SEMIOTICS, PRAGMATISM AND EXPERT SYSTEMS

J.C.A. van der Lubbe
Delft University of Technology
Dept. of Electrical Engineering
P.O. Box 5031, 2600 GA Delft
The Netherlands

D. Nauta
University of Twente
Dept. of Philosophy
P.O. Box 217, 7500 AE Enschede
The Netherlands

1. INTRODUCTION

In the present paper attention will be paid to semiotics and pragmatism and the role, which they can play with respect to the understanding of the structure of expert systems as well as to the development of those systems.

Although the paper is mainly related to the meaning of semiotics and pragmatism with respect to the rather technical field of artificial intelligence and expert systems, the discussion is also of importance for (computational) linguistics. For, generally speaking, the implementations of computational linguistics are just as paradigmatic for artificial intelligence as expert systems are. More specifically, there is a fundamental connection between computational linguistics and expert systems in that both are dealing with the rational aspects of the use of a particular sign-system. Still more in particular, the relevant consonance between linguistics and expert systems lies in what may be called the pragmatist's conviction (cf. the maxim of pragmatism as is to be found to be a universally valid maxim of logic connected with the validity of inferences, in e.g. Peirce, 1931-1958, Vol. 5, section 9 and section 402, and Vol. 8, section 191), viz. that all the meaning aspects associated with any specific natural language utterance are rendered by drawing such inferences as make sense to the (competent) native speakers of that language. For, this means that understanding language is making inferences that are validated by the competent user of that language. And this is exactly what one is doing with expert systems; making valid inferences but now with the help of machines.

Using the terms semiotics and pragmatism, primarily the semiotics and pragmatism of the American philosopher Charles Sanders Peirce (1839 - 1914) are meant here. One may ask: what makes Peirce relevant for today's research in language technology, artificial intelligence and expert systems? Answering this question rhetorically, it would suffice to indicate that Peirce as a logician and methodologist presents the most remarkable case of neglection and belated recognition in the history of philosophy. As a logician, for instance, he is second to neither Aristotle nor Frege. Any specific answer, however, that goes into what matters to the engineer, could be summarized by remarking that Peirce's philosophy represents the very blend of pragmatism and logic that any technician occupying himself with innovative design and research in the field of knowledge- and language-technology is in need of. This is what the explications of this paper purpose to make explicit.

For that very reason, a brief introduction to Peirce's philosophy should not be wanting in this paper. In Section 2 those characteristics of his philosophy are introduced that are definitive of (Peirce's blend of) pragmatism. Semiotics being basic for it, Peirce's pragmatism will be indicated as *semiotic pragmatism*; and this in view of its differentiation from ordinary as well as vulgar notions of pragmatism. Special attention is due to what qualifies the overall structure of semiotic pragmatism as well as its universal applicability, viz. the semio-logico based *categorical framework* invented by Peirce. This is summarily treated in Section 3. In Section 4 Peirce's categorical framework is applied to expert systems and their internal structure, with special attention to the inference mechanism. The representation of the characteristics of inference processes under uncertainty, the main problem in the development of non-trivial expert systems, is studied in Section 5. Finally, some conclusions are given in Section 6.

2. PEIRCE'S PRAGMATISM

Before specifying the cash value of pragmatism for contemporary technology, especially for the intelligent design of "intelligent" machines, we specify what is typical of the Peircean conception of pragmatism; thereby distinguishing it from vulgar conceptions of it that have only eyes for the effect of "cash" (bipolar thought models) instead of defining the latter in terms of the effect of "value" (triadic process-models). The very conception of what could be "intelligent" or "cognitive" in machines (in a more intelligent way than the way in which a telephone book is cognitive) has to do with this very distinction.

We restrict ourselves in the first place to some introductory specifications. Next, in 2.2, some interrelated epistemological notions are introduced that are necessary for a clear understanding of what will follow. Here the founding function that semiotics has for pragmatism will become evident. Semiotics has itself no foundation without the common understanding, and has been developed nearly from scratch by Peirce.

2.1 PRAGMATISM INTRODUCED

Basically the history of Western philosophy can be characterized by a continuous sequence of attempts in order to answer the question concerning the relation between on the one hand the words and concepts we are using and on the other hand the reality we try to conceive and to talk about with these concepts and words. A most radical answer was given by Descartes. For Descartes there was not only a clear distinction but even a gap between the reality and the image we have about this reality; there is no direct relation between them, only a correspondence. Furthermore, this correspondence is not the result of some process like e.g. experience but is a priori given and has its ground in some Supreme Being, which also guarantees the truth of our image of reality. Descartes' philosophy is basically bipolar, as is evidenced by this distinction between reality and its image, as well as by similar Cartesian distinctions such as 'matter' and 'thought', 'object' and 'subject' etc. Moreover, the entities are considered as standing in and from themselves.

Charles Sanders Peirce's triadistic methodology, instead of opposing this bipolar-isolationist way of thinking (and thus recreating a zero-sum way of conceiving and redesigning the world), comprehends it and relates it to its broader context where it may stand on its own. In making emerge his methodology, his triadistic way of conceiving, doing and re-designing, Peirce became the inventor of the word as well as the idea of pragmatism. The latter is related to the diversifications of Cartesianism in modernism, say *semantism,* as pragmatics is to semantics: where semantics comprehends syntactics in its self-containment to the formal study of sign-sign relations by including bipolarities like: sign-referent, referent-meaning, meaningful map-actuality, pragmatics comprehends the latter again by adding the dimension of Design (including normativity, i.e. value-use-plan as guiding-principle). Pragmatism, as Peirce might say, is connecting the Past with the Actual by relating both to the Future. Thus far, i.e. nearly 80 years since his death in 1914, Peirce has been by far the main developer of the idea of pragmatism, developing it into a methodological framework for the universal realisation of 'connectivity'. Everything we can feel, dream, think with (including our intuitions, emotions, our purposeful acts etc.) is interrelated, i.e. is related (directly or indirectly) to what might be called 'reality'. Peirce reduces the idea that there are entities which exist in and from themselves, ab-soluted, say, from the commonsensical world of subjective and inter subjective experiences, to the idea of objectivity as that which makes a community of researchers - realising to what extent their concepts have the status of dreams - (re)design their conceptions. The objective world, say objectivity, could not stand in and by itself, but is related (in whatever way) to our experiences. For the empirical scientist (Peirce himself was originally a chemist) this is a matter of course. For logic and philosophy, however, this meant a revolution and is still very much so: everything whatever, being no-thing in itself, has sign-character.

