1 INTRODUCTION

- 1.1 Artificial Intelligence 2
- 1.2 Expert Systems and Knowledge Engineering 3
- 1.3 Benefits of Applying Expert System Technology 3
- 1.4 Expert Systems and Experts 5
- 1.5 Roles of Expert Systems 6
- 1.6 Application Areas of Expert Systems 7
- 1.7 Special Capabilities and Features of Expert Systems 7
- 1.8 Limitations of Expert Systems 8
- 1.9 Developing an Expert System 9

BASIC CONCEPTS OF EXPERT SYSTEMS 11

- 2.1 Developing an Expert System 12
- 2.2 Knowledge Acquisition 12
- 2.3 Development of an Expert System Program 16
- 2.4 Structure of an Expert System 17
- 2.5 AI Knowledge Representation Paradigms 18
 - 2.5.1 Production Rules 18
 - 2.5.2 Frames, Inheritance, and Object-Oriented Programming 23

3	PLANNING AND MANAGING THE DEVELOPMENT 29
3.1	Initial Phases 30
	3.1.1 Project Start-up 30
	3.1.2 Selection of the Domain 34
	3.1.3 Selection of the Development Environment 36
3.2	Core Development Phases 38
	3.2.1 Development of a Feasibility Prototype System 38
	3.2.2 Development of a Full Prototype System 42
3.3	Final Development and Deployment Phases 44
	3.3.1 Development of a Production System 45
	3.3.2 System Deployment 48
	3.3.3 System Operation and Maintenance 50
Checkli	st 51
4	
	FORMING THE TEAM 55
4.1	Project Technical Leader 56
4.2	Project Manager 58
4.3	Domain Selector 58
4.4	Domain Expert 59
4.5	Consulting Domain Expert 60
4.6	Hardware and Software Selector 60
4.7	Knowledge Acquirer 61
4.8	Knowledge Representer 62
4.9	Knowledge Implementer 63
4.10	Systems Engineer 64
4.11	Project Tool Developer 65
4.12	Corporate/Client Interface 65
4.13	Technical Documenter/Writer 67
4.14	System Tester and Evaluator 68
4.15	System Deployer 69
4.16	Trainer 70
4.17	System Operator 70
4.18	System Maintainer 71
4.19	Consultant 72
4.20	Fnd User 73

Checklist 74

5.1 5.2 Checkl	SELECTING THE DOMAIN: THE PROCESS 77 Importance of Domain Selection 78 A Method for Evaluating Application Domains 79 ist 96
6.1	SELECTING THE DOMAIN: DESIRED DOMAIN ATTRIBUTES 97 Basic Requirements 98
	6.1.1 Need for the Expert System Approach 98
	6.1.2 Existence of Experts 99
	6.1.3 Need to Capture the Expertise 101
	6.1.4 Limited Success Is Acceptable 102
	6.1.5 Payoff 102
	6.1.6 Risk versus Payoff 105
6.2	Type of Problem 106
	6.2.1 Use of Symbolic Reasoning 106
	6.2.2 Use of Heuristics and Other Task Characteristics 107
	6.2.3 Widespread Knowledge and Common Sense 107

