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Book Review

Stuart Russell and Peter Norvig, *Artificial Intelligence: A Modern Approach* ★

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1. Introductory remarks

I am obliged to begin this review by confessing a conflict of interest: I am a founding director and a stockholder of a publishing company that competes with the publisher of this book, and I am in the process of writing another textbook on AI. What if Russell and Norvig's book turns out to be outstanding? Well, it did! Its descriptions are extremely clear and readable; its organization is excellent; its examples are motivating; and its coverage is scholarly and thorough! End of review? No; we will go on for some pages—although not for as many as did Russell and Norvig.

In their Preface (p. vii), the authors mention five distinguishing features of their book: Unified presentation of the field, Intelligent agent design, Comprehensive and up-to-date coverage, Equal emphasis on theory and practice, and Understanding through implementation. These features do indeed distinguish the book. I begin by making a few brief, summary comments using the authors' own criteria as a guide.

- Unified presentation of the field and Intelligent agent design. I have previously observed that just as Los Angeles has been called "twelve suburbs in search of a city", AI might be called "twelve topics in search of a subject". We textbook authors have tried stuffing the hodge-podge that is AI into alternative Procrustean beds: ones based on problem solving, production rules, search, or logic, to name just a few of the possible organizing themes. Each accommodated only a part of its over-sized occupant. Russell and Norvig (henceforth abbreviated to R&N), use what I think is the best theme of all, namely *Intelligent agent design*. Their treatment begins by describing desired abilities of an intelligent agent, and the rest of the book shows how these abilities might be realized. Along the way, the reader is taught the technologies that are most relevant to agent design: search, logic, knowledge representation and reasoning, planning and acting, reasoning and acting under

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uncertainty, learning, generating and understanding communicative acts, machine vision, and robotics. Although the design of intelligent agents provides a unifying motivation for these technologies, the reader who is interested in other applications of AI can find plenty of material and examples that stray from the theme of robots and softbots.

- Comprehensive and up-to-date coverage. Any book of over 900 pages better be comprehensive, and this one does not disappoint. It includes some topics that arguably could have been left out of an introductory text and fails to cover some that perhaps should have been covered. And, the level of coverage is a bit uneven. For example, the subject of truth maintenance (pp. 325ff) is covered at about the level of detail that might be expected in an introductory text—a nice summary but nothing too deep. On the other hand, R&N go into probably more-than-needed detail on such subjects as dynamic decision networks and chart parsing, to name just two examples.

  The student who completes the two-semester course required to assimilate all of this material probably will know more than do many practitioners. (R&N painlessly filled in gaps in my own knowledge resulting from my inattention to some of the recent literature.) Adding any additional material would have risked Knuthian fission of the book into several volumes. The purposes of some readers might be better served by a shorter introductory book accompanied by one of a series of more detailed volumes on the many topics covered. In recognition that the entire book covers the union of many needs, R&N prescribe (on p. ix) seven different subsets of chapters appropriate for one-semester or one-quarter courses. Don't be frightened by the length—some material can be omitted.

- Equal emphasis on theory and practice. Underlying both *theory* (i.e., definitions, theorems, analysis) and *practice* (i.e., programs, implementational tricks, engineering lore) is the vastly more important body of knowledge that comprises the key *ideas* of a field. For example, the concept of a problem space and its representation as a graph structure that can be searched by heuristic methods are important ideas in artificial intelligence. Built on these ideas is all the theoretical apparatus of admissibility, complexity analysis, and so on. Also stemming from these ideas are the efficient programming methods for search. I could give other examples; in fact the landscape of artificial intelligence is richly populated with ideas developed over the last forty years: declarative representations of knowledge, production rules, Bayes networks, speech acts, neural networks, STRIPS-like rules, partial-order planning, configuration spaces, and so on. Each idea brings forth important theory and implementations. R&N actually concentrate (appropriately, in my opinion) more on the ideas than they do on either the deep theory or on detailed practical matters, and they explain the ideas especially well.

  The book is not heavily theoretical; most of the theory involves statements about the computational complexity of various algorithms. They do provide a proof of the completeness of resolution (pp. 286ff) and a nice outline of a proof of Gödel's Incompleteness Theorem (p. 288). The reader who is not overly intimidated by discrete mathematics, logic, probability theory, and a wee bit of calculus will have no difficulty.

The "practice" part of the book involves discussion of some 1990s AI programs and many useful observations about practical implementations. Including discussions of actual systems is risky in a textbook because such material will soon be dated. But overall, I think R&N have achieved the balance they sought.

