u>and</u> a falling tile as messages, one addressed to a destination, the other the 'message' of a roof damaged by a storm to its environment. Since moreover Definition 10 only posits that the structural difference of M relative to S must be empty and not vice versa, any element of S can basically be generated as a message. This agrees very well with the observation that a living being can at all times transmit anything it knows in any combination as a message to its environment.

An information structure $M \in TH(i)$ is a possible message of another information structure $S \in TH(i)$ if there is a relational element $r \in DSE(S)$ such that at the same time $r \in DSY(M)$. This leads one to assume that all information structures $T \in TH(i)$ that are referred to by an element r' from DSE(S) can also be considered as possible messages of S. This would mean that for each of these T it is true that: $SD_{T,S} = \emptyset$, which is generally not likely. Nevertheless there will be an information structure $T' \in T$ for every such T that satisfies that criterion. To give an example: Let $S \in TH(i)$ be an individual and $T \in TH(i)$ a car used by S. Assuming that S is not an expert on the structure of T, this structure will never be known to him down to the last detail. But there will certainly be a substructure $T' \in T$ such as the outer form of the vehicle that S knows sufficiently to inform another individual about it. If $T' \supset \emptyset$, then T' stands for a possible message. But if $T' = \emptyset$, for example because $SC_{S,T} = \emptyset$, then no non-empty message can be generated on the basis of $r' \in DSE(S) \cap DSY(T')$. This need not disturb us. It simply marks a limit case. We can now formulate the following theorem:

Theorem 1: Let $S \in TH(i)$ with $i \in I$ be an information structure and let further be $r \in DSE(S)$ and $r \in DSY(T)$ for a suitable $T \in TH(i)$, then there is an information structure $T' \in T$ with $SD_{T',S} = \emptyset$.

Proof: It follows from Definition 9 that

$\exists T' \in SC_{T,S}$ with $SD_{T',S} = \emptyset$ QED

An information process whereby a destination $Y \in TH(i)$ is informed by an information source $X \in TH(i)$ can now be viewed as a process that reduces the structural difference $SD_{X,Y}$ of the destination relative to the information source and at the same time integrates the new elements in the knowledge structure of Y in such a way that Y is again an information structure. Therefore the next definition is:

Def 11: Let $X(t_1)$, $Y(t_1) \in TH(i)$ with $i \in I$ be two information structures at a time t_1 with $SD_{X,Y}(t_1) \neq \emptyset$, then we can say that:

- An element $x \in X(t_1)$ at the time $t_2 > t_1$ is called '**integrated**' in $Y(t_2)$, if: $Y(t_2)$ is an information structure and $x \in SD_{X,Y}(t_1)$ and $x \notin SD_{X,Y}(t_2)$. We note this as $Y(t_2) = Y(t_1) \lrcorner \{x\}$.
- The set $X(t_1)$ at the time $t_2 > t_1$ is called '**partially integrated**' in $Y(t_2)$, if: $Y(t_2)$ is an information structure and $SD_{X,Y}(t_1) \supset SD_{X,Y}(t_2) \neq \emptyset$. We note this as $Y(t_2) = Y(t_1) \lrcorner (X(t_1) - SD_{X,Y}(t_2))$.
- The set $X(t_1)$ at the time $t_2 > t_1$ is called '**completely integrated**' in $Y(t_2)$, if: $Y(t_2)$ is an information structure and $SD_{X,Y}(t_2) = \emptyset$. We note this as $Y(t_2) = Y(t_1) \lrcorner X(t_1)$.

The complete integration of a set $X(t_1)$ in the set $Y(t_2)$ with $t_2 > t_1$ can thus be interpreted as meaning that all elements of $X(t_1)$ that have no equivalent in $Y(t_1)$, yet, will acquire one by a complete integration. Thus the information process can be represented as follows:

Def 12: Let $X(t_1)$, $Y(t_1) \in TH(i)$ with $i \in I$ be two information structures at the time t_1 and let $M \in TH(i)$ be a message of $X(t_1)$. The '**information process**' $IP(M,Y(t_1))$ which transmits the message M from $X(t_1)$ to $Y(t_1)$ at the time t_1 has the following effect at the time $t_2 > t_1$:

- $Y(t_2) = Y(t_1) \lrcorner M$.
- $\exists r \in TH_B(i)$ with $r \in DSE(Y(t_2)) \wedge r \in DSY(M)$ as well as $r \notin DSE(Y(t_1))$.