2.2 SEMIOTICS AND PRAGMATISM

Here is where semiotics comes in as the universal theory of signs and sign systems, and as such a methodological generalization of linguistics, also appropriate for the analysis of non-verbal signs. The universal sign-process, in which anything present is identified (fulfilling a specific criterion or norm) and through which anything not immediately present is made identifiable and may be identified, is the underlying notion. It is called *semiosis*. It is defined by Peirce and by Morris as the process in which something, some presentation, is meaningfully functioning as a sign. According to semiotic pragmatism, anything: any idea, objective identity, or idol, appearing between heaven and earth, i.e. identifiably partaking in the worlds of dreams, public reality or imagination, is (at least, potentially) a Sign. This is to say, that anything whatsoever that might ever be relevant is (at least) of the order of an information-vehicle, i.e. is something that has the power to function meaningfully as a Sign. We dream, feel, act, know and think in signs. This is what Peirce's pragmatism teaches us, and what is curiously enough at the heart of what makes Peirce's philosophy so relevant for today's engineering: knowledge is not something static, resting in itself, it is of the character of designing and doing. For, knowledge - like thinking - is a realisation, something that may only be manifest - as a design c.q. process of designing - in semiosis, i.e. as part of processes, in which a knowing subject gives meaning to what is taken to be the event by way of signs.

Due to the process aspect of semiosis, the concepts in Peirce's philosophy are not fixed contentions, but only guidelines; knowledge is fallible. As semiosis is in fact subject-dependent, knowledge is only possible by existence of some social group or communication community which realizes the co-ordination of interpretants and the conduct of rules for e.g. the use of signs, etc. Therefore, in a given context universality is something that can be realized only provisionally (in and through signs). However, according to Peirce the sociocentric method of pragmatism will ultimately lead to its Destination: universal Truth.

Summarizing now what is new in Peircean pragmatism as compared to those characteristics of traditional philosophy that still have a stronghold in the scientific and technological habits of contemporary research, we find:

1. Process is substituted for substance (semiosis or sign process being the key concept).
2. There is no static logic of certainty, but probabilism and uncertainty are integrated in every piece of knowledge and in every inference-process (the belief-doubt duality being the key-concept here).
3. Pragmatism is relationalistic; it is a heuristic of heuristic processes, and as such it purports to be in its very fallibility the self-improving method of methods (Kevelson, 1987, especially Chapter 2). This pretension is sustained by the fact that Peircean pragmatism is the very methodology professing the irreducible integration of pragmatics (this all-encompassing complexity for which linguistic engineers have catched a phobia or a dyslexia witness most contemporary research in linguistic technology).
4. Triadistic design is substituted for secular Cartesian linearism, as is inherent in bipolarities like: body-mind, opposition-synthesis, object-subject, matter-form, extension-intension, expressed reality-expression, reality-model, realism-idealism, actuality-potentiality.

The way this bipolar linearism is comprehended within triadic (re)presentations and (re)constructions is explicated in the next section.

3. PEIRCE'S CATEGORICAL FRAMEWORK

3.1 THE THREE CAT EGORIES

The methodology inherent in semiotic pragmatism can be clarified more deeply by considering Peirce's categorical framework. As has already been explained in the foregoing a main tenet of Peirce's philosophy is that all that exists, all there is to talk or think about, is participant in semiosis, i.e. is part of a sign-process. Constitutive of the universal signprocess three categories play a role simultaneously, viz. signhood, actuality and designhood (the latter is meant as a contraction of: conception, destination and realisation). Thus semiosis is to be understood as the universal process in which a second category, viz. some potential Actuality, is *mediately* taken account of (Morris, 1938, Chapter II Section 1); the mediation, originating from some thing that in and through the process is functioning as a Sign, is actually realised by a mediator, called Interpretant by Peirce; this third category is realising some wholeness by design. These three categories are indicated by Peirce in their most general abstraction as Firstness, Secondness and Thirdness.

These categories are so interrelated that the First is involved in and presupposed by the Second and the First and the Second in and by the Third; something like a triadic hierarchy exists: a triarchy. The interrelation between the categories is dynamic and cyclic: the triarchy is a tri-an-archy. The position within the scheme can change; what is actually functioning as a First in one context may be a Second in another context etc. The characteristics of the three categories can be summarized by the following typifications. Distinction is made here with respect to the different modes of being defined by Peirce (1), Peirce's categorical definitions of the three as primaries (2), the tri-an-archy inherent in semiosis (3) and the dimensional plurality inherent in the very conception of each of the three (4).

FIRSTNESS

1. Possibility/potentiality; what might be; what has the character of a premise; signhood. "Mere quality, or suchness, is not in itself an occurrence, as seeing a red object is; it is a mere may-be" [1.304, where 1.304 denotes Peirce (1931/35), Volume 1, paragraph 304]. "The idea of Firstness is predominant in the idea of freshness, life, freedom" [1.302].
2. "Firstness is the mode of being of that which is such as it is, positively and without reference to anything else" [8.328]. The tenet of pragmatism implied here has a substantial philosophical import: the mode of being of substantiality (being a self-sufficient or autonomous entity) is restricted to mere possibility.
3. Sign. That on which any reference is based. A sign is more or less self containing. It is any presentation or point of depart: a sensation, a quality or suchness, a feeling, an intuition.
4. Monadicity (e.g. being such), unrelatedness, punctuation.

Self-containment (absoluteness, autonomy).

SECONDNESS

1. Actuality; what happens to be; anything that can truly be said to exist as a particular spatio-temporal object or event. The mode of being of an occurrence c.q. experience. Secondness is "predominant in the ideas of causation and of static forces" [1.325].
2. "Secondness is the mode of being of that which is such as it is, with respect to a second but regardless of any third" [8.328].
3. Object (in its broadest sense). That on which the collective goal-directed usage of signs is based; in Peirce's terminology: Ground. A referent is the object or actual occurrence referred to by the sign. There is no Ding an sich. A referent presupposes a sign.
4. Polarity (e.g. action-reaction), relatedness, concatenation of binary relations, linear extension.

Zero-summation (either/or, more/less).

THIRDNESS

1. Generality; what (necessarily) would be under specifiable conditions; what is destined to be in the long run. Unlike might-be's (mere possibilities), would-be's, c.q. rules or cognition, are habits and laws of nature (habits of nature) that can "only be learned through observation of what happens to be" [6.327]. It is predominant in "generality, infinity, continuity,... intelligence" [1.340].
2. "Thirdness is the mode of being of that which is such as it is, in bringing a second and a third into relation to each other" [8.328].
3. Interpretant. The interpretant is the conception, design or guiding principle, i.e. the cognitive, functional or rule-governed context, relating a sign to its referent or application. It is of the character of a general order or regularity.
4. Complementarity (e.g. part-in-whole complementarity), interrelation, trianarchic circularity.

Synergetic exchange (both/and, even the weakest link is fed forward).

3.2 Linguistic-Cognitive Application of the Three Categories

The reader's relevant conception of the three categories may be expanded now by applying Peirce's frame more specifically in the field of verbal communication (linguistic semiosis). As applied to language in use and information theory Peirce's three categories represent the triads word-object-concept and information vehicle (data) - situation referred to (actualization, application) - interpretant (meaning allocator) respectively.

