Sami Paavola

On the Origin of Ideas: An Abductivist Approach to Discovery

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Abstract

The purpose of this study was to analyze and develop various forms of abduction as a means of conceptualizing processes of discovery. Abduction was originally presented by Charles S. Peirce (1839-1914) as a "weak", third main mode of inference -- besides deduction and induction -- one which, he proposed, is closely related to many kinds of cognitive processes, such as instincts, perception, practices and mediated activity in general. Both abduction and discovery are controversial issues in philosophy of science. It is often claimed that discovery cannot be a proper subject area for conceptual analysis and, accordingly, abduction cannot serve as a "logic of discovery". I argue, however, that abduction gives essential means for understanding processes of discovery although it cannot give rise to a manual or algorithm for making discoveries.

In the first part of the study, I briefly present how the main trend in philosophy of science has, for a long time, been critical towards a systematic account of discovery. Various models have been suggested. I outline a short history of abduction; first Peirce's evolving forms of his theory, and then later developments. Although abduction has not been a major area of research until quite recently, I review some critiques of it and look at the ways it has been analyzed, developed and used in various fields of research. Peirce's own writings and later developments, I argue, leave room for various subsequent interpretations of abduction.

The second part of the study consists of six research articles. First I treat "classical" arguments against abduction as a logic of discovery. I show that by developing *strategic* aspects of abductive

inference these arguments can be countered. Nowadays the term ‘abduction’ is often used as a synonym for the Inference to the Best Explanation (IBE) model. I argue, however, that it is useful to distinguish between IBE (“Harmanian abduction”) and “Hansonian abduction”; the latter concentrating on analyzing processes of discovery. The distinctions between loveliness and likeliness, and between potential and actual explanations are more fruitful within Hansonian abduction. I clarify the nature of abduction by using Peirce’s distinction between three areas of “semeiotic”: *grammar*, *critic*, and *methodeutic*. Grammar (emphasizing “Firstnesses” and iconicity) and methodeutic (i.e., a processual approach) especially, give new means for understanding abduction. Peirce himself held a controversial view that new abductive ideas are products of an *instinct* and an *inference* at the same time. I maintain that it is beneficial to make a clear distinction between abductive inference and abductive instinct, on the basis of which both can be developed further. Besides these, I analyze abduction as a part of distributed cognition which emphasizes a long-term interaction with the material, social and cultural environment as a source for abductive ideas. This approach suggests a “trialogical” model in which inquirers are fundamentally connected both to other inquirers and to the objects of inquiry. As for the classical Meno paradox about discovery, I show that abduction provides more than one answer. As my main example of abductive methodology, I analyze the process of Ignaz Semmelweis’ research on childbed fever.

A central basis for abduction is the claim that discovery is not a sequence of events governed only by processes of chance. Abduction treats those processes which both constrain and instigate the search for new ideas; starting from the use of clues as a starting point for discovery, but continuing in considerations like elegance and 'loveliness'. The study then continues a Peircean-Hansonian research programme by developing abduction as a way of analyzing processes of discovery.

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Part II. Original Articles

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List of original publications

In the text, the original publications are referred as 'articles' with Roman numerals I – VI.

I Paavola, Sami (2004a), "Abduction as a Logic of Discovery: The Importance of Strategies", *Foundations of Science 9*(3): 267-283. Reproduced with permission of the publisher.

II Paavola, Sami (2006), "Hansonian and Harmanian Abduction as Models of Discovery", *International Studies in the Philosophy of Science 20*(1), 91-106. Reproduced with permission of the publisher.

III Paavola, Sami (2004b), "Abduction through Grammar, Critic and Methodeutic", *Transactions of the Charles S. Peirce Society, 40*(2): 245-270. Reproduced with permission of the publisher.

IV Paavola, Sami (2005), "Peircean abduction: instinct, or inference?", *Semiotica 153*(1/4): 131-154. Reproduced with permission of the publisher.

V Paavola, Sami & Hakkarainen, Kai (2005), "Three Abductive Solutions to the Meno Paradox – with Instinct, Inference, and Distributed Cognition", *Studies in Philosophy and Education 24*(3-4): 235-253. Reproduced with permission of the publisher.

VI Paavola, Sami, Hakkarainen, Kai & Sintonen, Matti (2006), "Abduction with Dialogical and Trialogical Means", *Logic Journal of the IGPL 14*(2), 137-150. Reproduced with permission of the publisher.

Part I. Introductory Essay

1. Introduction

Abduction, interpreted as a logic of discovery, faces many challenges. There are various interpretations of abduction, and it is not clear if it could or should be interpreted from the point of view of discovery, nor if abduction is basically logic at all but rather something else like instinct or intuition. Discovery as such is a challenging theme in philosophy of science because the prevalent thought in 20th-century philosophy was that discovery (at least in a fundamental sense) is not amenable to a conceptual analysis. Processes of discovery (so this argument goes) involve such things as creativity, genius, surprising coincidences, happy guesses, which might be an object of inquiry for empirical sciences, but not for philosophy. Nowadays there is more room for the idea that the area of discovery can also be analyzed conceptually, both in the philosophy of science and in more empirically oriented sciences. Various discovery models are being developed in logic, artificial intelligence, and cognitive sciences. Still the question prevails to what extent it is possible to conceptualize discovery in a fundamental sense. It is not clear, further, what 'logic' in the 'logic of discovery' could mean: an algorithm for making discoveries; a formalized system; a more loosely defined conceptual analysis; or something else? And if abduction is a main mode of reasoning different from deduction and induction, does it mean that the way logic is defined must be broadened?

The quandary for the logic of discovery can be presented with the classical *Meno paradox* as a dilemma between novelty and method (Blachowicz 1998, 11-16, 30-31; Nickles 1997; Paavola & Hakkarainen 2005 [article V]; see also Nesher 2001). Are novelty and method the two horns, demands which are not attainable at the same time? If there were a "Method" for making inquiry (and discoveries) would it not mean that things were foreseeable and thus not new; at least in a fundamental sense? And if we want to have new ideas and theories, do we have to break away from previous ways of doing or understanding things, to give up or change our earlier methods? The issue arises whether there is any

way of avoiding this dilemma. This raises the further issue of how scientists or inquirers in general avoid this quandary.

Charles S. Peirce faced this quandary by maintaining that there is a third, weak mode of inference, i.e., abduction, besides deduction and induction, which is about the way new ideas are generated. Peirce's philosophy, I would propose, is at least a very promising starting point if the aim is to conceptualize processes of discovery. Peirce developed a systematic and broad outlook for conceptualizing various kinds of sign and inferential processes. Peirce was a true forerunner of cognitive sciences by emphasizing formal methods and conceptual clarity combined with a broad interest in human cognitive processes and activities (Tiercelin 1995). Peirce's writings form a fertile basis for developing abduction, but they are not, by themselves, a sufficient basis for understanding it. There are several ways that abduction has been further developed in subsequent literature.

Peirce's abduction did not raise any notable attention for a long time. In the 1950s and 1960s Norwood Russell Hanson maintained, against thought styles then prevalent in philosophy, that logic of discovery is an important research area, fruitfully addressed by Peirce's abduction. Hanson's writings have been a source of inspiration for subsequent research on abduction, but his formulations, like Peirce's before him, have been widely criticized. Gilbert Harman's Inference to the Best Explanation model, which is closely related to Peirce's abduction, made abduction an appealing topic for philosophy. A new interest in discovery has arisen little by little, after the 1970s and 1980s, and made abduction a central topic in such research areas close to philosophy, as for example artificial intelligence.

This study continues the Peircean-Hansonian research programme by seeking to develop abduction as a way of analyzing discovery with philosophical means (see also Paavola 2001). The title makes a bit presumptuous allusion to the Darwinian theory of evolution, but in fact I do not maintain that abduction is similar to the process of natural selection based on a trial-and-error mechanism.[*] This could be one way of interpreting Peirce's

[*] The title can also be interpreted as an allusion to David Hume and to inductivism; the second section of Hume's *An Enquiry Concerning Human Understanding* (1748) is called "Of the Origin of Ideas". But in contrast to

abduction (see Peirce CP 1.107, c. 1896; CP 7.38, 1907; see also MS L75d:270, 1902[1]; cf. Niiniluoto 1978/1984, 25-27; Peirce 6.476, 1908). Like the trial-and-error method, an abductive model emphasizes that there is no mechanical way for making discoveries. Still, there is a clear difference between these two models. According to a methodology based on abduction, there is logic in discovery, although its basis is a weak form of inference (i.e., abduction) (see especially Paavola 2004a [article I]; Paavola & Hakkarainen 2005 [article V]).[2] The title is chosen mainly because discovery is nowadays still a quite mysterious process, similar to the origin of species in Darwin's time. I maintain also (again analogically to Darwinian theory) that a central focus of investigation should be those processes, how things change and turn up, and not points of origination as such. The quest for an absolute starting point might blur these processes also in relation to discovery.

Rather than a direct analogy to natural selection, the idea is that Peirce's theory of signs (connected to mediated activity more generally) gives a parallel basis for understanding processes of human inquiry to natural selection in biology. I will show that much light will be thrown on the processes of discovery if the formulations of abduction are developed further. According to Peirce, the question "How synthetical reasoning is possible at all" is the "lock upon the door of philosophy" (Peirce CP 5.348, 1869). Abduction is thus a key to fundamental philosophical questions (cf. also Davis 1972; Hintikka 1998).

Humean empiricism a basic answer here to the "Hume's problem" is abduction.

[1] MS L75 refers to Peirce's correspondence concerning an application for the Carnegie Institution. This manuscript is available (most parts of it) at the internet, edited by Joseph Ransdell (see Ransdell 1998). The letter and numbers after MS L75 refer to different draft versions of the manuscript & page numbers.

[2] One middle ground between abductive methodology for discovery and a pure trial-and-error method is Rescher's "methodological Darwinism," (Rescher 1978), according to which human beings use methods which make inquiry something else than blind trial-and error process, but these methods themselves have emerged as a result of trial-and-error processes. In abductive methodology the trial-and-error method is replaced with abductive search for hypotheses and subsequent tests and modifications of these hypotheses.

2. Aims of the present study

I was led to the research area on abduction and discovery quite long a time ago (I analyzed abduction in my master's thesis in 1993). I felt convinced that abduction is a useful way of conceptualizing a central but often neglected, or even denied, area in methodology, that is, discovery. I thought that Peirce and Hanson (and others using their concepts) tried to say something important about processes of discovery by abduction. But the problem was that these formulations were criticized by most researchers in philosophy of science as inadequate. Was my impression wrong, or could abduction be interpreted so that it will meet these criticisms? I also noticed that there are different interpretations concerning abduction. Discovery is a recurring theme in the literature on abduction, but not always. Many proponents of the Inference to the Best Explanation model talk about abduction without any emphasis on discovery.

The central aim of this thesis is to conceptualize the area of discovery with the means of abduction. Can abduction be defended as a logic of discovery? How is one to develop basic formulations of abduction as a way of conceptualizing processes of discovery? My area is not logic as such, but rather abduction as a conceptual means for analyzing the area of discovery. Abduction, said Peirce, is a main mode of inference, but it is closely related to many kinds of cognitive processes, for instance, to perception, instincts, practices, habits, mediated activities. What is the nature of abduction as a part of human activities in general and what are its different forms?

The first part of the thesis presents background and overview of the topics elaborated in the second part: I will present background for the idea that abduction can be understood and developed as a way of conceptualizing discovery. At the outset, I analyze discussions surrounding the idea of logic of discovery in the 20th-century philosophy of science in relation to abduction. Then, I outline a short history of abduction first by Peirce and what has

happened after Peirce, as well as ways of classifying different forms of abduction. At the end of the first part, I give short summaries of the articles in the second part of the study, and some concluding remarks. I have included to this introduction a long list of references to help those who are searching for literature on abduction.

The second part of the study involves six articles on abduction, especially in relation to discovery. I will maintain that abduction can be developed as a "Hansonian" logic of discovery, that is, abduction gives various new means for conceptualizing the area of discovery. I will show that basic criticisms against abduction as a logic of discovery can be countered. Various *inferential* aspects of abduction will be developed further (especially in articles I, II, and III). Peirce's original conceptions of abduction, and various ways of interpreting them are one central starting point for my work (especially articles III and IV). I also maintain that an analytic distinction between abductive *inference* and abductive *instinct* should be made (articles IV and V). Besides these, my aim is to develop abduction further in relation to modern ideas about distributed cognition and mediated activity in general (articles V and VI). Neither Peirce nor Hanson interpreted abduction explicitly from this perspective, but it gives additional means for understanding processes of discovery and helps with the resolution of the classic Meno paradox.

3. Discovery with philosophical means: some background

It is often remarked that in the philosophy of science the discussions around the area of discovery, especially the *logic* of discovery, are quite confusing (Laudan 1980; Gutting 1980; Nickles 1985; Musgrave 1989; Aliseda 2006). First of all, there are various ways of understanding the concept of 'discovery' (Curd 1980; Gutting 1980; Wartofsky 1980; Nickles 2000). For some, it means the original generation of an idea, for others, the outcome of the whole process of inquiry (if 'discovery' is taken as a "success-

word," an indicator of finding something shown to be true). Or is discovery something in between these two extremes, like a preliminary evaluation of an idea? For some, it means a specific "Eureka"-*moment* when an idea turns up, or, alternatively, a (first) *phase* in process of inquiry, or it can mean a certain kind of a "stance" on ideas (discovery means then that ideas are taken as something to be developed further, and not, for example, as something ready to be tested). The context of discovery can refer to the actual processes of reasoning, or, on the other hand, logic of discovery might try to reconstruct rational elements within discovery, or the way hypotheses are justified in a preliminary way. The term 'logic' in 'logic of discovery' can also be interpreted in several ways. For some it means valid systems of deductive logic, for others, formal or normative methods of inquiry or, more generally, rational elements involved in discovery, or possibly a conceptual analysis of the area of discovery. Before the 1850s, 'logic' of discovery was taken in a more descriptive manner, but after the rise of modern logic, it has been interpreted in a more normative manner (Aliseda 2004, 21). For Peirce, and for many modern proponents of the research on discovery, logic should be developed in both of these ways (Nickles 1980a).

These kinds of distinctions and a variety of interpretations of "logic of discovery" are not so confusing by themselves. Many central concepts in the philosophy of science have a variety of meanings and interpretations. But, in the case of "logic of discovery," this variety is connected to the fact that philosophers of science, especially in the 20th-century, have been eager to define some areas of discovery and inquiry *beyond* philosophical and conceptual treatment. And there is no unanimity what these areas are, or even, whether there are any such areas. Many of those who were defending the analysis of discovery defined some areas of discovery outside philosophy (see Nickles 1980a, 29). So the question still remains, if there even is--or in what sense there can be--the area of discovery for a philosophical analysis.