We designate by $SG(IP(M,Y(t_1))) = Y(t_2) - Y(t_1)$ the '**real structural growth**' of $Y(t_2)$ due to the information process $IP(M,Y(t_1))$.

Definition 12 captures two important features of information: First of all it shows that a message which is integrated by the information process of a destination can be reproduced as a message by this destination. Secondly, Definition 12 makes clear that an information process is only non-trivial, i.e. can only modify a structure, if: M, $SG(IP(M,Y(t_1))) \neq \emptyset$. We can now derive the following theorem:

Theorem 2: Let $X(t_1)$, $Y(t_1) \in TH(i)$ with $i \in I$ be two information structures at the time t_1 and let M $\in TH(i)$ be a message produced by $X(t_1)$. After every information process $IP(M,Y(t_1))$ which transmits the message M from $X(t_1)$ to $Y(t_1)$ at the time t_1:

$$CARD(DSE(Y(t_2))) \geq CARD(DSE(Y(t_1))) \qquad \text{with } t_2 > t_1$$

Thus the information process $IP(M,Y(t_1))$ entails that the cardinality of the d_semantic closure of information structure Y(t) and thus the capacity to form messages increases or remains the same.

Proof: According to Definition 12 it follows that:

$$DSE(Y(t_2)) \supseteq DSE(Y(t_1)) \cup \{r\} \qquad (\text{ with } r \in DSE(Y(t_2)) \wedge r \in DSY(M))$$

From this the proposition of Theorem 2 follows trivially!

Thus Theorem 2 means that with each information process the cardinality of the destination structure increases or remains the same. Because this proposition also applies to mental information processes, the knowledge of the destination system always increases or at least remains constant in this kind of information process, but never decreases. This claim is in tune with the information model which is presented and illustrated with an example in chapter 4.3.

4.4.4 A measure for information

In conclusion to the formal definition of the concept of information the question arises what is the formal measure of information. To be more precise, we would like to know what is the measure for the amount of information of an information carrier. Since according to Note 2 an information structure S is called an information carrier if and only if $DSE(S) \neq \emptyset$, i.e. if its d_semantic closure is not empty, and because according to Theorem 1 it is precisely the elements of DSE(S) that refer to the possible messages of S, this measure must logically make a quantitative statement about the d_semantic closure of S. Such a measure must increase in line with the cardinality of DSE(S), and it must be capable of taking into account the elements of DSE(S) weighted according to the probability that an element will be part of a message. These requirements are fulfilled by Shannon's formula for the amount of information H in Formula 1 (cf. chapter 2.1.2).

One problem that still awaits its solution is the definition of the above-mentioned selection probability for the elements of the d_semantic closure of an information structure S. The basis for a solution is already there in the structure of these elements, for the selection counter s_r for every relation $r \in DSE(S)$ contains an empirically produced value that expresses the selection frequency of r as part of a message. The selection probability q(r) relative to the other elements of DSE(S) can now be calculated by dividing s_r by the sum of all s_c with $c \in DSE(S)$, as can be seen from the following definition:

Def 13: Let $S \in TH(i)$ with $i \in I$ be an information structure and let further $r = (a_r, i, t_r, s_r) \in DSE(S)$. Let the function $q: DSE(S) \rightarrow [0,1]$ be defined as follows:

$$q(b) = \frac{s_b}{\sum_{c \in DSE(S)} s_c}$$

We call q(r) the '**selection probability**' of the relation $r \in DSE(S)$ relative to the other relations $c \in DSE(S)$.

Thus we have a basis for the definition of the measure for the amount of information:

Def 14: Let S ∈ TH(i) with i ∈ I be an information structure and let further r = (a_r, i, t_r, s_r) ∈ DSE(S), then:

$$H(S) = -K \sum_{b \in DSE(S)} q(r) \log q(r) \qquad \text{Formula 4}$$

H(S) is the **'amount of information'** or the **entropy** of the thing S.