A Sign in itself does not (re)present existence; there should be a connection with a referent. Something *functioning* as a sign succeeds in triggering the referent-interpretant relation. Referring to Figure 1 (see for Figure 1 to Figure 5 the end of this paper), the concept apple (Thirdness) cannot be real without materialization in a particular apple (Secondness). Both are presented in the word 'apple' (Firstness). There is, however, no direct relation between the word 'apple' and the object apple as is expressed by the dotted line in the figure; words are related to objects via concepts. Conventionalised habits play a role here. Linguistic communication is conventional in character, making use of symbolic signs. In animal communication non-symbolic or natural signs are used. Here sign and object are more directly coupled, although a mediator or interpretant is never lacking even there (cf. Morris, 1938). Now let us try to see what it means to say that linguistic signs (symbols) are primarily related to concepts. A word or symbolic expression such as 'apple', 'unicorn', 'this is red' is always used in an actual context. Given this context, the symbol in question may be related to an actual (or actually imagined) apple, unicorn, or situation. This process of existential realisation is mediated by concepts (conceptual realisation), viz. the idea of, or criteria for, an apple, the image of a unicorn, and the purport of the proposition in question. Concepts are habits or combinations of habits that have been formed and are being formed on the basis of contextual experience with occurrences of apples, parts or images of unicorns, contents of propositions, etc. Apparently the mediation process is circular (cf. Figure 5). Generally speaking, i.e. relating not only to linguistic semiotics but to semiotics in general, the interrelations between object, sign and interpretant are dynamical. Objects can only be known through signs, signs will always be developed by interpretants. The Interpretant is the meaning aspect that presupposes a sign and reference relation. However, it should be noticed here, that the meaning of a sign is always tentative (for the time being) and capable of change. This holds for interrelations in general.

It is clear that it is exact the dynamical and circular interrelation between object, sign and interpretant by which the bipolar way of thinking of Descartes is surmounted.

Within the broader context of culture and society (the verbal expressions of) perceptions, reasoning processes and social conventions or agreements can be characterized as a typical sequence of linked semiotical triangles within an infinite field of possible semiotic triangles. Compare Figure 2. During perceptive learning, whatever functions as an object on the one level, can become a sign on the next level. As reasoning processes and the configuration of agreements proceed interpretants on the one level can function as signs c.q. objects on the next level.

Finally, it is relevant to stipulate here that the well-known semiotico-linguistic tripartition: syntactics, semantics and pragmatics, is directly related to Peirce's notions of Firstness, Secondness and Thirdness. Syntactics is related to the combinations of and relations between signs and is as such related to Firstness. Semantics is related to the reference of signs, with emphasis on referents, i.e. Secondness. Pragmatics is related to Thirdness as being the study of the interpretant; the guiding principle relating signs to references.

4. PEIRCE'S CATEGORICAL FRAMEWORK APPLIED TO EXPERT SYSTEMS

4.1 PRE-CONDITIONS FOR APPLICATION

The categorical framework being introduced, it is now possible to apply it in the field of artificial intelligence; more specifically, to relate Peirce's tri-an-archy to the structure of expert systems. Considering the universal character of the three categories, it may be concluded that kind and number of application of Peirce's scheme are unlimited. The fundamental question here is whether his triadic scheme applies to all tripartitions whatever, including all tripartitions of components of expert systems. It is inherent in the Peircean framework (though not stated as such by Peirce himself) that the following three pre-conditions for appropriate application should be satisfied:

1. The condition of completeness.
The three components should belong together and constitute a whole. There should be no category mistake, comparing sheep with goats (e.g. 'land', 'sea' and 'apple').

2. The condition of semi-autonomy.
According to this condition, the presupposed or included component, i.e. the First as related to the Second and the Second as related to the Third, should still have a certain independence, a certain autonomy or identity of its own. More precisely, a component should neither be completely defined (context-freely implied) by the next component, nor have a completely independent status: each should be semi-autonomous.

3. The condition of hierarchy.
The order of the three components should not be random, but hierarchical. This means that the Third should imply, presuppose or include the Second, just as the Second should imply the First (or find its forebodings in it).

Relating Peirce's categories to expert systems these conditions should be taken into account. Before doing this, first some remarks about expert systems.

4.2 Expert Systems

In general expert systems can be considered as computer programs that have been made apt for support in complex decision making situations at a level comparable to that of human experts. Their applications are manifold. Expert systems exist, which diagnose medical diseases, which help short term weather forecasting, which advise geologists with respect to mineral exploration, etc. What all these systems have in common is that they simulate allegedly human reasoning, at least with respect to the input-output performance. For this reason, the main challenge in expert system development is to build systems that are apt to handle decision making under uncertainty conditions adequately.

The key parts of an expert system are a global data base, a knowledge base and an inference mechanism. These three elements can be distinguished in any expert system. Their defining characteristics are as follows:

1. Global data base: that part of the expert system which contains the relevant data with respect to the problem application domain, as well as intermediate results.

2. Knowledge base: that part of the expert system that contains a fixation of the relevant knowledge of the expert. It can be considered as a model of the knowledge of the expert. In most expert systems this knowledge is represented in the form of so-called "if-then" rules, e.g.: "if ice is heated, then it will melt".

3. Inference/control mechanism: that part of the expert system which contains procedures in order to make inferences on the basis of the knowledge base and the state of the global data base and performs the reasoning process.

4.3 First-Order Application

Taking into account that the conditions of completeness, semi-autonomy and hierarchy are fulfilled, we now try to apply Peirce's categorical frame to the three elements: global data base, knowledge base and inference mechanism relating them to Peirce's Firstness, Secondness and Thirdness, respectively. The reasons why we consider this mapping to be fitting may be specified as follows.

The global data base contains un-interpreted data: these function as signs, which are still open for interpretation. The data at this level express 'potentiality' and as such the global data base is typically related to Firstness. The knowledge base presents a model of the experience of the expert; this is clearly related to Peirce's Secondness. Furthermore, if-then rules also correspond to Secondness in the sense of 'polarity' and 'action-reaction' relations. Finally, the inference/control mechanism exhibits a rational control function on the basis of a routine-interpretation of a priori given data and expert knowledge; such a guiding principle for relating a First to a Second is typically what Thirdness is about.

A conclusion of this mapping is that the three distinguished parts of an expert system: global data base, knowledge base and inference mechanism, are not independent, just as it is not the case in respect to Peirce's three original categories. Until now, this fact was not perceived within the field of expert system development. Inference mechanisms are usually developed independently of the types of knowledge and data.

