

Introduction to Artificial Intelligence

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Preface

While we have no evidence, we suspect that most professors write textbooks because they are going to teach a course for which none of the existing texts are suitable. Whether or not this is typically the case, it was certainly the reason for the book you are now holding. There were three things we wanted from a text on Artificial Intelligence (from now on “AI”).

- It had to include those aspects of the field that we felt would prove to be enduring (for example, low-level vision research, which is given short shrift in most AI textbooks).
- It should present AI as a coherent body of ideas and methods, drawing on the work of the last twenty years, but translating it into a more uniform set of concepts, favoring clarity over journalistic accuracy.
- It should acquaint the student not only with the classic programs in the field, but the underlying theory as well: mathematical logic for knowledge representation and inference, linguistics for language comprehension, etc.

In brief, our belief was that AI is distinguished by its subject matter, not its history or methods. Its subject matter is the mind, considered as an information processing system:

When each of us became aware that the other was thinking along these lines, we decided to pool our efforts and write a textbook to reflect our view of the field. Four years later, here is the result.

Writing a textbook turned out to be a good way to develop humility about the shortcomings of other textbooks. For one thing, a general-purpose textbook must cover the significant results in *all* aspects of the field, including some its authors know little about. So we had to do some reading and writing we hadn't anticipated.

Second, we have been made aware just how hard it is to extract coherent and lasting theories from a field developing as rapidly as AI. While we have succeeded to some degree in finding some unifying concepts and notations, the book still has aspects of the usual AI “grab-bag.” We managed to throw out a few dusty programming techniques, but there are many areas where there is no satisfactory theory as yet, so we have had to present the traditional, unsatisfactory one instead. We have felt free to “editorialize” at several points about the inadequacies of current theories.

On balance, however, we are pleased by our book. We have some strong opinions about what good AI is, and we were gratified about how much of it there is to report on, and how often our opinions meshed into a coherent framework for reporting on it. We hope the audience sees the same coherence we did.

While we wrote this book for introductory undergraduate AI courses, at the second to fourth year level, there is wide variety in the kinds of students who might take such a course. “Ideal” students would come to the study of AI with a rather long list of previous courses. From computer science they would have had introductory programming (including recursion), data structures, logic (including the first order predicate calculus), and a smattering of formal language theory. From linguistics, they would have had a course in generative grammar, and perhaps one in semantics as well. Naturally, it would help if they had the calculus, a first course in physics (so as to better understand the work in low-level vision) and a course in statistics (for the treatment of medical diagnosis).

Naturally, *no* student will have this panoply of prerequisites. Furthermore, since we wanted the book to be usable in a variety of classroom situations, we did not want to absolutely assume *any* of the prerequisites, except some programming experience. So, while a course in AI for cognitive scientists should have people with linguistics backgrounds, they may or may not know much about logic. On the other hand, while upper level undergraduates in computer science will have had most of the computer science background, they may not have had formal language theory, and, if our experience has been typical, their grasp of predicate calculus will be tenuous.

Our solution to this problem has been to try to explain everything. However, typically our explanations will be fast, and thus instructors would be well advised to give extra material on those areas in which their students will be unprepared. One exception is the differential and integral calculus, which, for obvious reasons, we did not want to summarize. Fortunately, the calculus is only needed in one section on vision, and it can be skipped if need be. We have also tried to separate more advanced material into optional subsections. Thus we hope that this book can find a home in many climates.

Everything in the book depends on Chapter 1, in which we introduce the idea of “internal representation” for facts and rules. The need to devise flexible and efficient representations occurs in almost all subfields of AI.

Chapter 2 is an introduction to the programming language Lisp and is optional since we have made the rest of the text pretty much independent of the

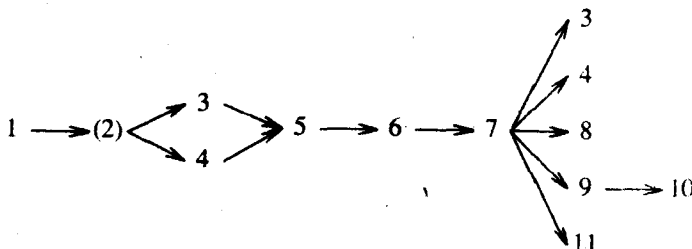
language. Thus it should be possible to teach the course using another symbol-manipulation language, like Prolog. If you do, let us know. Indeed, one could read the book and profit from it without touching a computer, but it wouldn't be much fun. Part of the attraction of AI is getting a machine to exhibit some "mental" faculty, and readers shouldn't deny themselves this experience.