- Understanding through implementation. Many of the *ideas* of artificial intelligence involve algorithmic procedures. One cannot understand these algorithms adequately unless they are defined precisely. R&N provide easy-to-understand "pseudo-code" for over 100 algorithms. (Some of the pseudo-code uses English and mathematics to avoid more complex formal locutions.) Occasionally (pp. 152 and 663, are examples), the use of pseudo-code to describe "agents" seems a bit pedantic. R&N have also provided a repository of written Lisp code implementing these algorithms. To receive instructions on how to get this code, they advise (p. 857): " ... send an electronic mail message to `aima-request@cs.berkeley.edu` with the word "help" in the subject line or in the body".

  In addition, R&N exhort readers to write their own programs to search, to unify, to prove, to parse, and so on.

2. Summary of the major parts

The book is divided into eight parts. These are (along with excerpts from R&N's own summary of each):

(1) Artificial Intelligence. "The two chapters in this part introduce the subject of artificial intelligence or AI and our approach to the subject: that AI is the study of *agents* that exist in an environment and perceive and act."

(2) Problem Solving. "In this part we show how an agent can act by establishing *goals* and considering sequences of actions that might achieve those goals. A goal and a set of means for achieving the goal is called a *problem*, and the process of exploring what the means can do is called *search*. We show what search can do, how it must be modified to account for adversaries, and what its limitations are."

(3) Knowledge and Reasoning. "In this part, we extend the capabilities of our agents by endowing them with the capacity for general logical reasoning. A logical, knowledge-based agent begins with some knowledge of the world and of its own actions. It uses logical reasoning to maintain a description of the world as new percepts arrive, and to deduce a course of action that will achieve its goals."

(4) Acting Logically. "... [here, we] build *planning agents*. At the most abstract level, the task of planning is the same as problem solving. Planning can be viewed as a type of problem solving in which the agent uses beliefs about actions and their consequences to search for a solution over the more abstract space of plans, rather than over the space of situations. Planning algorithms can also be viewed as special-purpose theorem provers that reason efficiently with axioms describing actions."

(5) Uncertain Knowledge and Reasoning. "... we reexamine the very foundation of the logical approach, describing how it must be changed to deal with the often

unavoidable problem of uncertain information. *Probability theory* provides the basis for our treatment of systems that reason under uncertainty. Also, because actions are no longer certain to achieve goals, agents will need ways of weighing up the desirability of goals and the likelihood of achieving them. For this, we use *utility theory*. Probability theory and utility theory together constitute *decision theory*, which allows us to build rational agents for uncertain worlds."

(6) Learning. "Whenever the designer has incomplete knowledge of the environment that the agent will live in, learning is the only way that the agent can acquire what it needs to know. Learning thus provides *autonomy* in the sense defined in Chapter 1. It also provides a good way to build high-performance systems—by giving a learning system experience in the application domain."

(7) Communicating, Perceiving, and Acting. "In this part, we concentrate on the interface between the agent and the environment. On one end, we have *perception*: vision, hearing, touch, and possibly other senses. On the other end, we have *action*: the movement of a robot arm, for example.

"Also covered in this part is *communication*. A group of agents can be more successful—individually and collectively—if they communicate their beliefs and goals to each other. We look more closely at human language and how it can be used as a communication tool."

(8) Conclusions. "In this part we summarize what has come before, and give our view of what the future of AI is likely to hold. We also delve into the philosophical foundations of AI, which have been quietly assumed in the previous parts."

In addition to introductions to each part, R&N begin each of the twenty-seven chapters with a summary paragraph or two, preceded by "pooh-like" sentences. The first of these goes, "*In which we try to explain why we consider artificial intelligence to be a subject most worthy of study and in which we try to decide what exactly this is, this being a good thing to decide before embarking.*" The last goes, "*In which we take stock of where we are and where we are going, this being a good thing to do before continuing.*"

3. Special features and highlights

At the end of each chapter is a collection of bullets summarizing the main topics, ideas, and results. The bold-faced terms in some of these summaries are a useful checklist for the student.

Following the chapter summaries are bibliographic and historical notes. These notes are scholarly and exceedingly well researched (by Douglas Edwards). I learned a great deal from them and noted only an occasional minor error. The reader will be treated to several interesting (if not always compellingly relevant) pointers, such as: "*Dung Beetle Ecology* (Hanski and Cambefort, 1991) provides a wealth of interesting information on the behavior of dung beetles". Many historical and bibliographic comments occur sprinkled throughout the body of the book as well.

