An AI criterion for an account of inference: How to realize a task

Pınar Öztürk
Department of Informatics
Norwegian University of Science and Technology
N-7034 Trondheim, Norway
E-mail: pinar@ifi.ntnu.no

Abstract

We point to two different motivations underlying investigation of relations between various types of inference. The former considers inference as an evidential process and the latter as a methodological process. Furthermore, the approaches in the former group classify inferences differently as they utilize different criteria such as 'validity' or 'value of productiveness' of conclusions. In AI terminology, the evidential approach aims at constructing an ontology of inferences on the basis of characteristics of the conclusions they draw, without regard to the type of process they involve, while the methodological approach is concerned with the characteristics of these processes. From the AI perspective and particulary in the context of knowledge based systems, the answer to the question of how closely related abductive and inductive inferences depends on the issue of to what extent they do utilize the same set of primitive methods in order to be realized. We model 'from effects to cause' type of inference on the basis of case-based reasoning paradigm and utilize contextual information as a means for focusing the generation of hypotheses.

1 Introduction

The relationship between different forms of inference has long been investigated in philosophy. In logic, abduction has often been seen in close connection with induction. The word abduction was first used by Peirce in order to define a distinct inference type which traces back to Aristoteles. In AI it was taken up in 1973 by Pople, in the context of diagnosis. Even though that the attempts to classifying these inference types have such a long history, the literature does not yet provide a commonly agreed upon classification. Peirce's early and late theories on inference have been referred to as "syntactical" and "inferential" perspectives [Flach 96]. We also emphasize the change in Peirce's view and further analyse the underlying change in his motivations responsible for this change in his view.

In our interpretation we will partly explain the tangled accounts in the literature by emphasizing the existence of rather different motivations behind different accounts. Two main motivations are those of investigating evidential and methodological aspects of the inference process. The evidential approach consider inference rules as patterns of justification while the methodological approach studies the processes underlying these rules.

In AI terms, we may say that the evidential approach studies only the characteristics of the conclusions and aims at constructing an inference ontology along with different dimensions, such as "validity" or "productiveness", of the conclusions they draw. On the other hand, the methodological approach is concerned with the use of various inference types in complex applicatio tasks such as scientific inquiry and diagnosis and thus studies the characteristics of the the inference procedure. We may say that evidential approach has a rather static view while the methodological one is more dynamic.

So, in our understanding, even if Peirce did not explicitly state the difference in his motivations as such, he first constructed an inference ontology and then investigated whether and how he could use this ontology when modeling the line of reasoning underlying the very task of scientific inquiry.

After analysing the different motivations and dimensions that triggered different accounts of the relations between inference, we will elaborate our interests in inference methods from an application viewpoint.We are interested in inferences as methods that are capable of realizing a particular class of application tasks, e.g., diagnosis. In this sense, our motivation for understanding inferences is related to when each type of inference is to be used and how it can be realized in terms of lower-level methods.

2 Inference as an evidential process

Classifying inferences according to *validity* of conclusions they draw: A "traditional" classification of inference is concerned with the "correctness" of the conclusions drawn by different types of inference. This approach classifies inferences based on their ability to draw "secure" conclusions. Hence, inferences are partitioned into sound and fallible types. In this account, only deductive inferences were sound and inductions were fallible. Abduction was not yet recognized and therefore did not occur in this classification. So, the main concern was a conclusions's degree of certainty.

Classifying inferences according to *productiveness* of conclusions they draw: In his early work Peirce also classified inferences. His emphasis, however, was on the conclusion's "value in productiveness" [Peirce, 8.384]. The subject matter was the question of whether an inference creates new ideas. Peirce classified induction and abduction as "ampliative" inferences which create new ideas, and

deduction as "explicative" which do not. The difference was that of abduction's hypothesizing unobservable entities and induction's creating generalizations.

In AI terminology, we may say that his classification is based on the notion of 'knowledge refinement and extension' or 'development of domain theory' which is an important characteristic of problem solving with an incomplete domain theory.

3 Inference as a methodological process

In his later period, Peirce's motivation changed radically. His main concern became that of how and which types of inferences the mind was utilizing when discovering scientific theories. He become interested in the roles of various inferences in science, and regarded inference as a methodological process. This lead to his investigating the relationship between various types of inference in the very context of scientific inquiry, and to the notion of "three stages of inquiry" corresponding to three types of inference. From the AI view, we may say that he was studying the methods that realize the very particular application task of scientific inquiry.