Chapters 3 and 4 examine transduction of information into internal representation for sight and language, the two senses most intensively studied by AI researchers.

The central chapters of the book are 6 and 7, which deepen the ideas sketched in Chapter 1 on internal representation and reasoning. We recommend doing one of 3 and 4 before these chapters, to see where the internal representations come from. Chapter 5, on search, presents the notion of a goal tree, which is used in many of the subsequent chapters.

Chapters 8, 9, 10, and 11 cover four important topics, reasoning under uncertainty, robot planning, language understanding, and learning. For the most part they are independent of each other, except that the work in Chapter 10 on motivation analysis depends on Chapter 9.

In summary, the order to do the book in is this:



Chapter 2 is in parentheses because readers not interested in programming can skip it. Chapters 3 and 4 appear twice because they can be done in either place, although at least one of them ought to be done before 5. There are some local interchapter dependencies not shown in this diagram. These are indicated in the opening material at the front of each chapter.

Through out all of the chapters we have tried to give the reader some idea of the history of the field, as well as the intellectual filaments that connect AI to related disciplines. For this reason we have included various "boxes" covering topics which, while connected to the main body of the text, are nevertheless excursions. There are boxes on the history of AI, its relation to cognitive science, its relation to the rest of computer science, details of Lisp, etc. Often diversions are the most enjoyable parts of class lectures, and we hope these boxes give something of the same flavor.

Naturally, the most important way to make connections is through references, and we know from experience that many textbooks find their greatest use as reference works later. We have provided as many pointers into the AI literature as possible, but no effort has been made to find the earliest references to

some idea for the sake of giving credit. Rather we have tried to confine our references to those that would be useful to someone today, and that are published in accessible places, such as books, journals, and conference proceedings. We probably have not succeeded at this, but have come close enough to offend someone who, if this were a research paper, would have had his out-of-print, but seminal, technical report mentioned. We apologize on both counts.

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We would like to take this opportunity to note that the order of the names on the cover is alphabetical, and has no other significance.

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D.V.M.

Contents

1 AI and Internal Representation	1
1.1 Artificial Intelligence and the World	1
1.2 What Is Artificial Intelligence?	6
1.3 Representation in AI	8
1.4 Properties of Internal Representation	11
1.5 The Predicate Calculus	14
1.5.1 Predicates and Arguments	15
1.5.2 Connectives	16
1.5.3 Variables and Quantification	18
1.5.4 How to Use the Predicate Calculus	18
1.6 Other Kinds of Inference	21
1.7 Indexing, Pointers, and Alternative Notations	22
1.7.1 Indexing	24
1.7.2 The Isa Hierarchy	25
1.7.3 Slot-Assertion Notation	27
1.7.4 Frame Notation	28
1.8 References and Further Reading	28
Exercises	29
2 Lisp	33
2.1 Why Lisp?	33
2.2 Lisps	34

2.3 Typing at Lisp	34
2.4 Defining Programs	37
2.5 Basic Flow of Control in Lisp	39
2.6 Lisp Style	42
2.7 Atoms and Lists	44
2.8 Basic Debugging	48
2.9 Building Up List Structure	53
2.10 More on Predicates	56
2.11 Properties	58
2.12 Pointers, Celi Notation, and the Internals (Almost) of Lisp	59
2.13 Destructive Modification of Lists	65
2.14 The for Function	70
2.15 Recursion	72
2.16 Scope of Variables	73
2.17 Input/Output	76
2.18 Macros	78
2.19 References and Further Reading	80
Exercises	80
 3 Vision	 87
3.1 Introduction	87
3.2 Defining the Problem	89
3.3 Overview of the Solution	93
3.4 Early Processing	97
3.4.1 Gray-Level Image to Primal Sketch	99
3.4.2 Convolution with Gaussians (Optional)	101
3.4.3 Virtual Lines	111
3.4.4 Stereo Disparity	113
3.4.5 Texture	120
3.4.6 Intrinsic Image	126
3.4.7 Cooperative Algorithms	131
3.4.8 Vertex Analysis and Line Labeling	137
3.5 Representing and Recognizing Scenes	143
3.5.1 Shape Description	144
3.5.2 Matching Shape Descriptions	150
3.5.3 Finding a Known Shape to Match Against	153
3.5.4 Describing a Seen Shape	155

