Artificial Intelligence and Mathematical Theory of Computation

Papers in Honor of John McCarthy

edited by
Vladimir Lifschitz

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Preface

This is a collection of papers by distinguished researchers, colleagues and former students of Professor John McCarthy, published on the occasion of his sixty-fourth birthday.

The papers discuss technical, historical and philosophical problems related to two areas of computer science: artificial intelligence and the mathematical theory of computation. The range of subjects discussed here includes automated deduction, logic programming, and the logic approach to artificial intelligence; knowledge representation and commonsense reasoning; nonmonotonic reasoning and circumscription; robotics and the commercial applications of artificial intelligence; functional programming, LISP and symbolic computation; the semantics of programming languages and proving properties of programs; abstract data types and parallelism. The book creates a broad picture of computer science research in 1991. It also shows how much the computer science of today owes to John McCarthy's ideas and leadership.

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A Short Sketch of the Life and Career of John McCarthy

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John McCarthy was born on Sept. 4, 1927 in Boston, Massachusetts. He received his B.S. in Mathematics from the California Institute of Technology in 1948, and his Ph.D. in Mathematics from Princeton University in 1951. After a brief stint at Princeton as a research instructor (1951-1953), he taught at Stanford (1953-1955) and Dartmouth (1955-1958). In 1958, he moved to MIT as an Assistant Professor of Communication Science; he was promoted to Associate Professor in 1961. McCarthy then moved to Stanford as a Professor of Computer Science in 1962. In 1987, he became the Charles M. Piggot Professor of Engineering; in the fall of that year he was the Bobby R. Inman Professor of Computer Science at the University of Texas at Austin. Other honors and distinctions include: Sloan Fellow in Physical Science (1957-1961), ACM National Lecturer (1961), A.M. Turing Award from the ACM (1971), Sigma Xi National Lecturer (1977), Research Excellence Award, International Joint Conference on Artificial Intelligence (1985), the Kyoto Prize (1988). Professor McCarthy has received honorary degrees from Linköping University (1986), Colby College (1990), and Universidad Politecnica de Madrid (1991). He has been elected to the American Academy of Arts and Sciences, the National Academy of Engineering (1987), and the National Academy of Sciences (1989). He has been President of the American Association for Artificial Intelligence (1983-1984) and since 1975, a member of the editorial board of *Artificial Intelligence Journal.*

In November, 1990, Professor McCarthy was awarded the National

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Medal of Science by President Bush in a ceremony at the White House. The Medal of Science is the nation's highest honor in science.

Professor McCarthy has made fundamental contributions to both the theory and practice of computer science. Perhaps more than that of any single researcher since Turing, his work has shaped ideas about Symbolic Computation. In particular, he can with some justice be said to have created the field of artificial intelligence (AI) and has long been among the most important researchers in the field. He coined the term *artificial intelligence* (1955), and organized the first major conference on AI, the Dartmouth Conference of 1956. While at MIT, he and Marvin Minsky organized and directed the Artificial Intelligence Project. Under their leadership, the MIT AI Lab became the locus of an extraordinary flowering of significant and pioneering work in a wide range of fields, from robotics to theory of computation to computer music and research on human-computer interfaces. In 1963, Professor McCarthy organized the Artificial Intelligence Laboratory at Stanford University and was its director until 1980. In addition to his intellectual leadership, Professor McCarthy has long been active in support of the human rights of computer professionals, especially those from Eastern Europe and the Soviet Union. (For more on this, see Jack Minker's contribution at the end of Chapter 17.)

In 1958, McCarthy developed the LISP (for LISt Processor) programming language. For over 30 years, LISP has been the principal programming language in AI. At the same time that he was developing LISP, McCarthy was also a leading member of the groups that developed ALGOL 58 and ALGOL 60. The design of programming languages remains an important concern for Professor McCarthy. Beginning in the early '80s, he began thinking about very high-level programming languages whose central features derived from aspects of the human use of natural languages in communication. His first such effort was the Common Business Communication Language (1982). Most recently, he has been developing Elephant 2000, a progamming language based on ideas from the theory of speech acts. This work brings together McCarthy's research interests in the theory of programming languages and in the representation of common-sense knowledge.

In 1962, McCarthy published the first fully worked out design proposal for time-sharing ("Time-Sharing Computing Systems") and played a crucial role in implementing the first widely used time-sharing system at BBN. Very soon after arriving at Stanford, Professor McCarthy led the group that developed THOR, the first display-oriented time-sharing system ("THOR—A Display Based Time-Sharing System"). THOR represented an important advance over teletype-based systems and included many of the features found in modern PCs and workstations. Indeed, by the early '70s, Professor McCarthy had already begun thinking about the potential of networks of personal computers in the home ("The Home Information Terminal," first presented in 1972).