An "orthodox" view of discovery in the 20th -century philosophy of science made a sharp distinction between the *context of discovery* and the *context of justification* (see Sintonen & Kiikeri

2004; Nickles 2000). The latter was supposed to be an area for logic and philosophy, the former for empirical sciences. This division has its basis in Hans Reichenbach's distinction between these two (1938, 5-6; 1951, 230-231), although it is not quite clear how Reichenbach himself meant this distinction to be taken. The distinction has been interpreted in various ways (Curd 1980, 209-211; Nickles 1980a, 8-18; Lugg 1985, 218-219; Jung 1996, 7-14; Sintonen & Kiikeri 2005, 212-213). It has mainly been interpreted either as a distinction between the actual activities of inquiry versus the rational or logical reconstruction of this activity, or / and between the discovery of a hypothesis versus its justification. According to the orthodox view, rational reconstruction can only reach the context of justification, that is, the way hypotheses are tested and evaluated. Those investigators more amenable to discovery have maintained, in contrast to this view, that the way hypotheses are discovered can also be rationally reconstructed.

A clear exposition of the orthodox view and historical reasons which led to it were presented by Laudan (1980). According to him, the logic of discovery flourished before 19th-century, among scientists and philosophers, but it is different from the modern approach because epistemologically it was connected to the logic of justification. Epistemology leaned on *infallibilistic* ideas, and the goal was to find a method for inquiry and discovery which would give justified knowledge. Things changed when fallibilism came into the picture in the 1820s and 1830s, and when complex and explanatory theories (and not just generalizations based upon observations) were seen as basic objects of science. Then, from the point of view of well-foundedness of knowledge, the process of discovery was irrelevant, and the problem of justification prevailed (which had been, according to Laudan, the central concern also before). Quite characteristically for the orthodox view, Laudan ends up conceding that there surely *is* also a heuristic problem about how theories are generated, but it is not clear if philosophy or epistemology can illuminate this area of inquiry. Laudan's conclusion is that in order to discuss the logic of discovery within philosophy, one should specify the philosophical or epistemological problem(s) to which it will be a solution, and

Laudan seemed to be very sceptical if there could be any. In this way, Laudan's position explicitly presented a challenge for the programme of logic of discovery.

Influential methodological models which clearly represent this orthodox view are Karl Popper's model of conjectures and refutations (Popper 1959; 1963), and the hypothetico-deductive model of inquiry (e.g., Hempel 1966). Both have quite a similar approach to discovery. The claim is that because there cannot be any inductive route from observations to theories, and because discovery involves creative imagination, there cannot be a logical reconstruction of the generation of new ideas (Hempel 1966, 6-18; Popper 1959, 31-32).[3] Still, the difference to discovery programmes is not *necessarily* as abrupt as it might seem at first. Several writers have noted that Popper's views on epistemology have clear affinities to Peirce's epistemological approach (Haack 1977; Niiniluoto 1978/1984, 18-60; Rescher 1978, 41-63; Chauviré 2005). In a broad sense, both Popper and Hempel were conceptualizing processes of discovery; they were analyzing the whole process of inquiry and its dynamics (see Aliseda 2004; 2006, 12-20). What is not so often remarked is that both Popper and Hempel did, in fact, conceptualize discovery in the narrow sense (that is, not just the overall process of inquiry) through offering meta-level comments on discovery: for example, they maintained that discovery involves such things as luck, happy guesses, creative imagination, and so on. So they were very much conceptualizing and analyzing the area of discovery with philosophical means. But the central difference to Peirce's (and Hanson's) models prevails; both Popper and Hempel argued that there is no *logic* for generating new ideas (Haack 1977, 70-71; Chauviré 2005, 212-213; cf. also Niiniluoto

[3] This can be compared to Reichenbach's view (1951, 230-231; see also Hempel 1965, 11-18) according to which induction is not about finding a theory but about justifying it in terms of observational data. When it comes to discovery, Popper and Reichenbach (and Hempel) seem to agree: "The act of discovery escapes logical analysis", there is no "discovery machine" (Reichenbach 1951, 230-231)

1978/1984, 30-36; Rescher 1978, 41-63; Anderson 1987, 47; Levi 2004; Colapietro 2005, 219-220).

Another influential approach which more or less countered the idea of logic of discovery is Thomas Kuhn's model of science and scientific revolutions (Kuhn 1970). Kuhn's approach emphasized, not methodo-*logical* aspects of inquiry but sociological and historical elements influencing scientific research. Kuhn's approach to science was quite different to Popper's model of science. But when it comes to logic of discovery, the basic attitude seems to have much in common; discovery is not supposed to be guided, basically, by logical principles but rather by sociological or even aesthetic principles (see ibid., 94, 155-158, 198-199).

A clear and at one time almost the only opponent to the tide against logic of discovery was Norwood Russell Hanson.[4] Hanson maintained that reasons for *suggesting* hypotheses in the first place should and could be also analyzed philosophically, not just reasons for *accepting* hypotheses (Hanson 1958b; 1961a). Hanson argued that philosophers at his time were interested in the "logic of the finished research report" whereas his interest was in discovery (Hanson 1961a, 21); or in theory-finding and not just theory-using (Hanson 1958a, 3). Hanson appealed to Aristotle and especially to Peirce's abduction and maintained that although there is *no* manual for making discoveries, there is a conceptual and logical issue how hypotheses are suggested. This should be of a special interest for a philosophical and a methodological analysis. Hanson opposed both the hypothetico-deductive and the inductive methodologies as inadequate because they both neglect the abductive process, which moves from data to theories and to new explanations, hypotheses and conceptual patterns (Hanson 1958a).

Hanson also referred to F. C. S. Schiller as one predecessor to his own distinction (Hanson 1961a, 20-21). Schiller had made a distinction between the area of logical *proof* and the process of *discovery*. Schiller maintained that logic of his time gives a skewed

[4] Unless the 'logic of discovery' is interpreted as the whole process of inquiry like, for example, Popper seems to have done (Gutting 1980, 221, Aliseda 2006, 12-14).

picture of scientific inquiry whereas he hankered after a reformed logic which would include scientific method in its entirety (Schiller 1917/1955, 235-236; Schiller 1921). He emphasized that this logic should take into account, for example, how the meanings of scientific terms, or theories, or those things that are conceived as facts, change during the progress of science. There are no absolute certainties to start the inquiry; on the contrary, the initial facts of research are also unsure. According to him, the process of actual discovery is different from the subsequent logical reflection, but it does *not* mean that discoveries were just "happy thoughts" and no logical analysis of discovery could be given (ibid., 252-253). Also processes of discovery can be reconstructed with logical and philosophical means. Schiller's own ideas about this logic of discovery were quite rudimentary (ibid., 258-259, 273-4), but in their basics, they have many similarities to Hanson's approach.

Hanson's ideas on discovery were one essential basis for a new interest in the topic in the late 1970s and early 1980s (Nickles 1980b; 1980c). Many "friends of discovery"[5] maintained that philosophy of science as interpreted by Popperians or by logical empiricists had too much restricted its area of research when it comes to discovery. Inspired by historical case studies, they emphasized--instead of *logic* of inquiry--a more broadly conceived *rationality* of inquiry. Many defended the view that there is a third context between the context of discovery and the context of justification to which they assigned various names, such as "plausibility considerations" (Salmon, 1966, 114; cf. also Thagard 1981b), "context of pursuit" (Nickles 1980a, 18-22; Laudan 1980, 174), "the logic of pursuit and/or of preliminary evaluation of hypotheses" (Tursman 1987, 13-14). A basic idea was that philosophers of science can say more about discovery than the old discovery vs. justification distinction had implied although the inquirers were still quite sceptical towards logic of discovery. For example, Hanson's ideas were often interpreted so that Hanson,

[5] The term "friends of discovery" is often used to refer to researchers who around 1980 raised the issue of discovery to the discourse (see Nickles 1980a, 1; Sintonen & Kiikeri 2004, 214).

without intending it, showed that there are issues within the logic of pursuit which were neglected before, but which are *not*, contrary to his own claims, a basis for a logic of *discovery* (Schon 1959, 501-2; Kapitan 1990, 503; 1992, 2; Tursman 1987, 14).

The distinction between three major "contexts" of inquiry (justification, pursuit, discovery) was closely related to uneasiness on the logic of discovery in the *generative* sense (see e.g., Sintonen & Kiikeri 2004, 214). Many "friends of discovery" wanted to broaden the area of philosophy but leave the study of *generation* outside, as something that cannot be dealt with by philosophical means (Nickles 1980a, 29). There were different and somewhat undecided ways of interpreting this "generative sense". For example, in his extensive introduction to the book "Scientific Discovery, Logic and Rationality" (1980), Thomas Nickles defended a position which according to him was a minority even among the "friends of discovery" at that time, namely, "that the philosophical study of generation is important and possible" (Nickles 1980a, 28), but, on the other hand, he wrote in that same article that a "genuine discovery" appears to be a mystical and unintelligible process; and so something unanalyzable with logical means (ibid., 27).[6] So it seems that although many friends of discovery wanted to abandon the strict dichotomy to "empirical" / "mystical" context of discovery and "conceptual" / "logical" context of justification, they left a corner for discovery in "genuine" sense, which has many of the features of the old context of discovery, i.e., that is not amenable to conceptual analysis or logic but is empirical, mystical and inexplicable.

As a matter of fact, despite the general trend within 20th-century philosophy of science, there have been many candidates suggested for the role of logic or a method of discovery (although they have not been generally accepted). Paradoxically, even Popper's ideas

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[6] Later, Nickles introduced the idea of *discoverability* (i.e. "generative justification", or rational reconstruction of a potential discovery) which is one way of trying to analyze the area of discovery but leaving actual discovery intact (Nickles 1985; Sintonen & Kiikeri 2004, 223-227).

(e.g. Popper 1959; 1963) about there *not* being any logic of discovery can be interpreted as a supposed method for discovery (see Nickles 2000, 92-93). The same holds for *evolutionary epistemologies* more generally (e.g., Campbell 1974). The idea is to maintain that new comes with random variation (and subsequent selection), which means that this is a supposed method for making discoveries.[7] Another "anti-methodological method" for discovery is the idea that discovery in genuine sense is *serendipitous*. This is a variant of evolutionary epistemology. In routine or "normal" science deductive inferences, experiments, observations, and inductive generalizations are important. But significant progress, real and revolutionary novelties are made (according to this approach) only by serendipity (see Kantorovich & Ne'eman 1989, Kantorovich 1993; Nickles 2000). Serendipity means "discoveries which are made when scientists unintentionally solve a problem (or explain a phenomenon), while intending to solve a different problem (or to explain a different phenomenon)" (Kantorovich 1993, 7). This is not supposed to be a *logic* of discovery because the basic idea is to maintain that discoveries are not made by logical means (ibid., 2, 61-68), but still it is a strong claim that this is the only way how real novelties can turn up. It becomes then very near to being a supposed method for discoveries. Kantorovich calls it "a manifestation of universal phenomena" (ibid., 2); which works especially if these processes or phenomena are cultivated (ibid., 113-115).

Another strong candidate for the logic of discovery is the *interrogative model of inquiry*, in various versions (Hintikka 1985; 1999; Kleiner 1993; Jung 1996; Sintonen 1996). According to this approach, inquiry in general has its basis in question – answer steps, and processes of discovery should be seen as a part of this more general epistemological approach. Instead of focusing just on formal or abstract "logic," these models have conceptualized scientific inquiry as structured by systematic and deliberate processes of interrogation or by processes where interrogative and

[7] Although it can be debated how realistic this model is for simulating the way how human beings make discoveries.

inferential moves are combined. Questions constrain and guide the processes of inquiry where heuristic and strategic aspects of inquiry are important. The secret for discovery is not logic as such, but the skills of putting forward and producing good and answerable questions during the process of inquiry. A basic, and as it seems still open, question with respect to discovery within this approach, is how good and fertile questions are generated (see Sintonen & Kiikeri 2004, 228-229).

Other candidates have also been suggested. The hypothetico-deductive model of inquiry has its basis in the claim that new ideas, especially new conceptual structures, cannot be generated inductively from data (e.g., Hempel 1966). Still there has been advocates for an *inductive logic of discovery* also in the 20th-century (Pera 1981; McLaughlin 1982; Gillies 1996; cf. Reichenbach 1938). It is usually maintained that deductive logic cannot be a logic of discovery because of its nature as a necessary and non-ampliative form of reasoning. But this view also has been challenged with *deductive logics of discovery* (Nickles 1998, 100; Hintikka 1997; Meheus 1999). Another candidate for the method of discovery has been Imre Lakatos' (1978) *'methodology of scientific research programmes',* which aimed at reconciling Popper's methodology with Thomas Kuhn's theory of scientific progress by emphasizing various heuristic elements within "research programmes". Blachowicz has suggested a "*logic of correction*" (Blachowicz 1998). According to it human beings can transcend the Meno paradox, i.e., are able to make inquiries into an unknown by means a give-and-take conversation between what we know and what we desire to know. An old and honourable candidate for a general method of science is the *method of analysis and synthesis* (Hintikka & Remes 1974). Especially within the interrogative models of inquiry, this method has been suggested as an essential element of the logic of discovery (Hintikka 1999). These various candidates and approaches indicate the plurality of stances towards discovery nowadays. My intention is not, however, to analyze or compare these various approaches here in any detail.

There have been contributions to the investigation of discovery from special and applied sciences which adjoin philosophy. One

important reason for new interest in discovery has been various methods and logics of discovery developed within artificial intelligence and cognitive science. This has influenced the "*computational philosophy of science*" (Thagard 1988, 1992; also Magnani 2004b; see also Aliseda 2006; Simon 1977). Instead of asking *if* processes of discovery or inquiry can be analyzed conceptually, this approach has asked *how* various processes of discovery and inquiry can be analyzed and implemented computationally. If the idea is to simulate or implement various cognitive processes, there is no strong need, a priori to make any sharp distinctions between logic and psychology or to maintain that there are some areas of discovery which cannot in principle be grasped (Thagard 1988, 51-56; see also Gabbay & Woods 2005, 2, 107). Such potential elusiveness, it is assumed, will become evident after the continuing design process. This kind of a "simulation" approach has meant a different kind of an attitude towards discovery although critics have maintained that these models have not succeeded in simulating how human beings make genuine and novel discoveries (see e.g., Sintonen & Kiikeri 2004, 233-238).