The following quotation on the relation between abduction and induction hints that he was not concerned with the characteristics of the conclusions being inferred but rather with the procedure that infers these conclusions: "..as far as their ampliative character goes, that is, as far as they conclude something not implied in the premissess depend upon one principle and involve the same procedure. All are essentially inferences from sampling". (6.40). An inconsistency between Peirce's early and late view arose because he viewed abduction as the only "ampliative" type of inference in his later theory. Accordingly, he redefined abduction and induction. In the present account abduction was extended to cover part of what has been called induction before, and induction is restricted to 'confirming a hypothesis'. In fact, in his later account Peirce seems to propose that any hypothesis that is entertained as possibly true, whether it is a nonobservable entity or a generalization, is arrived at by abduction.

In our understanding, Peirce, Harman [Harman 65], and Josephson are all concerned with the inferences in terms of *how t*hey justify the conclusion. Seen from this window, both 'from effects to cause' type of inference and inductive generalization (on Josephson's view, or enumerative inductionon Harman's view) can be seen as belonging to the same type of inference. However, as elaborated in section 4.2, they may show difference in terms of 'primitive methods' which they need in order to be realized.

4 An AI view

The AI view, as presented here, related to different types of inference, can be considered to have a methodological stance. That is, the emphasis is on how and when to use different types of inferences for realizing a particular task, i.e., achieving a goal.

Two important AI issues regarding inference are its role in knowledge refinement and extension, and its role in realizing an application task, e.g., diagnosis, planning, etc. The former can be related to the "productivenevess" aspect of inference pointed to by Peirce's early work. That is, how productive an inference is and in what way it is productive. This concern is important particularly for incomplete knowledge bases. The latter is important when implementing a system that should accomplish a particular application task. In other words, the former is related to learning, and the latter is related to problem solving.

4.1 Inference and knowledge refinement and extension

A central problem of knowledge based systems working with incomplete knowledge is knowledge-base refinement and extension. A key idea used to extend an incomplete domain knowledge is learning by solving problems. Based on this idea, a new curriculum has recently been developed in medical education to teach problem solving and problem based learning[Schmidt 93, Barrows 80]. The curricula emphasizes that the development of expertise is closely related to the learning of cognitive structures that describe the features of prototypical or individual patients. Such structures are acquired through extended practice. While diagnosing routine cases, an experienced physician operates upon cognitive structures which we call 'scripts' and 'cases'. Scripts contain more general, prototypical information and rules that may cover more than one actual patient. A case structure, on the other hand, contains information about an actual patient, such as, '25-year-old, drug-addict, mala with fever and chills has diagnosis bacterial endocarditis'. These structures contain mainly shallow knowledge, such as associations between a disease, its consequences, and the context in which it develops. It has been proposed that the development of expertise involves learning both cases and scripts, and such knowledge is organised as a hierarcy of knowledge structures varying in abstraction degree.

At the end of each problem solving process, a new case representing the solved problem can be learned. Another issue is the assessment of whether the new case should be integrated with other structures(s) to result in a more general structure. This is done when a new case is similar enough to others that were solved in the past. Both types of learning are instances of refining an incomplete knowledge base, but they show difference with respect to the way and the level they integrate new knowledge into the knowledge base; one patches new knowledge structures while the other blends a new structure with existing ones.

The connection between learning, and the issue of relationship between abduction and inference depends upon the question of whether learning at different levels involves different types of inferences. The answer to this question may depend on the motivations and needs of the questioner. If the questioner were Peirce in his early period, he would say that these two types of learning involve different types of inferences: cases are learned by abduction while script learning involves an inductive pattern. If the questioner were Peirce in his late period he would say that learning both scripts and cases involves an abductive pattern.

