

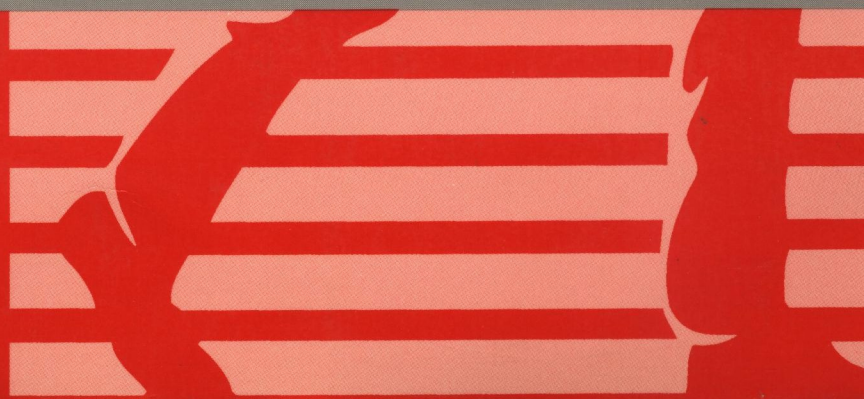
PRENTICE
HALL
INTERNATIONAL
EDITIONS



THE ENGINEERING OF
KNOWLEDGE-BASED SYSTEMS
THEORY AND PRACTICE

AVELINO J.
GONZALEZ

DOUGLAS D.
DANKEL





Contents

1	INTRODUCTION TO KNOWLEDGE-BASED SYSTEMS	1
1.1	Introduction	1
1.2	Algorithmic Methods in Computing	3
1.3	Search as the Foundation of Artificial Intelligence	3
1.3.1	Searching a Problem Space	9
1.3.2	Depth-first Search	10
1.3.3	Breadth-first Search	10
1.3.4	Beam Search and the Use of Knowledge	11
1.3.5	Hill-climbing Search	11
1.3.6	Branch and Bound Search	12
1.3.7	Best-first Search	14
1.3.8	A* Search	15
1.4	Expertise and Heuristic Knowledge	19
1.5	Knowledge-based Systems—A Definition	21
1.6	Knowledge-based Systems and the Various Types of Expertise	24
1.6.1	Associational Knowledge	24
1.6.2	Motor Skills	25
1.6.3	Theoretical (Deep) Knowledge	25
1.7	Features of Knowledge-based Systems	26
1.7.1	Advantages	26
1.7.2	Disadvantages	27
1.8	GenAID—A Case Study	28

1.9	Development of Knowledge-based Systems	30
1.10	Chapter Review	31
1.11	Problems	32
2	KNOWLEDGE-BASED SYSTEMS STRUCTURE	34
2.1	Introduction	34
2.2	System Components—End-User's View	35
2.2.1	The Intelligent Program	35
2.2.2	The User Interface	35
2.2.3	The Problem-specific Database	36
2.3	System Components—Knowledge Engineer's View	37
2.3.1	Intelligent Program	37
2.3.1.1	The knowledge base	37
2.3.1.2	The inference engine	38
2.3.2	The Development Shell	40
2.3.2.1	Knowledge acquisition tool	40
2.3.2.2	Test case database	40
2.3.2.3	Developer's interface	41
2.4	System Components—Tool Builder's View	41
2.5	Knowledge-based Tools	43
2.5.1	Shells	43
2.5.2	Developing a System from Scratch	44
2.6	Chapter Review	45
2.7	Problems	46
3	LOGIC AND AUTOMATED REASONING	47
3.1	Introduction	47
3.2	Propositional Logic	48
3.3	Predicate Logic—A Means of Representing Knowledge	51
3.3.1	Predicates and Terms	52
3.3.2	Variables and Quantifiers	53
3.3.3	Unification	55
3.3.4	Converting English Statements into wff's	57
3.4	Logical Inferences and Automated Reasoning— Manipulating the Knowledge	58
3.4.1	Deduction	60
3.4.2	Abduction	61
3.4.3	Induction	62