Historical case studies have also been influential within the philosophical discussions on discovery, especially after Hanson and Kuhn. In contrast to computational approaches, historical reconstructions tend to abandon a general "logic" of discovery and instead analyze the rationality involved in some specific, long term historical processes (see e.g., Lugg 1985; Nickles 2000). Clear challenges, also, for the old preconceptions and distinctions concerning a logic of discovery are sociological theories and social history of science. According to them, cognitive or logical processes leading to discoveries are not so important, and they might be even impossible to trace. Discoveries are more about social attributions and negotiations among social agents, often long after the ideas have been generated for the first time (Brannigan 1981; Schaffer 1994; Sintonen & Kiikeri 2004, 238-242).

All in all, there is, then, a variety of approaches connected to the issue of a logic or method of discovery. Some of these approaches compete with each other, but these contrasts can also be

overemphasized. To some extent, these models and approaches can complement each other, for example, by combining the interrogative model and serendipity (see Kleiner 1993, 40-59; 1999); or by combining logical and historical approaches (Aliseda 2004); or social attribution theory and cognitivism (Sintonen & Kiikeri 2004, 240-242), or serendipity, abductive and deductive inference and emotional cognition (Thagard 2002). Meheus and Nickles have summarized the current view, in contrast to previous ones concerning discovery, by saying that "[a] large majority of philosophers of science and epistemologists agrees nowadays that the classical conception [discoveries with standardized procedures] as well as the romantic conception [discoveries through strokes of genius or luck] are mistaken" (Meheus & Nickles 1999, 231; cf. Sintonen & Kiikeri 2004). Still there are big differences as how to interpret this situation. Some researchers come close to the "romantic" conception by emphasizing, for example, luck and serendipity as a source for novel ideas (see Kantorovich 1993), and others are closer to the "classical" conception of a clear logic of discovery by focusing on new formal systems of logic (see Meheus 1999). I think this plurality of views is for good reasons. Discovery seems to involve both of these aspects and be so complex a process that it is not to be explained by just one method or conception.

New kinds of logical systems have been developed which provide better conceptual tools for analyzing processes of discovery in relation to traditional systems of logic (Hintikka 1999; Meheus et al. 2002; Aliseda 2003; 2006; Gabbay & Woods 2005). A related or a competing approach is to broaden the horizon to include methodological processes more generally (Nickles 1980b; Kleiner 1993; Jung 1996). Aliseda has maintained that this has meant a move towards pre-Fregean conception of logic, where boundaries between logic and general methodology are rather fluid (Aliseda 1997, 37). The specific realms of logic and empirical (and/or historical) issues are not seen as necessarily exclusive of each other. A broader perspective interprets discovery and inquiry more generally within cognitive processes of human beings (Nesher 2001). A still more radical approach is to seek alternatives

to cognitivist and mentalist models of discovery, where the role of external artefacts and models, social practices and collaboration is strongly taken into account as a basis for discoveries (Magnani 2001, 53-69; 2004b).

Is it then possible to answer to the "Laudan's challenge" (presented above) against the discovery programme? Laudan nicely captured some basic sceptical suppositions prevalent in the 20th-century philosophy of science, suppositions still very much alive. His challenge has various components, suggesting that it could be answered through varied approaches and ways. The discovery programme should, from an epistemological point of view, point out why it is important. Laudan maintained that when the post hoc logic of theory testing and justification had become central, the logic-of-discovery programme should show its relevance for justification, otherwise it is more or less redundant epistemologically. He was also sceptical whether philosophy has anything to offer for discovery heuristically. He solicited philosophical problems to which the discovery programme is an answer.

One clear answer to Laudan's challenge is to maintain that a methodological and epistemological understanding of the area of discovery is essential for philosophy of science even if such understanding is not related to justification. This assertion is a sort of a counter-challenge to anti-discovery programmes: "to ignore discovery, innovation, and problem solving in general is to ignore most of the scientists' activities and concerns, in many cases not only the most interesting phases of scientific research but also (more importantly) phases highly relevant to epistemology" (Nickles 1980a, 2). Hanson (1967) presented a similar rationale for his philosophical interest in discovery, which he called "Mallorian"[8]. The rationale was "Because it's there!" It would be odd if philosophy would have no interest or nothing to say about

[8] He named it 'Mallorian' because it was the same answer as the famous mountain climber Mallory gave as the rationale of his urge to climb to a certain difficult mountain.

such an interesting topic as discovery.[9] A related answer can be given by emphasizing the meaning of *heuristic* aspects in philosophy of science. Nickles (1989) has argued that philosophy traditionally emphasized "epistemological appraisal," i.e., retrospective appraisal of scientific results. But philosophy *should* be--and now *is*, according to Nickles--more interested in "heuristic appraisal, " i.e. forward-looking, heuristic assessment.

Laudan's challenge is a good example of putting the epistemological appraisal at the forefront. His point was that although there is the area of discovery and heuristics in inquiry, philosophy has very little to say about it. He seems to take it for granted that philosophy has much to offer for the area of justification and hypothesis testing, but not for discovery and heuristics. But he gives very scant reasons why this should be so. Hintikka has provided one clear answer to Laudan's challenge although not explicitly in a connection to this problem. Laudan's one basic concern was to call for specification of those epistemological problems to which a logic of discovery would be an answer (Laudan 1980, 173). Hintikka (1998) has maintained that the basic question of contemporary epistemology is the problem which Peirce brought forward with abduction, and which more generally stated is "What is ampliative reasoning like?" According to Hintikka, the answer cannot be given by deductive logic as such, but it is not a valid contention that the area of discovery is in principle cut off from logical or epistemological means (ibid., 506). This position is reminiscent of Peirce's dictum:

> According to Kant, the central question of philosophy is "How are synthetical judgments *a priori* possible?" But antecedently to this comes the question how synthetical judgments in general, and still more generally, how synthetical reasoning is possible at all. When the answer to the general problem has been obtained, the particular one

[9] This reminds one of Peirce's corollary for his "first rule of reason" (and of learning & inquiry): "Do not block the way of inquiry" (Peirce RTL, 178).

> will be comparatively simple. This is the lock upon the door of philosophy. (Peirce CP 5.348, 1869)

From this point of view, abduction brings forth an absolutely focal problem of philosophy. *Because* the area of discovery is so confusing (both in philosophy and more generally) it should not be neglected but be investigated as ever more interesting and important for philosophical analysis.

4. A short history of abduction

4.1. Abduction for Peirce

Peirce presented the distinction between three modes of inference in his very early works. He insisted that besides deduction and induction there is a third basic form of inference. There are many predecessors (before Peirce) for this conception in various methodological and logical ideas. Peirce himself referred, for example, to several earlier writers who used the term "hypothesis" in a sense of "the conclusion of an argument from consequence and consequent to antecedent" (see EP 1:34-35, note, 1868). Quite clear influences on Peirce, regarding abduction, were Aristotelean syllogisms, the scholastic tradition, and Kantian philosophy, all of which Peirce modified to a direction of his own (Peirce MS L107 [Stuhr 1987, 26], 1904; MS 475, 1903; Murphey 1961, 56-68; Fann 1970, 11-17; Proni 1988; Hilpinen 2000; see also Redding 2003). Peirce wanted to develop an architectonic system of universal categories and conceptions which included a general and systematic theory of representations, logic and reasoning. In his early works, this development started from an analysis of propositions and is clearly seen in "On a New List of Categories", a famous, concise and intricate paper by Peirce published in 1868 (Peirce CP 1.545-559, 1868). Peirce ended up with a three-fold classification of modes of reasoning when he developed a systematic theory of various forms of syllogistic reasoning, including deductive as well as synthetic forms of reasoning. Peirce

called the third mode of reasoning by various names during his long career, but mostly 'hypothesis', 'retroduction', or 'abduction' (or variants of these terms, like 'making an hypothesis') (see Bergman & Paavola 2003). In his very first papers concerning this mode of inference, that is, his Harvard Lectures in 1865, he also used the term "reasoning à posteriori" in parallel with the term "hypothesis" (W 1:180, 266-267, 1865) and in entries he penned for the Baldwin dictionary in 1901-02 he used the term "presumption" (Peirce CP 2.774-777, 791, 1902)[10]. I will use the term 'abduction' as a general term for this third mode of inference because this appellation is established as current usage although, from the Peircean point of view, 'retroduction' and 'hypothesis' would be at least as good alternatives.

Peirce changed his conceptions and theories concerning abduction during his long career (Fann 1970; Richter 1995; Paavola 2004b [article III]; 2005 [article IV]). As a typical feature of Peirce's architectonic philosophy in general, these were not so much abrupt changes but rather new developments and emphases or new kinds of classifications which had their background already in his earlier views. One clearer change, however, has been often noted in relation to abduction (Burks 1946, 301; Fann 1970, 9-10; Reilly 1970, 34; Thagard 1981a; Anderson 1987, 19-23; Flach & Kakas 2000b, 58; cf. Buchler 1939, 130-136; Hilpinen 2000; Levi 2004). In his earlier writings, abduction ('hypothesis') was treated as an evidencing process; Peirce classified various forms of inference and their nature. In his later writings, it was interpreted more as a part of a methodological process; abduction is the first stage of inquiry within which hypotheses are invented; they are then explicated with deduction and tested with induction. According to Thagard, this was a change from the context of justification (where the 'hypothesis' as a weak form of inference belonged) to the context of discovery (with the later theory of abduction). This change also entailed that a guessing *instinct* was an uneliminable element of abductive reasoning in Peirce's later theory. In his later writings,

[10] Peirce mentioned in the Baldwin dictionary that his *own* favourite term also at that time was 'abduction' – see CP 2.774, 1902.

Peirce emphasized abduction as a way of generating new ideas (Peirce HP 2:878-879, 1900; CP 2.776-777, 1902; CP 5.145, 5.171-172, 1903; CP 5.590, 1903; CP 8.209, c. 1905; CP 6.475, 1908).

It is not clear at what time, exactly, the trichotomy of reasoning came to Peirce's mind, but, according to some of his own testimonies, it was in the early 1860s (Fann 1970, 11; see Peirce CP 7.98, c. 1910; CP 8.385, 1903; see also Peirce MS L107 [Stuhr 1987, 26]). In his manuscripts, it is clearly represented not until in his Harvard lectures "On the logic of science" from 1865 and in Lowell lectures "The logic of science: or, induction and hypothesis" from 1866 (W 1:161-302, 1865; W 1:357-504, 1866). There he represented a correlation between three modes of inference and three figures of Aristotelean syllogisms, and proposed the irreducibility of these three syllogistic figures (Fann 1970, 11; see also Peirce MS 475, 1903). Accordingly, deduction, induction, and abduction (then called 'reasoning a posteriori' or 'hypothesis') are irreducible to each other although deduction is a sort of paradigmatic case for syllogisms. Abduction is "the inference of a cause from its effect" (Peirce W 1:180, 1865); it solves why-questions (see W 1:426, 1866). Peirce developed this "syllogistic" (or "evidential") viewpoint of abduction in many articles after the late 1860s (see Peirce CP 2.461-516, 1867; CP 2.391-426, 1867; CP 1.545-559, 1868; CP 5.264-317, 1868; CP 5.318-357, 1869; CP 2.619-644, 1878). Rough formulations for abductive and inductive inferences can be made by inverting the deductive syllogism (which proceeds from major and minor premises to conclusion). *Induction* is the inference of the major premise (rule) from the minor premise (case) and the conclusion (result), and *abduction* the inference of the minor premise (case) from the conclusion (result) and the major premise (rule) (Peirce CP 5.275-276, 1868; CP 2.623, 1878). These formulations do not yet indicate the strength of these modes of reasoning. At that time Peirce quite often presented abduction as a form of a probable reasoning (Peirce CP 2.511, 1867; CP 5.276, 1868; CP 5.349, 1869), or as a weak form of reasoning (Peirce CP 2.623-625, 1878), or without making any clear specifications about its strength (e.g., Peirce CP 1.559, 1867).

The syllogistic viewpoint culminated in two papers, "Deduction, Induction, and Hypothesis" in 1878, and "A Theory of Probable Inference" in 1883. The first one is a paper meant for a wide audience and not just for experts in logic. Peirce presents abduction as a weak kind of an argument for "making an hypothesis":

> Hypothesis is where we find some very curious circumstance, which would be explained by the supposition that it was a case of a certain general rule, and thereupon adopt that supposition. (Peirce CP 2.624, 1878)

He gave also some simple examples of abduction, for example, how numberless documents and monuments referring to Napoleon are explained by supposing that this man really has existed, or how fish and shell fossils in the interior of the country are explained by supposing that sea once washed that land (Peirce CP 2.625, 1878).

In his 1883 paper, he clearly presented abduction (still called 'hypothesis') as a form of probable inference (Peirce CP 2.694-754, 1883). He made a distinction between induction and abduction (see Peirce CP 2.713-714, 1883) but at the same time called abduction 'induction of characters' (Peirce CP 2.707, 1883). In the end of the paper he speculated that human mind must be adapted to guessing the laws and facts of nature, otherwise the amount of our knowledge nowadays would be inexplicable: "… all human knowledge, up to the highest flights of science, is but the development of our inborn animal instinct" (Peirce CP 2.754, 1883). But at that time Peirce explicitly denied that this 'instinct' is a basis for abduction:

> Others have supposed that there is a special adaptation of the mind to the universe, so that we are more apt to make true theories than we otherwise should be. Now, to say that a theory such as these is *necessary* to explaining the validity of induction and hypothesis [abduction] is to say that these modes of inference are not in themselves valid, but that their conclusions are rendered probable by

> being probable deductive inferences from a suppressed (and originally unknown) premiss. But I maintain that it has been shown that the modes of inference in question are necessarily valid, whatever the constitution of the universe, so long as it admits of the premisses being true. (Peirce CP 2.749, 1883; cf. also 6.417-418, 1878)

In his early works Peirce often also related conceptions, sensations, and emotions to abduction (i.e., to the 'hypothetic inference'). The Kantian idea of bringing a manifold of sensations or experience to unity was a link connecting abduction and these notions (see e.g. Peirce W 1:471-472, 1866; Reilly 1970, 32-34; Davis 1972, 81-84).

