Abduction and Induction

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Abduction and Induction

Essays on their Relation and Integration

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Foreword

Reasoning in reverse

Logic is the systematic study of cogent reasoning. The central process of reasoning studied by modern logicians is the accumulative *deduction*, usually explained semantically, as taking us from truths to further truths. But actually, this emphasis is the result of a historical contraction of the agenda for the field. Up to the 1930s, many logic textbooks still treated deduction, induction, confirmation, and various further forms of reasoning in a broader sense as part of the logical core curriculum. And moving back to the 19th century, authors like Mill or Peirce included various non-deductive modes of reasoning (induction, abduction) on a par with material that we would recognize at once as 'modern' concerns. Since these non-deductive styles of reasoning seemed irrelevant to foundational research in mathematics, they moved out quietly in the Golden Age of mathematical logic. But they do remain central to a logical understanding of ordinary human cognition. These days, this older broader agenda is coming back to life, mostly under the influence of Artificial Intelligence, but now pursued by more sophisticated techniques – made available, incidentally, by advances in mathematical logic...

The present volume is devoted to two major varieties of non-deductive inference, namely *abduction* and *induction*, identified as logical 'twins' by C.S. Peirce, but discovered independently under many different names. Roughly speaking, abduction is about finding explanations for observed facts, viewed as missing premises in an argument from available background knowledge deriving those facts. Equally roughly speaking, induction is about finding general rules covering a large number of given observations. Both these phenomena have been studied by philosophers of science since the 1950s, such as Carnap (the pioneer of inductive logic) and Hempel (whose 'logico-deductive' model of explanation has unmistakable abductive features). Another major contribution was made by Popper. If good news travels in this forward direction, bad news travels in the opposite. Valid consequences also take us from false conclusions to falsity of at least one of the premises, allowing us to learn by revision – even though we may have some latitude in where to assign the blame. Thus, reasoning is also tied up with scientific theory change, and more generally, flux of our commonsense opinions. What the present volume shows is how these concerns are

converging with those of logicians and computer scientists, into a broader picture of what reasoning is all about.

A pervasive initial problem in this area, even if just an irritant, is *terminology*. Some people feel that 'abduction' and 'induction', once baptised, must be real phenomena. But they might be mere terms of art, still looking for a substantial denotation... Indeed, it is not easy to give a crystal-clear definition for them, either independently or in their inter-relationship. (Of course, this is not easy for 'deduction' either.) Fortunately, the editors do an excellent job in their introductory chapter of clearing up a number of confusions, and relating abduction and induction in a productive manner. No need to repeat that. Instead, let me highlight how the subject of this book intertwines many general features of reasoning that need to be understood – and that somehow manage to escape from the usual logical agenda. For this purpose, we must make some distinctions.

Every type of reasoning revolves around some underlying *connection*, giving us a link with a certain 'quality' between input (data) and output (conclusions). The classical schema for this connection is the binary format $P, Q, \ldots \models C$. But this format leaves many 'degrees of freedom', that are essential to reasoning. First, the *strength* of the connection may vary. With Tarski it says "all models of the premises $P, Q, \ldots$ are also models for the conclusion C". But there are respectable alternatives which ask less: replacing "all" by "almost all" (as happens in some probabilistic reasoning), or by "all most preferred" (as in non-monotonic logics in AI). This variety of 'styles of reasoning' can be traced back to the pioneering work of Bolzano in the early 19th century, including an awareness – wide-spread now, but quite novel then – that these different styles differ, not only in the individual inferences they sanction, but also in their general structural rules, such as Monotonicity of Transitivity. Second, varieties of logical consequence multiply by the existence of very different viewpoints on the connection. All variations so far were *semantic*, in terms of models, truth, and preference. But we can also analyse cogent reasoning in a *proof-theoretic* manner (consequence as derivability), giving us options between classical, or intuitionistic, or linear logic – or a *game-theoretic* one (where valid consequence is the existence of a winning strategy for a proponent in debate), giving us yet further logical systems.

Another key dimension to reasoning is *direction*. Standard logical inference moves forward, from given premises to new conclusions. But abduction moves backwards, looking for premises that imply a given conclusion. The backwards direction is often less deterministic, as we can choose from a vast background reservoir of knowledge, prejudices, hypotheses, etc. Indeed, to put backwards reasoning in proper perspective, we need richer formats of inference. An example is Toulmin's schema from the 1950s, where claims follow from data via a 'warrant', where data are backed up by evidence, and warrants by background theory. Thus, we are led naturally to a study of *theory structure*. The latter is prominent in the philosophy of science, where assertions may fall into laws, facts, and auxiliary hypotheses. This structure seems essential to logical analysis of reasoning. Thus, abduction looks for facts, while induction searches for regularities. Indeed, would the same distinctions make sense in the forward direction?