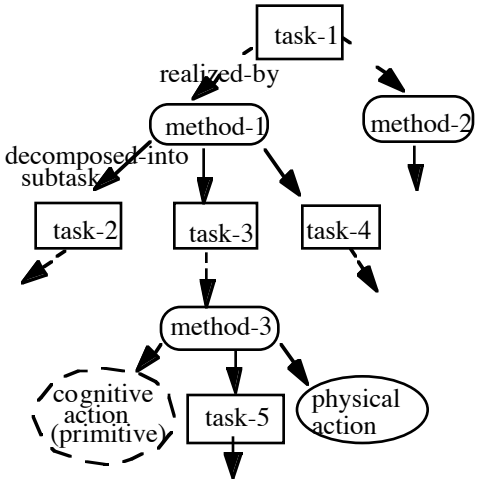
Finally, most satisfying answer cannot be given in isolation from the question of which primitive methods underlie each learning type. We will elaborate this matter in the next section.

4.2 Inference in application-task context

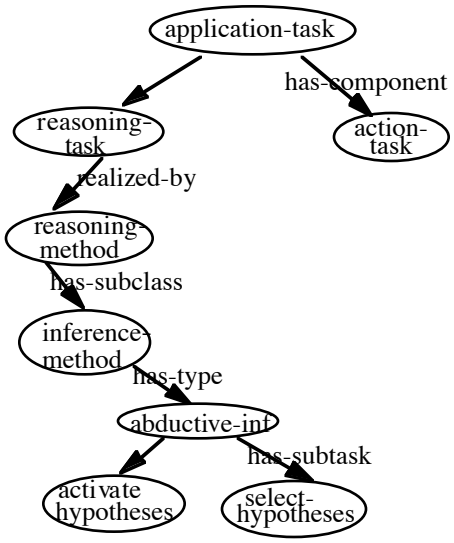
From an ontological perspective, inference types are different to the extent that their conclusions differ with respect to certain criteria. Such an ontological approach considers

inferences as black boxes of which inputs (premisses) and outputs (conclusions) are known, but what is inside the box is not interesting. The matter of how their insides are configured is not within the scope of ontological approach.

On the other hand, from an application perspective, inferences are regarded as method types which are capable of realizing certain subtasks of the main application task.



(a)



(b)

Figure 1. Decomposition of tasks by methods into their subtasks and primitive methods (ellipses in the leaves). (a) Conceptualization of application tasks (such as sceintific inquiry or diagnosis) as being realized collectively by reasoning methods and actions. (b) Abductive inference is a type of reasoning method.

Consequently, the insides of the black boxes are of great importance.

In AI implementations, an overarching application task, such as diagnosis, is characterized by the goal it achieves and may be realized by at least one method. A method specifies how a complex task can be decomposed into its simpler subtasks and/or into its primitive methods. Subtasks may involve reasoning (cognitive tasks) and/or acting (physical tasks). An acting-task is accomplished by taking actions in the physical world while a reasoning task is realized by a reasoning method. We may imagine the tasks and methods related to a problem as modeled in the form of a hierarchical tree structure (see figure 1-a). At the lowest level are the primitive methods which are directly executable.

There are different approaches as to which inference type each method in the task hierarchy corresponds to. In particular, some approaches consider that a rather high-level task is realized by an abductive inference while others consider a method in a much lower level as abductive. For example, according to [Josephson 94] , abduction includes almost everything underlying the whole process of scientific discovery. Thus, we may say that, in his account, the top-level method corresponding to the complex task of scientific inquiry is of abductive type and includes acts in the physical world as well as the whole line of reasoning. In such an approach, different types of inferences may consequently have tangled relations in an AI application.

We keep inference methods as simple as possible and conceptualize more complex inferences in terms of a combination of inference and (possibly) action methods. This gives possibilities for combining various types of inferences according to changing needs of complex tasks. We define an inference method in terms of "primitive" methods by which it gets realized. As such, an abductive method, for example, does not realize an entire complex task such as diagnosis or scientific inquiry, but a simpler one corresponding to a subtask of it, e.g., 'hypothesis generation'. According to this view, abductive inference is the particular type of reasoning method which may be imagined to be located next to the lowest level in the method hierarchy, and which consists of two subtasks: 'activate-hypotheses' and 'select-hypothesis' , i.e., the procedures of forming plausible hypotheses and selecting the most promising one, respectively (see figure 1.b).