> The function of hypothesis is to substitute for a great series of predicates forming no unity in themselves, a single one (or small number) which involves them all, together (perhaps) with an indefinite number of others. It is, therefore, also a reduction of a manifold to unity. (Peirce EP 2:34, 1868; see also e.g. Peirce W 1:516, 1866)

This process of generation of a hypothesis is, according to Peirce, analogical to conceptions, sensations, and emotions: [for] "…a sensation is a simple predicate taken in place of a complex predicate; in other words, it fulfills the function of an hypothesis." (Peirce CP 5.291, 1868; see also CP 2.712, 1883; CP 6.145-146, 1892). Thus abduction "produces the sensuous element of thought" in contrast to induction's "habitual element" and deduction's "volitional element" (Peirce CP 2.643, 1878).

After his 1883 paper, there was a break in Peirce's discussions on abduction. Burks and Fann have treated the year 1891 as the beginning of a transitional period between "evidential" and "methodological" viewpoints on abduction (Burks 1946, 301; Fann 1970, 9). In any case, in 1892 (at "The Law of Mind", Peirce CP 6.102-163), the basic idea was still quite similar to the 1883 paper. Abduction ('hypothesis') was equated with "induction from qualities" (Peirce CP 6.145, 1892), and both induction and abduction were seen as forms of probable inference (Peirce CP 6.147, 1892; see HP 2:114, 1893). The change is clearly seen in a manuscript "Lessons from the History of Science" (dated by

editors of Collected Papers to c. 1896)[11]. As a mark of this change he used the term 'retroduction' instead of 'hypothesis'. "Retroduction is the provisional adoption of a hypothesis" (Peirce CP 1.68, c. 1896). And now it is explicitly connected to a supposed tendency of human beings to find fertile ideas:

> It is certain that the only hope of retroductive reasoning ever reaching the truth is that there may be some natural tendency toward an agreement between the ideas which suggest themselves to the human mind and those which are concerned in the laws of nature. (Peirce CP 1.81, c. 1896; see also CP 1.121)

Peirce maintained that Aristotle had been after this form of reasoning in his *Prior Analytics* (with 'apagoge,' which is translated as 'abduction') but this sense had been lost because the text of Aristotle had been corrupted and misunderstood (Peirce CP 1.65, c. 1896; RTL, 140-141, 1898; also CP 7.248-253, c. 1901; CP 2.776, 1902; CP 5.144, 1903). This is why Peirce at first did *not* use the term 'abduction' (which term was interpreted differently at that time in a relation to Aristotelean syllogisms). But after a while he started to use the term 'abduction' (Peirce HP 895-904, 1900) (and also again the term 'hypothesis' – see Peirce HP 876-890, 1900). His basic idea had changed from the early theory, so that abduction was now connected firmly to a sort of guessing instinct or supposed natural tendency of human beings for finding true ideas. Peirce himself characterized this change

> … Abduction. Upon this subject, my doctrine has been immensely improved since my essay "A Theory of Probable Inference" was published in 1883. In what I there said about "Hypothetic Inference" I was an explorer upon untrodden ground. I committed, though I half corrected, a slight positive error, which is easily set right without

11 Wiener has suggested (Wiener 1952, 344n5; Fann 1970, 29-30) that this manuscript should be dated already to the years 1891-92 which would be in accordance with the view that Peirce changed his conceptions on abduction earlier. But the date is not sure.

> essentially altering my position. But my capital error was a negative one, in not perceiving that, according to my own principles, the reasoning with which I was there dealing [abduction] could not be the reasoning by which we are led to adopt a hypothesis, although I all but stated as much. But I was too much taken up in considering syllogistic forms and the doctrine of logical extension and comprehension, both of which I made more fundamental than they really are. As long as I held that opinion, my conceptions of Abduction necessarily confused two different kinds of reasoning. When, after repeated attempts, I finally succeeded in clearing the matter up, the fact shone out that probability proper had nothing to do with the validity of Abduction, unless in a doubly indirect manner. But now a number of considerations offered themselves as possibly connected with the solution of the problem, and owing to the extreme weakness of this form of inference, it was difficult to make sure that they were irrelevant. I seemed to be lost in a pathless forest, until by minute application of the first principles, I found that the categories, which I had been led to neglect from not seeing how they were to be applied, must and in fact did furnish the clue that guided me through the maze. (Peirce CP 2.102, c. 1902)

As I read this passage, it says that after this point, Peirce did not consider abduction as a form of *probable* reasoning. He says that the way he had characterized abduction (or 'hypothesis') earlier (especially in the 1883 paper) was in fact induction. Further, he is now of the view that abduction should be defined differently, and seen as weaker than in the earlier presentations (see also Peirce HP 2:1031-1032, 1902; MS 475, 1903; CP 8.227-228, 234, c. 1910). But he does not mean to say that all of his earlier writings had been wrong in these respects, but only that he had confused abduction and induction in many of them (Peirce MS L75e:167-173, 1902; also MS 475, 1903). He now says that categories furnished the clue for a new theory. In the new theory, abduction, a weak form of inference, is connected to guessing, and to "may-be's" (which are connected to "Firstness" in Peirce's categorical system – see e.g. Peirce CP 1.356-357, c. 1890; CP 2.85, c. 1902). I think that, according to Peirce, previous syllogistic treatment of abduction

was not enough because it did not explain how hypotheses are generated, nor characterize abductive generation, in a distinctive way. Yet abduction, a weak form of inference, is not hopelessly weak if we suppose that human beings have a tendency to find fertile ideas. Peirce started to speak about the "economy of research" in connection to abduction which should assure that human beings can find fertile hypotheses effectively (Peirce CP 7.220-223, 1901; MS L75a:35-36, b279, 1902; HP 2:1034, 1902; CP 5.600-604, 1903). He did not abandon the syllogistic formulation of abduction, for "although it [abduction] is very little hampered [guided] by logical rules", it still has "a perfectly definite logical form" (Peirce CP 5.188, 1903). Now abduction is treated as a first stage of inquiry with which hypotheses are invented and provisionally adopted but because of its weakness these hypotheses must then be made clearer with deduction, and tested with induction (Peirce HP 2:895-896, 1900; CP 7.218, 1901; CP 6.469-473, 1908).

Peirce developed this "methodological" (or "methodeutical") viewpoint (Burks 1946) in many manuscripts and writings after the turn of the century (see Peirce HP 876-879, 1900; HP 890-904, 1901; CP 6.522-547, 1901; CP 7.164-255, 1901; CP 2.1-202, c. 1902; HP 1022-1042 [MS L75], 1902; CP 7.110-130, 1903; CP 5.590-604, 1903; HP 2:1011-1021, 1903; EP 2: 258-299, 1903). Especially well known are his "Lectures on Pragmatism" from 1903. There he presented a basic formula for abduction (Peirce CP 5.189, 1903):

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

The form is similar to a syllogistic formulation but with some additions; "the surprising fact" as a starting point, "as a matter of course" in the second premise and "reason to suspect" in the conclusion. This is in line with the methodological viewpoint where abduction concerns the first stage of inquiry. Peirce connects abduction in these papers also to an "insight" (i.e., a sort of a guessing "instinct") for coming up with true theories that is not

supposed to be infallible but strong enough to help make discoveries (Peirce CP 5.172-174, 1903). There are some special features in these lectures which are not so clearly emphasized in Peirce's other writings. He connects, for example, abduction to his pragmatism, and specifically to a "maxim of pragmatism" (Peirce CP 5.196-197, 1903). And he maintains that abduction "shades into perceptual judgment without any sharp line of demarcation between them," (Peirce CP 5.181, 1903) which means that abductive inferences and perceptual judgments (or perception in general) involve important common elements, that is, they both have characters "proper to *interpretations*" (Peirce CP 5.181-188, 1903).

At about 1905 Peirce started to use the term 'retroduction' (again) instead of 'abduction' (e.g. Peirce CP 2.755, c. 1905). It seems that there was no big change in the theory itself. In other later writings he also used the term 'hypothesis' again (e.g. Peirce CP 8.238, c. 1910). Peirce himself wrote:

> I have hitherto called this kind of reasoning which issues in explanatory hypotheses and the like, *abduction*, because I see reason to think that this is what Aristotle intended to denote by the corresponding Greek term '[apagoge]' in the 25th chapter of the 2nd Book of his Analytics … But since this, after all, is only conjectural, I have on reflexion decided to give this kind of reasoning the name of *retroduction* to imply that it turns back and leads from the consequent of an admitted consequence, to its antecedent. (Peirce MS 857:5, n.d.; cf. also MS 756:v3-5)

So it seems that a main reason for returning to the term 'retroduction' was that he had begun to doubt his own previous theory about the interpretation of Aristotle's text (cf. also Peirce CP 8.209, c. 1905). Peirce developed and presented his later theory in various manuscripts and letters (see Peirce CP 2.755-772, c. 1905; CP 8.205-213, c. 1905; NEM 3:211-217, 1910; CP 8.214-238, c. 1910; CP 7.97-109, c. 1910; NEM 3:159-210, 1911; CP 8.380-388, 1913). The basic idea of abduction was then:

> *Retroduction*, or Hypothetic Inference, which depends on our hope, sooner or later, to guess at the conditions under which a given kind of phenomenon will present itself. (Peirce CP 8.385, 1913)

Two articles of his later works in relation to abduction may be mentioned separately. The first one is "Guessing" (Peirce MS 687, 1907)[12]. This paper does not concern abduction explicitly but is connected to it in many ways. It is about "puzzles" or "mysteries" surrounding man's ability at "guessing"; that is, finding true explanations and theories for various phenomena. Peirce enlivens his article by describing a case where he himself revealed a culprit who had stolen his things in a boat trip. One of his principal explanations for this ability at guessing was that people can observe such intimations of truth which they are not able to specify consciously. This paper has especially inspired interpretations of abduction as a methodology and reasoning used by detectives who encounter clue-like signs (Sebeok & Umiker-Sebeok 1983; cf. Burton 2000).

Another influential article of Peirce's later works has been "A Neglected Argument for the Reality of God" (Peirce CP 6.452-491, 1908). There Peirce presents a bit enigmatic argument concerning the reality of God and at the same time describes his theory of scientific reasoning. He describes abduction ('retroduction') as "the spontaneous conjectures of instinctive reason" (Peirce CP 6.475, 1908) and connects it to a "Play of Musement" which is a kind of a reverie or speculation about some things and their causes (see Peirce CP 6.458-459, 1908) especially between things in various "universes of experience", that is, between ideas, brute actualities, and intermediating signs (Peirce CP 6.455, 1908). The Play of Musement is not restricted to abduction but, clearly, it is an essential element in Peirce's eloquent description of it:

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[12] Some parts of this manuscript are published in Peirce CP 7.36-48, 1907, without the detective case. The whole paper is published in *Hound & Horn* magazine from 1929, pp. 267-282 and described at length in Sebeok & Umiker-Sebeok 1983.

> Every inquiry whatsoever takes its rise in the observation, in one or another of the three Universes, of some surprising phenomenon, some experience which either disappoints an expectation, or breaks in upon some habit of expectation of the *inquisiturus*; and each apparent exception to this rule only confirms it. [---] The inquiry begins with pondering these phenomena in all their aspects, in the search of some point of view whence the wonder shall be resolved. At length a conjecture arises that furnishes a possible Explanation, by which I mean a syllogism exhibiting the surprising fact as necessarily consequent upon the circumstances of its occurrence together with the truth of the credible conjecture, as premisses. On account of this Explanation, the inquirer is led to regard his conjecture, or hypothesis, with favor. As I phrase it, he provisionally holds it to be "Plausible"; this acceptance ranges in different cases -- and reasonably so -- from a mere expression of it in the interrogative mood, as a question meriting attention and reply, up through all appraisals of Plausibility, to uncontrollable inclination to believe. The whole series of mental performances between the notice of the wonderful phenomenon and the acceptance of the hypothesis, during which the usually docile understanding seems to hold the bit between its teeth and to have us at its mercy, the search for pertinent circumstances and the laying hold of them, sometimes without our cognizance, the scrutiny of them, the dark laboring, the bursting out of the startling conjecture, the remarking of its smooth fitting to the anomaly, as it is turned back and forth like a key in a lock, and the final estimation of its Plausibility, I reckon as composing the First Stage of Inquiry. Its characteristic formula of reasoning I term Retroduction [i.e., abduction] … (Peirce CP 6.469, 1908).

Although abduction is related to a guessing instinct, it is also "reasoning from consequent to antecedent" (see above). He also states that abduction involves generating hypotheses with different strengths as to plausibility: from "a question meriting attention" to "uncontrollable inclination to believe".

In short, I have tried to give a brief outline of main trends of Peirce's versatile writings on abduction. In his early writings, Peirce presented abduction especially syllogistically. He changed

and broadened this approach towards a methodological treatment of abduction (as a first phase of inquiry) in order to explain how hypotheses are generated. In his later writings he presented abduction as a weak form of inference, and connected with this he emphasized the role of instinctual and/or perceptual elements as a basis for abduction. These approaches have left room for various subsequent interpretations of abduction.

4.2. Abduction after Peirce

For long after Peirce's death, abduction raised but marginal interest. Not only was Peirce' philosophy studied quite little, but abduction itself seems not to have been very amenable to those conceptions which become prevalent in the first half of the 20th-century philosophy--and actually long after that. Not even pragmatists seemed to show any clear and explicit interest in it (either in the syllogistic form and the methodological-instinctual interpretation). For example, Dewey, whom one would have expected to analyze abductive inference, never mentioned it in his writings, although "the presence of the activity these terms are invoked to represent is unmistakable in Dewey's approach to logic" (Marcio 2001, 102; see also Prawat 2001, 689-693; Garrison 2001, 722-738; Stanic & Russell 2002, 1257; see also Roth 1988; Alexander 1990; Brogaard 1999a).

I think that the 20th-century writings concerning abduction (following Peirce) can be analyzed roughly into four main trends for present purposes, 1) *critical comments* on abduction as a form of reasoning, and especially in relation to discovery, 2) *favourable accounts* of Peirce's abduction and endeavours *to develop it further*, 3) *scholarly work* related to abduction in the context of Peirce's philosophy in general, and 4) abduction interpreted in areas of research other than philosophy (often favourable accounts which have had influences on philosophical discussions). These emphases have not necessarily excluded one another (for example, the analyses on Peirce's writings have paved the way for the new interpretations).

Ernst Nagel represented a critical viewpoint by likening Peirce's views to "a self-corrective hypothetico-deductive method" (Nagel 1933, 381). Nagel maintained that there is only a psychological, not a logical difference between statistical deduction and the modes of ampliative inference (both abduction and induction) (ibid., 382-3). Similarly, R. B. Braithwaite studied Peirce's later view of abduction, and concluded that the difference to an "orthodox account" was "merely a verbal one" so that Peirce seemed to call an act of insight, reasoning (Braithwaite 1934, 510; cf. Buchler 1939, 176).[13] So with the rise of analytic philosophy, the need for a special ampliative mode of reasoning was usually neglected and Peirce's views were easily interpreted either as confused, or basically similar to the hypothetico-deductive methodology. The distinction between deduction and induction (which included all non-deductive inference) was prevalent at that time.