6.2.4 Not Driven by a Particular Technology 108

6.2.8 Similarity to Successful System 112

6.3.1 Experts Are Better than Novices 113

6.4.2 Estimated Lower Bound on Task Knowledge6.4.3 Estimated Upper Bound on Task Knowledge

6.5.1 Domain Personnel's Expectations of Success 116

6.5.2 Domain Leaders' Task Agreement and Continuing Involvement 117

6.3.2 Availability of Expertise6.3.3 Utilizing a Single Expert114

6.4.1 Bounds on Task Difficulty 114

Domain Area Personnel and Politics 116

6.5.3 Problem Previously Identified 118

6.4.4 Narrowness of Task 116

6.5.4 Top-Level Support 118

6.2.5 Task Definition 1106.2.6 Task Inputs 1106.2.7 Task Outputs 111

Expertise 112

Task Bounds 114

6.3

6.4

6.5

	6.5.5 Users Want It 118
	6.5.6 Introduction of the System 119
	6.5.7 Cooperative User Group 120
	6.5.8 Political Problems Related to System Control 120
	6.5.9 Political Problems Related to System Results 121
	6.5.10 Problems Related to the Sensitivity of the Knowledge 121
6.6	Development, Testing, and Deployment 122
	6.6.1 Incomplete Coverage 122
	6.6.2 Decomposability 123
	6.6.3 Teachable Skill 124
	6.6.4 Written Material 124
	6.6.5 Availability of Test Cases 125
	6.6.6 Real-Time and Performance Issues 125
	6.6.7 User Interface 126
	6.6.8 Long-Term System Need 127
	6.6.9 No Alternative 128
	6.6.10 Stability 129
	6.6.11 Project Dependencies and Milestones 129
	6.6.12 Tolerance to Incorrect Results 130
	6.6.13 Measurable Payoff 131
	6.6.14 Expert Agreement on Correctness 132
Checkli	ist 134
Check	
	SELECTING THE HARDWARE AND THE SOFTWARE
7	DEVELOPMENT TOOL 139
7.1	A Process for Selecting the Development Environment 141
7.2	Criteria and Parameters for Comparing Software Tools or Hardware 146
7.3	Obtaining the System 147
	7.3.1 Availability 147
	7.3.2 Cost 148
	7.3.3 Legal Arrangements 148
	7.3.4 Integration into Environment 149
	7.3.5 Uniformity with Others 149
7.4	Background and Prospects 150
	7.4.1 Vendor Track Record and Prospects 150
	7.4.2 System History 151
	7.4.3 Stage of Development 151
	7.4.4 System Upgrading 152
	7.4.5 System Maintenance by the Vendor 152

7.5	Learning to Use the System 153
	7.5.1 Training Materials 153
	7.5.2 Training Courses 153
7.6	System Usability and General Features 154
	7.6.1 System Interface 154
	7.6.2 Supportive Programming Environment 154
	7.6.3 Efficiency of the Programming Environment 155
	7.6.4 Software Engineering-Related Facilities 155
	7.6.5 Documentation 155
	7.6.6 Performance 156
	7.6.7 Size 157
	7.6.8 System Interfaces 157
	7.6.9 Security 158
	7.6.10 User Support and Consultants 158
7.7	Special Features Related to Software 159
	7.7.1 Building or Buying a Software Tool 159
	7.7.2 Knowledge Representation Paradigms 160
	7.7.3 Incorporation of a Computer Language 162
	7.7.4 Match to Problem 162
	7.7.5 Access to Source Code 163
7.8	Special Features Related to Hardware 163
	7.8.1 Computer Type 164
	7.8.2 System Software and File System 164
	7.8.3 Support for Multiple Tools 165
7.9	Issues Related to Deployment 165
	7.9.1 Use as Deployment Vehicle 165
	7.9.2 Easy Transfer to Deployment Vehicle 166
	7.9.3 Operation and Maintenance of the Deployed Expert System 167
Checklis	t 169

SELECTING THE DOMAIN EXPERTS 173

- **8.1** Responsibility for Selecting the Experts 174
- 8.2 Attributes of Good Domain Experts 175
 - 8.2.1 Existence of Domain Expertise and Experience 175
 - **8.2.2** Level of Expertise **175**
 - 8.2.3 Extensiveness of Experience 176
 - 8.2.4 Reputation 176
 - 8.2.5 Finding Experts with the Right Experience 177

	8.2.6 Communication Skills 178
	8.2.7 Temperament 179
	8.2.8 Cooperativeness 180
	8.2.9 Working Relations 181
	8.2.10 Availability 181
	8.2.11 Management Support for Expert Involvement 182
	8.2.12 Computer and AI Background 183
	8.2.13 Experts as Domain Representatives 184
	8.2.14 Expectations 186
8.3	The Process of Selecting Domain Experts 186
8.4	When No Experts Are Available 190
8.5	The Number of Domain Experts 192
	8.5.1 Using a Single Expert 192
	8.5.2 Using Multiple Experts 194
8.6	Consulting Domain Experts 195
Checklis	st 197
9	
	ACQUIRING THE KNOWLEDGE 199
9.1	Considering Knowledge Acquisition at the Project's Beginning 201
7.1	9.1.1 Selecting the Domain with a View toward Knowledge Acquisition 201
	9.1.2 Selecting Experts with a View toward Knowledge Acquisition 202
9.2	Knowledge Acquisition Meetings 203
,	9.2.1 Maximizing Access to the Experts 203
	9.2.2 Allowing the Experts to Demonstrate their Expertise 204
	9.2.3 Minimizing Interruptions 205
	9.2.4 Accessing the Implementation 206
	9.2.5 Locating Meetings at the Project Team's Site 207
9.3	Beginning the Knowledge Acquisition 208
,,,,	9.3.1 Meeting Atmosphere 208
	9.3.2 Focusing the Knowledge Acquisition 209
	9.3.3 Getting Background Domain Knowledge 209
	9.3.4 Preparing a Tutorial Document 210
	9.3.5 Giving the Domain Experts Some AI Background 211
	9.3.6 Using Written Materials for Initial Knowledge 211
	9.3.7 Initial Steps 212
9.4	Documenting the Knowledge 213
	9.4.1 Using Quasi-English Knowledge Acquisition Rules 213