3.6 References and Further Reading	159
Exercises	160
4 Parsing Language	169
4.1 Levels of Language	169
4.2 Expressing the Rules of Syntax	174
4.2.1 Why We Need Rules of Syntax	174
4.2.2 Diagraming Sentences	175
4.2.3 Why Do We Care about Sentence Structure?	177
4.2.4 Context-Free Grammars	179
4.2.5 Dictionaries and Features	183
4.2.6 Transformational Grammar (Optional)	188
4.3 Syntactic Parsing	194
4.3.1 Top-Down and Bottom-Up Parsing	194
4.3.2 Transition Network Parsers	197
4.3.3 Augmented Transition Networks (Optional)	206
4.3.4 Movement Rules in ATN Grammars (Optional)	210
4.4 Building an ATN Interpreter (Optional)	214
4.4.1 A Non-Backtracking ATN Interpreter	215
4.4.2 A Backtracking ATN Interpreter	218
4.4.3 Alternative Search Strategies	222
4.5 From Syntax to Semantics	223
4.5.1 The Interpretation of Definite Noun Phrases	223
4.5.2 Case Grammar and the Meaning of Verbs	230
4.6 When Semantics, When Syntax?	238
4.6.1 The Syntactic Use of Semantic Knowledge	238
4.6.2 The Organization of Parsing	241
4.7 References and Further Reading	245
Exercises	246
5 Search	255
5.1 Introduction	255
5.1.1 The Need for Guesswork	255
5.1.2 Search Problems	257
5.2 A Search Algorithm	259
5.3 Goal Trees	270
5.3.1 Formal Definition	271
5.3.2 Searching Goal Trees	274

5.3.3 Formalism Revisited	275
5.3.4 ATN Parsing as a Search Problem (Optional)	278
5.4 Game Trees (Optional)	281
5.4.1 Game Trees as Goal Trees	281
5.4.2 Minimax Search	286
5.4.3 Actual Game Playing	290
5.5 Avoiding Repeated States	294
5.6 Transition-oriented State Representations (Optional)	297
5.7 GPS	300
5.8 Continuous Optimization (Optional)	306
5.9 Summary	309
5.10 References and Further Reading	310
Exercises	311
6 Logic and Deduction	319
6.1 Introduction	319
6.2 Using Predicate Calculus	321
6.2.1 Syntax and Semantics	321
6.2.2 Some Abstract Representations	323
6.2.3 Quantifiers and Axioms	333
6.2.4 Encoding Facts as Predicate Calculus	337
6.2.5 Discussion	343
6.3 Deduction as Search	344
6.3.1 Forward Chaining and Unification	345
6.3.2 Skolemization	349
6.3.3 Backward Chaining	351
6.3.4 Goal Trees for Backward Chaining	353
6.4 Applications of Theorem Proving	360
6.4.1 Mathematical Theorem Proving	361
6.4.2 Deductive Retrieval and Logic Programming	365
6.5 Advanced Topics in Representation	369
6.5.1 Nonmonotonic Reasoning	369
6.5.2 Using λ -Expressions as Descriptions (Optional)	371
6.5.3 Modal and Intensional Logics (Optional)	375
6.6 Complete Resolution (Optional)	378
6.6.1 The General Resolution Rule	379
6.6.2 Search Algorithms for Resolution	382

6.7 References and Further Reading	385
Exercises	386
7 Memory Organization and Deduction	393
7.1 The Importance of Memory Organization	393
7.2 Approaches to Memory Organization	396
7.2.1 Indexing Predicate-Calculus Assertions	396
7.2.2 Associative Networks	400
7.2.3 Property Inheritance	405
7.3 Data Dependencies	411
7.4 Reasoning Involving Time	416
7.4.1 The Situation Calculus	417
7.4.2 Temporal System Analysis	420
7.4.3 Time-Map Management	429
7.5 Spatial Reasoning	433
7.6 Rule-Based Programming	437
7.7 References and Further Reading	440
Exercises	442
8 Abduction, Uncertainty and Expert Systems	453
8.1 What Is Abduction?	453
8.1.1 Abduction and Causation	453
8.1.2 Abduction and Evidence	454
8.1.3 Expert Systems	455
8.2 Statistics in Abduction	457
8.2.1 Basic Definitions	457
8.2.2 Bayes's Theorem	460
8.2.3 The Problem of Multiple Symptoms	461
8.3 The Mycin Program for Infectious Diseases	465
8.4 Search Considerations in Abduction	468
8.4.1 Search Strategy in Mycin	468
8.4.2 Bottom-Up Abduction	469
8.4.3 Search in Caduceus	471
8.5 Multiple Diseases	471
8.5.1 Multiple Diseases According to Bayes	471
8.5.2 Heuristic Techniques	472
8.6 Caduceus	474
8.7 Bayesian Inference Networks	477