A short critical paper, often referred to, was that of Harry G. Frankfurt (1958). It is an analysis of the contention that Peirce's abduction could be "originative" and also a form of logical inference. Frankfurt maintained that Peirce held a paradoxical view that hypotheses are at the same time products of an *imaginative* faculty and of *logical* inference (ibid., 594; cf. Buchler 1939, 37; Santaella Braga 1991; Wirth 1995, 407-408; Merrell 2004; Santaella 2005; Tiercelin 2005; Paavola 2005 [article IV]). He also presented an argument, which is much used later, that in the form of abductive inference the hypothesis is already in the premises, so it *cannot* be a way of originating hypotheses as a conclusion of an inference (cf. Paavola 2004a [article I]). He also remarked that the form of abduction seems to allow the possibility of an infinite number of hypotheses. Frankfurt concluded by admitting that the form of abduction can establish "the admissibility of hypotheses to

[13] Both Nagel's and Braithwaite's views were presented within reviews of the *Collected Papers of Charles Sanders Peirce*, an edition of volumes of Peirce's papers started at 1931 which had aroused some interest also on Peirce's theory of abduction.

rank as hypotheses" (ibid., 597), but he did not develop this idea any further.

In 1946 Arthur W. Burks defended abduction as a logic of discovery in a short paper stating that Peirce's logic in general was meant to cover critical logic ("logica docens") and also one's instinctual habits ("logica utens") (Burks 1946).[14] Burks aimed at interpreting abduction so that it can deal with logic and instinctive habits at the same time. Burks also made a distinction (referred to above) between two major periods in Peirce's treatment of abduction: 1) as an evidencing process, and, 2) after 1891, as including methodological processes besides (ibid., 301).

As was mentioned above, N. R. Hanson was, however, the first who seriously started to develop Peirce's abduction as a way of conceptualizing the area of discovery. It is important to note, however – as Hanson himself emphasized -- that he was not after any "manual" for making actual discoveries, but rather a means of analyzing discoveries conceptually (see Hanson 1961a, 20-21).[15] In his famous book, *Patterns of Discovery,* Hanson treated abduction as a form of reasoning from surprising phenomena to explanatory hypotheses (Hanson 1958a, especially p. 85-92). Further, he connected abduction to perception, and to some sort of an insight (for "seeing that"), or as a "dawning of an aspect," these being connections that Peirce had emphasized in his Pragmatism lectures of 1903. Accordingly, abduction is involved when scientists struggle for new kinds of intelligible "patterns" in some puzzling data or phenomena. Hanson contrasted his model especially with inductivism and with the hypothetico-deductive model of inquiry. In his subsequent papers Hanson defended abduction as a way of analyzing reasons for *suggesting* hypotheses, which are, according to him, logical not just psychological reasons (in contrast to conceptions prevalent at the time) (Hanson 1958b, 1963, 1965/1971; cf. Gabbay & Woods 2005, 107; see critical counter-comments:

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[14] See Bergman & Paavola 2003 for Peirce's characterizations for these terms 'logica docens' and 'logica utens'.

[15] This same argument can be found in many places of Hanson's writings (e.g. Hanson 1961b, 41; 1960, 183; 1965, 44, 65; 1965/1971, 299-300; 1967)

Schon 1960). He developed his formulations further by making a distinction between reasons for suggesting some *particular*, minutely specified hypothesis, and reasons for suggesting a hypothesis of some *kind* (or type) (Hanson 1960). The argument was that "… *before* having hit a hypothesis which succeeds in its predictions, one can have good reasons for anticipating that the hypothesis will be one of some particular *kind*" (Hanson 1961a, 23). Hanson (1965, 47-50) maintained that abduction included three components: A) setting phenomena into some pattern (emphasized in Hanson 1958a); B) considering the type of an explanation before having some particular hypothesis (Hanson 1961a); and C) reasoning "backwards" from an anomaly to an explanation (Hanson 1963). As he summarized (Hanson 1965, 50):

> A Logic of Discovery should concern itself with the scientists' actual reasoning which
>
> C. proceeds retroductively, *from an anomaly* to
>
> B. the delineation of a *kind* of explanatory H which
>
> A. fits into an organized *pattern* of concepts.

In the beginning of the 1970s, Peter Achinstein made partly approving, partly critical comments on abduction. Achinstein agreed with Peirce and Hanson that, contrary to the hypothetico-deductive model, scientists *can* and do make inferences to explanations and laws (Achinstein 1970, 1971; also 1987). But he especially criticized Hanson's formulations as inadequate in their given form. These formulations did not take the role of a theoretical background into account, but suggested that scientists always start by simply observing the phenomena. On the other hand, these formulations are fallacious because they allow inferences to all sorts of wild and crazy hypotheses (Achinstein 1970, 91-93; 1971, 117-119; cf. Paavola 2004a [article I]).

At the end of the 1970s, Isaac Levi interpreted abduction in the context of his own theory of growth of knowledge. According to him, abduction provides criteria for evaluating whether potential answers qualify as potential answers to a given question (Levi 1978; 1980, 41-50). Abduction deals with potential answers, but not

with all possibilities, rather those which are "serious" possibilities (i.e., those possibilities which are in relation to cognitive states and knowledge of rational agents or inquirers) (ibid.). Rescher (1978, 41-63) also argued that there must be a way of limiting an area of promising candidate hypotheses, which is more effective than just a trial-and-error method suggested by Popper. Rescher analyzed Peirce's abductive solution for this puzzle, that is, how people find out plausible hypotheses with an instinct. Rescher himself suggested, however, that this mysterious capacity of insight or instinct should be replaced by "methodological Darwinism," i.e. human beings use methods which guide inquiry and which make it something other than a blind trial-and error process, and which themselves have emerged as a result of trial-and-error processes. Rescher also emphasized the *economy of research* as a leading principle within Peirce's conception of abduction (Rescher 1978, 65-91; cf. also Thagard 1981b).

Around the 1980s many "friends of discovery" held a quite similar stance as Achinstein towards Hanson's formulations. Hanson's work was acknowledged because he had recognized that the area of discovery can and should be dealt with by philosophical means, but at the same time abduction as formulated by Hanson was criticized as an inadequate form of inference (see especially Nickles 1980a, 22-25). Hanson's abduction seemed to be too narrow an approach which does not take into account various kinds of constraints (provided by background knowledge, alternative explanations, etc.) on scientists' reasoning to new hypotheses (ibid.; also Gutting 1980, 227-9). As noted above in chapter 3, Hanson's claim to provide a logic of *discovery* was criticized because it was maintained that Hanson's abduction provides at most some sort of a logic for evaluating hypotheses in a preliminary way, not for generating them (Nickles 1980a, 22-25; Schaffner 1980, 173-179; cf. also Thagard 1981b). Martin V. Curd, however, maintained that besides logic of pursuit, abduction *can* be a rational reconstruction of inferences to the theory, so it can reconstruct theory generation, at least in some senses (Curd 1980). Still it seemed that a new hypothesis is supposed to be known prior to an abductive step (because the hypothesis is already in the

premises in the formula of abduction) so the real difference to the hypothetico-deductive model was questioned (Nickles 1980a, 23; Gutting 1980, 225-227; cf. Curd 1980, 213).

All along, after the Second World War there had been some research on Peirce's philosophy that did not have so much influence on philosophical mainstream, but was important for the research on abduction.[16] For example, in Thomas A. Goudge's book *The Thought of C.S. Peirce* there is a presentation of various aspects of Peirce's theory of abduction (Goudge 1950, 195-211; see also Feibleman 1946, 116-123, 135-143; or already Buchler 1939, 36-44, 128-139). It took some time, however, before more extensive studies on Peirce and abduction were published. K. T. Fann's short book *Peirce's Theory of Abduction* was published 1970 (written already in 1963 as a M. A. thesis). Fann refers approvingly to Hanson's way of conceptualizing the area of discovery (1970, 3-5), but the basic idea is to trace various phases and elements in *Peirce*'s own theory. Fann's book has been for long the most thoroughgoing analysis of Peirce theory of abduction (cf. Richter 1995). Influential also has been Francis E. Reilly's book, *Charles Peirce's Theory of Scientific Method* (1970). It includes a short description of Peirce's abduction (see especially pp. 23-55) as a part of Peirce's scientific method more generally. Reilly especially analyzes the role of observation and experience as a starting point for abductive inference and how they are related to imagination and instinctual aspects of forming and choosing hypotheses. William H. Davis' book *Peirce's Epistemology* has also been much used in connection to Peirce's abduction. It aims at a more general outlook on epistemology on the basis of Peirce's philosophy. Davis emphasizes the meaning of abduction: "I do not find most students of Peirce seeing the importance, the truly revolutionary importance, of the doctrine of abduction that I see" (Davis 1972, 2). He interprets abduction especially as a creative insight with which

[16] This was backed up with new short editions of Peirce's own texts besides the *Collected Papers of Charles Sanders Peirce* (Vols. 7 and 8 of Collected Papers were published in 1958); see Buchler 1955; Tomas 1957; Wiener 1958.

the human mind finds novel unity and coherence of some problematic situation. This was in contrast to Reilly's viewpoint which, although emphasizing the instinctual nature of abduction, warned against exaggerating the role of instincts as a basis for new ideas (Reilly 1970, 43-44; 188-189 n100). Peirce's theory was interpreted also in various journal articles in the 1970s, especially in the *Transactions of the Charles S. Peirce Society* (founded in 1965). By emphasizing different aspects of Peirce's theory, they ended up to various interpretations of abduction. Sharpe (1970), for example, maintained that Peirce's own theory of abduction would imply that science progresses in leaps whereas according to Sharpe, abductive inferences, like induction, rely on previous experience. Ayim (1974) interpreted abduction as an instinctive activity, but at the same time something which is deliberate, voluntary and controlled. Thagard (1977) analyzed Peirce's early theory of abduction ('hypothesis') especially from the point of view of syllogisms and explanation.

The research on abduction was influenced also by another line of research. Gilbert Harman formulated "the Inference to the Best Explanation" (IBE) model in the late 1960s (1965; 1968). He maintained that IBE is a basic form of all non-deductive reasoning. The model did *not* start so much from Peirce's abduction, but rather from a more general claim that a typical case of non-deductive reasoning is inference to a hypothesis which best explains the evidence. According to IBE, we are then warranted in making the inference from alternative explanations to the (probable) truth of the one which is the best explanation. This model has awakened a lot of interest and debate among philosophers of science, especially within discussions on scientific realism (for a short review, see Day & Kincaid 1994; also Lipton 2004; cf. Smart 1963, 39[17]). Peirce's and Hanson's abduction are typically mentioned in these discussions, but they have *not* been

[17] Smart mentioned *Peirce's* notion of abduction when talking about the so-called cosmic coincidence argument in favour of realism (he maintained that abduction is an inference from a previously surprising fact to an assumption after which it is no longer surprising).

the starting point for IBE (see e.g., Harman 1965, 88; Josephson & Josephson 1994; Barnes 1995, 251; Psillos 2002, 614; Lipton 2004, 56-57). A bit confusingly, the Inference to the Best Explanation model is nowadays often called 'abduction'. Newer versions of IBE take Peirce's formulations of abduction more explicitly into account (see Psillos 2000; Flach & Kakas 2000a). But I would argue that it is advantageous to see "Harmanian abduction" (i.e. IBE) and "Hansonian abduction" (abduction as a way of analyzing the context of discovery) as separate models (Paavola 2006 [article II]; see also Minnameier 2004; Tiercelin 2005, 407-409; Schurz, in press).

In the context of artificial intelligence, Pople's (1973) work is often referred as an important starting point for research on abduction. Pople maintained that *deductive* inference was inadequate for many types of problem solving activities, and referred to Peirce and abduction for remedies. He aimed at modelling abductive processes where "[t]he essence of abductive inference is the generation of hypotheses, which, if true, would explain some collection of observed facts" (ibid., 147). In research on artificial intelligence, there is usually *no* clear distinction between Peirce's abduction and the Inference to the Best Explanation model. For AI researchers, abduction has usually included both the construction and the evaluation of explanatory hypotheses and not just the initial formulation which was Peirce's basic idea of abduction (O'Rorke, Morris & Schulenburg 1990, 205-6; Josephson & Josephson 1994, 5-9; cf. Gabriele 1993; Flach & Kakas 2000a). It seems that abduction within AI started to have increasing importance in the middle of the 1980s (Charniak & McDermott 1985) and after that its prominence has grown rapidly (e.g., Shrager & Langley 1990; Peng & Reggia 1990; Hobbs et al. 1993; Josephson & Josephson 1994).

Before the 1980s, Peirce's abduction had also been used and developed in other areas of research besides philosophy and AI research, especially in linguistics. These uses also show a variety of interpretations concerning abduction. Noam Chomsky mentioned, at the end of the 1960s, Peirce's abduction as a stance which supports his approach to universal grammar (e.g., Chomsky 1968,

76-81). He interpreted Peirce to maintain that there must be an innate limitation to admissible hypotheses, and this limitation is provided with a guessing instinct, that is, with abduction. Henning Andersen (1973) also used abduction within linguistics, but interpreted it differently (cf. also Anttila 1972, 196-203). Andersen emphasized abduction as reasoning from the result and the rule to the case, and as a reasoned guess, not as instinctual. The basis of abductive guesses in this interpretation is observations and experience rather than innate properties (see also Savan's [1980] semeiotic account of Andersen's theory).

Peirce's abduction did not stir broader attention until the 1980s. One clear source was *semiotic* research on abduction (see also e.g. Eco 1976, 131-133). Umberto Eco and Thomas A. Sebeok (1983) collected a volume of papers, *The Sign of Three: Dupin, Holmes, Peirce*, where abduction was compared to methods used by Sherlock Holmes and other famous detectives (also to historical predecessors such as Voltaire's Zadig). The use of clues and imagination, observation of trifles, and the meaning of a guessing instinct were emphasized in various articles in relation to abduction (see also Savan 1980; Spinks 1983; Thagard 1986; Eco 1990). The book contains different kinds of interpretations of abduction and defends the idea that the area of discovery can be analyzed with semiotic and philosophical means. After this, the interest within semiotics regarding abduction calmed a bit down, but has continued all along in various forms (see Ponzio 1985; Proni 1988; Bonfantini 1988; Chanady 1991; Santaella Braga 1991; Schillemans 1992; Gorlée 1996; see also Wirth 1995; Merrell 2004, 254-255).