	9.4.2 The Knowledge Document 214
	9.4.3 Readability of the Knowledge Documentation 216
	9.4.4 Terminology Used in the Knowledge Documentation 216
	9.4.5 Devising Terminology for Documentation and Discussion 217
	9.4.6 Identifying the Knowledge Acquisition Rules and Procedures 219
	9.4.7 Organizing the Knowledge Acquisition Rules and Procedures 220
	9.4.8 Utilizing an Explanatory Clause 220
	9.4.9 Domain Description and Glossary 221
9.5	Acquiring the Knowledge 221
	9.5.1 Basic Knowledge Acquisition Cycle before Implementation 221
	9.5.2 Basic Knowledge Acquisition Cycle after Implementation Has Begun 22
	9.5.3 Using Test Cases to Elicit Expert Knowledge 225
·	9.5.4 Using Acquired Knowledge to Guide Related Knowledge Acquisition 226
	9.5.5 Using Knowledge Acquisition Formalisms Directly 227
	9.5.6 Updating the Knowledge Documentation 227
	9.5.7 Deferring Specification of Certain Details 227
	9.5.8 Generating Test Cases from Test Cases 228
	9.5.9 Establishing a Default for Close Decisions 229
_	9.5.10 Finding the Extent of Rules 229
9.6	Recording the Knowledge 230
	9.6.1 Flexibility 230
	9.6.2 Recording Reminders 231
	9.6.3 Recording Benefits of the Expert System 231
Checkli	ist 233

10 REPRESENTING THE SYSTEM KNOWLEDGE 237

10.1 10.2 10.3	
10.5 10.6 10.7	Object-Oriented Programming 257

Checklist 263

11	IMPLEMENTING THE SYSTEM 265
11.1	Expert System Implementation Compared with the Implementation of Conventional Programs 266
11.0	11.1.1 Implementation without a Full Specification 266 11.1.2 Reimplementing the Implementation 269
11.2	Some Techniques for Knowledge Implementation 277 11.2.1 Correspondence of Knowledge Acquisition Rules and Implementation Rules 277
	11.2.2 Grouping Rules in Rulesets 278
	11.2.3 Implementing and Debugging 279
11.3	11.2.4 Documentation 280
11.5	Managing the Implementation and Promoting Maintainability 282 11.3.1 Software Modularity and Task Assignment 283
	11.3.2 Uniformity of Style 284
	11.3.3 Use of Paradigms that Promote Maintainability 286
	11.3.4 Configuration Management and Control 288
	11.3.5 Data Flow and Access 290
	11.3.6 Control Flow 292
	11.3.7 Input/Output 293
Checklis	t 296
12	TESTING AND EVALUATING THE SYSTEM 299
	TESTING AND EVALUATING THE STSTEM 299
12.1	Validation and Verification during Expert System Development 300
	12.1.1 Validation and Verification as Inherent Parts of Knowledge Acquisition 300
10.0	12.1.2 Validation Testing by Consulting Experts 302
12.2	Validation of the Developed Expert System 303
	12.2.1 Validating Absolutely 303
	12.2.2 Validating against Expert Performance 306 12.2.3 Validation by Field Testing 307
12.3	Verification of an Expert System Program 308
12.4	Evaluation Effort and Standards 310
Checklis	it 312

TRANSFERRING AND DEPLOYING THE SYSTEM 315 13.1 Developing an Expert System with Technology Transfer and Deployment in Mind 316 13.1.1 Issues Related to Domain Selection 316 13.1.2 Issues Related to Knowledge Representation and Implementation 318 13.2 Technology Transfer 319 13.3 Organizational Roles and Activities in Technology Transfer 321 13.4 Transferring AI Expertise 324 13.4.1 General Training Requirements 324 13.4.2 AI Techniques, Tools, and Systems Training 325 13.4.3 Domain Training 326 13.4.4 Training on the Expert System Program 327 13.4.5 Knowledge Acquisition Training 328 13.5 Deployment 328 13.5.1 Deployment Environment 328 13.5.2 Reliability, Maintainability, and Security 331 13.5.3 Integration of the Expert System 333

13.6 Gaining User Acceptance of the Deployed Expert System
13.6.1 Educating the Users 334
13.6.2 Introducing the Expert System 336
13.6.3 Use of the Expert System 337

Checklist 339

14 EX

EXPERT SYSTEM TRENDS AND DIRECTIONS 341

Glossary 347 Index 353