A THEORY AND METHODOLOGY OF INDUCTIVE LEARNING

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ABSTRACT

The presented theory views inductive learning as a heuristic search through a space of symbolic descriptions, generated by an application of various inference rules to the initial observational statements. The inference rules include generalization rules, which perform generalizing transformations on descriptions, and conventional truth-preserving deductive rules. The application of the inference rules to descriptions is constrained by problem background knowledge, and guided by criteria evaluating the "quality" of generated inductive assertions.

Based on this theory, a general methodology for learning structural descriptions from examples, called Star, is described and illustrated by a problem from the area of conceptual data analysis.

4.1 INTRODUCTION

"...Scientific knowledge through demonstration¹ is impossible unless a man knows the primary immediate premises ... We must get to know the primary premises by induction; for the method by which even sense-perception implants the universal is inductive..."—Aristotle, Posterior Analytics, Book II, Chapter 19 (circa 330 B.C.)

The ability of people to make accurate generalizations from a few scattered

¹That is, what we now call "deduction".
facts or to discover patterns in seemingly chaotic collections of observations is a fascinating research topic of long-standing interest. The understanding of this ability is now also of growing practical importance, as it holds the key to an improvement of methods by which computers can acquire knowledge. A need for such an improvement is evidenced by the fact that knowledge acquisition is presently the most limiting "bottleneck" in the development of modern knowledge-intensive artificial intelligence systems.

The above ability is achieved by a process called inductive learning, that is, inductive inference from facts provided by a teacher or the environment. The study and modeling of this form of learning is one of the central topics of machine learning. This chapter outlines a theory of inductive learning and then presents a methodology for acquiring general concepts from examples.

Before going further into this topic, let us first discuss the potential for applications of inductive learning systems. One such application is an automated construction of knowledge bases for expert systems. The present approach to constructing knowledge bases involves a tedious process of formalizing experts' knowledge and encoding it in some knowledge representation system, such as production rules [Shortliffe, 1976; Davis & Lenat, 1981] or a semantic network [Brachman, 1979; Gaschnig, 1980]. Inductive learning programs could provide both an improvement of the current techniques and a basis for developing alternative knowledge acquisition methods.

In appropriately selected small domains, inductive programs are already able to determine decision rules by induction from examples of expert decisions. This process greatly simplifies the transfer of knowledge from an expert into a machine. The feasibility of such inductive knowledge acquisition has been demonstrated in the expert system PLANT/DS, for the diagnosis of soybean diseases. In this system, the diagnostic rules were developed in two ways: by formalizing experts' diagnostic processes and by induction from examples. In an experiment where both types of diagnostic rules were tested on a few hundred disease cases, the inductively-derived rules outperformed the expert-derived ones [Michalski & Chilausky, 1980]. Another example is an inductive acquisition of decision rules for a chess end-game [Michalski & Negri, 1977; Quinlan, 1979; Shapiro & Niblett, 1982; O'Rorke, 1982]. (See also Chapter 15 of this book.)

A less direct, but potentially promising, use of inductive learning is for the refinement of knowledge-bases initially developed by human experts. Here, inductive learning programs could be used to detect and rectify inconsistencies, to remove redundancies, to cover gaps, and to simplify expert-derived decision rules. By applying an inductive inference program to the data, consisting of original rules and examples of correct and incorrect results of these rules' performance in new situations, the rules could be incrementally improved with little or no human assistance.

Another important application of inductive programs is in various experimental sciences, such as biology, chemistry, psychology, medicine, and genetics. Here they could assist a user in detecting interesting conceptual pat-