5 A criterion for investigating the relations between inferences

An important AI issue is how to conceptualize the primitive tasks, and consequently whether these are 'reusable' in different task contexts. This is also a useful dimension when deciding whether a particular method is of abductive or inductive type. From our application oriented view,

> Two methods can be argued to be of the same inference type as long as their procedures consist of the same set of primitive methods and these methods are executed in the same sequence.

So, two inference methods, one of which generates unobservable entities and the other which generates generalizations can be said to belong to the same inference type if they are realized in the same way, with regard to the primitive methods they are composed of.

6 Efficiency of the abductive process

Fallible conclusions should be justified by explaining, as Harman states "...when a person is and when he is not warranted in making the inference..". In the case of abductive generation of hypotheses, it is usually possible to generate a large number of candidate hypotheses. In order to make this process efficent there must be some mechanisms and means that limit the number of hypotheses in a justifiable manner. In our view, the inference should be consistent with the context in which it is made, in order to be justified. Context can be utilized both for focusing the process of evoking the hypotheses and for subsequently selecting the most promising one. In the former process, context includes the elements that help to make the situation more familiar and natural to our minds. These are important with respect to the psychological simplicity of the hypotheses. As Peirce mentions, the hypotheses that are familiar to us and thus psychologically simpler are preferred over others. Context provides additional information that has been left out by the 'to-be-explained' observations. For example, the age, sex, previous diseases, family medical history of a patient constitute additional information which enables us to better situate the problem in our minds or memories. Another component of context may provide a bridge to the realities of the world, and thus situates the problem in the real world. The elements of such context are related to the notions of policy and utility, and supply information as to the most promising hypotheses.

7 Diagnosis as a context-guided incremental explanation

In our approach a diagnosis task is realized by a 'context-guided-incremental-explanation' method which decomposes the overarching diagnosis task into its subtasks 'generate-diagnostic-hypothesis' and 'test-hypothesis-against-reality'. Hypotheses are generated abductively, and there may exist several methods that are capable of doing so. In our approach, this subtask is realized by the 'retrieve-diagnostic-hypothesis' method which employs a case-based reasoning approach. The method further decomposes the generation of hypotheses into two subtasks corresponding to the two stages of abductive inference: 'activate-hypotheses' and 'select-hypothesis'. The former of these is realized by the primitive method 'activate', while 'explain' and 'focus' primitives collectively realize the 'select-hypothesis' subtask. The activate-explain-focus cycle is a general mechanism modeled in the Creek system [Aamodt 95] and realizes the abduction of the most promising hypothesis on the basis of the case-based reasoning paradigm. The utilization of context for improving abductive efficiency goes hand in hand with improving the retrieval of better cases [özturk 97] . The case-based method of Creek relies heavily on an extensive body of general domain knowledge in its problem understanding, similarity assessment, case adaptation, and learning.

The underlying case-based interpreter in Creek contains a three-step abductive process of 1) activating relevant parts of the semantic network, including cases pointing to hypotheses (see figure 2), 2) explaining why the reasoner activated these hypotheses and thus explaining her beliefs regarding how well each explains the surprising facts, and 3) focusing towards a conclusion that conforms with the task goal as well as pragmatical concerns. In our clinical diagnostic problem solving model, two types of cases are considered: explanation cases and plan cases (see figure 3). The first is the encoding of the explanation that connects the relevant features to the disease.

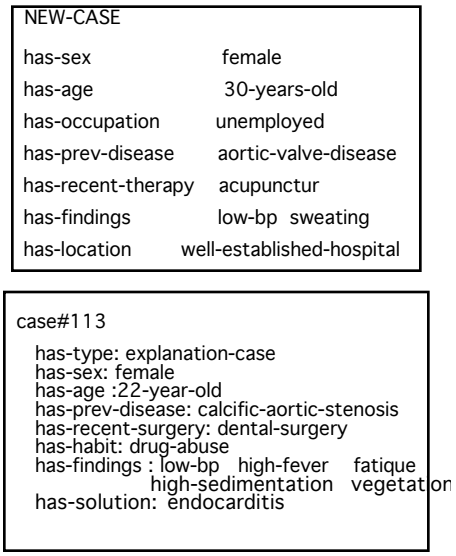


Figure 2: Representation of cases

The second is the encoding of a plan that includes a sequence of diagnosis and therapy actions, such as defining an examination protocol, selecting the way to perform a particular test, recommending a treatment, etc.

