ABDUCTIVE REASONING

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ABDUCTIVE REASONING

LOGICAL INVESTIGATIONS INTO DISCOVERY AND EXPLANATION

by

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To Rodolfo

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Foreword

Many types of scientific reasoning have long been identified and recognised as supplying important methodologies for discovery and explanation in science, but many questions regarding their logical and computational properties still remain controversial. These styles of reasoning include induction, abduction, model-based reasoning, explanation and confirmation, all of them intimately related to problems of belief revision, theory development and knowledge assimilation. All of these have been addressed both in the philosophy of science and in the fields of artificial intelligence and cognitive science, but their respective approaches have been in general too far apart to leave room for an integrated account.

My general concern in this book is scientific discovery and explanation. The point of departure is to address an old but still unsettled question: does scientific methodology have a logic? There have been several conflicting stances about how to pose this question in the first place - not to mention the solutions - each of which rests on its own assumptions about the scope and limitations of scientific methodology and also in their attitude to logic. This question has been posed within several research traditions and for a variety of motivations and purposes, and that fact has naturally shaped the way it has been tackled. In this respect the answer is often already implicit in the very posing of the question itself, which in any case is not a yes-no matter.

Thus a closer look at aspects of this question is in order. While it is clear to everyone that scientific practice indeed involves both processes of discovery and explanation, the first point of disagreement is concerned with the proper scope of the methodology of science. In the predominant view of XXth century philosophy of science, creativity and discovery is simply out of bounds for philosophical reflection, and thus the above question is focused mainly on issues of explanation and testing. It is well known that great philosophers and mathematicians have been brilliant exceptions in the study of discovery in science, but their contributions have set no new paradigms in the methodology of

science, and instead have inspired research in cognitive science and artificial intelligence. There is indeed a rapidly growing research on issues of computational scientific discovery, which is full of computer programs which challenge the philosophical claim that the so called 'context of discovery' does not allow for any formal treatment. Thus, in this tradition discovery is part of scientific methodology, on a par with explanation.

As for the place of logic, there are also a variety of instances of what 'logic' amounts to in posing the above question. On the one hand, in XXth century positivist philosophy of science deductive logic was the predominant formal framework to address issues of explanation and evaluation. From the start it was clear that inductive logic had too little on offer for a proper logical analysis of scientific methodology, and this provided the leeway for alternative proposals, such as Popper's conjectures and refutations logical method. Computer oriented research, on the other hand, identifies logic with 'pattern seeking methods', a notion which fits very well their algorithmic and empirical approach to the above question. In any case, the use of the term 'logic' regarding discovery has had little to do with providing logical foundations for their programs, either as conceived in the mathematical logical tradition or as in artificial intelligence logical research, both of which regard inference as the underlying logical notion. It is clear that classical logic cannot account for any kind of ampliative reasoning, and so far as the logical tools developed in artificial intelligence are concerned, not many of them have been applied to issues of discovery in the philosophy of science.

Aim and Purpose

In this book I offer a logical analysis of a particular type of scientific reasoning, namely abduction, that is, reasoning from an observation to its possible explanations. This approach naturally leads to connections with theories of explanation and empirical progress in the philosophy of science, to computationally oriented theories of belief change in artificial intelligence, and to the philosophical position known as Pragmatism, proposed by Charles Peirce, to whom the term abduction owes its name. The last part of the book is concerned with all these applications.

My analysis rests on several general assumptions. First of all, it assumes that there is no single logical method in scientific practice in general, and with respect to abduction in particular. In this my view is pluralistic. To be sure, abduction is not a new form of inference. It is rather a topic-dependent practice of explanatory reasoning, which can be supported by various notions of inference, classical and otherwise. By this assumption, however, I do not claim it is possible to provide a logical analysis for all and every part of scientific inquiry. In this respect, my enterprise is modest and has no pretensions that it can offer either a logical analysis of great scientific discoveries, or put forward a set of

logical systems that would provide general norms to make new discoveries. My aim is rather to lay down logical foundations in order to explore some of the formal properties under which new ideas may be generated and evaluated. The compensation we gain from this very modest approach is that we can gain some insight into the logical features of some parts of the scientific discovery and explanation processes. This is in line with a well-known view in the philosophy of science, namely that phenomena take place within traditions, something which echoes Kuhn's distinction between normal and revolutionary science. Hence, another general assumption is that a logical analysis of scientific discovery of the type I propose is for normal science, not denying there may be a place for some other kind of logical analysis of revolutionary science, but clearly leaving it out of the scope of this enterprise.

Another general assumption is that the methodological distinction between the contexts of discovery and justification is an artificial one. It can be dissolved if we address abduction as a process rather than as a ready-made product by itself for us to study. Historical as well as computationally oriented research of scientific discoveries show very clearly that new ideas do not just come out of the blue (even though there may be cases of sudden flashes of insight), and that the process of discovery often involves a lot of explanation, evaluation and testing on the way, too. So, it may be possible to address the justification part of science all by itself, as contemporary philosophy has done all along, but once discovery issues come into play, an integrated account of both is needed.

Content Description

This book is divided into three parts: (I) Conceptual Framework, (II) Logical Foundations, and (III) Applications, each of which is briefly described in what follows.