8.8 Still More Complicated Cases	480
8.9 References and Further Reading	482
Exercises	482
9 Managing Plans of Action	485
9.1 Introduction	485
9.2 A Basic Plan Interpreter	489
9.3 Planning Decisions	499
9.3.1 Anticipating Protection Violations	499
9.3.2 Choosing Objects to Use	511
9.3.3 Temporally Restricted Goals	512
9.3.4 Planning by Searching through Situations	514
9.3.5 Shallow Reasoning about Plans	518
9.3.6 Decision Theory	519
9.4 Execution Monitoring and Replanning	524
9.5 Domains of Application	527
9.5.1 Robot Motion Planning	527
9.5.2 Game Playing	535
9.6 References and Further Reading	542
Exercises	543
10 Language Comprehension	555
10.1 Story Comprehension as Abduction	555
10.2 Determining Motivation	557
10.2.1 Motivation Analysis = Plan Synthesis in Reverse	557
10.2.2 Deciding Between Motivations	560
10.2.3 When to Stop	566
10.3 Generalizing the Model	567
10.3.1 Abductive Projection	567
10.3.2 Understanding Obstacles to Plans	569
10.3.3 Subsumption Goals and repeat-until	572
10.4 Details of Motivation Analysis (Optional)	573
10.4.1 Abductive Matching	573
10.4.2 Finding Possible Motivations	578
10.5 Speech Acts and Conversation	581
10.5.1 Speech Acts in Problem Solving	584
10.5.2 The Recognition of Speech Acts	586
10.5.3 Conversations	589

10.6 Disambiguation of Language	591
10.6.1 Referential Ambiguity and Context	592
10.6.2 Conversation and Reference	597
10.6.3 Word Sense Disambiguation	598
10.7 Where We Have Been, and Where We Are Going	601
10.8 References and Further Reading	603
Exercises	604
11 Learning	609
11.1 Introduction	609
11.2 Learning as Induction	610
11.2.1 The Empiricist Algorithm	611
11.2.2 Generalization and Specialization	614
11.2.3 Matching	621
11.2.4 A Matching Algorithm (Optional)	624
11.2.5 Analogy	626
11.2.6 Indexing for Learning	629
11.2.7 Assessment	633
11.3 Failure-driven Learning	635
11.4 Learning by Being Told	638
11.5 Learning by Exploration	642
11.6 Learning Language	650
11.6.1 An Outline of the Problem	650
11.6.2 Determining the Internal Representation	651
11.6.3 Learning Phrase-structure Rules	652
11.6.4 Learning Transformational Rules	654
11.7 References and Further Reading	659
Exercises	660
References	663
Index	687

1

Notes in this position at the beginning of chapters give the reader guidelines on what previous material is required for the chapter, and to what degree it is important that the chapter be read in sequence. Obviously, this chapter requires no previous material. All subsequent chapters make use of material covered here.

AI and Internal Representation

1.1 Artificial Intelligence and the World

As with many branches of computer science, it is unlikely that the average reader will come to this book with no idea of what Artificial Intelligence (AI) is, or what it is good for. At times it seems that one cannot read a newspaper or weekly magazine without some reference to the field, and the interest is certainly understandable. AI researchers are trying to create a computer which thinks. The very idea is intriguing, and reflection does not lessen the hold that such ideas have. What would the world be like if we had intelligent machines? What would the existence of such machines say about the nature of human beings and their relation to the world around them? Would college professors become obsolete?

We raise these questions not because this book will answer them; it will not. Ultimately these are questions about economics, psychology and, at the deepest level, the nature of human values. Rather we mention them to illustrate the ramifications of the science we will be describing in this book.

But even at a more mundane level of everyday economics, AI has tremendous implications. One subarea of AI is robotics. Figure 1.1 shows the use of robots to weld car bodies together. Many of the issues that arise in the construction of such robots are more properly in the domain of mechanical engineering than AI (e.g., can one create a motor which will allow a mechanical arm to move in certain ways?). Nevertheless questions like how to get a robot arm from one place to another without killing anybody are standard AI problems.