The margins of the book are judiciously populated with terms and phrases occurring in the adjacent text; these might be helpful for locating topics looked up in the extensive index. Especially important passages are noted with a finger-pointing icon.

The index is very thorough (28 pages) and helpful. Of my many uses of it, I was only foiled once: when I attempted to find something about language generation, I soon tried "generation (of language)". There, I was told to "*see* natural language, generation", where I was told to "*see* language, natural", where there was no mention of "generation".

Exercises at the end of each chapter vary from technically sharp to tedious. Here are examples in each category:

"Show that convolution with a given function f commutes with differentiation, that is, $(f * g)' = f * g'$." (p. 771).

"Read this chapter from the beginning until you find ten examples of homophones." (p. 772).

Many of the exercises expand on examples presented in the text. Probably the list will evolve as more experience is gained with the book in courses.

The book is full of interesting insights, and fresh and compelling illustrations. To give the reader a feeling for proprioceptive feedback, for example, R&N suggest an interesting eyes-closed experiment which illustrates that human finger-positioning repeatability (based on proprioception alone) is better than finger-positioning accuracy.

Helpful footnotes abound; on p. 314, for example, we learn that "Rete is Latin for net. It rhymes with treaty." There are occasional frivolous ones as well (see p. 476).

Many of their explanations connect to topics already known to the reader. For example (p. 266), based on the statement "there is a number that ... satisfies the equation $\mathrm{d}(x^y)/\mathrm{d}y = x^y$...", R&N point out that the name we use for this number is e—establishing the fact that the mysterious Skolem constants soon to be introduced are really already quite familiar. Several helpful analogies are based on computer science ideas. For example, they compare (on p. 379) a "critic" in a hierarchical planner to a "peephole optimizer" in a compiler.

And here (p. 190) is a technical point I hadn't thought about very much: In $(\forall x)[Cat(x) \supset Mammal(x)]$, quantification ranges over *all* objects in the domain—not just over cats!

There are very few typographical errors. The book's www page (see below) lists those in the first and second printings that are known to the authors. Here are two treasure-hunt challenges, not on the www page, for the careful reader: find the places where R&N use "vary" when they meant "very" and "Finish" when they meant "Finnish".

The book also has its own world-wide web home page. It's URL is: http://www.cs.berkeley.edu/ russell/aima.html. Here is what is available through this page (words in italics are hot links):

- *Ordering*: how to get a copy of the book. Or check your *local bookstore*. If you are a professor teaching AI you can *order a sample copy*.
- *Brief* and *complete* tables of contents.
- *Preface*: Excerpts from the preface.
- *Comments*: Comments on the book by various instructors, students, and other reviewers.
- *Code*: How to get Lisp programs that support the material in the book.
- *Index to code*: Pages and files where all functions, types and variables appear.
- *Errata*: typos and other errors that have been spotted by alert readers.
- *Clarifications*: Clarifying remarks and additional material.

- *Cover*: A large (590K) version of the cover image.
- *Surveys*: Results of student questionnaires from several schools.
- *Other books*: The Prentice Hall Series in Artificial Intelligence.
- *Other courses*: Home pages for introductory AI courses at various universities.
- *Other sites*: Other servers on the web with information on AI.

4. More detailed comments on content and organization

In a book of this length and depth, an experienced reader of even the most carefully crafted book will find a number of places where he or she feels compelled to make some minor marginal notes. Sometimes this interruption by the "trees" interferes with sizing up the "forest". In the following, I'll give a chapter-by-chapter discussion of my view of the forest interspersed with comments about some of the trees that arrested me.

Part I: Artificial Intelligence

In Chapter 1, R&N begin with a discussion of the foundations and history of AI. This chapter is very well researched—going all the way back to Plato. I would have mentioned the subsumption architecture, situated automata, and the so-called "animat approach" to AI in the section dealing with recent history. These topics have influenced the field at least as much as have neural networks, which were cited.

For additional interesting historical material about the development of AI, the reader might want to see the histories written about the early days of each of four major AI labs [1,6–8].

In Chapter 2, AI is defined as the study of "intelligent agents". Agent complexity varies along a spectrum; some agents merely react to stimuli, some react to a combination of stimuli and internal state, and some take explicitly provided goals into account. Those capable of "high-quality behavior" are "utility-based agents", which compute what to do based on knowledge of the environment and its dynamics, knowledge of the effects of actions, and the utility to the agent of various environmental states. This spectrum provides a rough guide for the order of presentation of topics in the book.