One line of research that had close connections to AI research, but at the same time referred especially to Peirce's abduction was Paul Thagard's *computational philosophy of science*. Thagard interpreted and developed abduction in connection to PI, a computer program for problem solving and induction (Thagard

1988, 52-65; 1992, 52-54; see also 1986).[18] He argued that from this point of view there is no such clear distinction between justification and discovery, or between logic and psychology, as philosophers of science had been accustomed to make.

In the 1980s, the research on Peirce's philosophy strengthened. Abduction was used and analyzed in various ways (see e.g. Skagestad 1981, 181-193; Hookway 1985; already Bertilson 1978, 88-101, 182-192), and also defended as a way of conceptualizing creative inferences. Douglas R. Anderson analyzed, in an influential book, *Creativity and the Philosophy of C. S. Peirce* (1987), abduction and its interpretations in the context of scientific and artistic creativity as a weak, "possibilistic" form of inference which concludes "may-be's" (see also Anderson 1986). One central problem for him was to analyze how Peirce's abduction can be both an insight and an inference (cf. Roth 1988; Turrisi 1990), and how it can include both control and originality (cf. Hull 1994). Various other aspects of abduction were also brought forward in journal articles and books, for example: abduction as a solution to Goodman's new riddle of induction (Harris & Hoover 1983); the economy of abduction (Brown 1983); abduction as the process of interpreting *indexical* signs (Kruse 1986); interpretations concerning first (abductive) phases of inquiry (Shanahan 1986); abduction within Peirce's more general theory of scientific discovery (Tursman 1987); the meaning of abduction for educational research (Shank 1987); Peirce's categories as a clue for making abduction understandable (Turrisi 1990; Staat 1993); the relationship of abduction to the enthymeme in a rhetorical context (Sabre 1990); and to perceptual judgments (Hausman 1990).

Also more critical commentaries on Peirce's and Hanson's formulations of abduction continued, especially on abduction treated as a logic of discovery. Kleiner (1983) argued that Peirce's and Hanson's formulations of abduction are inadequate because they fail to take into account the role of research programmes in

[18] Cf. Simon 1977 – Simon had referred approvingly to Hanson and abduction in relation to models of discovery in his works from the 1960s and 1970s (Simon 1977, 25-45 [1968], 151-152 [1965], 326-327 [1973]).

innovative inquiry. Later, emphasizing the role of questions in epistemology, Kleiner *defended* Hanson's views about the logic of discovery in contrast to the hypothetico-deductive (HD) model because the latter offers no guidelines or constraints for discovery (Kleiner 1993, 286-8, 317). Yet Kleiner maintained that Hanson's abduction is an insufficient model for discovery (ibid., 288-290, 16-7)[19]. Similarly Jung (1996) argued, on the basis of the interrogative approach to inquiry, that although Peirce's and Hanson's formulations are improvements in relation to the HD-model, they are inadequate both as a logic of generation and as a logic of preliminary appraisal (ibid., 51-59). Tomis Kapitan has also criticized the creative function of abduction in many articles (1990, 1992, 1997; see also Danneberg 1988). Kapitan brought forward, in a systematic way, counter-arguments against abduction, that it cannot, for example, be a logic of discovery because the hypothesis sought for is supposed to be known in the premises, and, also, because abduction was for Peirce basically guessing or something instinctual, not inference (Kapitan 1990; cf. Paavola 2004a [article I]; 2005 [article IV]). Kapitan has the view that abduction concerns heuristics or practical phases of inquiry, and is not an autonomous mode of reasoning.

Above, I have sketched some main trends connected to various uses and developments concerning Peirce's abduction till the early 1990s. I haven't been able to take into account all papers and even lines of research, although I have tried to depict the most influential ones, especially from the point of view of philosophy. When it comes to research in the 1990s and after, it is even more difficult to describe various interpretations and uses of abduction (even if the literature concerning the "Harmanian abduction," i.e., IBE, is mostly excluded from this review). I'll still try to give some idea of the amount of the literature and various approaches.

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[19] One indication of a change concerning abduction, more generally, is Kleiner's more recent work, (1999, 60-63), which states that he has changed his assessment of Hanson's abduction and clearly sees it as more useful than before.

The "Model-Based Reasoning" (MBR) conferences starting in 1998, at Pavia, Italy (organized especially by Lorenzo Magnani), have been one essential instigator and arena for discussions surrounding abduction. These conferences have been followed by edited books where abduction has been an important theme, especially *Model-Based Reasoning in Scientific Discovery* (1999, ed. by Magnani et al.), *Logical and Computational Aspects of Model-Based Reasoning* (2002, edited by Magnani et al.) three special issues: in *Philosophica* (1998, vol 61, no 1), in *Foundations of Science* (2004, vol 9, no 3), and in *Logic Journal of the IGPL* (2006, vol. 20, no 1). Besides these, new books have appeared focusing especially on abduction, from the point of view of philosophy, logic, logic programming and AI (Flach & Kakas, 2000a), from the point of view of philosophy of science and cognitive science (Magnani 2001), logic and philosophy (Aliseda 2006; Gabbay & Woods, 2005; see also Aliseda 1997), argumentation, especially everyday argumentation, medicine, science, and law (Walton, 2004). This last one, like Flach and Kakas' book, has strong emphasis on IBE but also has clear connections to Peircean abduction. A special issue on abduction appeared in *Semiotica* (2005, vol 153 - 1/4)[20].

Abduction has, over recent years, been applied and discussed in relation to various philosophical questions, such as debates on *scientific realism* (de Regt 1999), *perception* (Tiercelin 2005; cf. Buchler 1939, 38-44; Bernstein 1964; Reilly 1970, 46-53), *hypothesis of God* (Delaney 1992; Nubiola 2004), *empirical progress or truth approximation* (Kuipers 1999), epistemological *coherentism vs. foundationalism* (Kleiner 2003; Minnameier 2004), *Peirce's phenomenology* (Rosenthal 2005), *problems of induction* (Misak 1991, 96-100; cf. Davis 1972, 27-45; Rescher 1978, 76-79), *Meno paradox* (Prawat, 1999; Hoffmann 2004; Semetsky, 2005), *theory of decision* (Brogaard 1999b), and *creativity* and *knowledge generation* (Hoffmann 1999; 2004; Minnameier 2004). It has been developed in relation to various topics, such as *geometrical analysis* (Niiniluoto 1999b), *(Aristotelian) syllogistic account* (Hilpinen 2000; Levi 2004),

[20] See also Wirth (2000) which contains many articles on abduction especially from a semiotic point of view (in German).

Polanyi's tacit knowledge (Mullins 2002), *interpretation* (Wirth 1999; Arrighi & Ferrario 2005), *hermeneutics* (Heelan & Schulkin 1998), *esthetics* (Anderson 2005; Redding 2003), *narratives* (Oatley 1996), *constructing conceptual knowledge* (Hatano & Inagaki 1992), *Hegel's philosophy* (Redding 2003), Jorge Luis *Borges' thinking* (Almeida 2002), *Hitler's rhetorics* (Novak 1999), *methodology* (Bertilson 1996; Hendricks & Faye 1999; Locke et al. 2004), *interrogatives* (Levi 1978; 1991, 71, 77; Hintikka 1998; Sintonen 2004; Hookway 2005). It has been applied and developed in various areas of research, such as in *logic* (Meheus 1999; Gabbay & Woods 2005), in *learning* (Shank & Cunningham 1996; Prawat 1999; Nesher 2001; Kim & Cunningham 2003; Midtgarden 2005), in *semiotics* (Merrell 2004), in *law* (Schum 2001), in *detective stories* (Pyrhönen 1999; Wouters 2001), in the *context of graph and inscription interpretation* (Roth 2003), in *neurocomputational approach* (Burton 1999), in *translation studies* (Gorlée 1976). These lists are not exhaustive in any way (see more references, e.g. Wirth 1995[21]; Aliseda 1997, 18-26; Aliseda 2006, 38-44; Magnani 2001, 16; Gabbay & Woods 2005, 59) but they show that the debates and uses of abduction have broadened immensely especially after the latter half of the 1990s.

5. Ways of interpreting and classifying abduction

As seen in chapter 4.1. Peirce himself somewhat changed his interpretation of abduction, and he also characterized abduction in various ways. Throughout his career, Peirce was searching for ways of presenting this third main mode of inference, which is weaker than deduction or induction. A basic formula of abduction (presented in his Harvard lectures at 1903; see above, or Peirce CP 5.188-189, 1903) brings forth central elements which appear in many other formulations of Peirce's abduction (see e.g. Peirce CP 2.623-625, 1878; CP 7.202, 1901; CP 2.776, 1902; CP 6.469-470, 1908). It means, first, that he presents abduction usually *syllogistically* as

[21] Wirth's article is an excellent review on literature on abduction with a special emphasis on articles and papers written in German.

the inversion of deduction, that is, an inference to the 'minor premiss' of a syllogism from the 'conclusion' and the 'major premiss' (or with other terms: an inference of the case from the result and the rule). Abduction is a *weak* form of inference (which asserts "its conclusion only problematically or conjecturally", Peirce CP 5.188). It is especially related to *explanations* and explanatory hypotheses. And it starts with a *curious* or *surprising* fact (or facts), which the abductive conclusion is supposed to explain.

Peirce's texts give, however, means for various interpretations of abduction. One reason is that Peirce changed his theory of abduction somewhat during the years. Besides syllogisms and inference (emphasized in his early papers) abduction can be connected to the first phase in a methodological process of inquiry (starting with a surprising phenomenon and with a search for an explanatory hypothesis). But besides these, Peirce analyzed abduction in various contexts that support different emphases in his subsequent interpretations. These interpretations highlight the element of

- *guessing* (Peirce CP 7.219, 1901; HP 2:898-899, 1901; NEM 3:203-204, 1911; see e.g., Sebeok & Umiker-Sebeok 1983; Burton 2000; Almeida 2002; Santaella 2005; Paavola 2005 [article IV]),
- *insight* (Peirce CP 5.173, 1903; CP 5.604, 1903; see e.g., Davis 1972; Paavola 2005 [article IV]),
- *instinct* (Peirce CP 1.80-81, c. 1896; CP 7.220, 1901; HP 2:900-901, 1901; see e.g., Ayim 1974; Paavola 2005 [article IV]),
- *perception* and perceptual judgments (Peirce CP 8.64-65, 1891; CP 5.180-194, 1903; see e.g., Hanson 1958a; Hausman 1990; Hoffmann 1999; also Apel 1981, 39-4, 164-176; Paavola 2005 [article IV]),
- *sensations, emotions* (Peirce W 1: 471-472, 1866; CP 5.291-292, 1868; CP 2.643, 1878; see e.g. Alexander 1990; Santaella Braga 1991; Redding 2003; Anderson 2005; Thagard 2006),
- *conceptions* (Peirce W 1: 471-472, 1866; W 1: 516, 1866; CP 2.776, 1901; EP 2:287, 1903; see e.g., Thagard 1992),

- *pattern recognition* and making a confused tangle of things comprehensible (Peirce PPM 282-283, 1903; MS 856: 3-4, 1911; MS 857: 4-5, n.d.; see e.g., Hanson 1958a; Paavola 2004a [article I]; cf. also Thagard 1986),
- the *maxim of pragmatism* (i.e., the 'pragmatic maxim') (Peirce CP 5.195-197, 1903; see e.g., Aliseda 2006),
- the *economy of research* (Peirce RTL, 141-142, 1898; CP 7.220n18, 1901; NEM 4:37-38, 1902; CP 5.598-602, 1903; see e.g., Rescher 1978, 65-91),
- *interrogation* (Peirce HP 2:878-879, 1900; HP 2:898-899, 1901; CP 6.525, 528, 1901; EP 2:287, 1903; see e.g., Hintikka 1998; Sintonen 2004; Hookway 2005; Paavola, Hakkarainen & Sintonen 2006 [article VI]),
- an *inference of a cause from its effect* (Peirce W 1:180, 1865; see e.g. Niiniluoto 1999b),
- the category of *Firstness* (Peirce CP 2.89-102, c. 1902; PPM 276-277, 1903; see e.g. Anderson 1987; Paavola 2004b [article III]),
- an *inference through an icon* (Peirce CP 2.96, c. 1902; MS L75e:169, 1902; PPM 276-277, 1903; EP 2:287, 1903; see e.g. Ponzio 1985; Merrell 2004; Paavola 2004b [article III]).

These interpretations do not necessarily exclude each other, and the interpretations of abduction are usually mixtures of these various elements. Abduction can also be developed in relation to other aspects of Peirce's philosophy, and in directions which Peirce himself did not emphasize in his own theory of *abduction*, such as his doubt-belief theory (see Aliseda 2000)[22], various aspects of his theory of signs (see Savan 1980; Shank & Cunningham 1996; Houser 2005), the role of aesthetics (and ethics) within abduction (see Redding 2003), his realism, his ideas concerning mediation with signs, or his ideas concerning social character of science and logic. I am not maintaining that these lists are a basis for as many

[22] It seems that Peirce himself never compared his doubt – belief theory to the cycle of abduction, deduction, and induction. This is a bit curious because they seem to be parallel ways of presenting the cycle of inquiry for Peirce.

conceptions of abduction; many of these are closely connected. Still, they show that Peirce's abduction can and has been interpreted with a variety of emphases.

The strength of abduction can also be interpreted differently. In his earlier writings Peirce often presented abduction as a mode of probable inference (Peirce CP 2.511, 1867; CP 2.706-707, 1883; see e.g., Niiniluoto 1999a). Later he emphasized that abduction "merely suggests that something *may be*" (Peirce CP 5.171-172, 1903; NEM 3:203-204, 1911; 8.238, c. 1910; see e.g. Anderson 1986; 1987; Hilpinen 2000, 118-123), or states the conclusion to be plausible (Peirce CP 6.469, 1908; see also CP 8.222-223, c. 1910; CP 2.662, 1910; see e.g. Rescher 1978, 41-63). It is not totally clear, either, to which phase of inquiry abduction is supposed to belong. Peirce's early theory interpreted abduction more in the context of justification, and the later theory in the context of discovery (Thagard 1981a). Some formulations emphasize the element of discovery: "All the ideas of science come to it by the way of Abduction. Abduction consists in studying facts and devising a theory to explain them." (Peirce CP 5.144-145, 1903). It is an "originary" argument (Peirce CP 2.96, c. 1902). On the other had he often wrote that abduction consists of "adopting" a hypothesis (Peirce RLT 140, 1898; CP 5.188-189, 1903), or "the invention, selection, and entertainment of the hypothesis" (Peirce HP 2:895, 1901) which seem to imply both "the context of discovery" and "the context of pursuit" (using modern terminology) where the selection among competing hypotheses is included within abduction (see also Peirce CP 6.524-525, 1901).

