DESIGN OF SELF-ADAPTATION IN DISTRIBUTED EMBEDDED SYSTEMS

Dissertation

for the degree of
Doctor of Natural Sciences (Dr. rer. nat.)
Department of Computer Science
University of Augsburg

Dipl.-Inform. Gereon Weiß

2014
## Contents

Abstract iii

Zusammenfassung v

Acknowledgments vii

Glossary xiii

1 Introduction 1
   1.1 Motivation 1
   1.2 Research Questions and Contributions 3
   1.3 Organisation of this Thesis 4

2 Self-Adaptive Distributed Embedded Systems 5
   2.1 Embedded Systems and Self-Adaptation 5
      2.1.1 Distributed Embedded Systems 6
      2.1.2 Variability 7
      2.1.3 Self-Adaptation 8
   2.2 Model-Driven Development of Embedded Systems 14
      2.2.1 Unified Modeling Language 15
      2.2.2 Architectural Description Languages 16
   2.3 Present Design of Self-Adaptation 18
      2.3.1 Self-Adaptation through Software-Product-Lines 18
      2.3.2 Design of Modal Behavior 21
      2.3.3 Discussions on the Design of Self-Adaptation 24
   2.4 Example Domain for Distributed Embedded Systems 25
      2.4.1 AUTOSAR 28
      2.4.2 Runtime Variability 29
      2.4.3 Mode Management 30
   2.5 Challenges for the Development 32
      2.5.1 Constraints for Distributed Embedded Systems Development 32
      2.5.2 Challenges for the Design of Self-Adaptation 34
   2.6 Conclusions 35

3 Related Work 37
   3.1 Design Approaches for Self-Adaptation 37
      3.1.1 DiVA 38
      3.1.2 Genie 38
      3.1.3 MADAM & MUSIC 39
      3.1.4 Construction of Self-Organized Multi-Agent Systems 40
### 3.1.5 DySCAS ................................................................. 40
### 3.1.6 Self-Optimizing Concepts and Structures in Mechanical Engineering .................................................. 41

#### 3.2 Design of Modal Behavior ........................................ 42
- 3.2.1 Multimodal Control with Supervisory Control Theory .......... 42
- 3.2.2 COLA Component Language ........................................ 42
- 3.2.3 Metamodes for Dynamic Reconfiguration .......................... 43
- 3.2.4 Gaspard2 .............................................................. 44

#### 3.3 Software Product Lines for Runtime Adaptation ................ 45
- 3.3.1 Flexible Feature Composition ...................................... 45
- 3.3.2 Chameleon & MARS .................................................. 45
- 3.3.3 Dynamic Software Product Line Approaches .................... 46

#### 3.4 Runtime Information ............................................... 47
- 3.4.1 Stitch .................................................................. 47
- 3.4.2 XML-based Runtime Descriptions ................................. 48
- 3.4.3 Binary Runtime Descriptions ...................................... 49
- 3.4.4 Reflection for Self-Adaptation .................................... 49

#### 3.5 Conclusions .............................................................. 50

### 4 Model-Driven Design of Self-Adaptation .......................... 53

#### 4.1 Novel Approach for the Design of Self-Adaptation .......... 53
- 4.1.1 Basic Concepts ...................................................... 54
- 4.1.2 Design Levels of Abstraction ..................................... 56
- 4.1.3 System Model .......................................................... 57
- 4.1.4 Degree of Variability .............................................. 63

#### 4.2 Self-X Profile ............................................................ 66
- 4.2.1 Architectural Elements ............................................. 67
- 4.2.2 Adaptation Elements ............................................... 69

#### 4.3 Validating Design Architectures through Execution ........... 70
- 4.3.1 SystemC TLM .......................................................... 71
- 4.3.2 Integration of EAST-ADL and SystemC ......................... 72

#### 4.4 Example Application Case Studies ................................. 77
- 4.4.1 Case Study Self-Adaptive Body Control ....................... 77
- 4.4.2 Enabling Self-Adaptation in Today's Distributed Embedded Systems ................................................. 83

#### 4.5 Conclusions .............................................................. 88

### 5 Novel Design Concepts for Self-Adaptation ....................... 91

#### 5.1 Context Model for Self-Adaptation ............................... 92
- 5.1.1 Concepts for the Context Model .................................. 92
- 5.1.2 Context Model Integration ......................................... 96
- 5.1.3 Context Model for the Body Control Case Study ............... 97

#### 5.2 Modal Behavior for Self-Adaptive Systems ..................... 98
- 5.2.1 System with Modal Behavior ...................................... 99
- 5.2.2 Design Integration of Extended Modal Behavior ............... 105
- 5.2.3 Designing Self-Adaptation of the Body Control Case Study .................................................................................. 107

#### 5.3 Runtime Information as Self-Descriptions ....................... 110
- 5.3.1 Concepts for Self-Descriptions .................................... 111
- 5.3.2 Self-Descriptions Integrated in the Design .................... 113
B.4 Configuration Spaces .................................................. 232
B.5 Self-Descriptions for Finding Allocations ......................... 240

C Infotainment Case Study .......................... 247

D Smart Car Case Study .............................. 249
  D.1 Adaptive Modes ............................................. 251
  D.2 SPL Feature Tree ........................................... 256

E Publications ..................................... 257