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Volume 1

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GUEST FOREWORD

Artificial Intelligence (AI) is a domain of research, application, and instruction concerned with programming computers to perform in ways that, if observed in human beings, would be regarded as intelligent. Thus intelligence is attributed to human beings when they play chess or solve the Tower of Hanoi puzzle. A computer that can perform one of these tasks even moderately well is regarded as an example of artificial intelligence.

Research in AI began in the mid-1950s, shortly after the first digital computers emerged from their wartime security wraps. The computer was designed primarily to carry out numerical computations in an efficient way. But it was soon observed (the English logician, A. M. Turing, was perhaps the first to make this observation) that computers were not limited to numbers, but were capable of quite general processing of all kinds of symbols or patterns, literal and diagrammatic as well as numerical. AI programs exploit these capabilities.

A digital computer is an example of a physical symbol system, a system that is capable of inputting (reading); outputting (writing); organizing (associating); storing, copying, and comparing symbols; and of branching—following different courses of action depending on whether a comparison of symbols led to judging them to be the same or different. The fundamental hypothesis of AI is that these are just the capabilities it requires to exhibit "intelligence." Two corollaries follow from the hypothesis. First, since computers demonstrably have these capabilities, they are capable of being programmed to behave intelligently. Second, since people are capable of behaving intelligently, their brains are (at least) physical symbol systems.

The fundamental hypothesis of AI and its corollaries are empirical hypotheses, whose truth or falsity are to be determined by experiment and empirical test. Research aimed at testing them leads to the two main branches of AI:

1. AI in the narrow sense is a part of computer science, aimed at exploring the range of tasks over which computers can be programmed to behave intelligently. It makes no claims that computer intelligence imitates human intelligence in its processes—only that it produces intelligent responses to the task demands. AI programs in this category may, for example, use rapid arithmetic processes at a rate that people are incapable of. Thus, an AI chess program may explore a million branches of the game tree before choosing a move, while a human grandmaster seldom explores more than a hundred.
2. The second branch of AI, part of the new field of cognitive science, is aimed at programs that simulate the actual processes that human beings use in their intelligent behavior. These simulation programs are intended as theories (systems of difference equations) describing and explaining human performances. They are tested by comparing the computer output, second-by-second when possible, with human behavior to determine whether both the result and also the actual behavior paths of computer and person are closely similar.

Early research in AI was directed mainly at studying well-structured puzzle-like tasks, where human behavior in the laboratory could be compared with the traces of the computer programs. This work produced a basic understanding of problem solving as (nonrandom) search guided by heuristics or rules of thumb. It confirmed Duncker's* early emphasis upon means-ends analysis as a central tool for solving problems.

As research expanded into domains like chess-playing and medical diagnosis, two tasks that have been prominent in the literature, evidence grew that successful task performance depends on rapid access to large bodies of knowledge by a process of cue recognition (often called "intuition"). Experiments showed that the human expert in such domains is capable of recognizing 50,000 or more chunks—familiar patterns—using this recognition to access information stored in long-term memory relevant to the patterns. Thus, the physician recognizes patterns corresponding to disease symptoms, and thereby gains access to his knowledge about the diseases, their treatment, and further diagnostic tests.

Research in the cognitive science branch of AI up to the present (1986) has placed particular emphasis on problem solving, on the organization of long-term memory (semantic memory), and on learning processes.

From the beginning, research in both branches of AI was facilitated by the invention of programming languages especially adapted to their needs. The so-called list processing languages, first developed in 1956, allowed for flexible, associative organization of memory and convenient representation of such psychological concepts as directed associations and schemas. Around 1970, production-system languages were developed, whose basic instruction format represents a sophisticated elaboration of the connection betwen stimuli and

* K. Duncker, "On problem solving," *Psychological Monographs* **58**(5), whole No. 270 (1945).

responses, and provides a direct representation of the recognition process mentioned above. (The condition part of each production, when it matches the information held in short-term memory, causes an associated action to be performed. Upon matching the conditions of a production in an act of recognition the action may simply be to retrieve associated information from memory, or it may be an actual motor response.)