Structured theories fix different roles for assertions. A more radical view would be that such roles are not fixed globally, but just represent a focus in the current *con-*

text. What counts as a 'relevant' assertion, or as an 'explanation' for a given observation, may depend on the dynamics of some ongoing argument – and the topic of conversation. This epistemic flux reflects a general modern concern. Inferential connections and theory structures are static entities, but actual reasoning is a *dynamic process*, driven by purposes over time. This dynamics is reflected in standard accounts of abduction and induction, as being about 'finding' explanations or generalizations. But even standard deduction is usually dynamically goal-driven, say by a conjecture, pulling us toward intermediate results. Of course, we need to 'compare like to like': abduction, induction and deduction all have both static and dynamic aspects.

Another dimension of fine-structure is the role of *language* in reasoning. Eventually, one cannot understand the workings of a style of inference without understanding its concomitant language design. E.g., the above distinction between individual facts and general assertions is language-dependent. (I do not know of any conclusive semantic underpinning for it.) Likewise, the choice of concrete and abstract vocabulary is essential to perspicuous theory structure, as is well-known from philosophy of science. But also, different notions of consequence suggests different vocabularies of logical operators reflecting 'control structures' of the process, witness classical, intuitionistic, or modal logic. Modern non-standard logics invite even more exotic new operations.

Finally, this book highlights issues of *combination*. Different forms of reasoning do not live in isolated domains, they interact. This is clear even in classical mathematics, where backwards problem Analysis lived side-by-side with forward proof Synthesis. Logic systems like semantic tableaux have this same dual character. In this book, abduction and induction occur intertwined, which raises many additional questions. This is one instance of a more general trend toward understanding the *architecture* of logical systems, and its effects on the *complexity* of their behaviour in bulk.

Reasoning is a many-dimensional process, involving a complex interplay of inferential connections, language design, changing directions, and larger-scale combinations. Naturally, the present Book does not address all this once and for all. But it does throw open windows towards understanding the true complexities of reasoning, by presenting abduction and induction intertwined as a fascinating case study for 'real logic'.

Johan van Benthem

Preface

From the very beginning of investigation of human reasoning, philosophers had identified – along with deduction – two other forms of reasoning which we now call abduction and induction. Whereas deduction has been widely studied over the years and is now fairly well understood, these two other forms of reasoning have, until now, eluded a similar level of understanding. Their study has concentrated more on the role they play in the evolution of knowledge and the development of scientific theories.

In an attempt to increase our understanding of these two forms of non-deductive reasoning, this book presents a collection of works addressing the issues of the relation between abduction and induction, as well as their possible integration. These issues are approached sometimes from a philosophical perspective, sometimes from a (purely) logical perspective, but also from the more task-oriented perspective of Artificial Intelligence. To a certain extent, the emphasis lies with the last area of Artificial Intelligence, where abduction and induction have been more intensively studied in recent years.

This book grew out of a series of workshops on this topic. The first of these took place at the Twelfth European Conference on Artificial Intelligence (Budapest, August 1996), and concentrated on the general philosophical issues pertaining to the unification or distinction between abduction and induction. The second workshop took place at the Fifteenth International Joint Conference on Artificial Intelligence (Nagoya, August 1997), with an emphasis on the more practical issues of integration of abduction and induction. Taking place in parallel with the preparation of this book, a third workshop was held at the Thirteenth European Conference on Artificial Intelligence (Brighton, August 1998). Detailed reports on the first two workshops have been published as (Flach and Kakas, 1997a; Flach and Kakas, 1998); these reports, as well as further information about the workshops (including submitted papers), are available on-line at `http://www.cs.bris.ac.uk/~flach/abdind/`.

After the first two workshops, we invited the participants to submit a longer paper based on their workshop contribution(s), suitable for publication in an edited volume. Following a careful reviewing process, thirteen of the submitted papers were selected for publication. In addition, we invited four well-known authors to contribute a paper: John Josephson, Luca Console, Lorenza Saitta, and David Poole.

Following a general introduction into the subject, the book is structured into four main parts. The first two parts take a more theoretical perspective, while the remaining two parts address the more practical issue of integrating abduction and induction. Part 1 contains three papers addressing philosophical aspects of abduction and induction. In Part 2, four papers investigate the logical relation of the two forms of reasoning. The four papers in Part 3 deal with integration of the two forms of reasoning from the perspective of Artificial Intelligence, while the five papers that can be found in Part 4 address this problem within the more particular framework of Logic Programming. The book starts off with an introductory chapter aimed at helping the reader in two ways. It provides background material on the general subject of the book and exposes the main issues involved. At the same time it positions the other contributions in the book within the general terrain of debate.

The present book is one of the first books to address explicitly the problem of understanding the relation and interaction between abduction and induction in the various fields of study where these two forms of reasoning appear. As such, it should be relevant to a variety of students and researchers from these different areas of study, such as philosophers, logicians, and people working in Artificial Intelligence and Computer Science more generally.