A part of diagnostic task structure is illustrated in figure 3, related to an example. The upper part of the figure shows the task hierarchy linked to some example cases. To achieve a diagnostic goal, two subtasks must be invoked: Generating a diagnostic hypothesis, and testing the hypothesis. As shown, cases of type explanation-case are used for hypothesis generation. They contain solutions that are regarded as diagnostic hypotheses. 'Plan cases' are used in the testing stage.

Generation of hypotheses: The task of generating hypothesis involves retrieving a set of candidate cases from the case base, followed by selection of the best one. This case is then evaluated. The inputs to the task of generating candidate cases are the current goal, the new case, and the case base from which the candidate cases will be generated. The output is a set of candidate cases. The second subtask of hypothesis generation, 'selection of the best case', takes as input the set of candidates, the new-case, the general domain knowledge base, and knowledge related to the task. The output is the most similar case to the new case. In psychological terms, this type of retrieval is a "cued recall".

For candidate generation, all the cases having at least one relevant feature that also exists in the new case are initially activated. The cases for which the total activation strength (combining all features) exceeds a threshold value are selected as candidates.The selection of the best case is based on the similarity judgment of candidate cases. Similarity can be exposed directly or indirectly. Direct match occurs when two cases have identical slot-value pairs, e.g, both cases having has-sex:female. Indirect match happens when a path

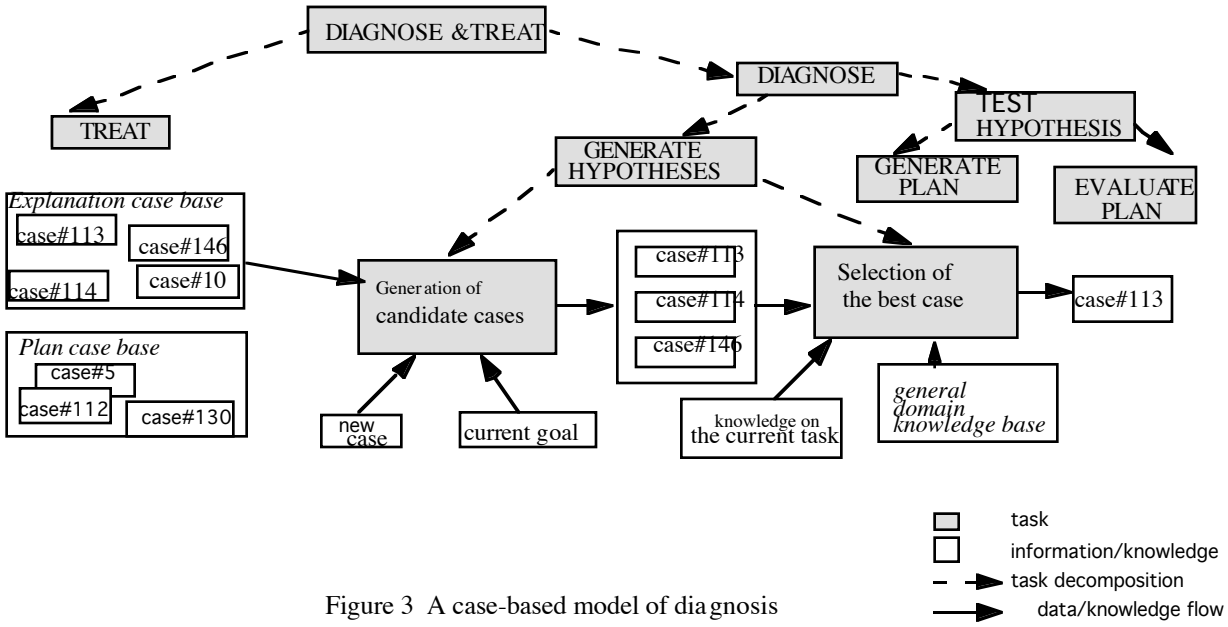


Figure 3 A case-based model of diagnosis

between slot values of the two cases is found in the general domain knowledge. For example, the information *has-occupation:unemployed* in the new case *has-habit:drug-abuse* in case#113 are found indirectly to weakly match, asexplained by the path 'DRUG-ABUSE *CAUSES* IMMUNOSUPRESSION *CAUSED-BY* MALNUTRITION *CAUSED-BY* BAD-ECON-SIT *ASSOCIATED-WITH* UNEMPLOYED'. This explanation is relevant in the context of the activated hypothesis *endocarditis* .