Peirce did not make any subdivisions in relation to abduction, and he seemed to be undecided if there are any. He once even mentioned that he had found "no essential subdivision of Abductions" (Peirce PPM 276-277, 1903). But it should also be noted that here 'abduction' is in plural, and in another context he gave a more definite impression of many forms of abduction: "Abduction, in the sense I give the word, is any reasoning of a large class of which the provisional adoption of an explanatory hypothesis is the type." (Peirce CP 4.541n1, 1906; cf. also NEM 3.203-204, 1911; CP 6.469, 1908).

A basic, modern definition of abduction along Peirce's line--in Thagard's words-- would be that it "is inference to a hypothesis that provides a possible explanation of some puzzling phenomenon" (Thagard 1988, 51-2; cf. Aliseda 2006, 26; Magnani 2001, 15-29). Reflecting a variety of meanings, one finds that Woods and Gabbay characterize abduction as "ignorance-preserving" reasoning, in contrast to deduction as "truth-preserving" and induction as "probability-enhancing" (Woods & Gabbay 2005, 40-43). They also argue that abduction should not cover just explanatory accounts but, more broadly, transformations of "ignorance problems" or "cognitive-deficit" problems with abductive means (ibid., 47-9). Among the literature in philosophy and methodology providing various emphases and interpretations concerning abduction are, e.g., Rescher 1978; Gooding 1996; Blachowicz 1996; Thagard & Shelley 1997; Hintikka 1998; Niiniluoto 1999a; Pape 1999; Hoffmann 1999; Magnani 2001; Nesher 2001; Nubiola 2004; Locke et al. 2004; Aliseda 2006. Peirce's abduction is nowadays often merged with the Inference to the Best Explanation model where the *selection* from among alternative candidate hypotheses is emphasized (Psillos 2000; Magnani 2001, 19). In artificial intelligence, abduction is often treated as backward deduction with additional conditions (Aliseda 2006, 38).

There are also more specific subdivisions suggested in relation to abduction. Bonfantini and Proni (1983; see also Bonfantini 1988, 1250-1251) divided degrees of originality and creativity of abduction, based on the role of the "rule" or "major premise" in the basic formula of abduction. Umberto Eco (1983; cf. also Eco 1984, 39-43) named these as: 1) *overcoded abduction* where the rule is given automatically or semiautomatically, 2) *undercoded abduction* where the rule must be selected from a series of equiprobable rules, and 3) *creative abduction* where the rule must be invented ex novo. Eco added a fourth class, 4*) meta-abduction* which "consists in deciding as to whether the possible universe outlined by our first-level abductions is the same as the universe of our experience" (ibid., 207). This is a useful and often referenced division (e.g., Schillemans 1992; Schum 2001; Bertilsson 2004) although its details could be analyzed further. I think it is not, for example, clear in

which sense "creative" abduction can start totally "ex novo", and if overcoded abduction is more inductive than abductive[23], and if meta-abduction is a distinct type of abduction (or rather a second-order abduction).

Other ways of dividing various forms of abduction has also been presented. Thagard (1988, 54-63) distinguished various abductions in relation to his PI-model. This distinction emphasizes the nature of the results of abduction: 1) simple abduction, which results to hypotheses about individual objects; 2) existential abduction, which postulates the existence of previously unknown objects; 3) rule-forming abduction, which produces rules that explain other rules (important in generating theories); and 4) analogical abduction which uses past cases to generate hypotheses similar to existing ones (this is especially important in the formation of complex hypotheses).

Gary Shank has made a division in relation to Peirce's theory of signs (see Shank & Cunningham 1996; Shank 1987). This division is made on the basis of possible sign classes (cf. Liszcka 1996) which are the result of abduction, and ends up with six classes of abduction:

1) *Open Iconic Tone* (or Omen / Hunch), which deals with the possibility of a possible resemblance;
2) *Open Iconic Token* (or Symptom,) which deals with possible resemblances;
3) *Open Iconic Type* (or Metaphor / Analogy), which means the manipulation of resemblance to create or discover a possible rule;
4) *Open Indexical Token* (or Clue) to determine whether or not our observations are clues of some more general phenomenon;
5) *Open Indexical Type* (or Diagnosis / Scenario), which means the formation of a possible rule based on available evidence;

23 It is worth remembering that these distinctions are very close to each other and Peirce himself maintained that what he had in some earlier writings taken as abduction were more like abductive induction (Peirce HP 2:1031-1032, 1902; MS L75e: 167-171; cf. HP 2:897, 1901; 6.526, 1901).

6) *Open Symbolic Type* (or Explanation), which deals with a possible formal rule

This division is then made on the basis of the "products" of inference (see also Cunningham 1998). Although Shank does not do so, it seems that a similar division may characterize various sign relations which are interpreted with abductive means, not just the results (cf. also Houser 2005). So the reasoner could get, for example, "hunches" not just concerning iconic relationships but also concerning indexical or symbolic sign relationships.

Aliseda has systematically divided forms of abduction by distinguishing main parameters within the inferential structure of abduction (Aliseda 2006, 44-48). There may be, then, different forms of abduction on the basis of

1) an inferential parameter, i.e., the logical relationship involved in the explanation which is obtained by abduction (derivability, semantic entailment, probability, dynamic inference),
2) those "triggers" which are the starting point for an abductive process (novelty or anomaly), and
3) the outcome of abduction (facts, rules, or theories).

The subdivisions above partly overlap and could be developed further (see also e.g., Buchler 1939, 131-132; Pape 1999, 248-252; Reid 2003; Kim & Cunningham 2003; Schurz, in press). I am not trying to decide in this paper how to treat this variety of interpretations. They show, however, that many fine-grained distinctions can be made in relation to abduction, and that basic formulations of abduction entail various aspects within themselves (cf. Merrell 2004, 269-270). These distinctions are generally made in relation to an inferential form of abduction, Shank's division being an exception. I still want to add further distinctions which I think are central for getting a more extensive picture of abduction.

Lorenzo Magnani (1999; 2001; 2004a; 2006) has made distinctions of abduction to take into account more recent developments in cognitive sciences, although these distinctions

have clear connections also to Peirce's philosophy (cf. also Gooding 1996; Burton 1999; Nesher 2001). Magnani's approach suggests that one does well to take into account not just an internal process of reasoning with symbols, but also other forms of representation with distributed cognitive means, and with external artifacts. Magnani differentiates two forms of '*theoretical abduction*' that is, '*sentential abduction*' and '*model-based abduction*' (Magnani 2001, 17-36). Syllogistic treatment of abduction is a good example of the sentential abduction. Model-based abduction has its basis in model-based reasoning which "indicate[s] the construction and manipulation of various kinds of representations, not necessarily sentential and/or formal" (Magnani 2004a, 228). A central subcategory of model-based abductions is '*visual abduction*' (Magnani 1999, 228; Magnani 2001, 97-115). Visual abduction operates with visual mental imageries or image-based hypotheses (ibid.; Shelley 1996; Thagard & Shelley 1997).[24] Besides these 'theoretical abductions' Magnani has emphasized '*manipulative abduction*,' closely connected to the idea of *distributed cognition* among people and with external artifacts (not just within human mind). It refers to "thinking *through* doing and not only, in a pragmatic sense, about doing" (Magnani 2004a, 229; see also Magnani 2006). It seems that the exact nature of manipulative abduction is not yet very clear, but it highlights the meaning of practices, and the collaborative use of external tools and "mediators" within abduction. Peirce himself sometimes connected abduction to his famous maxim of pragmatism (or 'pragmatic maxim') (see above; Peirce CP 5.195-197, 1903) which would bring it close to some tenets of manipulative abduction. Peirce, however, equated his later theory of abduction with "*il lume naturale*" (i.e., with a sort of an instinct; e.g., Peirce CP 1.80-81, c.

[24] Thagard & Shelley (1997, 418) provides a nice exemplary situation where visual abduction is used in an everyday situation. If you find a big scratch on a door of your car when returning to your car you might start thinking verbally how it has come up. But in addition to this a natural way of reasoning for humans in these kinds of situations is with visual imagery start to solve how the scratch has turned up to the door.

1896) whereas abduction connected to distributed cognition would refer more to "*il lume culturale* " (see Bonfantini & Proni 1983, 134; Bonfantini 1988, 1253-1254; cf. Apel 1981, 170-171), where social collaboration is emphasized. Magnani presents also, for example, '*temporal abduction*' which emphasizes the role of time in abduction (Magnani 2001, 115-124).

6. A short overview of the original studies and their results

The present articles were made during a five-year period of time (the first paper, article I, is originally made for the MBR-conference at May 2001 and last ones finished 2006), and are partly overlapping. These articles can be connected to the "trends" within research on abduction that I outline in chapter 4.2.

A main result of this thesis is to give answers to the criticisms which have been presented against abduction as a logic of discovery and to give various new means and directions for developing abduction further. Abduction, as interpreted here, is about those ways in which various things both constrain and instigate the search for new ideas. In articles I and II, abduction is developed as an inferential model for analyzing processes of discovery, that is, a "Hansonian" kind of a logic of discovery. First, I proceed by emphasizing strategic aspects of abduction (article I; see also article III), and then, making a comparison between Hansonian abduction, the Inference to the Best Explanation model ("Harmanian abduction"), and the hypothetico-deductive model (article II). The next two articles (III and IV) concentrate more on Peirce's original conceptions on abduction although my aim is not just scholarly work on Peirce's theories but all the time developing the Peircean framework further in relation to modern conceptions on abduction. In article III, I use Peirce's distinction between grammar, critic, and methodeutic in order to illuminate various elements of abductive inference. Abduction is a weak form of inference where iconicity and "loveliness" are essential (see articles II and III). Article IV (see also article V) makes a distinction

between abductive *inference* and abductive *instinct*, which I maintain is needed in order to understand Peirce's controversial claims about abduction. The last two articles (V and VI) interpret and develop abduction through a more general framework concerning distributed cognition and mediated activity, which emphasizes a long-term interaction with the material, social and cultural environment. First, three basic ways of answering the classical Meno paradox with abduction are analyzed (article V). Then the idea that abduction can be analyzed as a part of distributed cognition is developed further; and the relation of abduction to the interrogative model of inquiry is discussed (article VI).

I provide, below, a short description of the each article in a more detail.

Article I

Paavola, S. (2004a). Abduction as a logic and methodology of discovery: The importance of strategies. *Foundations of Science 9* (3), 267-283. Available also: http://www.helsinki.fi/science/ commens/ papers/abductionstrategies.html

In this paper I defend abduction as a "logic of discovery". Abduction has been, for long, criticized in philosophy of science by maintaining that despite Peirce's and N. R. Hanson's claims abduction *cannot* be a logic of discovery (see e.g., Frankfurt 1958). I assess two "classical" arguments defending this claim: 1) abduction is too weak a mode of inference to be of any use, and 2) in the basic formulation of abduction, the hypothesis is already presupposed to be known, so it is not the way hypotheses are discovered in the first place. I maintain that by developing *strategic* aspects of abductive reasoning these arguments can be countered.

Jaakko Hintikka (1998; see also Schurz, in press) has emphasized the meaning of strategic rules within reasoning in general, and also in connection to abductive inference. Hintikka has not, however, developed the strategic approach in relation to Peirce's and Hanson's formulations of abduction (it seems that he

even denies abduction as a separate form of reasoning). I delineate strategic aspects of abduction. It means that the reasoner takes the goal into account and tries to anticipate things by taking many argumentative steps into account at the same time. Strategies are also involved when abduction starts from *anomalous* phenomena.[25] I give some remarks how these kinds of abductive strategies fit to Charles Darwin's methodology.

I also discuss how the strategic approach is anticipated in Peirce's and Hanson's formulations of abduction although they did not use the term 'strategies' in their writings. I maintain that in Peirce's architectonic system of signs and logic, strategies would belong to the area of 'methodeutic' (a third area of logic besides grammar and critic). Hanson's distinction of three ingredients of logic of discovery, that is, *anomalous phenomena*, the delineation of the *type* of hypotheses, and the search for a *pattern*, can also be

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25 Other referee of this thesis remarked that I do not look into the meaning of 'surprise' (or anomalous phenomena) in Peirce's formulations of abduction, nor am I clear about my position regarding strategies, because in some passages I seem to emphasize more the role of surprise (Paavola 2004a [article I], 274) than in others (Paavola 2004b [article III], 261). I acknowledge that Peirce usually emphasized surprise in his formulations, and my aim is not to reduce the meaning of it as a starting point for abduction (actually quite the contrary), although I think that the reasoner can start to draw abductive inferences also with non-surprising phenomena (e.g. if a murder has happened in a neighbourhood where there have been a lot of murders during the past years, the police might still start drawing abductive hypotheses of potential suspects or explanations; if there are no obvious suspects). I maintain that it is a strategic point, in relation also to the economy of research, to concentrate on surprising phenomena. This is because, if there are no obvious candidate explanations available (in which case there were no need for further abductions) it is a strategic point to concentrate on curious or surprising phenomena – the idea is that there must be some reasons for these surprising phenomena, and by finding them the case is often solved. It has been maintained that this is, at least, how the famous detectives like Sherlock Holmes operate (see e.g. Sebeok & Umiker-Sebeok 1983, 52 n.19).

interpreted strategically. In summary, abduction is a weak form of reasoning and the hypothesis is in the premises but still it can conceptualize the area of discovery if the whole strategic process of reasoning is taken into account.

Article II

Paavola, S. (2006). Hansonian and Harmanian Abduction as Models of Discovery. *International Studies in the Philosophy of Science 20*(1), 91-106.

Nowadays the term 'abduction' is often used as a synonym for the Inference to the Best Explanation (IBE) model. IBE has its basis especially Gilbert Harman's writings in the 1960s although Peirce is also referred as one precursor of this idea ("Harmanian abduction"). A closely related but different conception is a "Hansonian" version of abduction. N. R. Hanson maintained in the 1950s and 1960s that Peirce's abductive inference gives a way of conceptualizing the area of discovery. I maintain in the article II that these two uses of abduction should be discriminated (see also Minnameier 2004), and for analyzing processes of discovery, "Hansonian abduction" is a more fruitful model, especially when it is developed further.