Thus it is possible to calculate the amount of information for each information structure S, regardless of the part it plays in an information process. According to Definition 14, the amount of information of S calculated in this way is primarily a measure for the cardinality of the d_semantic closure of S, which could be understood as a measure for the 'semantic content' of an information structure. Thus with his formula for the calculation of the amount of information, Shannon unknowingly created the basis for a measure for the 'semantics' of an information structure.

The fact that the measure for the cardinality of the d_semantic closure of an information structure shows an obvious relationship to the thermodynamic concept of entropy (see chapter 2.1) inevitably raises the question whether the amount of information as defined in Definition 14 is also governed by a law that is related to the second law of thermodynamics [(41).] Such a law would go as follows: The amount of information in a closed system will either increase with time or remain the same. The prerequisites for the formulation of such a law are already in place. First of all the concept of the information process developed in chapter 4.4.3 is to be understood according to the model of the universal communication system of Figure 6. This model is self-contained since the factors that might interfere with a communication are already part of the system, in the shape of the schematically drawn noise source. Moreover Theorem 2 on p. 74 demonstrates that the cardinality of the d_semantic closure of an information structure Y at the time t_2 (after the information process has taken place) increases or remains the same compared to the cardinality at time t_1 (before the information process), but never decreases. For that reason the amount of information H(Y(t_2)) after every information process is greater than H(Y(t_1)) or remains the same, as the following conclusion, entitled the 'Law of Information Theory,' proves:

Theorem 3: Let X(t_1), Y(t_1) ∈ TH(i) with i ∈ I be two information structures at the time t_1 and let M ∈ TH(i) be a message of X(t_1). Let further IP(M,Y(t_1)) be an information process which transmits the message M from X(t_1) to Y(t_2) at the time t_1, with $t_2 > t_1$, so that an r' ∈ TH(i) results, with r' = ($a_{r'}$, i, $t_{r'}$, $s_{r'}$) ∈ DSE(Y(t_2)) ∧ r' ∈ DSY(M). To such an information process the following formula applies:

$$\Delta H \geq 0 \qquad \text{Formula 5}$$

Proof:

$$\Delta H = H(Y(t_2)) - H(Y(t_1))$$

$$according\ to\ def\ 13,14: \Delta H = -K\Big(\sum_{r \in DSE(Y(t2))} q_r \log q_r - \sum_{r \in DSE(Y(t1))} q_r \log q_r\Big)$$

$$according\ to\ def\ 12,14: \Delta H \geq -K\Big(\sum_{r \in DSE(Y(t1))} q_r \log q_r + q_{r'} \log q_{r'} - \sum_{r \in DSE(Y(t1))} q_r \log q_r\Big)$$

$$\Rightarrow \Delta H \geq K * q_{r'} \log q_{r'}$$

$$\Rightarrow \Delta H \geq 0$$

$QED.$

---

(41) The second law of thermodynamics says that in a closed system entropy will either increase or remain the same, but never decrease.

Thus the non-trivial information processes according to Definition 12 show an affinity to irreversible physical processes and accordingly the trivial information processes an affinity to reversible physical processes.

Thus the non-trivial information processes according to Definition 12 show an affinity to irreversible physical processes and accordingly the trivial information processes an affinity to reversible physical processes.

4.5 Conclusions

In summary, the comments in chapter 4 have shown that the formulation of a unified information theory that integrates all known aspects of the problem is possible. It has been demonstrated eo ipso that when Donald MacKay and Doede Nauta Jr. demanded special information theories for different aspects of information they were taking the wrong direction. At the same time it has become clear that the three questions in chapter 2.4 which put up for discussion the basic concepts of information, information carrier and the measure for information can now be replaced by three answers as follows:

1) Information is neither a general term for the processes that increase knowledge nor can it be equated with knowledge as a structure itself. Both views only capture partial aspects of the functional-cybernetic or the structural-attributive views of information, which are in turn only partial aspects of a comprehensive information theory. In such a theory, information is postulated as the set of all information carriers and information elements, which is equivalent to the set of all things that can be constructed by any individual brain.

2) The ultimate carrier of information is neither bit_1, the representative of the smallest set from which a selection is still possible, nor is it the sign as the smallest unit of perception. Rather, it is the individual thing as constructed by a brain that is the information carrier, so that of course those entities that can function as bit_1 or as signs can become information carriers. Finally the information elements that are conveyed by such a thing correspond to the relations that point from a thing as information carrier to other things.