Part II: Problem-Solving

Postponing treatment of simple reactive agents until later in the book, R&N proceed directly in Chapter 3 to consider what they call *problem-solving agents*. Such agents search a *problem space* using state descriptions, operators, and goal descriptions. The chapters in this part present up-to-date material on uninformed and heuristic search, including game-tree search. Although R&N adhere to their agent-based approach by using some robot-like illustrative examples, they also employ standard ones like the 8-puzzle.

I think that R&N were overly impatient to get into "real AI" by beginning with problem-solving agents instead of with simple reactive ones. Much of the material that occurs later in the book (some visual processing, neural net learning, production-rule and subsumption-based action computation, and situated automata) could have been dealt with first; that order of treatment would have correlated nicely with the agent complexity spectrum. Situated automata, for example, constitute a fundamental topic in AI, yet they are mentioned only in Chapter 25—a chapter that occurs in only one of R&N's recommended seven alternative one-quarter or one-semester syllabi.

Part III: Knowledge and Reasoning

After dealing with AI search methods, R&N segue brilliantly, in Chapter 6, into logic and its methods for knowledge representation and reasoning. Using the example of an agent in the "wumpus world", they show how manipulating knowledge about the world can be used to augment an agent's immediate sensations to help it compute appropriate actions. They introduce many of the needed concepts using propositional logic, and then, in Chapter 7, elegantly show how first-order logic greatly reduces the representational burden.

In my opinion, their use of *semantics* in Chapter 6 to help introduce and motivate *syntax* risks conflating these two quite separate notions—which shouldn't really be joined until the propositional truth table is described. The syntax-semantics distinction is just one of many that must be observed in the study of logic. Another, which isn't adequately stressed, is the difference between meta-symbols used in statements *about* logic, such as "$\vdash$" and "$\models$" and linguistic symbols, such as "$\Rightarrow$", used in logical sentences.

R&N (unfortunately, I think) introduce the situation calculus and the frame problem in Chapter 7 rather than waiting until their chapters on planning. Although there is still debate about whether *reasoning* about actions using the situation calculus can be made efficient enough for an agent to *compute* which actions to perform, the approach taken later in Part IV suggests that reasoning be limited to establishing what is true in each world state and that extra-logical methods be used for computing a plan of action to traverse the states.

In the section of Chapter 7 dealing with extensions to logic (pp. 194ff), R&N might have mentioned modal logics.

One of the high points of the book is Chapter 8, *Building a Knowledge Base.* R&N use the domain of digital circuits to illustrate how knowledge of specialized subject matter can be represented in first-order logic. This example permits them to describe the process of deciding "what to talk about", what should be the "vocabulary", how to "encode general rules", how to encode the "specific instance" of the problem at hand (a full adder with carry), and how to "pose queries to the inference procedure" (which latter, by the way, the reader hasn't heard about yet). This chapter also deals with the following important notions: categories, measures, composite objects, time, space, change, events, processes, physical objects, substances, mental objects, and beliefs. Applications of these ideas are illustrated in a "grocery shopping world".

One of the advantages claimed for sentences in knowledge bases is that they are "self-contained" or context independent (p. 222). The *meanings* of sentences, though, are context dependent in that the set of models of a knowledge base depends on all of the sentences in it; models can be eliminated by the addition of new sentences.

I applaud R&N's bravery in attempting this chapter—a lot of material rolled into less than 50 pages. Personally, I would have advised them to get on with the fundamentals of inference, planning, and uncertain reasoning and then cover the more advanced topics (such as events, time, processes, and substances) later in the book. The grocery shopping example could still have been introduced in simplified form at this stage and then reconsidered later to illustrate the use of additional technical apparatus.

The reader is likely to be confused by the paragraph at the bottom of p. 237. There, the expression $T((At(Agent, Loc_1) \wedge At(Tomato_1, Loc_1)), I_3)$ is pointed out as flawed because a sentence appears as the first argument of the predicate T. Yet later, after introducing the function *And*, the expression $T(And(At(Agent, Loc_1), At(Tomato_1, Loc_1)), E)$, is held up as OK, where $At(Agent, Loc_1)$ has suddenly now changed from a sentence into an "event category". That went by a bit fast.