4.4 Second-Order Applications

Peirce's categorical framework can also form the basis for a further distinction between the relevant elements within the global data base, the knowledge base and the inference mechanism. With respect to the latter, this leads to a tripartition that was already introduced by Peirce himself. As already mentioned, the elements of the categorical framework are semi-autonomous. This implies that each category includes elements of the other category. This makes it possible to apply the categorical framework also to what will be called here 'lower' levels. Lower-order application means the application of the categorical scheme to the analysis of what was the outcome of previous applications of the scheme. Hence, one winds up, e.g. what can be described as a Firstness of a Third, the Secondness of that Third, and the Thirdness of that Third, etc. A comparison with fractals and fractal theory forces itself here.

The Global Data Base

With respect to the global data base a distinction can be made among three types of data or information vehicles, which - following common usage (see Nauta, 1972) - may be designated as signal, sign and symbol. These emphasize the potential, referential and interpretable aspect, and thus a predomination of Firstness, Secondness and Thirdness, respectively. Note that 'sign' in this context is used as a specific term to be distinguished from Peirce's general sign. The specific terms, 'signal', 'sign', 'symbol', correspond to Peirce's terms "icon", "index", and "symbol", respectively.

THE KNOWLEDGE BASE

With respect to the knowledge base, Firstness is related to 'descriptive knowledge', identifying and describing the relevant parameters within some application domain. This part of the knowledge base thus represents the relevant parameters, i.e. those features that are taken to present the building stones for the type of knowledge in question. For instance, in a meteorological expert system for weather forecasting, features like 'temperature', 'humidity', 'cloudiness', etc. are assumed to be relevant within the application domain, i.e. forecasting the weather.

The 'relational knowledge base' specifies the relations between relevant parameters. Usually this knowledge is represented by means of a semantic network that can be considered as a graph, in which the nodes represent the relevant parameters and the lines between them the existence of some relation. With respect to the meteorological expert system the relational knowledge states e.g. that 'cloudiness', 'humidity', etc. are related to the occurrence of 'rain'; 'temperature' is related to the occurrence of 'thunderstorms', etc. Due to its indicational or bipolar character this part clearly pertains to Secondness.

Finally, Thirdness corresponds to that part of the knowledge base that contains 'heuristic knowledge'. This refers to, e.g. rules together with the conditional qualifications of relevant parameters like 'high temperature', 'low humidity' and with the strength of the relation between the conditioning part ('high temperature') and the concluding part ('thunderstorm'). This does not pertain to knowledge in the form of formal if-then rules (which, being bipolar, belong to relational knowledge) but to interpreting knowledge in the form of *pragmatic* if-then rules; where it is understood, in accordance with semiotic pragmatism, that pragmatics implies interpretation processes (including heuristics) under uncertainty and on the basis of experience.

THE INFERENCE MECHANISM

If the inference mechanism of the expert system is considered in more detail, then in fact we obtain Peirce's well-known types of inference: abduction, deduction and induction. Abduction is related to Firstness as potentiality, deduction is related to Secondness as actuality, and induction to Thirdness as generality.

It is a characteristic of each inference that it is basically related to three propositions, usually indicated as maior and minor (the two premises), and conclusion (the result). According as the third proposition (i.e. the conclusion or result of the inference) has the status of an actuality (including general actuality in case the second premise or minor is a general, where 'all these' has been substituted for 'this' in the following examples), a rule, or a hypothesis we have deductive, inductive or abductive inference respectively; and these are of the character of Secondness, Thirdness and Firstness respectively.

The differences among the three types of inference can be illustrated with the help of the following examples.

Deduction:
First: Red apples are sweet (rule or maior, i.e. general premise)
Second: This apple is red (minor or factual hypothesis)
___
Third: This apple is sweet (actuality)

Induction:
First: These apples are red (factual hypothesis)
Second: These apples are sweet (sampled actuality)
___
Third: Red apples are sweet (rule)

Abduction:
First: This apple is sweet (actuality)
Second: Red apples are sweet (rule)
___
Third: This apple is red (hypothesis)

Clearly, these three types of inference have different starting points. In the case of deduction, one comes to a conclusion by applying a rule to a specific case through the intermediary of a specific premise. Induction comes down to the generation of a general rule on the basis of a specific premise, that guarantees the relevant condition, and evidence from well-conditioned samples. Finally, abduction, starts from considering how a given *queer* actuality (e.g. this apple being sweet, where

- according to the experiential context - most apples are not sweet) might be explained through the intermediary of a rule that fits the actuality, thus arriving at a hypothesis that is explanatory indeed of the actual situation.

These three types of inference will be considered in more detail in the following section. At the end of this section we summarize by way of Figure 3 the first- and second-order applications of Peirce's categorical scheme to the internal structure of expert systems.

5. Reasoning Under Uncertainty

5.1 Certainty Factors

In the foregoing section, it was mentioned that a characteristic of expert systems is that they are thought to imitate or represent human reasoning; at least with respect to the input-output performance. The latter means that, given the application domain and given the particular problem to be solved, both the human expert and the expert system should come to the same conclusion on the basis of an identical input. However, there is more complication than actually is accounted for in many models. Common sense tells us, for instance, just as Peirce's critical commonsensism does, that reasoning is not simply reasoning in signs, but is so under conditions of uncertainty. As for Peirce, his pragmatism was designed as a methodology for coping with uncertainty as something inevitable in the context of the continuous struggle for belief against an impressing chaotico-creative background of doubts (see Peirce, 1877).

The types of inference exampled in the foregoing section are primarily related to situations that justify a flip-flop mapping of truth values on to the propositions in question (100% true or 100% false). However, in the present context the definitions are extended to situations in which some degree of uncertainty presents itself in the inference process. Although it can be the rule that red apples are sweet (assuming that we have a clear idea about 'red' and 'sweet'), in practice it is not always clear to what degree an apple is really red: an apple can be a little bit red, yellow red, fiery red etc. What about the sweetness of the apple in that case? Moreover, assume that we have indeed an apple that is really red (without discussion), then still it is not sure that it is sweet; there is a possibility that some red apples are not sweet at all etc.

One way in which these types of uncertainty can be incorporated into expert systems is by means of so-called 'certainty factors'. Certainty factors express the degree of belief or certainty etc. with respect to observed phenomena; e.g. the redness of an apple. Certainty factors can also be attached to e.g. if-then rules as a whole, hence expressing the certainty of the conclusion part (result) if the conditioning part (fact or actuality) of the if-then rule is completely certain. As such the certainty factor of the rule 'red apples are sweet' expresses the certainty that a red apple is sweet, if there is complete certainty about the redness of the apple.