The existence of such paths contribute to the similarity of two cases. The strength of this similarity depends on the strength of the relations connecting the concepts on the path, as well as the length of the path. So, the indirect matching process involves a search in the general domain knowledge that investigates whether apparently dissimilar features could be similar through a finer grained matching process.

Testing hypotheses: The solution of the best case is now the hypothesis which will be tested. A typical characteristic of new cases in a medical setting is that they contain incomplete information. Therefore, an information-gathering process begins, in order to determine whether other consequences of the hypothesis (the disease) are also present in the new situation. The retrieved case guides the information-gathering process. The goal is now to collect data on the findings on which the retrieved case has information while the new one does not. The task of evaluating hypotheses invokes two subtasks: 'Generate plan' task, and 'evaluate plan' task. Generation of plans occurs by retrieving past plans from the case base. The process of plan evaluation involves executing the retrieved plan. A plan is indexed with the 'information goals', i.e, features to be gathered. These features refer to the consequences expected to be present if the hypothesis (the disease) is correct. For example, assume that the retrieved explanation case has solution endocarditis (current hypothesis) which is expected to cause low blood pressure, and that the new case lacks information about blood pressure. One of the information goals becomes ' blood pressure ', and a plan to gather this information, among others, will be retrieved. A plan case also includes the set of actions to take in order to gather such information.

If the results of the plan, when executed, indicates that the actual situation is different from than that predicted, then the hypothesis may be refuted and a new cyle of hypothesis generation and testing may start.

8 Conclusion

Both common sense and expert reasoning are marked by weak and open domain theories, as well as incomplete problem descriptions. Problem solving in such domains calls for abductive reasoning. Our interest is focused on diagnostic problems, so the problem solving includes inference 'from effects to cause'. We adopt a case based reasoning approach in order to model, in terms of primitive methods, 'from effects to cause' type of inference. We realize this type of inference by the collection of primitive methods 'activate' 'explain' and 'focus'.

In order to assist the the process of suggesting plausible hypotheses, we utilize contextual information as a focusing mechanism. The use of context as additional information limits the number of hypotheses evoked in the first place, as it leads to a better assessment of hypothesis plausibility. Another component of context is related with pragmatical aspects and preferences of the reasoner. Such context elements are utilized when seleting the hypothesis that is best with respect to testing considerations.

Acknowledgements

I would like to thank Agnar Aamodt for his helpful comments and to Keith Downing for proofreading this document.

References

[Aamodt 95] Aamodt, A. Knowledge acquisition and learning by experience-the role of case specific knowledge, in *Machine learning and knowledge acquisition*, Tecuci,G and Kodratoff, Y (eds), Academic press, 1995, pp 197-245.

[Barrows 80] Barrows, H. S. and Tamlyn, R. M. Problem based learning, Springer Publishing comp. , New York...

[Boshuizen 94] Boshuizen, H.P. A. Cognitive effects of practical experience in high- and low-achieving medical students, in *Learning and instruction* , 1994 vol. 4, pp. 313-329.

[Flach 96] Flach, P. Abduction and Induction: Syllogistic and inferential Perspectives, in *ECAI-96 Workshop on Abductive and Inductive reasoning,* 1996.

[Harman 65] Harman, G. The inference to the best explanation, in *Philosophical Review*, 1965 ,vol. 74, pp 88-95.

[Josephson 94] Josephson, J. and Josephson, S. G. (Eds.) Abductive Inference: Computation, Philosophy, Technology, 1994 Cambridge University Press,New York.

[Peirce 60] Peirce, C. S. Collected papers. 1960, The Belknap press of Harvard University Press.

[Schmidt 93] Schmidt, G.H. and Boshuizen H.P.A. On acquiring expertise in medicine, in *Educational Psychology Review*, 1993, vol. 5, No. 3 pp 205-225.

[özturk 97] özturk, P. and Aamodt, A. Towards a model of Context for case based diagnostic problem solving, in *Proceedings of CONTEXT-97 conference*., 1997, pp 198-208.