3) As for the measure of information, the application of Shannon's entropy concept in the context of the new information theory suggests itself. This measure is postulated in Definition 14 as a general measure for the cardinality of the d_semantic closure of a thing, regardless of the role it plays in an information process. The counterproposal to Shannon's concept of entropy from chapter 2, namely MacKay's descriptive information content of the structural cardinality of a thing, must not be seen as intrinsically false. On the contrary, this concept of a measure can be seen as an alternative to entropy, yielding a measure for the cardinality of the d_syntactic closure of a thing. For every MacKay logon, which pro memoria represents the structural component of an information element, we have a d_syntactic relation pointing towards a thing. The metron, a binary value that is added to the so-called weight of evidence of a logon, as well as the metron content, which as an integer contains the sum of all metrons of a logon and thus marks the plausibility of a logon, have no direct equivalent in the formalisms of chapter 4.4. This lack could easily be amended by extending the structure of the thing from Definition 7 by a further component that would represent the metron content. By means of this component, the descriptive information content of a thing could then be calculated according to the formulations in [MacKay 1969, p. 156 ff.]. The reason why Shannon's concept of entropy is preferred to MacKay's descriptive information content is first of all that the concept of entropy has stood the test of practical application and has been widely accepted, while the descriptive information content is today largely forgotten. Moreover it is the author's contention that information theory can be more easily integrated into the natural sciences with a generalised concept of entropy than with a generalised descriptive information content.

The theoretical framework that allowed these answers to be formulated also makes it possible to clarify further difficulties identified in the course of the present study. For example, the issue of the persistence of information can be answered easily in the new framework. Peter Heyderhoff and Theodor Hildebrand's claim that information loses its value after it has been evaluated because it is only needed for one decision and is exhausted after the decision (cf. [Heyderhoff/Hildebrand 1973, p. 2]) can no longer be upheld. Since both the information process and its outcome are only aspects of information, it has to be mentioned that the individual information process effects an overall increase in information. Heyderhoff and Hildebrand can only be said to be right insofar as they intend to claim that the destination's difference of knowledge about the information object relative to that of the information source is reduced after the information process.

A similar problem was raised by Donald M. MacKay, namely the question whether the amount of information is increased by the multiple reproduction of text documents (for example when printing newspapers), because the same contents can reach more individuals, or whether it remains the same because nothing new is created by mere copying. MacKay himself favours the second view, since he believes that in printing newspapers, regardless of the number of copies made, one only produces mutually redundant copies of a defined original which incorporates all the information in question. In line with the view advocated in the present study, though, the first opinion will have to be favoured. Each printed copy of a newspaper is in itself again a thing that exists independently of the other copies. Every copy increases the possibility that one more individual will integrate and help disseminate further the information it contains.

A further difficulty can be found in the confusion about the relation of Shannon's information theory to the two semiotic dimensions of syntax and semantics. Shannon himself explicitly considered the semantic aspects of communication as irrelevant to his information theory (see Figure 1). For this reason many commentators have called Shannon's theory a syntactic information theory. But other researchers took a different view. Doede Nauta, for example, who develops his approach to the concept of information which is pervaded by semiotic ideas on the basis of the i-system in Figure 2, notes that in Shannon's communication theory there is no reference to semiotics. Thus he thinks it a great mistake to assume that Shannon treats of syntactic information. Instead, Nauta proposes calling Shannon's work a zero-semiotic information theory. On the other hand, Nauta considers a theory of syntactic information to be realised in MacKay's theory of descriptive information.

The present study has shown that Nauta is only right in the latter case. As has been shown above, MacKay's descriptive information content can be used to calculate the (d_syntactic) structural content of a thing with only slight modifications. On the other hand, Nauta's claim that there is no semiotic content in Shannon's theory is based on a biased understanding of semantics. If, as proposed in the present study, a relation is called d_syntactic or d_semantic depending on its direction with respect to the thing under scrutiny, Shannon's concept of entropy turns out to be the measure for the cardinality of the d_semantic closure of this thing. This strengthens Warren Weaver's claim that Shannon's concept of information and the concept of meaning behave like a pair of canonically conjugate variables.