Next, in Chapter 9, R&N deal with inference, unification, and resolution. They make what I think is the unfortunate choice of using "implicative normal form" rather than conjunctive normal form for the clauses used in resolution refutations. Although implications are perhaps more understandable than clauses, the alleged pedagogic value of this appealing and familiar form is sullied by the necessity of a more complex resolution rule and the need to remember that antecedents are conjunctions and consequents are disjunctions. (Matt Ginsberg succumbed to the same temptation in his text *Essentials of Artificial Intelligence*).

R&N state (on p. 281) that each step in the conversion of a sentence to normal form does not change the meaning of a sentence. That's not strictly true of Skolemization because $(\exists x)P(x)$ doesn't logically entail its Skolem form, $P(Sk)$. What is true is that a set of formulas, Δ, is satisfiable if and only if the Skolem form of Δ is. Or, more usefully for purposes of resolution refutations, Δ is unsatisfiable if and only if the Skolem form of Δ is unsatisfiable [4].

As regards collecting substitutions during a resolution refutation in order to provide "who" or "what" answers, R&N make no mention of the "answer literal" construction [5], which provides a nice way of maintaining a "... composed unifer so that a solution is available as soon as a contradiction is found" (p. 283).

In Chapter 10, R&N lump together theorem provers, logic programming languages, production systems and the rete algorithm, semantic networks, terminological logics, and truth maintenance systems. It's unclear what thread links these disparate topics. I probably would have parcelled them out to other chapters.

There is little or no mention of deductive databases and the connections between research in that area (magic sets, negation as failure, stratification) and logic programming languages discussed in this chapter. [Although, R&N do cite [9] in the historical section (p. 328).]

It ought to be pointed out that "metareasoning" (p. 309) is important beyond the realm of logic programming.

Part IV: Acting Logically

Without spending much time on the situation calculus (already prematurely mentioned in Chapter 7) or STRIPS-style planners, R&N move directly to "plan space" representations in Chapter 11. Their discussion of partial-order planning (POP) systems is well motivated and clear, illustrated by a nice example loosely based on the grocery shopping world.

The footnote on p. 361 that correctly points out that "Shakey was never dextrous enough to climb on a box or toggle a switch", should have been used to qualify their sentence on p. 360, which claimed "Shakey can ... climb on and off rigid objects (such as boxes), and turn light switches on and off".

In Chapter 12, they extend their discussion of planning to include several important "scaling-up" topics: hierarchical planners, operators with conditional effects, and the use of "resources". I would have included hierarchical planning in Chapter 11 devoted to basic ideas rather than in one concentrating especially on "practical planning".

The statement (p. 371) that "SIPE ... was the first planner to deal with the problem of replanning, ..." is inaccurate; both STRIPS/PLANEX and NOAH did that.

Chapter 13, "*In which planning systems must face up to the awful prospect of actually having to take their own advice*", deals with matters involved in executing plans: the use of run-time conditionals in plans, execution monitoring, and replanning.

Part V: Uncertain Knowledge and Reasoning

In Chapter 14, R&N confront the difficulty that most knowledge is uncertain. They give a good account of the basic ideas of probability theory including a discussion of its axiomatic basis, conditional and joint probabilities, and Bayes' rule. With this foundation, they then move on in Chapter 15 to present Bayes belief networks—structures that graphically stipulate conditional independencies which greatly simplify representations of joint probabilities. Some of the more complex mathematical material in the book, that dealing with inference in Bayes nets, is presented here (although no mention was made of techniques based on "arc reversal"). The reader will no doubt need to read these pages two or more times (as did I). More examples of the use of these methods would have been welcome. Dempster–Shafer theory and fuzzy logic are briefly treated. R&N mention default reasoning (nonmonotonicity, etc.) under "Other Approaches to Uncertain Reasoning". Perhaps that topic should have been taken up back in the logic chapters. They do not discuss the closed-world, unique names, nor domain-closure assumptions.

This part concludes with two chapters on the use of probabilities and utilities to make decisions. Material covered in these two chapters includes: rational decision making, utility theory, decision networks, the value of information, dynamic programming, value and policy iteration, and dynamic belief and decision networks. Although these topics seem fashionable in AI these days, I think they could have been safely omitted from an introductory text.