In general, the certainty factors take values on the continuous interval [-1,+1], where +1 corresponds to complete certainty with respect to the truth of a proposition concerning facts or results, -1 to complete certainty with respect to its falsehood, and 0 to complete uncertainty or ignorance. It is remarked here that certainty factors can be related to different types of (un)certainty: e.g. a priori probability, statistical certainty, credibility, reliability, distinctness, fuzziness etc. Referring to the example, the (un)certainty connected with the correlation between redness and sweetness may be defined as a statistical issue, but also as an issue of credibility. In practice these different types of uncertainty will lead to different calculi dealing with representation of (un)certainty and procedures for the combination and propagation of (un)certainties through inference processes. Here, we will not pay attention to the different calculi: our intention is to illustrate in quite general terms how the problem of modeling reasoning processes under uncertainty, proceeding along the three lines of inference as defined by Peirce, may be tackled.

5.2. Deductive Rule Inference Under Uncertainty

In the case of deductive reasoning under uncertainty, a conclusion is arrived at on the basis of a specific premise and by application of a general rule. Therefore, this type of inference is also called 'deductive rule inference' . Here it is assumed that both premise and rule are coupled with uncertainty in terms of so-called certainty factors.

Let the degree of certainty of the minor be denoted by cf-premise. Analogously, cf-rule and cf-conclusion are the certainty factors of the maior and the actuality, respectively. In practice, in human reasoning an estimation is performed of the certainty of the conclusion on the basis of the certainty factors of both the premise and the rule. In order to guarantee human-like reasoning, there should be a mechanism in the expert system which expresses the certainty of the achieved conclusion as a function of the certainty factors of the premise and the applied rule. This means that the calculus should be such that cf-conclusion can be determined on the basis of cf-premise and cf-rule, and this in such a way that the computed cf-conclusion corresponds with the degree of certainty ascribed to the conclusion by a human expert, who is considered to be an expert as well in adjugating the right degree of certainty.

One such a calculus issues from the SB-model introduced by Shortliffe and Buchanan (1975). According to this model the certainty factor of the conclusion is the product of the certainty factors of specific premise and rule:

cf-conclusion = cf-premise × cf-rule.

Complete uncertainty concerning one of the premises means ignorance about the truth of the conclusion, i.e. value zero. As the rule represents expert knowledge cf-rule cannot have a negative value in practice, the upshot being that cf-conclusion will not have a positive value due to the product of two negative factors. In the case that the premise consists of several or-connected clauses, the certainty factor of the premise equals the maximum of the separate certainty factors of the clauses according to the SB-model. The underlying idea is that in practice the most likely clause may be substituted for a whole series of or-connected clauses. Consider the following example, which is an extension of the earlier example:

If an apple is red or soft then its taste is sweet

Let the certainty factors relating to 'this apple is red' and 'this apple is soft' be given by 0.3 and 0.7, respectively. According to the SB-calculus, the overall certainty factor of the relevant specific premise now equals 0.7. This corresponds with the traditional logical conception of *or*, according to which (un)certainty is not associative over or-connected clauses (for reasons specified below it would be better to add to the maximum an associative sum of absolute values of the certainty factors of the other clauses). Let the certainty factor of the rule be equal to 0.9; that means that if there is no doubt with respect to the predicates red and soft that then the degree of certainty that the apple will be sweet is 0.9. The certainty factor of the apple being sweet in this particular case becomes then:

cf-conclusion = cf-premise × cf-rule
= 0.7 × 0.9 = 0.63

Analogously, it seems plausible that if a premise consists of and-connected clauses, the overall certainty factor of the premise is the minimum of the certainty factors of the clauses. Accordingly, in our example the cf-conclusion for:

If an apple is red and soft then it is sweet

is calculated to be:

0.3 × 0.9 = 0.27 (SB-calculus)

However, we think it more plausible to take the product value instead of the minimum value. The underlying idea is that the case of two and-connected clauses corresponds to the case of combining two separate premises. In our example, this would mean that cf-conclusion is to be calculated as:

0.21 × 0.9 = 0.19

This corresponds with an (un)certainty-associative conception of *and*; of course, if the minimum is negative (e.g. -0.3 instead of 0.3), some kind of product over absolute functions is to be taken. In practice the same conclusion may be achieved along different paths; so-called co-concluding rules. In that case the scoring results of the different rules should be combined to just one certainty factor. Without giving details, it is mentioned here that the SB-calculus includes procedures for this case.

5.3 Inductive Rule Generation and Classification Inference Under Uncertainty

In the foregoing paragraph, it was assumed that the expert knowledge can be expressed in terms of general rules along with some certainty measurement. However, depending on the application domain, it can occur that the expert knowledge is at first available only in the form of pieces of knowledge (samples), e.g. apples, preselected to be red (to a specific degree of certainty), samples of which have been testified to be sweet without exception (to a specific degree of certainty).

INDUCTIVE RULE GENERATION

In inductive reasoning general rules are generated on the basis of such sampled information, related to a preselection or specific premise. Strictly speaking, inductive reasoning is always subjected to uncertainty due to the fact that the general rule is generated on the basis of a limited number of samples. Moreover, the uncertainty also depends on the fact that the information from the samples can not be per se certain.

In the so-called 'inductive rule generation', on the basis of uncertain and incomplete knowledge, a general rule is generated together with the corresponding certainty factor. In Ho et al (1988) some methods are presented. As a matter of fact, the rules which are the result of this inductive rule generation process can again be used in a deductive reasoning process as such leading to conclusions about new samples.

INDUCTIVE CLASSIFICATION INFERENCE

However, sometimes the generalization from samples to a general rule is not performed. Then the samples are directly used for making conclusions about new samples: the so-called 'inductive classification inference'. Although classification inference is not induction in the pure sense, it can be considered as a type of inductive reasoning, since the generality of the samples is assumed in the sense that the correlation between the preselected variable (red) and the sampled information (sweet) applies as well to a set of samples that goes beyond the pre-given context or original learning set.

Assume n samples (e.g. n apples), where the certainty factors of the factual hypotheses (e.g. being red, being soft) and of the actualities (e.g. being sweet) are given for each sample. Let ^{r}-cf indicate the relevant certainty factor as related to sample r, r = 1,...,n. With respect to the relevant characteristics of apple r the certainty factors of factual hypotheses and actualities can now be denoted by ^{r}-cf-premise1, ^{r}-cf-premise2 and ^{r}-cf-conclusion, respectively. Assume a new apple for which the relevant degrees of certainty are given by cf-premise1 and cf-premise2 and for which the certainty factor cf-conclusion that that specific apple will be sweet should be determined. Then the problem can be formulated as follows:

Given certainty factors of n known samples:

^{1}-cf-premise1, ^{1}-cf-premise2, ^{1}-cf-conclusion

. .

. .

^{n}-cf-premise1, ^{n}-cf-premise2, ^{n}-cf-conclusion

Determine with respect to new sample:

cf-conclusion on the basis of cf-premise1 and cf-premise2.

In fact, inference is now reduced to a classification problem. For each sample the certainty factors connected with the two premises can combinedly be represented as a point in a 2-dimensional space. The corresponding certainty factor of the result can be considered as a 'label' to that point (see Figure 4). Also the combined certainty factors relating to the information about the apple for which a conclusion should be made can be represented as a point (see point • in Figure 4). However, for this point the label cf-conclusion should be determined.