A further contentious issue is the question whether information takes place purely on a mental level, as Titze thinks, or whether information, as Barwise and Perry think, is located in the world as so-called information about structured reality, in the form of constraints between the situation types that constitute the structure of reality. In line with the view favoured here, according to which information is to be considered as the set of all things that can be constructed by a brain, Titze's view on this point must be preferred. Yet because both constraints and situation types can be interpreted as brain constructs, the valuable insights of Barwise and Perry's theory of situation semantics still find their place in the new concept of information.

The fact that information can be viewed as a problem of the mind has some interesting consequences: As a brain construct, language, which according to Barwise and Perry is only the carrier of information, has the same structure as the things of the external world and can thus be integrated in the new information theory in the same way. This applies equally to verbal utterances in the sense of ordered sequences of well-defined words and to their content, which usually refers to other cognitive products of the brain that formulates them. These cognitive products are either representations of perceived reality or pure inventions of the individual brain. Among the latter are theoretical conclusions that are based on scientific findings as well as completely imaginary or deliberately false information. Thus the statement '1+1=3' may contain information in different ways: To those who have not yet been introduced to the functioning of the '+' operator this statement will contain a first definition on the way to an understanding of the operation of addition. Those who have already been introduced to this concept, on the other hand, will conclude that it is false and that the utterer either has no knowledge of the correct result or deliberately tries to deceive the destination.

In this way, false information can have a great impact on people and society. Sometimes 'false' statements will determine whole world views, even if they have been exposed as false. It is well-known that Claudius Ptolemy's geocentric universe remained valid, under Church pressure, throughout the late Middle Ages and the early modern period even though the natural sciences, represented by Nicolas Copernicus, Galileo Galilei and Johannes Kepler, had already furnished overwhelming evidence for a heliocentric universe. Thus information theory must accept the phenomenon that in communication the information we exchange contains not only truths, but also imaginary and even false statements. With the information theory proposed here, with information carriers and information elements that are always brain constructs, this kind of information can easily be integrated.

A further issue concerns the paradoxon that currently information according to Norbert Wiener is considered to be a process that integrates new elements in the existing structure of a thing in an ordered way, while at the same time Shannon's concept of entropy, which in thermodynamics represents a measure for disorder, is proposed as the measure for information. This only appears to be contradictory, since the different hypotheses are based on different premises. Information as a process of ordered integration obviously enlarges a structure by integrating new elements into it. This creates the impression that order will increase, which is true insofar as one considers a thing or its structure in isolation. The concept of entropy, on the other hand, makes a statement about the d_semantic relations of the thing to its environment. In Shannon's communication system these relations point towards the messages that an information source can transmit, the range of the messages of such an information source being determined by means of a calculation of its entropy. Since such messages can always be viewed as extracts from the knowledge of the information source, the range of the messages that can be produced will always increase in line with the growth of the information source's knowledge as structure. This in turn increases the d_semantic closure of the structure so that, according to Definition 14, its entropy increases accordingly. The more the cardinality of a structure is increased by an information process, the higher the entropy tends to be. So although an information process increases the 'orderedness' of a thing in terms of the number of structural elements it contains, its overall entropy and thus the potential 'disorderedness' of the thing increases in interaction with its surroundings or remains the same. Thus the concept of entropy proposed here agrees well with the second law of thermodynamics.

Moreover, the formal part of the present study shows in the definition of Theorem 3, entitled 'Law of Information Theory,' a possibility of deriving a proposition from the information theoretical concept of entropy that is closely related to the second law of thermodynamics. It reveals affinities between thermodynamic processes and information processes. To illustrate the plausibility of this idea, we can make the following thought experiment: Let the state of a gas in a closed system be the information source and its next possible states the messages that can be produced by such an information source; then the relations of the gas state to its next possible states correspond to the d_semantic closure. The information process could then be understood as the actual transition from one gas state into a selected next state. It is obvious that other physical processes can also be constructed on the principle of information processes.

With the same argument the causality principle can be integrated toto genere and almost naturally in the information theory outlined here. The causality principle says that every event has one or more causes and can itself become the cause of one or several events. Now, according to chapter 3, an event can be viewed as a thing, so that we can apply the insights gathered in the course of this study to events. So, the relations that point from the causes of an event to the event itself form its d_syntactic closure and the relations that point away from the event to the consecutive events caused by it are its d_semantic closure. Thus Hans Titze's conclusion, according to which information is nothing but the causal aspect of the causality principle can be dismissed: Information is not identical with the causal aspect of the causality principle; rather the causality principle as a whole and thus also its causal aspect are aspects of information.