3.4.4	Automated Theorem Proving and Resolution	63
3.4.5	Monotonic Verses Nonmonotonic Reasoning.....	66
3.5	PROLOG.....	69
3.5.1	A Basic Introduction.....	69
3.5.2	Facts.....	70
3.5.3	Rules.....	71
3.5.4	Backtracking and the Inference Process in PROLOG	72
3.5.5	The CUT	78
3.6	Advantages and Disadvantages of Predicate Logic as a Basis for a Knowledge-based System.....	81
3.7	Chapter Review.....	82
3.8	Problems.....	83
4	INTRODUCTION TO RULE-BASED REASONING	86
4.1	Introduction.....	86
4.2	What are Rules?.....	87
4.3	Rule-based Inference	88
4.4	The Reasoning Process	90
4.4.1	Forward Reasoning.....	94
4.4.2	Backward Reasoning	96
4.5	Rule-based Architectures.....	99
4.5.1	Inference Networks.....	99
4.5.2	Pattern-matching Systems	101
4.5.3	Evaluation of the Architectures	103
4.6	Disadvantages of Rule-based Systems	103
4.6.1	Infinite Chaining.....	104
4.6.2	Addition of New, Contradictory Knowledge	104
4.6.3	Modifications to Existing Rules.....	106
4.6.4	Additional Disadvantages	107
4.7	Advantages of Rule-based Systems	108
4.8	Chapter Review.....	108
4.9	Problems.....	110
5	DETAILS OF RULE-BASED REASONING	112
5.1	Introduction.....	112
5.2	Forward Reasoning	112
5.2.1	Example 1 of Forward Reasoning	113
5.2.2	Example 2 of Forward Reasoning	119

5.2.3	The Rete Algorithm	127
5.2.4	Conflict Resolution Schemes	132
5.2.5	Coding Forward Reasoning (optional)	134
5.3	Backward or Goal-directed Reasoning	138
5.3.1	Example 1 of Backward Reasoning	138
5.3.2	Example 2 of Backward Reasoning	142
5.3.3	Coding a Backward-Reasoning System (optional)	151
5.4	Chapter Review	155
5.5	Problems	156
6	ASSOCIATIVE NETWORKS, FRAMES, AND OBJECTS	159
6.1	Introduction	159
6.2	Associative (Semantic) Networks	159
6.2.1	General Introduction	160
6.2.2	Associative Network Example	167
6.2.3	Coding Associative Networks (optional)	170
6.2.4	Advantages and Disadvantages of Associative Networks	173
6.3	Frames	174
6.3.1	General Introduction	174
6.3.2	A More Detailed Example	177
6.3.3	Implementation of Frames (optional)	189
6.3.4	Frames in Knowledge-based Systems	195
6.3.5	Advantages and Disadvantages of Frames	196
6.4	Objects	197
6.4.1	General Introduction	197
6.4.2	Historical Perspective	199
6.4.3	Object-oriented Extensions to LISP	199
6.4.3.1	General features	200
6.4.4	Advantages and Disadvantages	203
6.5	Chapter Review	204
6.6	Problems	205
7	BLACKBOARD ARCHITECTURES	207
7.1	Introduction	207
7.2	The Blackboard Framework	208
7.2.1	The Knowledge Sources	210

7.2.2	The Blackboard	211
7.2.3	The Control	211
7.2.4	Execution of Blackboard System.....	213
7.3	Historical Perspective	213
7.4	Hearsay.....	215
7.5	Crysalis.....	220
7.6	AGE	224
7.7	Blackboard Development Environments	226
7.8	Advantages and Disadvantages	228
7.9	Chapter Review.....	230
7.10	Problems.....	230
8	UNCERTAINTY MANAGEMENT	232
8.1	Introduction	232
8.2	Bayesian Approaches.....	233
8.2.1	Background	233
8.2.2	Bayes' Rule and Knowledge-based Systems	235
8.2.3	Propagation of Belief	237
8.2.4	Advantages and Disadvantages of Bayesian Methods	238
8.3	Certainty Factors	239
8.3.1	Certainty Factor (CF) Formalism	240
8.3.2	Propagation of Certainty Factors	241
8.3.3	Dealing with Uncertain Evidence.....	241
8.3.4	Certainty Factor Example.....	242
8.3.5	Advantages and Disadvantages of Certainty Factors	246
8.4	Dempster-Shafer Theory of Evidence	247
8.4.1	Definition of Terms	247
8.4.2	Example	249
8.4.3	Evaluation.....	253
8.5	Fuzzy Sets and Fuzzy Logics	254
8.5.1	Definition of Terms	255
8.5.2	Example	257
8.5.3	Evaluation.....	259
8.6	Chapter Review.....	260
8.7	Problems.....	261

9	ADVANCED REASONING TECHNIQUES	263
9.1	Introduction	263
9.2	Model-based Reasoning in Diagnostic Applications	265
9.2.1	Description of a Model-based Reasoning System	267
9.2.2	Example of Model-based Reasoning	270
9.2.3	Advantages and Disadvantages of Model-based Reasoning	272
9.3	Qualitative Reasoning	273
9.3.1	QSIM—A Qualitative Reasoning Language	274
9.3.2	A Qualitative Simulation Example Using QSIM	276
9.4	Case-based Reasoning	279
9.4.1	Example of Case-based Reasoning	281
9.4.2	Advantages and Disadvantages of Case-based Reasoning	283
9.5	Temporal Reasoning	284
9.5.1	Intervals and Points of Time	288
9.5.2	The Time Unit System	288
9.5.3	Temporal Reasoning Example	289
9.6	Artificial Neural Networks	292
9.7	Chapter Review	294
9.7	Problems	295
10	THE KNOWLEDGE-BASED SYSTEM LIFECYCLE	296
10.1	Introduction	296
10.2	The Lifecycle of Conventional Software	296
10.3	Differences from Knowledge-based Systems	300
10.4	The Knowledge-based System Lifecycle Stages	304
10.5	Chapter Review	307
11	FEASIBILITY ANALYSIS	308
11.1	Introduction	308
11.2	Suitability of the Application	309
11.2.1	Does a Problem Really Exist?	309
11.2.2	Is a Knowledge-based Technique Suited?	310
11.2.3	Is a Knowledge-based Approach Justified?	312