For cases like this, classification methods as used in statistical pattern recognition can be applied, e.g. the m-nearest neighbour classifier. The m-nearest neighbour classifier searches for the m-nearest neighbours of the new sample in the 2-dimensional space and determines the certainty factor of the conclusion with respect to this new sample. This is done e.g. by taking the average of the certainty factors of the conclusions of the m nearest neighbours. Thus, if m = 1, the certainty factor of the conclusion for the new sample is uniquely determined by the certainty factor of the result of the nearest point. Referring to Figure 4, this implies that, for m = 1, cf-conclusion of the new sample is equal to that of sample i, expressing to what degree the new apple is expected to be sweet.

Aside it is mentioned here that in some sense neural networks can be considered as supporting a form of inductive classification inference.

5.4 ABDUCTIVE RULE GENERATION AND INFERENCE UNDER UNCERTAINTY

Above abduction was introduced as inferring a hypothesis on the basis of a rule and an actuality. As such, this corresponds to the inverse process of deduction; actuality and hypothesis having changed position. Abduction is the only type of reasoning which can extend knowledge by taking together the known and unknown. If we see somebody trying to open the consecutive house-doors in a street (puzzling actuality), the conclusion can be that presumably that person is a burglar. The underlying conceptual assumption (rule) is that people who try to open house-doors are burglars. The creative element in this abductive reasoning process is that trying to open doors and being a burglar are related to each other. However, this association is not per se true; it is possible that the person who tries to open doors suffers from forgetfulness and does not remember his house precisely. Thus, the result, as is the case with all types of abductive inference, is uncertain and has the status of a hypothesis. This type of inference is also called 'abduction to a hypothesis'.

In addition, there is also 'abduction to explanatory rules' or 'abductive rule generation'. Both types of abduction have in common that they are related to finding the relevant hypothesis for explaining puzzling phenomena. In the case of abductive rule generation the order of the second and the third proposition has been changed: both premises of the inference are actualities, the conclusion being a rule. As an example we have:

First: This apple is sweet (queer actuality),
Second: This apple is red (selected actuality),

Third: Red apples are sweet (hypothesized rule).

ABDUCTIVE RULE GENERATION

Sometimes abductive (explanatory) rule generation is confused with inductive rule generation as mentioned in the foregoing paragraph. However, whereas induction is based on a large number of instances/samples, in abduction a rule is hypothesized on the basis of some puzzling information and some actuality (or minor rule); as such it may be restricted to two single instances. This is because, in the latter case, the inference is intensional in character, relating *concepts* to each other; whereas, in the former case, the inference is extensional in character, being based on quantitative correlations.

The problem of abduction in general, and of abductive rule generation in particular, is defining a relevant (i.e. rule-pregnant) connection between a puzzling actuality (a first) and a factual hypothesis, that has to be selected as a second, in such a way that the latter may function as an explanatory actuality for the first. In fact, the number of candidate connectors is indefinite, and in a sense even infinite. However, within a given application domain usually there is some consensus among experts about that indefinite class **C** that is supposed to include all commonly accepted phenomena that need no explanation. This is to say, that any phenomenon in the domain not belonging to **C** (being considered exceptional or uncommon) actually belongs to the class **P** of potentially puzzling actualities. In our example 'sour' as concerns apples belongs to **C** and 'sweet' to **P**. Now, in order to find the relevant connection, the expert has to search selectively for another **P**-characteristic of the given sweet apple(s)-in-context, e.g. being red or being imported from an uncommon region. As long as such an additional **P**-characteristic does not enter his mind there is no key for explaining the queer sweetness of the apple. Two consecutive stages of difficulties come up here. In the easier type of cases the preliminary problem of the first stage has been solved already via linguo - perceptual habit. In these cases **C** is already definite with respect to the relevant second **P**-factor. What is common in this respect has already been given a name, for instance, 'green'. The problem is now to frame the relevant non-greenness as 'red' or maybe as 'orange' or 'speckled', etc. Here a potential infinity of shades presents itself, from which the solution might be selected. In the double problematic cases the preliminary problem is how to make **C** definite where it is still not clear to be relevantly indefinite. The differentiation between apples from common/uncommon regions as related to sweetness is a creative act from which may originate concept formations like 'apple from Spain', 'apples from India', etc. The resultant abductive rule might be that all red apples from India are sweet. For artificial intelligence the problem to be faced here is that 'red', 'from India', etc. should already have been defined a priori: **C** and **P** have to be definite already in all aspects that may still to be faced. It is clear that, in practice, this hinders building expert systems with a performance compatible with human-like reasoning. Where the human being is superior with respect to the generation of new associations, the expert system should a priori include well-defined relations and associations of all possible kinds.

Another unsolved problem is the assignment of certainty factors to rules generated by abduction. In general, they cannot be based on a large number of instances as already mentioned above. Certainty factors can be related here to degree of credibility; this means circularity, because the latter can only be based on induction (expert experience) and deduction. At the level of abductive rule generation, expert judgement is decisive in view of furnishing the necessary expert experience as well as (creating c.q. designing) the guiding concepts.

ABDUCTIVE RULE INFERENCE

A similar problem concerning the determination of certainty factors occurs with respect to abduction to a factual hypothesis. Even if the certainty factors of the queer actuality in question and the selected rule are known, this does not give per se information about the certainty factor of the resulting hypothesis. Here also we have to realise, that only in well-defined situations abduction to a hypothesis can be performed in such a way that the corresponding certainty factors can be computed. Peng and Reggia (1990) gave a method for the case that the certainty factors with respect to the actuality to be explained take as value only the two extremes of the interval (sure to be true and sure to be false). The method generates a set of specifications that together form the best explanation for the observed actuality. What should be understood as 'best' explanation is defined in terms of

- minimality: the set should be minimal; Ockham's razor,
- covering degree: the consequences of the explanatory set should include the actuality to be explained,
- optimal distance (in a Popperian sense) between the explanatory set and the actualities to be explained according to a likelihood function, related to the actualities to be explained and those results, which are also a consequence of the explanatory set, but which did not actually occur.

5.5 RELATION BETWEEN DEDUCTION, INDUCTION AND ABDUCTION

In the foregoing, three types of inference under uncertainty were considered. Cognitively, deduction, abduction and induction differ in the type of knowledge they use as well as with respect to learning aspects. Summarily, this can be put into formula as follows: whereas learning is implicit in the explicit use of deductive rules, induction is the explicit learning by way of samples without use of explicit rule-directed knowledge. Clearly, in deduction a guiding principle in the form of explicit rule covering knowledge is used, whereas such guidance is primarily absent in induction: it is the very function of induction to generate the kind of explicit rule covering knowledge that is used in deduction. This means with respect to induction (including classification inference) that the knowledge used there is of a factual kind, extending over actual samples, which form the ore for explicit learning; and, with respect to deduction, that its learning is implicit in rule inference, where only the results of learning, i.e. the rules, are dealt with. With respect to the results of abductive rule inference, both knowledge and learning are neither explicit nor implicit, but only potential, due to the hypothetical character of the results.