Not content with developing two of the most important high-level programming languages, McCarthy also made pioneering contributions in the mathematical theory of computation and the formal semantics of programming languages. In 1960, he presented both an operational semantics and a recursion theoretic analysis of LISP, and proved its universality, more properly the universality of its *apply* function. In 1966, he applied similar techniques to an analysis of a fragment of ALGOL. This work introduced a number of important ideas for proving properties of recursive programs, in particular the use of fixed point properties to prove program equivalence by way of a rule of recursion induction. McCarthy's work on the mathematics of computation was strongly influenced by the research of another 1990 National Medalist, Professor Stephen Kleene; indeed, it represented the first attempt to apply a Kleene-style framework for recursion theory, based on systems of equations defining functions, to real programming languages. While McCarthy has continued doing important work in the mathematical theory of computation, including further research on proof rules for recursive programs (1979) and on multiprocessing versions of LISP (1984), his attention has turned increasingly to fundamental problems in Artificial Intelligence.

The original impetus for the development of LISP was to experiment with his ideas for an "Advice Taker" (1958), a program for representing and solving problems—both mathematical and everyday nonmathematical problems—by performing derivations in a formal language known as the situation calculus, which extends first-order languages in certain ways, e.g. by the addition of conditional expressions (of the form *IF P then a ELSE b*, where P is a formula and a and b are terms) and first-order lambda expressions as function and predicate expressions. (The use of conditional expressions is also fundamental to both the design and the analysis of LISP.) The situation calculus is still widely used for representing nonmathematical problems, especially those that can be posed as involving a single agent.

The "Advice Taker" was the first systematic attempt to describe and analyze what might be called a *sentential automaton*—the term itself may be McCarthy's. The central idea was that all the basic features of a problem and of the ways of solving the problem (the applicable heuristics) should be representable in a formal language. Some sentences of the language were to be treated as imperatives; these were to be obeyed. Others were declarative; these were intended to be treated as descriptions of various aspects of the problem situation. The basic cycle of the program was somehow to choose a list of declarative sentences (premises) to apply a deduction routine to. Thus, what the system knows—has been told—is represented as an axiomatic theory. The crucial point was that one did not have to write new programs as new problems were confronted; one simply told the system new things. For McCarthy the most interesting applications were to everyday problems; this meant expressing everyday common-sense conceptions about familiar objects and our interactions with them, especially those conceptions involving our beliefs and knowledge, our abilities, and the preconditions and effects of our actions.

For more than 30 years, McCarthy has been pursuing, and has been urging others to pursue, the goal of a large, publicly accessible *common-sense knowledge base*, to be expressed in a logical formalism, and to be used in any one of a wide range of applications areas. Early on, it became clear to him that sound (truth-preserving) logical deduction was an inadequate model of common-sense reasoning. Such reasoning often involves nonstrict or *other things being equal* generalizations and it exhibits a certain *nonmonotonicity.* A set of premises Γ can be an adequate reason for inferring P, while a superset Γ' is not. For instance, Γ' might include the information that other things are not equal. This contrasts strikingly with the structure of deductive reasoning (proof). Much of McCarthy's work since 1980 has been devoted to analyzing and formally modeling such reasoning. In 1977, he introduced the idea of *circumscription*, which is a rule of conjecture to be applied to first-order theories; the point of such a conjecture is that a certain predicate, or more generally a certain formula, is to have the minimal extension consistent with the truth of the original theory. The intuitive force of the conjecture is that other things are indeed as equal as they can be, given the original premises (axioms). Thus, one can think of the strategy as minimizing exceptions or abnormalities. Professor McCarthy's working hypothesis is that the addition to first-order logic of this single schematic rule—and its intelligent use—is sufficient to provide a model of common-sense reasoning. A number of other formalisms for dealing with problems of common-sense reasoning have been introduced; but as with LISP and the situation calculus, McCarthy's contributions continue to be of central importance.

We end by quoting the citation for Professor McCarthy's National Medal of Science:

> [F]or his fundamental contribution to computer science and artificial intelligence, including the development of the LISP programming language, the mathematical theory of computation, the concept and development of time-sharing, the application

of mathematical logic to computer programs that use common-sense knowledge and reasoning, and the naming and thus definition of artificial intelligence itself.