Another area of AI research is *natural language comprehension*. (We say "natural" language to distinguish it from computer languages.) Figure 1.2 shows examples of the kinds of question answered by a database system which

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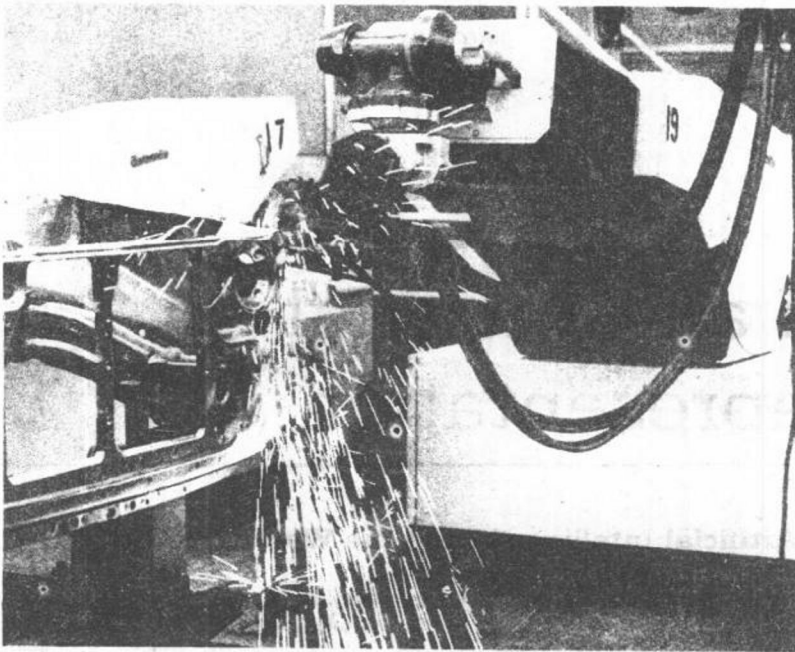


Figure 1.1 Robot welding machines

```

** (How many samples contain chromite?) ; The English query.
Interpretations:                       ; The translation into the
(printout                               ; database query language.
(number x6 / (seq samples) :           ; Asked to print out the
  (and T (contain x6 'chromite))))    ; number of things x6 that are
                                       ; samples containing chromite.
Executing: (3)                         ; There were three.
** (What are those samples?)           ; Second query.
Interpretations:                       ;
(for every x6 / (seq samples) :        ; For every sample x6 that
  (and T (contain x6 'chromite))      ; contains chromite
  (printout x6))                      ; print it out.
Executing: s10020                      ; The samples are s10020
        s10045                        ; s10045
        s10084                        ; and s10084.

```

Figure 1.2 Examples of the Lunar database query system

has a *natural language front end*. That is, there is a program which translates the query from natural language to some database query language — an artificial language designed to be used by computer databases. The particular front end we show is a relatively old one, the *Lunar* system [Woods72]. This program answered questions about the rock samples which were brought back from the moon.

Other researchers have been trying to get machines to do medical diagnosis. Figure 1.3 shows some output from the *Caduceus* program [Miller82]. This is a program which, given the symptoms of the patient, will suggest other tests to be performed, and once it has enough information will suggest what disease or diseases the patient has. According to its creators this program knows about two-thirds of the diseases which go under the heading of *internal medicine* (medicine of the internal organs, as opposed to, say, the eyes or the bones). Admittedly, doctors are still better than the machine, but progress has been considerable.

One AI program that has replaced people in its domain of expertise is the *Xcon* program [McDermott81] (originally called R1). *Xcon* configures computers (and in particular, the Digital Equipment Corporation's VaxTM computer).

(Doctor)	
Internist-1 consultation Sumex-aim ;	<i>Caduceus was originally named</i>
version	<i>; Internist. Sumex-aim is a group</i>
	<i>; of researchers in AI medicine who</i>
	<i>; share computational resources.</i>
Please enter findings	<i>; The program first asks the</i>
* sex male	<i>; doctor to enter the facts about</i>
* race white	<i>; the patient.</i>
* age 26 to 55	<i>; There is a fixed vocabulary of</i>
* alcoholism chronic	<i>; symptoms which must be followed.</i>
* go	<i>; This tells Caduceus to take over.</i>
Disregarding:	<i>; Caduceus finds a set of diseases</i>
exposure to rabbits	<i>; of which it suspects the patient</i>
leg weakness	<i>; has one. Symptoms not explained</i>
creatinine blood increased	<i>; by these diseases are put aside.</i>
Considering:	<i>; These are the symptoms that are</i>
age 26 to 55	<i>; explained by the diseases</i>
Ruleout:	<i>; that it is considering. It will</i>
hepatitis chronic	<i>; try to rule out all but one of</i>
alcoholic hepatitis	<i>; the diseases.</i>
Abdomen pain generalized?	<i>; In order to do this it asks</i>
* no	<i>; for further information.</i>
Abdomen pain right upper	
quadrant?	

Figure 1.3 Output from the *Caduceus* program