In the course of this study, Carl Friedrich von Weizsäcker's idea that energy might in the end turn out to be information, just as in modern physics matter has turned out to be energy, has gained in plausibility. While Norbert Wiener's thesis according to which information represents a separate physical quantity, like matter and energy, or Hansjürg Mey's speculation that matter, energy and information represent a triad of elements whose interaction produces the properties of an objet that can be perceived by us loses in evidence, information suggests itself as a concept situated in the context of the natural sciences that is suited to condensing mental and non-mental processes and objects under one heading.

4.6 Epilogue

It has been the aim of this study to make a contribution to the development of a unified concept of information. It has also been my intention to reveal and analyse problems and contradictions that arise from flaws in previous definitions of information, creating a basis for integrating these incomplete definitions in the framework of an interdisciplinary information theory. Yet the idea of such a general definition of information did not arise out of scientific necessity, but only reflects the author's private interests. Thus the concept of information developed here will have to face the tribunal of those theories whose findings are based on prior concepts of information. None of these theories was prevented from contributing to scientific progress by the flaws mentioned above. Thus the new concept of information will have to be tested as to its compatibility with those theories in the course of further research.

These compatibility tests must not be limited to the area of computer theory. Various insights of the modern natural sciences, such as current knowledge about the exchange of information between cells in an organism, are directly or indirectly based on Shannon's concept of information. But even in the humanities and the social sciences, notably certain fields in psychology, quite a few propositions are derived from theories about information processing that are based on traditional concepts of information. It is only the compatibility of the statements of such theories with the new concept of information that will decide whether it will indeed be applied across disciplinary boundaries. Finally, if Theorem 3 in chapter 4.4 is widely accepted, the impact on modern physics in particular and the natural sciences in general will have to be discussed carefully.

Some of the theses of the present study could not be derived from any other theory. Among those are the new view of syntax, semantics and pragmatics, as well as the idea that false statements should be taken into account in a formal theory of information. Although it was possible in this study to argue for a positioning of those two ideas both in the 'soft sciences' and the natural sciences, this does not suffice for a firm integration into the scientific universe. Only a broad discussion of these innovations will show whether they will last.

APPENDIX

A. Indexes

A.1 Figures

A.2 Formulas

A.3 Definitions

A.4 Theorems

A.5 Notes

B. Bibliography

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C. Curriculum vitae

Name:	Daniel Federico Flückiger	
Date of birth:	13 February 1957	
Address:	Casa la Glorietta, CH-6822 Arogno / TI Tel: +41 91 639 68 71	
Email:	federico.flueckiger@dir.supsi.ch / federico.flueckiger@acm.org	
URL:	http://mypage.bluewin.ch/federico.flueckiger/	
Marital status:	married	
Family:	Spouse:	Eveline, née Steck, 1961, qualified midwife
	Children:	Franz Kaspar, 1990
		Georg Valentin, 1992
		Rosina Henriette, 1995
Schools:	1964-1968	primary school at Pavillon Elfenau, Berne
	1968-1973	secondary school at Manuel, Berne
	1973-1977	grammar school at Kirchenfeld, Berne
	1977	Matura type C [42]
Studies:	1979-1983	University of Berne: degree course in secondary teaching
	1983	secondary teacher's diploma
	1983-1988	University of Berne: degree course in computer science
	1988	licence [43] in computer science (Faculty of Science)
	1990-1994	work on a doctoral thesis in computer science
Work:	1982-1985	part-time tutor at the Schule für Ergänzungsunterricht
	1985-1987	Gruppe für Angewandte Informatik GfAI: development of database applications
	1987-1989	Galenica AG: database administration
	1989-1992	College of Engineering Berne HTL [44]: part-time lecturer, teaching courses on databases and artificial intelligence
	from 1989	freelance computer scientist specialising in databases: modelling and applications

(42) Translator's note: The Matura is a Swiss school-leaving certificate entitling the holder to study at university; type C puts the main emphasis on scientific and technical subjects without neglecting the arts.

(43) Translator's note: The licence is the first degree at Swiss universities.

(44) Translator's note: Höhere Technische Lehranstalt = technical college.

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