In part I, the setting for the logical approach taken in this book is presented. One the one hand, chapter 1 offers a general overview of the logics of discovery enterprise as well as the role of logic in scientific methodology, both in philosophy of science and in the fields of artificial intelligence and cognitive science. The main argument is that logic should have a place in the normative study in the methodology of science, on a par with historical and other formal computational approaches. Chapter 2 provides an overview of research on abduction, showing that while there are general features and in most cases the main inspiration comes from the American pragmatist, Charles S. Peirce, each approach has taken a different route. To delineate our subject more precisely, and create some order, a general taxonomy for abductive reasoning is then proposed. Several forms of abduction are obtained by instantiating three parameters: the kind of reasoning involved (e.g., deductive, statistical), the kind of observation triggering the abduction (novelty, or anomaly with respect to some background theory), and the kind of explanations produced (facts, rules, or theories).

In part II, the logical foundations of this enterprise are laid down. In chapter 3, abduction is investigated as a notion of logical inference. It is shown that this type of reasoning can be analyzed within various kinds of logical consequence as the underlying inference, namely as classical inference (backwards deduction), statistical or as some type of non-monotonic inference. The logical properties of these various 'abductive explanatory kinds' are then investigated within the 'logical structural analysis', as proposed for non-monotonic consequence relations in artificial intelligence and dynamic styles of inference in formal semantics. As a result we can classify forms of abduction by different structural rules. A computational logic analysis of processes producing abductive inferences is then presented in chapter 4, using and extending the mathematical framework of semantic tableaux. I show how to implement various search strategies to generate various forms of abductive explanations. Our eventual conclusion for this part is that abductive processes should be our primary concern, with abductive explanatory inferences as their secondary 'products'.

Part III is a confrontation of the previous analysis and foundations with existing themes in the philosophy of science and artificial intelligence. In particular, in chapter 5, I analyze the well-known Hempelian models for scientific explanation (the deductive-nomological one, and the inductive-statistical one) as forms of abductive explanatory arguments, the ultimate products of abductive reasoning. This then provides them with a structural logical analysis in the style of chapter 3. In chapter 6, I address the question of the dynamics of empirical progress, both in theory evaluation and in theory improvement. I meet the challenge made by Theo Kuipers [Kui99], namely to operationalize the task of 'instrumentalist abduction', that is, theory revision aiming at empirical progress. I offer a reformulation of Kuipers' account of empirical progress into the framework of (extended) semantic tableaux, in the style of chapter 4, and show that this is indeed an appealing method to account for empirical progress of some specific kind of empirical progress, that of lacunae.

The remaining two chapters have a common argument, namely that abduction may be viewed as a process of epistemic change for belief revision, an idea which connects naturally to the notion of abduction in the work of Charles Peirce, and that of belief revision in the work of Peter Gärdenfors, thus suggesting a direct link between philosophy and artificial intelligence. In chapter 7, I explore the connection between abduction and pragmatism, as proposed by Peirce, showing that the former is conceived as an epistemic procedure for logical inquiry, and that it is indeed the basis for the latter, conceived as a method of philosophical reflection with the ultimate goal of generating 'clear ideas'. Moreover, I argue that abduction viewed in this way can model dynamics of belief revision in artificial intelligence. For this purpose, an extended version of the semantic tableaux of chapter 4 provides a new representation of the

operations of expansion, and contraction, all of which shapes the content of chapter 8.

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'Logics in Scientific Discovery', *Foundations of Science*, Volume 9, Issue 3, pp. 339–363. Kluwer Academic Publishers. 2004. (Chapter 1).

Seeking Explanations: Abduction in Logic, Philosophy of Science and Artificial Intelligence. PhD Dissertation, Philosophy Department, Stanford University. Published by the Institute for Logic, Language and Computation (ILLC), University of Amsterdam, 1997. (ILLC Dissertation Series 1997–4). (Chapters 2, 3, 4, 5 and 8).

'Mathematical Reasoning Vs. Abductive Reasoning: An Structural Approach', *Synthese* 134: 25–44. Kluwer Academic Press. 2003. (Chapter 3).

'Computing Abduction in Semantic Tableaux', *Computación y Sistemas: Revista Iberoamericana de Computación*, volume II, number 1, pp. 5–13. Centro de Investigación en Computación (CIC), Instituto Politécnico Nacional, México. 1998. (Chapter 4).

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'Lacunae, Empirical Progress and Semantic Tableaux', to appear in R. Festa, A. Aliseda and J. Peijnenburg (eds). *Confirmation, Empirical Progress, and Truth Approximation (Poznan Studies in the Philosophy of the Sciences and the Humanities*, vol. 83), pp. 141–161. Amsterdam/Atlanta, GA: Rodopi. 2005. (Chapter 6).

'Abduction as Epistemic Change: A Peircean Model in Artificial Intelligence'. In P. Flach and A. Kakas (eds). *Abductive and Inductive Reasoning: Essays on their Relation and Integration*, pp. 45–58. Kluwer Academic Publishers, Applied Logic Series. 2000. (Chapters 7 and 8).

'Abducción y Pragmati(ci)smo en C.S. Peirce'. In Cabanchik, S., etal. (eds.). *El Giro Pragmático en la Filosofía Contemporánea*. Gedisa, Argentina. 2003. (Chapter 7).

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