
TABLE OF CONTENTS

PART I: INTRODUCTION	21
CHAPTER 1. INTRODUCTION	23
1.1 Motivation	24
1.1.1 Self-Management	24
1.1.2 Runtime Maintenance	25
1.2 Overall Aim and Objectives	26
1.3 Research Methodology	28
1.4 Research Hypothesis	30
1.5 Thesis Overview	31
CHAPTER 2. CONTEXT	33
2.1 Introduction	33
2.2 Software Architectures	34
2.2.1 Definition	35
2.2.2 Basic Concepts	37
2.2.2.1 Component	37
2.2.2.2 Connector	38
2.2.2.3 Configuration	39
2.2.2.4 System	40
2.2.2.5 Port	40
2.2.2.6 Connection	40
2.2.2.7 Compositional Relationship	41
2.2.2.8 Other concepts	41
2.3 Aspect-Oriented Software Development	41
2.3.1 Aspect-Oriented Programming	42
2.3.2 Basic Concepts	44
2.3.3 Aspects in the Software Life Cycle	45
2.4 PRISMA	45
2.4.1 Model and ADL selection	46
2.4.2 Aspects as First-Class Citizens	47
2.4.3 PRISMA Architectural Elements	49

2.4.4	Levels of abstraction.....	51
2.4.5	Model-Driven Development Support.....	53
2.4.5.1	PRISMA in MOF.....	54
2.4.5.2	The PRISMA MDD Process.....	55
2.5	Conclusions.....	57
PART II: STATE OF THE ART		59
CHAPTER 3. DYNAMIC SOFTWARE EVOLUTION		61
3.1	Introduction.....	61
3.2	Software Evolution.....	61
3.2.1	Software Maintenance vs Software Evolution.....	62
3.2.2	Evolution as part of the Development Process	63
3.3	Dynamic Software Evolution.....	64
3.3.1	Changing software artefacts	64
3.3.2	Introducing changes at runtime.....	65
3.3.3	Dynamic Evolution: Definitions.....	66
3.3.4	Kinds of Dynamic Evolution.....	68
3.3.4.1	Granularity of changes	69
3.3.4.2	Activeness of change.....	70
3.4	Main Issues of Dynamic Evolution	71
3.4.1	Safe Stopping of Running Systems	72
3.4.1.1	Quiescence.....	72
3.4.1.2	Tranquillity	74
3.4.1.3	Other approaches for Safe Stopping.....	76
3.4.2	Updating Stateful Artefacts.....	78
3.4.2.1	No State Transfer.....	79
3.4.2.2	Delegated State Transfer	79
3.4.2.3	Automated State Transfer	80
3.5	Other approaches for dynamic change management	82
3.5.1	Control Systems	82
3.5.2	Autonomic Computing.....	83
3.5.3	Computational Reflection	87
3.6	Dynamic Evolution in Software Architectures	90
3.6.1	Dynamic Reconfiguration	90
3.6.2	Dynamic Evolution of Architectural Types.....	92
3.6.3	Combining both kinds of dynamism	93
3.7	Conclusions.....	93

CHAPTER 4. RELATED WORKS	95
4.1 Introduction	95
4.2 Dynamic Evolution Approaches.....	96
4.2.1 Formal, Dynamic ADLs for Reconfiguration.....	96
4.2.1.1 Process Algebra Formalisms	96
4.2.1.2 Graph-Based Formalisms.....	97
4.2.1.3 Reflection-Based Formalisms.....	99
4.2.2 Systems for Dynamic Change Support	100
4.2.2.1 Procedural and Object-Based Techniques	100
4.2.2.2 Dynamic Weaving Techniques in AOP.....	102
4.2.2.3 Component-Based Dynamic Frameworks	104
4.2.3 Self-Managed Software Architectures.....	108
4.2.3.1 Top-down approaches: Self-Adaptive Systems	108
4.2.3.2 Bottom-up approaches: Decentralized Architecture-Based Systems	114
4.2.4 AOSD & Evolution Concerns.....	117
4.3 Comparison of the different approaches	121
4.3.1 Description of the attributes selected.....	121
4.3.2 Comparison tables	124
4.4 Conclusions.....	128
PART III: DYNAMIC PRISMA	131
CHAPTER 5. CASE STUDY: AGROBOT.....	133
5.1 Introduction: Agricultural Robotics.....	133
5.2 Robotic Software Architectures	135
5.3 Dynamic Evolution in Robotic Software Architectures	136
5.4 Case Study: Agrobot, An Autonomous Robot for Plague control..	137
5.4.1 Main Architecture	138
5.4.2 Composite Components: VisionSystem	140
5.4.3 Simple Components: ImageProcCard	143
5.4.4 Aspects: ImageProcSwController	145
5.5 Dynamic Evolution Requirements of the Agrobot.....	147
5.5.1 Dynamic reconfiguration scenario: VisionSystem fault-tolerance support.....	148
5.5.2 Dynamic type evolution scenario: Changing the ImageProcSoftware component	152
5.6 Conclusions.....	155