In practice, in reasoning processes all the three types of inference play a role together. This is in line with Peirce's pragmatism, according to which the three types of inference are indissoluble (see Figure 5). By means of abduction the relevant factual hypotheses are selected, including those general ones that are fit for determining the sampling. The results of abduction can be generalized by induction and this, in turn, can be tested by deduction, etc.

Also from an implementation point of view, a combination of deductive/ abductive rule inference and inductive classification inference is attractive. In the case of rule inference the utility of the computational approach is usually lower than in the case of classification inference; in the latter case, we are dealing with a large amount of samples. However, classification inference has the advantage of learning capability by the possibility of adding new samples to the sample set. In operational environments, initially samples can be used for rule generation. On the basis of the generated rules deductive rule inference can be performed for new samples. The rules are updated only periodically on the basis of new samples. New rules and new relations between hypotheses and actualities result from abductive reasoning.

6. CONCLUSIONS

It may be concluded from this paper that Peirce's categorical framework can help to clarify human reasoning (or more general semiosis) and to give new insights into the internal structure of expert systems. The first- and second-order applications of the categorical framework illustrate that expert systems are Peircean in all their facets.

Furthermore, until now all realized expert systems support just one type of inference; usually deduction or induction, sporadically abduction. Since according to Peirce's pragmatism the three types of inference are very closely interrelated, implementation of all the three types within one and the same expert system seems inevitable in order that expert systems can do what they are expected to do.

It may also be concluded from the present paper that according to Peirce's semiotic pragmatism inference should be considered basically as inference dealing with uncertainty.

Considering the three types of inference, the implementation of abductive reasoning is still a hard problem in expert systems. Under strongly restrictive assumptions, some form of abduction can be performed. This is not sufficient in order to simulate human-like reasoning in expert systems. For this reason, abduction is one of the greatest challenges for the future development of expert systems.

Another challenge concerns the relation between knowledge and inference. Until now in expert systems knowledge and inference are strongly separated. However, relating Peirce's categorical framework to the three components of expert systems, it may be concluded, that there is no clear distinction between (represented) knowledge and inference. Stronger, according to semiotic pragmatism, knowledge as well as inference is a kind of process; viz. one of the manisplendoured manifestations of semiosis, i.e. the process in which something - becoming a sign - is begot of a meaning. What this means to expert systems and how to deal with it within expert systems and in developing expert systems is still much of an open problem.

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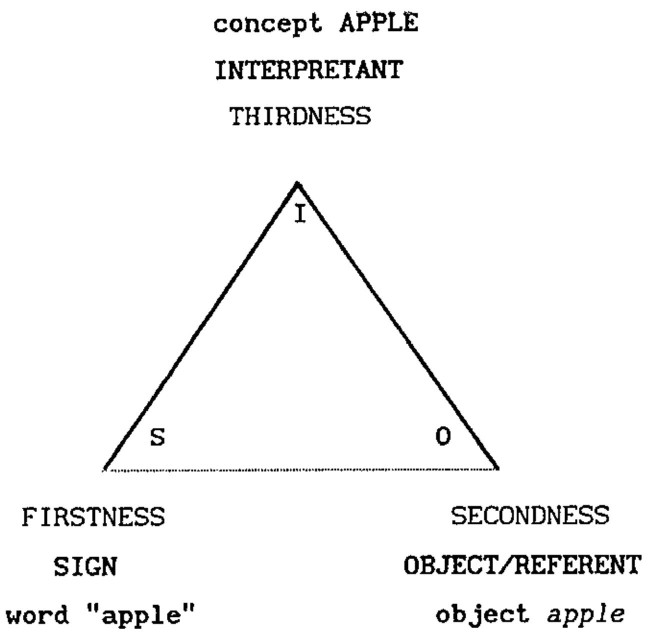

Figuur 1. Peirce's three categories.

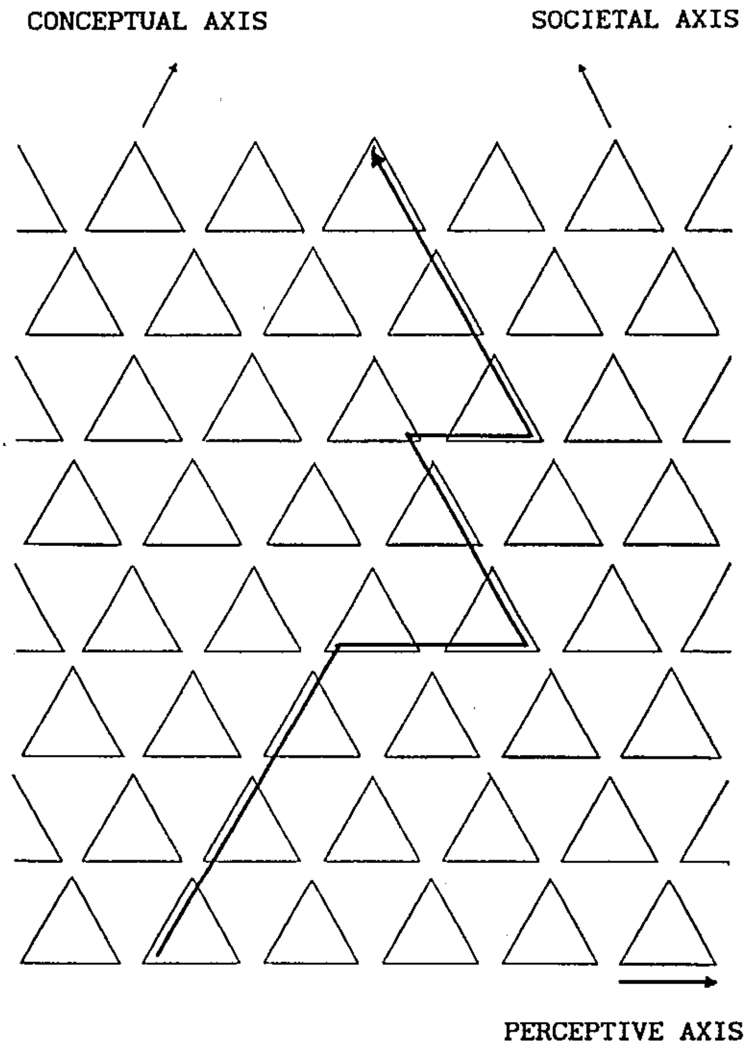

Figure 2. Reasoning processes within an infinite field of semiotical triangles.