11.3	Availability of Resources.....	313
11.3.1	Is There Management Support for the Project?.....	313
11.3.2	Is There Support on the Part of the Expert?.....	314
11.3.3	Is the Expert Competent?.....	314
11.3.4	Is the Expert Articulate?.....	315
11.3.5	Is the Expert in Physical Proximity?.....	315
11.4	Sample Application.....	316
11.5	Chapter Review.....	319
11.6	Problems.....	320
12	REQUIREMENTS SPECIFICATION AND DESIGN	324
12.1	Introduction.....	324
12.2	Requirements Specification.....	325
12.3	Preliminary Design.....	328
12.3.1	Selection of a Knowledge Representation Paradigm.....	328
12.3.2	Reasoning Method Selection.....	329
12.3.3	Tool Selection.....	330
	12.3.3.1 Custom or commercial shell?	330
	12.3.3.2 Criteria for selecting commercially available shells	331
12.3.4	Selection of Human Resources.....	335
	12.3.4.1 Choosing the right knowledge engineer	335
	12.3.4.2 Choosing the right team leader	337
	12.3.4.3 Choosing the right expert	338
12.3.5	Development Team Requirements.....	339
	12.3.5.1 Small knowledge-based systems	339
	12.3.5.2 Medium systems	340
	12.3.5.3 Large systems	342
12.4	Initial Prototype (IP).....	343
12.5	Detailed Design.....	344
12.6	Chapter Review.....	346
12.7	Problems.....	346
13	KNOWLEDGE ACQUISITION AND SYSTEM IMPLEMENTATION	348
13.1	Introduction.....	348

13.2	Knowledge Acquisition	348
13.3	The Basic Unstructured One-on-one Interview	349
13.3.1	Kickoff Interview	350
13.3.2	Knowledge Elicitation Sessions	351
13.3.2.1	General knowledge-gathering sessions	352
13.3.2.2	Specific problem-solving, knowledge-gathering sessions	353
13.3.3	Knowledge Organization	354
13.3.4	Knowledge Documentation	356
13.4	Knowledge Elicitation Techniques	360
13.4.1	Observational Techniques	361
13.4.1.1	Quiet on-site observation	361
13.4.1.2	On-site observation with discussion	362
13.4.1.3	Exercising the expert	362
13.4.1.4	Problem description and analysis	363
13.4.2	Intuitive Techniques	364
13.5	Chapter Review	364
13.6	Problems	365
14	PRACTICAL CONSIDERATIONS IN KNOWLEDGE ACQUISITION	367
14.1	Introduction	367
14.2	Team Interviewing	367
14.2.1	One-on-many Interviews	368
14.2.2	Many-on-one Interviews	369
14.2.3	Many-on-many Interviews	370
14.3	Planning Interviews	370
14.3.1	Interview Location	370
14.3.2	Interview Schedules	371
14.3.3	Preparation of Interview	371
14.3.3.1	Review of prior work	372
14.3.3.2	Setting session objectives	372
14.4	Conducting the Interview	373
14.4.1	Interpersonal Communications	374
14.4.2	Recording the Information Gained in Meeting	375
14.5	Handling Problem Experts	376
14.5.1	The Wimp Expert	376

