third edition

introduction to

## **EXPERT**

# SYSTEMS

**Peter Jackson** 



ADDISON-WESLEY

### Contents

### Preface

1	What Are Expert Systems?	1
1.1	The nature of expertise	1
1.2	The characteristics of an expert system	3
1.3	Fundamental topics in expert systems	4
1.3.1	Acquiring knowledge	4
1.3.2	Representing knowledge	6
1.3,3	Controlling reasoning	8
1.3.4	Explaining solutions	9
1.4	Summary and chapter plan	11
1.4.1	What is the state of the art?	11
1.4.2	Chapter plan of the book	12
Bibliog	graphical notes	13
Study	suggestions	14
2	An Overview of Artificial Intelligence	15
2.1	The Classical Period: game playing and theorem proving	16
2.1.1	State space research	16
2.1.2	Heuristic search	21
2.2	The Romantic Period: computer understanding	23
2.2.1	SHRDLU	23
2.2.2	Knowledge representation schemes	25
2.3	The Modern Period: techniques and applications	27
2.3.1	Knowledge is power	28
2.3.2	'AI winter' and 'AI spring'	31
	graphical notes	32
Study s	suggestions	32
3	Knowledge Representation	38
3.1	The representation of knowledge: principles and techniques	38
3.2	The STRIPS planner	41
3.2.1	Operator tables and means-ends analysis	41
3.2.2	Assessment of STRIPS representation and control	45
3.3	Subgoaling in MYCIN	46
3.3.1	Treating blood infections	46
3.3.2	MYCIN's knowledge base	48
3.3.3	MYCIN's control structure	50

CONTENTS				
3.4.1 3.4.2 Bibliogr	Evaluating and comparing expert systems  Evaluation of MYCIN  Comparison with STRIPS  aphical notes  aggestions	53 53 55 57 57		
4	Symbolic Computation	60		
4.2 4.3 4.3.1 4.3.2 4.3.3 4.3.4 4.3.5 4.4 4.4.1 4.4.2 4.5 Bibliog	Symbolic representation Physical symbol systems Implementing symbol structures in LISP LISP data structures LISP programs Functional application and lambda conversion List processing Pattern matching Why LISP isn't a knowledge representation language Symbol level versus knowledge level LISP and program design Languages for knowledge representation raphical notes uggestions	61 62 63 64 66 67 69 71 71 72 74		
5	Rule-Based Systems	76		
5.1 5.2 5.2.1 5.2.2 5.3 5.3.1 5.3.2 5.3.3 Bibliog	Canonical systems Production systems for problem solving The syntax of rules The working memory Controlling the behavior of the interpreter Conflict resolution Forward and backward chaining Rules and meta-rules graphical notes suggestions	77 78 78 81 85 85 87 93 96		
6	Associative Nets and Frame Systems	100		
6.1 6.2 6.2.1 6.2.2 6.3 6.3.1 6.3.2 6.3.3	Graphs, trees and networks The rise of associative networks The type-token distinction and cognitive economy Assessing the adequacy of associative nets Representing typical objects and situations Introduction to frame concepts Complex nodes in a network Defaults and demons	100 104 104 105 107 107 108 109		
6.3.4	Multiple inheritance and ambiguity	112 113		

	graphical notes suggestions	116 116
7	Object-Oriented Programming	120
7.1	Prototypes, perspectives and procedural attachment	121
7.2	LOOPS and Flavors	123
7.2.1	Message passing	123
7.2.2	The method combination problem	125
7.2.3	Metaclasses	127
7.3	CLIPS and the Common LISP Object System (CLOS)	129
7.3.1	Multiple inheritance in CLOS and CLIPS	129
7.3.2	Method combination in CLOS and CLIPS	131
7.3.3	Metaclasses in CLOS and CLIPS	133
7.4	Multiple inheritance in C++	135
7.5	Object-oriented analysis and design for expert systems	140
Biblio	graphical notes	141
Study	suggestions	141
8	Logic Programming	143
8.1	Formal languages	143
8.1.1	Propositional calculus	144
8.1.2	The predicate calculus	145
8.2	The PROLOG language	148
8.3	Resolution refutation	149
8.3.1	The resolution principle	149
8.3.2	Proof search in resolution systems	151
8.4	Procedural deduction in PLANNER	154
8.5	PROLOG and MBASE	156
8.5.1	PROLOG's search rules	156
8.5.2	Explicit search control in MBASE	157
Biblio	graphical notes	162
	suggestions	162
9	Representing Uncertainty	166
9.1	Sources of uncertainty	166
9.2	Expert systems and probability theory	168
9.2.1	Conditional probability	168
9.2.2	Certainty factors	170
9.2.3	Certainty factors versus conditional probabilities	172
9.3	Vagueness and possibility	175
9.3.1	Fuzzy sets	175
		177
9.3.3	D 11 11 1	178
9.4	The uncertain state of uncertainty	
	graphical notes	180
Study suggestions 181		