PEIRCE'S CATEGORIES			
	FIRSTNESS	SECONDNESS	THIRDNESS

	EXPERT SYSTEM			
I	GLOBAL DATA BASE	SIGNAL	SIGN	SYMBOL
II	KNOWLEDGE BASE	DESCRIPTIVE/ RELEVANT PARAMETERS	RELATIONAL/ SEMANTIC NETWORK	HEURISTIC/ PRAGMATIC RULES
III	INFERENCE/ CONTROL MECHANISM	ABDUCTION	DEDUCTION	INDUCTION

Figure 3. Peirce's categorical scheme and the internal structure of expert systems.

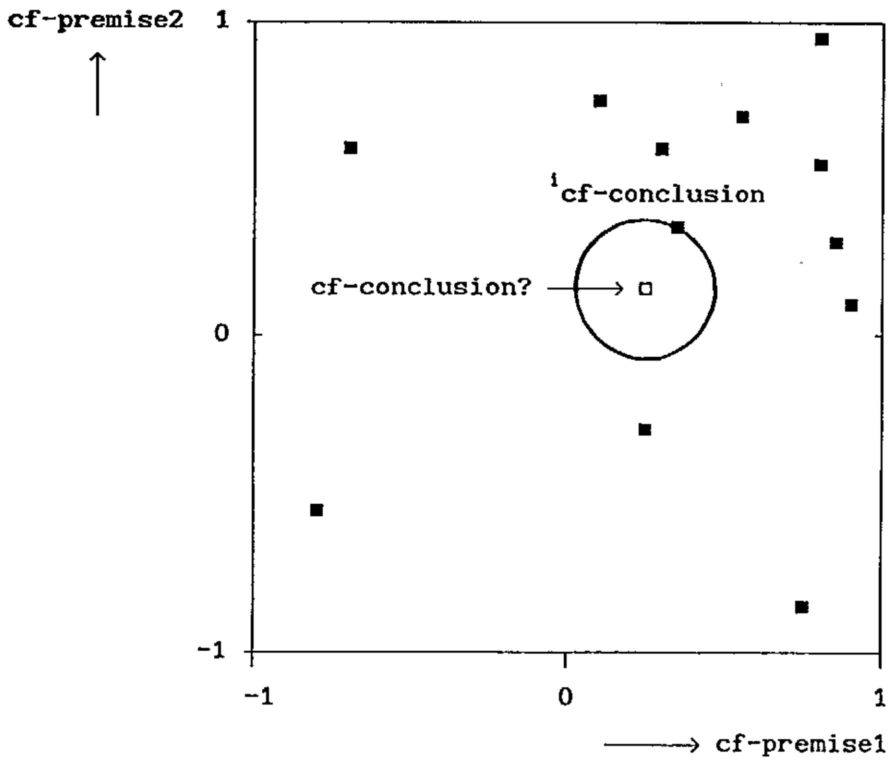

Figure 4. Inductive classification inference under uncertainty.

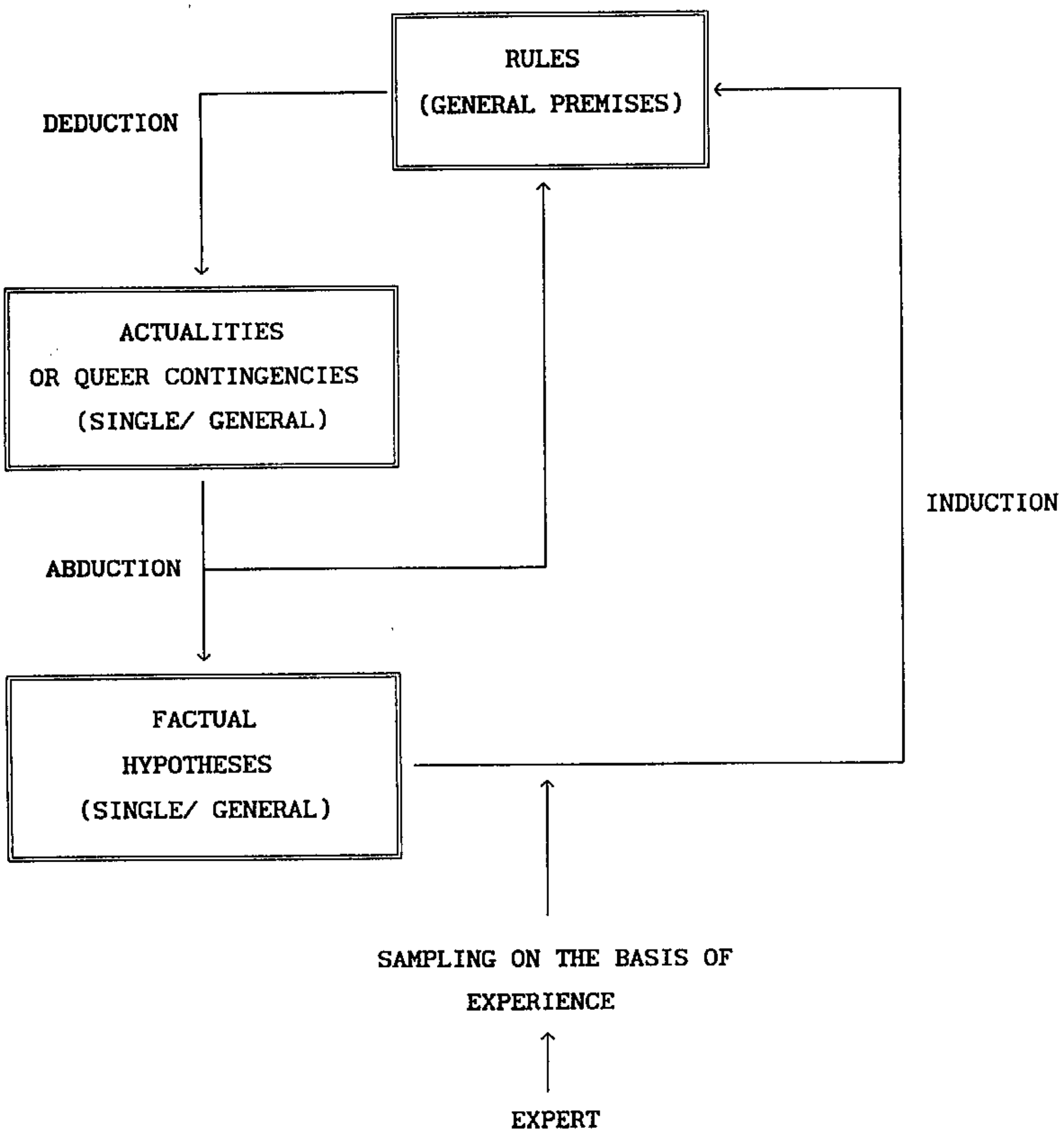

Figure 5. The relation between deduction, induction and abduction.