Foreword

Analogical reasoning is ubiquitous, whether in everyday common sense reasoning, in scientific discovery, or anywhere in between. Examples of analogical reasoning range from scientific theory creation, such as Bohr's planetary model of the atom, to problem solving where a teacher's solution of an illustrative example problem is used to guide the student in solving new, similar problems. Psychologists have studied how people reason analogically, though often severely simplifying the reasoning task in order to run controlled experiments. Artificial intelligence researchers, including this writer, have built computational models that exhibit various forms of analogical transfer, ranging from simple copy-and-modify processes to complex derivational-trace tracking and rejustifying reasoning steps for new problems. The underlying issues are not simple. For instance, in drawing an analogy, what should be kept invariant, what should be modified or mapped, and what should be discarded? At what level of reasoning is analogy most profitably applied – i.e., should the solution to a problem be transferred and modified, should the derivation of the solution be transferred instead, or should the underlying principles invoked in the derivation be the primary transfer vehicle? How does analogical reasoning interact with classical deduction or with inductive reasoning? And how can a solution drawn analogically be formally verified or refuted, in the sense of formal proof checking? These and other key issues lie at the heart of analogical reasoning research.

Artificial intelligence researchers and cognitive psychologists have addressed subsets of the analogical reasoning challenge. However, until now there has not been a true marriage of the psychological and the computational in the realm of analogical reasoning. Although both camps cite each other and mutually benefit from new results, Ute Schmid is the first to develop, implement, test, and evaluate analogical reasoning models in depth based directly on data from subjects performing that reasoning.

This book is a very thorough and clear report of Dr. Schmid's deep analysis of inductive and analogical reasoning, combining key aspects of artificial intelligence and algorithms on the one hand, and cognitive psychology on the other. Compared with related work, the comprehensive nature of the analogical reasoning model is evident: The case-based reasoning (CBR) community focuses primarily on indexing and retrieving relevant past cases, rather than deriving new solutions or solving significantly different problems. Earlier analogical reasoning work focused directly on problem solving – how to use past solutions for similar problems to help construct the solution to the new problem. Veloso combined CBR and analogical reasoning, enabling large-scale problem solving from second-principles. Subsequently, analogical reasoning has seen new extensions such as Melis's method for analogical construction of mathematical proofs and the use of analogy in intelligent tutoring systems. This book combines all the aspects of analogical reasoning, extends it to include other forms of inductive and deductive reasoning, and directly ties the computational methods to psychological results.

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Preface

In this book a novel approach to inductive synthesis of recursive functions is proposed, combining universal planning, folding of finite programs, and schema abstraction by analogical reasoning. In a first step, an example domain of small complexity is explored by universal planning. For example, for all possible lists over four fixed natural numbers, their optimal transformation sequences into the sorted list are calculated and represented as a DAG. In a second step, the plan is transformed into a finite program term. Plan transformation mainly relies on inferring the data type underlying a given plan. In a third step, the finite program is folded into (a set of) recursive functions. Folding is performed by syntactical pattern-matching and corresponds to inducing a special class of context-free tree grammars. It is shown that the approach can be successfully applied to learn domain-specific control rules. Control rule learning is important to gain the efficiency of domain-specific planners without the need to hand-code the domain-specific knowledge. Furthermore, an extension of planning based on a purely relational domain description language to function applications is presented. This extension makes planning applicable to a larger class of problems that are of interest for program synthesis.

As a last step, a hierarchy of program schemes (patterns) is generated by generalizing over already synthesized recursive functions. Generalization can be considered as the last step of problem solving by analogy or programming by analogy. Some psychological experiments were performed to investigate which kind of structural relations between problems can be exploited by human problem-solvers. Anti-unification is presented as an approach to mapping and generalizing program structures. It is proposed that the integration of planning, program synthesis, and analogical reasoning contributes to cognitive science research on skill acquisition by addressing the problem of extracting generalized rules from some initial experience. Such (control) rules represent domain-specific problem-solving strategies.

All parts of the approach are implemented in Common Lisp.

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