Production-system languages have proved to be convenient for research on learning, because programs can be written in a format that, in appropriate circumstances, simply creates new productions that are thereby annexed to the program and are executable. For example, programs have been written that learn to solve equations in algebra, by examining worked-out examples of solutions and then manufacturing new productions based in the processes observed in the examples.

AI has been most successful, up to now, in dealing with so-called higher mental processes, including language. Progress has been slower in imitating the sophisticated sensory and pattern-extraction processes of the human eye and ear and in linking these with motor processes (robotics). Research progress continues, however, on all fronts, with some degree of specialization of groups concerned with problem-solving and memory, with sensory pattern recognition, and with robotics, respectively. AI research is to be found primarily in computer science departments and psychology departments, but also to some extent in linguistics and in an increasing number of departments where AI techniques are being applied to disciplinary problems (e.g., architectural design, discovery of reaction paths for chemical synthesis, aids to expository writing, drawing, musical composition).

The introduction of AI methods and techniques was a principal factor in bringing about the so-called cognitive revolution in psychology, in the 1960s and 1970s, and the new methodologies of computer simulation and analysis of verbal protocols are now vital tools of research in experimental psychology.

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EDITOR'S FOREWORD

The *Encyclopedia of Artificial Intelligence* defines the discipline of Artificial Intelligence (AI) by bringing together the core of knowledge from all its fields and related disciplines. The articles are written primarily for the professional from another discipline who is seeking an understanding of AI, and secondarily for the lay reader who wants an overview of the entire field or information on one specific aspect. The *Encyclopedia* clarifies and corrects misperceptions as well as provides a proper understanding of AI.

The object of research in AI is to discover how to program a computer to perform the remarkable functions that make up human intelligence. This work leads not only to increasingly useful computers, but also to an enhanced understanding of human cognitive processes, of what it is that we mean by "intelligence" and what the mechanisms are that are required to produce it. AI is surely one of the most exciting scientific and commercial enterprises of our century. It's limits are yet to be discovered.

The *Encyclopedia* has significant contributions to the AI literature, not only because it brings many disciplines into one comprehensive reference, but also because it contains many landmark articles, such as: Blackboard Systems; Computer Chess Methods; Cognitive Psychology; Grammar (Augmented Transition Network; Case; Definite-Clause; Generalized Phrase-Structure; Phrase-Structure; Semantic; and Transformational); Limits of AI; Lisp; Natural-Language (Generation; Interfaces; and Understanding); Path Planning and Obstacle Avoidance; Reasoning (Causal; Commonsense; Default; Nonmonotonic; Plausible; Resource-Limited; Spatial; and Temporal); Robotics; Search (Best-First; Bidirectional; Branch-and-Bound; and Depth-First); and Social Issues of AI. All of the material is specifically written for the *Encyclopedia*.

In addition, the *Encyclopedia* has separate articles on various game-playing programs, vision, speech understanding, image understanding, matching, multisensor integration, and parsing, as well as many short articles.

The articles and the authors invited to write them were chosen with the cooperation of an editorial advisory board of distinguished authorities. The author of each article is a recognized research expert on the topic. Each article has a bibliography and extensive cross-references to other articles. The reader may start with almost any article and be led by cross-references to almost every other article in the *Encyclopedia*. There are more than 450 tables and figures. Stressing readability, accuracy, and completeness of facts as well as overall usefulness of material, this great work brings you the result of years of labor and experience.

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PREFACE

I became involved in the project to develop this *Encyclopedia of Artificial Intelligence* in the spring of 1983, when I was approached by Barbara Chernow, who had already had preliminary discussions with Martin Grayson of John Wiley & Sons and several prominent AI researchers and educators. Although I was warned by several people that this would involve much more work than I could imagine (and they were right), the opportunity to help create a definitive and comprehensive view of the field, authored by a wide variety of experts, each writing on his or her own area of expertise, and the promise of significant help from Wiley's Encyclopedia Department (this promise was more than fulfilled) was more than I could resist. Barbara and I put together the editorial board, and the board and I drew up the list of entries and the people we felt could best write the articles. David Eckroth joined the project as the managing editor and has done a massive amount of work to see it through to publication.