14.5.2	The Cynical Expert	377
14.5.3	The High Priest of the Domain Expert	377
14.5.4	The Paternalistic Expert	378
14.5.5	The Uncommunicative Expert	378
14.5.6	The Uncaring Expert	378
14.5.7	The Pseudo-AI-literate Expert	379
14.6	Chapter Review	379
15	ALTERNATIVE KNOWLEDGE ACQUISITION MEANS	381
15.1	The Knowledge Acquisition Bottleneck	381
15.2	Facilitating the Knowledge Acquisition Process	382
15.3	Machine Learning	387
15.3.1	Inductive Reasoning—Learning from Examples	388
15.3.2	Knowledge Acquisition through Inductive Tools	396
15.4	Automated Knowledge Extraction from Databases	397
15.5	Chapter Review	405
15.6	Problems	406
16	VERIFICATION AND VALIDATION	408
16.1	Introduction	408
16.2	A Comparison of the V&V of Knowledge-based Systems and Conventional Software	409
16.3	Verification	411
16.3.1	Specification Compliance	412
16.3.2	Developer-induced Errors	412
16.3.2.1	Redundant rules	413
16.3.2.2	Conflicting rules	414
16.3.2.3	Subsumed rules	414
16.3.2.4	Circular rules	414
16.3.2.5	Unnecessary IF conditions	415
16.3.2.6	Dead-end rules	415
16.3.2.7	Missing rules	416
16.3.2.8	Unreachable rules	416
16.3.3	When Semantic Errors Are Not Errors	416
16.3.4	Verification Tools	417
16.4	Validation	418
16.4.1	Significant Issues in Validation	418

16.4.1.1	What to validate	419
16.4.1.2	Validation methodology	419
16.4.1.3	Validation criteria	422
16.4.1.4	When is validation appropriate?	423
16.4.2	Errors	424
16.5	Case Studies—MYCIN and R1	425
16.6	A Practical Approach to V&V	428
16.7	Recommended Procedure for V&V	430
16.8	Chapter Review	433
17	LEGAL ISSUES IN KNOWLEDGE-BASED SYSTEMS	435
17.1	Introduction	435
17.2	The Law of Torts	436
17.3	Are Computer Programs Products or Services?	437
17.4	What About Knowledge-based Systems?	438
17.5	Software Protection	440
17.5.1	Copyright Protection	441
17.5.2	Patent Protection	441
17.5.3	Trade Secret Protection	442
17.6	Chapter Review	443
APPENDIX A	THE CLIPS SYSTEM	445
A.1	Introduction	445
A.2	The CLIPS System	445
A.3	Facts	446
A.3.1	Assertion of Facts	446
A.3.2	Retracting Facts	447
A.3.3	Initial Facts	448
A.4	Rules	449
A.5	Variables, Operators, and User-defined Functions	451
A.5.1	Variables	451
A.5.2	Special Symbols in Pattern	453
A.5.2.1	The wildcard	453
A.5.2.2	Field constraints	454
A.5.2.3	Mathematical operators	455
A.5.2.4	The test feature	456
A.5.2.5	Pattern connectives	456
A.5.3	User-defined Functions	458

A.6	Input/Output in CLIPS.....	458
A.6.1	The Fprintout Function	458
A.6.2	File I/O	459
A.6.3	Terminal Inputs	459
A.6.4	The MicroEMACS Editor	460
A.7	The CLIPS User Interface.....	460
A.8	Some Final Notes on CLIPS	468
 APPENDIX B THE PERSONAL CONSULTANT PLUS SHELL SYSTEM		 472
B.1	Introduction.....	472
B.2	Parameters.....	473
B.2.1	Parameter Properties	474
B.2.2	Required Parameters.....	474
B.2.2.1	The YES/NO parameter	474
B.2.2.2	The SINGLEVALUED parameter	474
B.2.2.3	The MULTIVALUED parameter	475
B.2.2.4	The ASK-ALL type	475
B.2.2.5	Parameter Example	475
B.2.3	Internal Parameter Properties.....	477
B.2.4	Optional Parameter Properties	477
B.3	Rules	478
B.3.1	The Abbreviated Rule Language	479
B.3.1.1	Arithmetic functions in ARL	480
B.3.1.2	Predicate functions	480
B.3.1.3	Text and graphics ARL functions	483
B.3.1.4	The conclusion ARL functions	485
B.3.1.5	The auxiliary ARL functions	485
B.3.2	Rule Properties.....	485
B.3.3	Meta-rules.....	486
B.4	The Knowledge Base Properties	486
B.4.1	The GOALS Property.....	487
B.4.2	The INITIALDATA Property.....	487
B.4.3	The DOMAIN Property.....	487
B.4.4	The TITLE Property	488
B.4.5	The PROMPTEVER and GPROMPTEVER Properties.....	488
B.4.6	The DISPLAYRESULTS Property	488
B.5	Certainty Factor Propagation.....	488
B.5.1	Certainty Factors	489
B.5.2	Belief Propagation	490

B.6 Interfacing with PC Plus 491

 B.6.1 The Developer's Interface 492

 B.6.1.1 The activities screen 493

 B.6.1.2 The knowledge base screen 494

 B.6.1.3 The properties screen 495

 B.6.1.4 The parameters screen 496

 B.6.1.5 The rules screen 498

 B.6.2 Additional Features of PC Plus..... 499

 B.6.2.1 The HOW command 500

 B.6.2.2 The WHY command 500

 B.6.2.3 The REVIEW command 500

B.7 Final Notes About PC Plus 500

REFERENCES

INDEX