10	Knowledge Acquisition	182
		183
10.1	Theoretical analyses of knowledge acquisition Stages of knowledge acquisition	183
	Different levels in the analysis of knowledge	184
	Ontological analysis	187
	Expert system shells	187
	EMYCIN as architecture and abstraction	188
	Maintaining and debugging knowledge bases in TEIRESIAS	189
	Knowledge acquisition methods	191
	Knowledge elicitation by interview in COMPASS	191
10.3.2	Automating knowledge elicitation in OPAL	193
10.3.3	A graphical interface to a domain model	194
	Efficacy of OPAL and related efforts	197
	Knowledge-based knowledge acquisition	197
	graphical notes	199
Study	suggestions	199
11	Heuristic Classification (I)	207
11.1	Classifications of expert system tasks	208
11.2		210
11.2.1	Heuristic matching	210
11.2.2	The generality of heuristic classification	212
11.3	Classification versus construction	215
	graphical notes	218
Study	suggestions	218
12	Heuristic Classification (II)	225
12.1	Mapping tools to tasks	225
	Heuristic classification in MUD and MORE	227
	A model of the drilling fluid domain	227
	Knowledge acquisition strategies	231
12.2.3	Confidence factors in MORE	234
12.2.4	Evaluating MORE	235
12.3	8 87	236
	Lessons of the GUIDON project	236
	NEOMYCIN's task structure	238
	graphical notes	240
Study	suggestions	240
13	Hierarchical Hypothesize and Test	243
13.1	Managing complexity	244
13.2	Structured objects in CENTAUR	245
	The structure of prototypes	246
	Rules embedded in prototypes	247
	Model-based reasoning in INTERNIST	248

13.3.2 13.3.3 13.4 Bibliog	Representing knowledge in a disease tree Focusing attention in INTERNIST Practical and theoretical problems with INTERNIST TDE as knowledge engineering workbench graphical notes suggestions	248 251 252 253 255 256
14	Constructive Problem Solving (I)	259
14.2.2 14.2.3 14.3 14.3.1 14.3.2 Bibliog	Motivation and overview A case study: R1/XCON Components and constraints Using contexts to impose task structure Reasoning with constraints: the Match method Elicitation, evaluation and extensibility Knowledge elicitation in R1/XCON The evaluation and extension of R1/XCON graphical notes suggestions	259 260 261 263 265 267 268 270 272
15	Constructive Problem Solving (II)	275
15.3.2 15.4 Bibliog	Construction strategies An architecture for planning and meta-planning Eliciting, representing and applying design knowledge Knowledge-based backtracking in VT Acquiring propose and revise knowledge in SALT Summary of constructive problem solving traphical notes suggestions	275 277 284 284 286 288 290 290
16	Designing for Explanation	294
16.1.1 16.1.2 16.2 16.2.1 16.2.2 16.3 16.3.1 16.3.2 16.3.3 16.4 Bibliog	uggestions	315 315
17	Tools for Building Expert Systems	
17.1	Overview of expert systems tools	320

17.2	Expert system shells	322
	Matching shells to tasks	322
	Shells and inflexibility	323
	High-level programming languages	324
	Constraints of production rule languages	324
	Evaluating object-oriented approaches	325
	Logic programming for expert systems	326
	Multiple-paradigm programming environments	328
	Additional modules	330
	Potential implementation problems	333
17.4.1	Common pitfalls and how to avoid them	333
17.4.2	Selecting a software tool	334
	How easy is it to use these tools?	336
17.4.4	What is good programming style?	338
17.5	More maxims on expert system development	339
Bibliog	raphical notes	341
Study s	uggestions	341
		2
18	Blackboard Architectures	344
18.1	The blackboard metaphor	344
	HEARSAY, AGE and OPM	346
18.2.1	Motivation for HEARSAY-II architecture	346
18.2.2	HEARSAY's use of knowledge sources	347
	HEARSAY-III: an abstract architecture	348
	Abstraction in AGE and OPM	349
	The blackboard environment BB*	350
	Architecture, framework and application	351
	BB1 and ACCORD as architecture and framework	351
	PROTEAN: application as framework instantiation	352
	Integrating different reasoning strategies	354
	Summarizing BB*	355
18.4	Efficiency and flexibility in blackboard frameworks: GBB and Erasmus	356
	Blackboard retrieval in GBB	356
	Blackboard configuration in Erasmus	357
18.5	Concurrency and parallelism in CAGE and POLIGON	358
-	graphical notes	360
Study	suggestions	360
40	Total M. Seteman Contains	362
19	Truth Maintenance Systems	
19.1	Keeping track of dependencies	362
	Relaxation in networks	363
	Belief revision	364
19.2	Revising propositional theories	366
10.3	Nonmonotonic justifications	367
19.4	Maintaining multiple contexts	371
19 4 1	Assumption-based maintenance	371