Part VI: Learning

As is often done, R&N treat "Learning" as a separate AI topic. To emphasize the point that learning is or could be used almost everywhere in AI systems, I would have spread discussion of learning methods throughout the book—treating neural nets, decision trees, decision lists, reinforcement learning, and genetic algorithms in chapters dealing with reactive agents. Whatever needs to be said in an introductory book about PAC learning could be mentioned back in those chapters also. Inductive logic programming could be moved into a chapter dealing with representing knowledge by sentences in first-order predicate calculus, and explanation-based learning could occur either in those chapters or in ones on planning. Notwithstanding that personal opinion, R&N give excellent descriptions of the major techniques in machine learning—including much post-1990 material on reinforcement learning and on learning Bayes networks.

Part VII: Communicating, Perceiving, and Acting

This part is the grand finale of the book. Agents that do none of these things can hardly be called agents. After briefly explaining varieties of "speech acts", R&N do an outstanding two-chapter job of describing natural language processing. They readily acknowledge the difficulty of capturing human language in grammars—even so, grammars are "useful tools for dealing with some aspects of natural language". R&N concentrate on definite clause grammars and their augmentations—first to enforce number and case agreements and second to implement the construction of the meaning of a sentence compositionally from the meaning of its components. Their strategy is to rely on compositional semantics for the context-free aspects of language and then to use pragmatics to resolve ambiguities. One chapter introduces the important ideas, and a second concentrates on the practical matters inherent in real-world applications. Among the topics covered in the "scaling-up" chapter are: database and information retrieval applications, chart parsers, more complex grammars, dealing with various forms of ambiguity, and discourse understanding.

In the historical section of Chapter 22, they might have mentioned LIFER [3] as an early example of a semantic grammar.

Even though the phrase "natural language processing", usually includes both "understanding" and "generation", there is no mention of generation methods in the book, outside of a brief discussion of generating speech acts.

Chapter 24 on perception concentrates mainly on machine vision but also includes material on speech recognition. (R&N credit Jitendra Malik with writing most of this chapter.) Basic material on image formation, image processing operations (averaging and edge detection), and methods for extracting 3-D information is clearly presented. I found the description of convolution and of the Canny edge detector particularly lucid. As is appropriate for a text based on intelligent agents, emphasis is placed on the *uses* of vision rather than on abstract "scene analysis". These uses are manipulation, navigation, and object recognition. There is a nice example on pp. 749 and 750 that clearly shows that "*for a specific task, one does not need to recover all the information that in principle can be recoverd from an image*".

The pages on speech recognition use Bayes' rule to break the problem into two components: one using a language model and the other an acoustic model. R&N approximate the language model by bigram and trigram statistics. Hidden Markov models are used for the acoustic model (of word pronunciation). As I mentioned earlier, except perhaps for speech recognition, this chapter on perception could have appeared earlier in the book. And, one could question why machine vision and speech recognition are in the same chapter.

The final chapter of this part is entitled "Robotics" (written mainly by John Canny). Fundamental ideas on sensing and effecting are described including the concepts of degrees of freedom, holonomism, rotary and prismatic motion, proprioception, force, tactile, and sonar sensing, and laser range finders. Robot architectures, "classical" and behavior-based, are briefly described. These architectural matters might have been more appropriately discussed in Chapter 13, Planning and Acting. The chapter concludes with a presentation of configuration spaces and their uses in navigation and motion planning.

Part VIII: Conclusions

Chapters 26 and 27 treat the reader to some philosophical and strategic big questions: Can machines think? What is consciousness? Have we succeeded yet? What exactly are we trying to do? What if we do succeed? In their discussion of consciousness, R&N concentrate on various things John Searle has had to say about it. Surprisingly, they don't refer to [2].

I was glad to see that these questions were addressed even though there are no real answers presently available.

Appendices A and B describe complexity analysis, O( ) notation, Backus-Naur form, the pseudo-code conventions, and the repository of Lisp code.

5. Final remarks

The study of AI requires near-renaissance universality. The components needed to mechanize intelligence fill an entire engineering curriculum; small wonder this book is so large. I am awed by the amount of work and study that must have gone into its writing. The authors (and their helpers) have done a remarkable job, and the field owes them a hearty thanks and "well done!". There are some major topics left out (how can that be in a book so thick?)—among them qualitative physics and a full discussion of "tractable" reasoning. There are some minor flaws; rather, there are things you or I might have done somewhat differently. On the www pages for the book, R&N state: "The second printing fixes typos on 68 pages, and leaves the other pages unchanged. ... (Look for a second edition in 1997 or 1998, and see the list of *clarifications* for some things that will be addressed in the second edition but were too costly to fix in a reprinting.)"

This book, and its promised second edition, will deservedly dominate the field for some time.

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