I analyze Peter Lipton's (2004) version of IBE. Lipton has made important distinctions in relation to IBE, especially between actual and potential explanations on the one hand, and likely and lovely explanations on the other hand. These distinctions bring IBE (i.e. Harmanian abduction) nearer to Hansonian abduction than standard versions of IBE. *Hansonian* abduction is still a more amenable model for discovery, basically because it is a weaker form of inference than IBE. I also maintain that Lipton's criteria for loveliness are better suited for *Hansonian* abduction than for IBE. Loveliness is a good strategic guide in discovery although it does not guarantee the truth of hypotheses.

As an example I analyze Ignaz Semmelweis' research on childbed fever which is a good case for a comparison because Hempel (1966) has used it as an example of the hypothetico-

deductive (HD) model of inquiry, and Lipton as an example of IBE. Lipton's reconstruction shows that, in contrast to HD-model, observations guided Semmelweis in his methodology. Hansonian abduction takes, however, more thoroughly into account the several phases in Semmelweis' research. He was basically *not* choosing the best explanation from various alternatives, but rather using various clues, information, and tentative restrictions as aids when searching for novel candidate explanations. He produced these one at a time until he found an alternative that helped him to reduce the mortality and gave a plausible explanation for the disease.

Article III

Paavola, S. (2004b). Abduction through Grammar, Critic and Methodeutic. *Transactions of the Charles S. Peirce Society 40*(2), 245-270. Available also: http://www.helsinki.fi/science/commens/papers/abduction_through.pdf

In article III I take Peirce's own conceptions concerning abduction as an object of a more thorough analysis. My aim is not, however, only a historical description of the development of Peirce's ideas but rather to use Peirce's conceptions for developing abduction further. Peirce's conceptions of abduction are usually divided into two phases, 1) an early period where Peirce understood abduction as an *evidencing* process, and 2) a later period where Peirce emphasized a *methodological* perspective on abduction. I agree with this but add that a clearer mark of a change was the role of an "instinct" for finding hypotheses; in his early conceptions instinct had no role *within* abduction but in later writings it was a central aspect of abduction.

I clarify the nature of abduction by using Peirce's distinction between three areas of logic or semeiotic, that is, the distinction between *grammar*, *critic*, and *methodeutic*. Debates on abduction have emphasized critic, which concentrates on the validity and the strength of abduction. These aspects should not be neglected, but grammar and methodeutic give new means for developing and

understanding abduction further. Peirce himself did not explicitly develop these aspects of abduction very much.

First, I analyze how Peirce's conceptions of the strength and the validity of abduction (i.e., critic) changed during the years. Grammar, on the other hand, focuses on the nature and meaning of categories and the sign relationships within abduction, especially on the special role of "Firstnesses" and iconicity. Methodeutic emphasizes a processual approach on inquiry. For Peirce this meant, for example, an economy of research. I maintain that Methodeutic should also involve strategic aspects, especially if abduction is interpreted as a logic of discovery. The concept of abduction then gives room for various forms of abduction.

Article IV

Paavola, S. (2005) Peircean abduction: instinct or inference? *Semiotica 153*-1/4, 131-154.

In this article, I analyze one basic problem within Peirce's later conception of abduction. Peirce held a controversial view that new abductive ideas and hypotheses are products of an *instinct* and an *inference* at the same time. There are different interpretations of how Peirce managed, or, *if* he managed to combine these elements within a mode of inference. In his early writings Peirce himself had left instinct outside of all reasoning, including abductive.

In various writings, Peirce gave different, interwoven bases for the abductive, guessing instinct, extending from naturalistic to idealistic (or metaphysical), even to theistic characterizations (see Shanahan 1986). I explicate these grounds, focusing especially on various ways of interpreting his naturalistic grounds for abduction by separating three varieties of it found within Peirce's texts; 1) 'adaptive instinct', 2) 'perceptual insight', and 3) 'guessing with non-conscious clues'.

As my own interpretation, I maintain that it is beneficial to make a clear, analytic distinction between abductive inference and abductive instinct. Accordingly, they are related, but distinct conceptions, which can both be developed further. In actual

problem-solving situations, both are needed. Although this interpretation differs from Peirce's own conception in his later work, it can be supported by Peirce's own writings.

Article V

Paavola, S. & Hakkarainen, K. (2005). Three abductive solutions to the Meno paradox – with instinct, inference, and distributed cognition. *Studies in Philosophy and Education 24*(3-4), 235-253.

This paper continues where the article IV ended. We analyze what kind of means abduction gives for answering the challenge provided by the classical Meno paradox. The Meno paradox (or its version concerning learning) problematizes the way human beings can conduct research or learn something new or conceptually more complex than before. Abduction is a good candidate for taking this challenge because it is meant to conceptualize the area of discovery.

We provide three interrelated answers on the basis of Peirce's ideas of abduction, and in relation to modern cognitive science. *Abductive "instinct"* means that human beings can use non-conscious clues when searching for new solutions. It has connections to experts' tacit knowledge, "intuition", and sense of promisingness. *Abductive inference* uses strategic rules when taking anomalous phenomena, tentative restrictions and many moves of reasoning into account at the same time. Besides these, abduction can be seen *as a part of distributed cognition*.

We delineate, in a preliminary fashion, how the interaction between cultural, social and material environment should be taken into account within abductive search for new ideas. Peirce's conceptions have affinities with modern ideas concerning distributed cognition, mediated activity, and the use of external artifacts as a basis for human cognitive activity. We develop further those ideas which Magnani (2001) has called *manipulative abduction*, which provides a kind of an interactionist or semeiotic solution to the Meno paradox.

Article VI

Paavola, Sami, Hakkarainen, Kai & Sintonen, Matti (2006). Abduction with Dialogical and Trialogical Means. *Logic Journal of the IGPL 14*(2), 137-150.

This study embeds abductive search for new ideas within a broader framework concerning human cognitive activity than just reasoning as such. Our aim is a model for conceptualizing basic epistemological processes needed for understanding dynamics of inquiry. First we analyze connections between abductive inference and the interrogative model of inquiry. Abduction is closely connected to questioning, especially to explanation-seeking why-questions. It is natural to interpret this process of explanation-seeking to happen as a sort of a game or a dialogue between the inquirer and the source of knowledge.

We suggest, however, that "dialogicality" should be broadened to a "trialogical" framework if modern ideas about distributed cognition and mediated activity are taken into account. We delineate some basic ideas for "trialogical" epistemology by comparing Pera's dialectical model of science, Davidson's theory of triangulation, Peirce's theory of signs, and Skagestad's augmentationism. There is no one-to-one match with these models but nevertheless fundamental similarities. Instead of conceptualizing human beings as processing information just in their "heads" inquirers are seen as fundamentally connected both to other inquirers (cultural resources, community) and "nature" ("world", indexical object of inquiry) through developing mediating artifacts and shared objects of activity collaboratively.

7. Conclusions and General Discussion

The aim of this study is to use and develop abduction to conceptualise processes of discovery: or, to put it differently, to determine whether and in which senses such development can be

carried out. As I see it, this means a continuation of a "Hansonian" (or a "Peircean-Hansonian") research programme (see Paavola 2001; cf. Gabbay & Woods 2005, 107-8). Hanson sought a "logic of discovery," but not as a mechanical device or an algorithm for making discoveries; rather the logic was to be a conceptual means for analysing the area of inquiry where hypotheses are introduced. Although there is no clear distinction between the context of discovery and the context of justification, Hanson was right in emphasizing that there are also reasons for *suggesting* hypotheses not just for accepting them. Hanson's own formulations of abduction are not, however, adequate (see e.g., Nickles 1980a; Lugg 1985), and my aim is to develop this Hansonian programme further by understanding abduction more broadly than through just one formulation of abduction, by focusing on *processes* of abduction, and by seeing abduction as one element within a large process of inquiry. My starting point is abduction as a *mode of inference*. This does not contradict more formal treatments (such as formal systems of abductive logic), nor more informal treatments (like abduction as a sort of a guessing capability) but the focus is on inferential structures as a basis for abduction.

Hanson sought a methodological model which would be an alternative to inductive and hypothetico-deductive (HD) models of inquiry. Most research in the 20th-century philosophy of science emphasized methodology that was akin to the HD-model. This emphasis fitted well with the idea that observations are always "theory-laden". Popper, as a clear representative of this view, emphasized that methodology cannot has its basis in an empiricist or inductive "bucket theory", that is, as if an inquiry could start from a bucket of observations and facts (taken as given), and then proceed to generalizations and new theories (Popper 1972, 60-64; 341-361). What Popper suggested was a "searchlight theory", that is, theories and hypotheses always guide observations (ibid.). Abductive methodology agrees in many ways with this model.[26]

[26] Similarly, a Hansonian model of abduction and T. S. Kuhn's theory of paradigm shifts, although at the first glance appearing very clearly opposite to each other, when it comes to logic of discovery, have

According to it, inductive methodology cannot be a basic model for inquiry, and theories and hypotheses essentially guide our observations and the interpretation of facts. Hanson also stressed that observations are always theory-laden (Hanson 1958a). But in contrast to Popper (and HD-model), abductive methodology highlights that the inquirers must have means for searching, finding or constructing "searchlights" (i.e., to have means for *finding* and *producing* fertile, tentative hypotheses, ideas and new theories). Otherwise, the process of inquiry cannot get started, but is a process of a random trial. The claim also is that, in cycles of inquiry, one has observations, facts and experiments (on one's own part) to guide the search for new hypotheses and theories, as much as hypotheses and theories guide the subsequent inquiry (cf. Thagard 1998b, 327-328). Theories are then "observation-laden" as much as observations theory-laden (Paavola 2001). In actual cycles of inquiry, abductive, inductive and deductive inferences interact with each other and cannot be separated from one another, except perhaps analytically (see also Johansen 1988, 1258-1259).

The 20th-century philosophy of science for long tried to make a clear distinction between philosophical (i.e., conceptual) issues and empirical sciences. Within this distinction, discovery (at least in a generative sense) is the area for empirical sciences, and not for philosophy. After the "naturalistic" (or "computational", or "pragmatic") turn in the philosophy of science, these distinctions became much less clear although they still have a strong effect on discussions concerning discovery (cf. Gabbay & Woods 2005, 3-5). The rise of cognitive sciences in the latter half of the 20th-century has had an effect on philosophical models on discovery. It is not so easy to make a distinction between "empirical" and "conceptual" parts of science, if the starting point is human beings making inferences and using all kinds of representations as a part of their

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interesting features in common. Although Kuhn was not seeking a logic of discovery, his account reminds one strongly of abduction: paradigm shifts start with anomalies, and end up with new paradigms (cf. Hanson's patterns) and they seem to leave room for a weak form of inference (see Kuhn 1970, 52-53, 64, 155-158).

cognitive activities. Abductive models typically operate in areas which lie between a pure "logicalism" and "descriptivism", or between "deductivism" and pure chance, and are intended to conceptualize new means for capturing processes of inquiry (see Aliseda 2004; 2006, 16; cf. Kleiner 1993, Jung 1996).

A central basis for abduction is the claim that discovery is not about pure chance, but there are and *must be* some things which both constrain and instigate the search for new ideas (cf. Rescher 1978, 41-63; Gorlée 1996; Almeida 2002). For Peirce himself, this meant both "instinctive" and "reasoned" considerations (see Peirce CP 7.220, 1901). This has left room for various interpretations concerning Peirce's abduction. Some have emphasized instinctual considerations guiding the search for new ideas (Davis 1972 Ayim 1974, Chomsky 1968, Fodor); others have highlighted reasoned, i.e., inferential principles (Hanson 1961a, Reilly 1970, Andersen 1973). I argue that it is beneficial to make an analytic separation of instinctual and inferential considerations, and develop both of them further. As a third main area, I differentiate abduction in relation to social practices and distributed cognition (see also Bonfantini 1988, 1253-1254; Oatley 1996, 135-139).

In my interpretation, strategic aspects of abductive inference are emphasized (see also Hintikka 1998, Magnani, 1999, 235–236; Brogaard 1999b; Schurz, in press). This brings abduction close to an old idea according to which problem solving has its basis in various search spaces, but within an abductive, weak mode of inference (see also Levi 1978; 1980, 41-50; Gabbay & Woods 2005, 56-62, 66-69).[27] The use of abductive strategies brings new meaning to this idea. Other important aspects from an inferential point of view are iconicity and the criteria of loveliness (like mechanism criterion, precision criterion, unification criterion, elegance and simplicity criterion) which give further means when fertile

27 Abduction is a play with possibilities. It is a sort of a logic of search. Or, as Peirce remarked, abduction aims at giving a good "leave" (with the language of billiard-players) (see Peirce CP 7.221, 1901) for further inquiry although the hypothesis might be of unclear status as to its truth (only a candidate to be tested or developed).

hypotheses are searched for. By contrast, perceptual judgments and abductive instinct capture processes which are similar to abductive inference but without an element of conscious control which is essential in inference. Actual processes of inquiry do not, however, happen just inferentially or within an inquirer's head, which means that the abductive search for new ideas should be seen within the framework of distributed cognition. A basis for abductive hypotheses are not just ideas residing within conceptual space, but an interaction with the social, material, and cultural environment in long-term processes. Abduction should be brought in the middle of these processes (cf. Thagard 1998a; 1998b; Nesher 2001). I think that Peirce's broad philosophical system gives elements for an epistemological model which is a clear alternative to traditional empiricist and rationalist models (cf. e.g. Bernstein 1964; Davis 1972, 5-21; Hausman 1990; Skagestad 1993; Minnameier 2004; Rosenthal 2005), and which focuses on an interaction between different sign processes and categories. Various abductive processes are central in this model.

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Part II. Original Articles

Article I:
Paavola, Sami (2004a).
Abduction as a logic and methodology of discovery: The importance of strategies.
Foundations of Science 9 (3), 267-283.

Article II:
Paavola, Sami (2006).
Hansonian and Harmanian Abduction as Models of Discovery.
International Studies in the Philosophy of Science 20(1), 91-106.

Article III:
Paavola, S. (2004b).
Abduction through Grammar, Critic and Methodeutic.
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Article IV:
Paavola, Sami (2005).
Peircean abduction: instinct or inference?
Semiotica 153-1/4, 131-154.

Article V:
Paavola, Sami & Hakkarainen, Kai (2005).
Three abductive solutions to the Meno paradox – with instinct, inference, and distributed cognition.
Studies in Philosophy and Education 24(3-4), 235-253.

Article VI:
Paavola, Sami, Hakkarainen, Kai & Sintonen, Matti (2006).
Abduction with Dialogical and Trialogical Means.
Logic Journal of the IGPL 14(2), 137-150.