19.5 Bibliog	Model-based diagnosis using ATMS Summary and comparison of TMSs graphical notes suggestions	374 377 378 378
20	Machine Learning	380
20.1	Overview of inductive learning	381
20.2	Early work: Meta-DENDRAL	383
	Rule generation and refinement	384
	Version spaces	386
	The candidate elimination algorithm	387
20.2.4	Matching instances to patterns in Meta-DENDRAL Building decision trees and production rules	388 390
	The structure of decision trees	390
	The ID3 algorithm	392
	Changes and additions to ID3 in C4.5	395
20.4	Tuning rule sets	397
Bibliog	raphical notes	399
Study s	suggestions	400
21	Belief Networks	402
	Dempster–Shafer theory	402
	Belief functions	403
	Applying Dempster–Shafer theory to MYCIN	404
21.2	Pearl's theory of evidential reasoning in a hierarchy	406
21.3	Comparing methods of inexact reasoning	408
21.4	Summarizing the state of uncertainty	410
	graphical notes suggestions	411 411
Study 8	suggestions	Had ATII
22	Case-Based Reasoning	413
22.1	The case base	414
22.1.1	The CHEF program	415
22.1.2	Retrieval and adaptation methods	416
22.2	Computer-aided instruction: the CATO system	418
	The domain of caselaw	418
	Legal research and legal reasoning	419
	CATO as an intelligent teaching system	420
22.3	Case-based report generation in FRANK Components of FRANK	422 423
	FRANK's blackboard system	424
	The CBR module of FRANK	424
22.4	Comparing case-based and rule-based systems	425
	graphical notes	427
ACCUMANTA DE LA COMPANSION DE LA COMPANS	suggestions	427

23	Hybrid Systems	430
23.1	Learning methods in ODYSSEUS	431
23.1.1	EBG as abstraction	431
23.1.2	Case-based learning	433
23.2	The ODYSSEUS and MINERVA systems	434
23.2.1	The MINERVA expert system shell	434
	Learning in ODYSSEUS	435
	Using cases to handle exceptions	437
23.4	Hybrid systems and connectionist approaches	439
	Why connectionism?	439
	SCALIR: a hybrid system for legal information retrieval	443
	Learning in SCALIR	446
23.6	The future of hybrid systems	447
	graphical notes	448
Study	suggestions	448
		450
24	Summary and Conclusion	450
24.1	The riddle of artificial intelligence	450
24.2	Knowledge representation revisited	452
24.3	AI programming languages	454
24.4	Practical problem solving	455
24.5	Expert system architectures	457
24.6	Expert systems research	458
24.7	Conclusion	459
	graphical notes	460
Study	suggestions	461
Annen	dix CLIPS Programming	462
		462
A1	A short history of CLIPS	463
A2	Rules and functions in CLIPS	463
A2.1	Facts	465
A2.2	Rules	467
A2.3 A2.4	Watching and dribbling	468
A2.4 A2.5	Using templates Defining functions	468
A2.3	Object-orientation in CLIPS	469
A4	The 'Knights and Knaves' example	474
A4.1	Understanding the problem	474
A4.1 A4.2	Ontological analysis and knowledge representation	476
A4.3	Writing the rules	478
A4.4	Extending the rules: logical compounds	481
A4.5	Backtracking and multiple contexts	488
A4.6	Handling reported speech	498
A4.7	Complete program listing	501

A5 CLIPS programming style Study suggestions	512 513
References	514
Index	532

CONTENTS | xvii

#### Trademark notice

The following names are trademarks or registered trademarks of the organizations given after each in brackets: ART, ART-IM, CBR Express (Inference Corporation); Eiffel (Nonprofit International Consortium for Eiffel); Flavors (Symbolics Inc.); KEE (Intellicorp Inc.); Knowledge Craft (Carnegie Group, Inc.); KRL, LOOPS, SmallTalk (Xerox Corporation); Macintosh (Apple Computer, Inc.); Neurosheet 2 (Neuron Data); PROLOG (Expert Systems International); UNIX (Licensed through X/OPEN Company Ltd); VAX-11/780 (Digital Equipment Corporation); Visual Basic, Visual C++, Windows (Microsoft Corporation); XCON (Carnegie-Mellon University/Digital Equipment Corporation).