AI is a relatively young field, and is still rife with controversy about what it is and about what constitutes good and valuable research. Some researchers felt that an encyclopedia was premature. There was controversy about the selection of articles, some mild, some quite heated. Nevertheless, I was extremely gratified with the number of people who were willing to take time from their already busy schedules to write and to review articles. Those involved constitute a significant percentage of all active AI researchers, from all the different "camps" and the major research institutes and universities. Now (summer 1986), as AI celebrates its thirtieth birthday, we offer this snapshot and prospectus of our field.

I am grateful to many people whose efforts have gone into making this *Encyclopedia:* Barbara Chernow and Martin Grayson, who started it; the members of the editorial board, who defined it; David Eckroth, who managed it all; the authors and reviewers, who created it; Elizabeth Harrison, Karen Thomsen, Beryl Matshiqi, Sally Elder, and Lynda Spahr, David's and my secretaries, who kept us all organized; and Caren, my wife, whose support and encouragement got me through.

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ABBREVIATIONS AND ACRONYMS

AA	ACT assisters
AAAI	American Association for Artificial Intelligence
AAR	*Association for Automated Reasoning*
AC	applicability conditions
ACH	*Association for Computers and the Humanities*
Ack	acknowledge
ACL	*Association for Computational Linguistics*
ACM	*Association for Computing Machinery*
ACT	accumulation time; actions or abstract nouns; Adaptive Control of Thought
ADJ	adjective
AFCET	*Association Francaise pour la Cybernetique Economique et Technique*
AFIPS	*American Federation of Information Processing Societies*
AGE	attempt to generalize
AGV	automatic guided vehicle
AI	artificial intelligence
AIM	artificial intelligence in medicine
AI/PL	AI Programming Language
AIRPLAN	planning military air-traffic movement
AISB	*Society for the Study of Artificial Intelligence and Simulation of Behavior*
AJCL	*American Journal of Computational Linguistics*
AKO	a kind of
ALCS	Analogue Concept Learning System
ALLC	*Association for Literary and Linguistic Computing*
ALPAC	*Automated Language Processing Advisory Committee*
ALU	arithmetic and logic unit
AM	Automated Mathematician
AML	a manufacturing language
AMRF	Automated Manufacturing Research Facility
AMS	*American Mathematical Society*
APIC	Automatic Programming Information Center
APL	a programming language
APSG	augmented phrase-structure grammar
AR	autoregressive
ARC	*Association pour la Recherche Cognitive*
ARMA	autoregressive/moving average
ARPA	Advanced Research Projects Agency, now called DARPA
ARPANET	ARPA's telecommunication network
ASCII	American Standard Code for Information Interchange
ASEE	*American Society for Engineering Education*
ATE	automatic test equipment
ATC	Air Traffic Control
AT/I	Advice Taker/Inquirer
ATN	augmented transition network
AU	argument unit
AUX	auxiliary
B&B	branch-and-bound
BC	behaviorally correct
BCD	binary coded decimal
BHFFA	bidirectional heuristic front-to-front algorithm
BIM	*Belgian Institute of Management*
BIP	Basic Instructional Program
BIT	built-in test
BNF	Backus Normal (Naur) Form
bpa	basic probability assignment
bps	bits per second
BRDF	bidirectional reflectance distribution function
BSC	Binary Synchronous Communication
BTN	Basic Transition Network
C	CONTACT; a popular programming language
ca	circa
CA	Concept Analyzer; *Chemical Abstracts*
CACM	*Communications of the Association for Computing Machinery*
CADAM	computer-augmented design and manufacturing
CAD/CAM	computer-aided design/computer-aided manufacturing
CAE	computer-assisted engineering
CAI	computer-assisted instruction
CAP	control agreement principle
CAR	contents of the address part of register number
CASNET	Causal Association Network
CASREP	Casualty Report
CAT	Computer Aided Tomography; category