CHAPTER 6. AUTONOMIC RECONFIGURATION	157
6.1 Introduction	157
6.2 Characteristics of the approach	158
6.3 Reconfiguration management model.....	161
6.3.1 A control loop for self-reconfiguration	162
6.3.2 Aspects versus modules	164
6.4 Description of the autonomic reconfiguration aspects	165
6.4.1 The Monitoring Aspect.....	166
6.4.1.1 Introspection Services.....	168
6.4.1.2 Runtime Status Information	172
6.4.1.3 Event Interception Services.....	173
6.4.2 The Reconfiguration Analysis Aspect	177
6.4.2.1 Structure of the Reconfiguration Analysis Aspect.....	177
6.4.2.2 Reconfiguration Triggers.....	181
6.4.2.3 Configuration Transactions	183
6.4.2.4 Adding Inference Mechanisms	188
6.4.3 The Reconfiguration Coordination Aspect	188
6.4.3.1 Domain-Specific Reconfiguration Services.....	189
6.4.3.2 Transactional Management of Reconfiguration Plans	192
6.4.3.3 Generic Reconfiguration Services	200
6.4.4 The Reconfiguration Effector Aspect.....	212
6.4.4.1 Services for Safe Stopping	213
6.4.4.2 Services for Reconfiguration	214
6.4.4.3 Services for Updating, Recovery and Mobility	215
6.5 The Evolver Component	220
6.5.1 Structure of the Evolver Component.....	220
6.5.2 Support for Reactive Reconfigurations	223
6.5.3 Weaving the Reconfiguration Aspects Together.....	227
6.5.4 Evolver Specification	231
6.5.4.1 Evolver Template: The User-Defined Part.....	231
6.5.4.2 Evolver Mechanisms: The Generated Functionality	234
6.5.4.3 Consistence of Generated Code	236
6.6 Example: autonomic reconfiguration in the VisionSystem architecture	238
6.7 Conclusions & further works.....	242
6.7.1 Conclusions.....	242
6.7.2 Further works	244
6.7.3 Results	245

CHAPTER 7. DYNAMIC EVOLUTION OF ARCHITECTURAL TYPES.....	247
7.1 Introduction	247
7.2 Basis of the dynamic evolution of architectural types.....	248
7.2.1 Definitions of Type, Instance and Architectural Type.....	248
7.2.2 Definition of the Dynamic Evolution of Architectural Types	250
7.3 Reflective Asynchronous Evolution of Architectural Types.....	251
7.3.1 System-level evolutions vs type-level evolutions.....	252
7.3.2 A reflective model for evolvable types	254
7.3.2.1 Reflection: The Abstract Model.....	254
7.3.2.2 Type Meta-Instances: The Concrete Model.....	255
7.3.2.3 Reification of Types	257
7.3.2.4 Evolution Process Overview	259
7.3.3 Evolving instances through transformations.....	261
7.3.4 An asynchronous model for types evolution.....	264
7.3.4.1 Modelling evolutions over time	264
7.3.4.2 Additional characteristics	269
7.3.5 Description of the evolution infrastructure	271
7.3.5.1 Type-level Evolution	272
7.3.5.2 Instance-level Evolution.....	297
7.3.6 Summary of the evolution process	311
7.4 Conclusions & further works	314
7.4.1 Conclusions.....	314
7.4.2 Further works	315
7.4.3 Results	316
CHAPTER 8. DESCRIPTION OF THE EVOLUTION SEMANTICS	319
8.1 Introduction	319
8.2 Challenges of asynchronous evolution.....	319
8.3 Evolution semantics	320
8.3.1 Specification of evolution processes.....	321
8.3.2 Version management: Evolution Tags	322
8.3.3 Formalisation of the evolution operations.....	325
8.3.3.1 Architecture-based Concrete Syntax	326
8.3.3.2 Graph-based Abstract Syntax.....	340
8.3.4 Discussion	347
8.4 Conclusions & further works	348
8.4.1 Conclusions.....	349
8.4.2 Further works	349
8.4.3 Results	350

PART IV: CONCLUSIONS & FURTHER WORK 351

CHAPTER 9. CONCLUSIONS353

- 9.1 Conclusions..... 353
 - 9.1.1 Contributions..... 354
 - 9.1.2 Evaluation of the approach 357
 - 9.1.3 Evaluation of the research..... 363
- 9.2 Results of the PhD 365
- 9.3 Further research 371
 - 9.3.1 Model-Driven Development support for evolvable systems 371
 - 9.3.2 Proactive non-programmed evolutions 372
 - 9.3.3 Definition of evolution constraints..... 372
 - 9.3.4 Coordination of decentralized Evolvers 373
 - 9.3.5 Formal analysis 373
 - 9.3.6 Tool support for advanced graph transformations 375

PART V: APPENDIXES 377

APPENDIX A. PRISMA SPECIFICATIONS OF THE VISIONSYSTEM.....379

- A.1 Specification of the VisionSystem type 379
 - A.1.1 Interfaces 379
 - A.1.2 Data Domains 380
 - A.1.3 External Functions 380
 - A.1.4 Architecture and configurations 381
 - A.1.5 Components..... 385
 - A.1.6 Connectors..... 387
 - A.1.7 Aspects..... 388
- A.2 Reconfiguration Elements 393
 - A.2.1 Interfaces 393
 - A.2.2 Evolver Component..... 395
 - A.2.3 Reconfiguration Analysis Aspect..... 400
 - A.2.4 Reconfiguration Coordination Aspect..... 404
 - A.2.5 Architecture Monitoring Aspect 414
 - A.2.6 Architecture Effector Aspect..... 415
- A.3 Type Evolution Elements..... 416
 - A.3.1 Data structures 416
 - A.3.2 Interfaces 420
 - A.3.3 Type Description Aspect 422
 - A.3.4 Type Evolution Aspect 426
 - A.3.5 Evolution Monitoring Aspect 427
 - A.3.6 Builder Aspect..... 428
 - A.3.7 Instance Evolution Planning aspect 430

A.3.8 Instance Monitoring aspect.....	432
A.3.9 Instance Effector aspect.....	432
APPENDIX B. EXTENSIONS OF THE PRISMA AOADL.....	435
B.1 Lists.....	435
B.2 Iterations and Loops	436
B.3 Partial Definitions of Software Artefacts.....	437
LIST OF FIGURES	441
REFERENCES	445