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We would like to thank all persons who helped in one way or another with the preparation of this book.

These are all those involved in the organisation of the three workshops on the subject at ECAI'96, IJCAI'97 and ECAI'98, where much of the groundwork for this book has been done. In particular, we would like to thank the other members of the organising committees of these workshops: Henning Christiansen, Luca Console, Marc Denecker, Luc De Raedt, Randy Goebel, Katsumi Inoue, John Josephson, Ray Mooney and Chiaki Sakama. A special thanks goes to the three invited speakers at these workshops, John Josephson, David Poole and Murray Shanahan. And of course we are grateful to all the participants, for the pleasant atmosphere and lively discussions during the workshops. Finally, we would like to thank the two European networks of excellence, Compulog-Net and ML-Net, for their financial support in organising these workshops.

We thank everybody who submitted a paper to this book; those who helped reviewing the submissions; the invited authors for their marvellous contributions; and Johan van Benthem for his beautiful and thought-provoking foreword.

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1 ABDUCTIVE AND INDUCTIVE REASONING: BACKGROUND AND ISSUES

Peter A. Flach and Antonis C. Kakas

1.1 INTRODUCTION

This collection is devoted to the analysis and application of abductive and inductive reasoning in a common context, studying their relation and possible ways for integration. There are several reasons for doing so. One reason is practical, and based on the expectation that abduction and induction are sufficiently similar to allow for a tight integration in practical systems, yet sufficiently complementary for this integration to be useful and productive.

Our interest in combining abduction and induction is not purely practical, however. Conceptually, the relation between abduction and induction is not well understood. More precisely, there are several, mutually incompatible ways to perceive this relation. For instance, Josephson writes that 'it is possible to treat every good (...) inductive generalisation as an instance of abduction' (Josephson, 1994, p.19), while Michalski has it that 'inductive inference was defined as a process of generating descriptions that imply original facts in the context of background knowledge. Such a general definition includes inductive generalisation and abduction as special cases' (Michalski, 1987, p.188).

One can argue that such incompatible viewpoints indicate that abduction and induction themselves are not well-defined. Once their definitions have been fixed, studying their relation becomes a technical rather than a conceptual matter. However, it is not self-evident why there should exist absolute, Platonic ideals of abduction and induction, waiting to be discovered and captured once and for all by an appropriate defini-

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tion. As with most theoretical notions, it is more a matter of pragmatics, of how useful a particular definition is going to be in a particular context.

A more relativistic viewpoint is often more productive in these matters, looking at situations where it might be more appropriate to distinguish between abduction and induction, and also at cases where it seems more useful to unify them. Sometimes we want to stress that abduction and induction spring from a common root (say hypothetical or non-deductive reasoning), and sometimes we want to take a finer grained perspective by looking at what distinguishes them (e.g. the way in which the hypothesis extends our knowledge). The following questions will therefore be our guidelines:

- When and how will it be useful to unify, or distinguish, abduction and induction?
- How can abduction and induction be usefully integrated?

Here and elsewhere, by *unification* we mean considering them as part of a common framework, while by *integration* we mean employing them together, in some mutually enhancing way, for a practical purpose.

The current state of affairs with regard to these issues is perhaps most adequately described as an ongoing debate, and the reader should look upon the following chapters as representing a range of possible positions in this debate. One of our aims in this introductory chapter is to chart the terrain where the debate is taking place, and to position the contributions to this volume within the terrain. We will retrace some of the main issues in this debate to their historical background. We will also attempt a synthesis of some of these issues, primarily motivated by work in artificial intelligence, sometimes taking positions that may not be shared by every author in this volume.

The outline of this chapter is as follows. In Section 1.2 we discuss the philosophical and logical origins of abduction and induction. In Section 1.3 we analyse previous work on abduction and induction in the context of logic programming and artificial intelligence, and attempt a (partial) synthesis of this work. Section 1.4 considers the integration of abduction and induction in artificial intelligence, and Section 1.5 concludes.

Before we embark on this, let us express our sincere thanks for all authors contributing to this volume, without whom we couldn't have written this introduction – indeed, some of the viewpoints we're advocating have been strongly influenced by the other contributions. Wherever possible we have tried to indicate the original source of a viewpoint we discuss, but we apologise in advance for any omissions in this respect.

1.2 ABDUCTION AND INDUCTION IN PHILOSOPHY AND LOGIC

In this section we discuss various possible viewpoints on abduction and induction that can be found in the philosophical and logical literature.The philosophical issue is mainly one of categorisation (which forms of reasoning exist?), while the logical issue is one of formalisation.

As far as categorisation is concerned, it seems uncontroversial that deduction should be singled out as a separate reasoning form which is fundamentally different from any other form of reasoning by virtue of its truth-preserving nature. The question, then, is how non-deductive reasoning should be mapped out. One school of thought holds