CATV	Community Antenna television system
CC	conceptual cohesiveness
CCD	charge couple device
CCITT	*Consultive Committee International for Telepathy and Telegraphy*
CCTA	*Central Computer and Telecommunications Agency*
CD	conceptual dependency; collision detection
CDR	contents of the decrement part of register number
CD-ROM	Compact disk read-only memory
CF	certainty factor; context-free
CFG	context-free grammar
CFL	context-free language
CF-PSG	context-free phase-structure grammar
CG	causal graph
CHI	computer-human interfaces
C^3I	command, control, communications, and intelligence
CIE	*International Commission on Illumination*
CIM	computer-integrated manufacturing
CIRP	*College Internationale de Recherches pour la Production*
CK	control knowledge
CKY	Cocke, Kasami, and Younger
CL	computational linguistics
CLS	Concept Learning System
CM	Connection Machine
CMU	Carnegie-Mellon University
CNC	Computer Numerical Controls
CNET	*Centre National d'Etudes des Telecommunications*
CNF	conjunctive normal form
Coax	coaxial cable
COLING	*International Conference on Computational Linguistics*
COMPCON	*Computer Society International Conference*
CPS	constraint-satisfaction problem
CPVR	*Computer Vision and Pattern Recognition*
CPU	central processing unit
CRC	cyclical redundancy check
CRIB	computer retrieval incidence bank
CRT	cathode-ray tube
CSCSI	*Canadian Society for Computational Studies of Intelligence*
CSG	context-sensitive grammar; constructive solid geometry
CSL	concept-learning program
CSMA	carrier sense-multiple access
CSP	Communicating Synthetic Processes
CSS	*Cognitive Science Society*
CTM	computational theory of mind
CWA	closed-world assumption
CWR	contents of the word in register number
DAG	directed acyclic graph
DARPA	*Defense Advanced Research Projects Agency* (DOD)
DBMS	database-management systems
DCE	data circuit-terminating equipment; data communication equipment
DCG	definite-clause grammar
DCL	Department of Computational Logic
DCS	Department of Computer Science
dcu	discourse constituent unit
DDL	data definition language
DDM	dynamic discourse model
DDP	distributed data processing
DET	determiner
DFA	deterministic finite state automaton
DFID	depth-first iterative-deepening
DH	direct header
DI/DO	digital input/output
DL	default logic
DLC	digital logic circuit; data link control
DLPA	decoupling, linearization, and poles assignment
DNF	disjunctive normal form
DO	derivation origin
DOD	US Department of Defense
DOF	degree of freedom
DOG	difference of Gaussians
DP	data processing; dynamic programming
DPS	Distributed Planning Systems
DRA	Data-Representation Advisor
DRS	Discourse Representation Structure
D-S	Dempster-Shafer
DSS	decision support system
DT	decision tree
DTC	Derivational Theory of Complexity
DTE	data terminal equipment
DU	Discourse Unit
DVA	dictionary Viterbi algorithm
DWIM	do what I mean
E....	episode
EBCDIC	extended binary-coded decimal interchange code
ECC	error-correcting code
EDC	error-detecting code
EDM	electron-density map
EDP	electronic data processing
EEG	electroencephalogram
e.g.	*exempli gratia,* for example
EGI	extended Gaussian image
EIU	Economist Intelligence Unit
EKG	Electrocardiogram
EL	electronics laboratory
ELI	English-language interpreter
E-MOP	episodic memory-organization packet
EMYCIN	Empty MYCIN
EPAM	Elementary Perceiver and Memorizer
ER	entity-relationship
ES	expert system
EST	Extended Standard Theory; Expert System Technology
EX	explanatory
FAA	Federal Aviation Administration
FA/C	functionally accurate, cooperative
FALOSY	fault localization system
FCR	feature cooccurrence restriction
FDM	frequency division multiplexing
FEP	front-end processor; Finite Element Program
FEM	Finite Element Method