Schäfer

Model-Based Development of Multimodal and Multi-Device User Interfaces in Context-Aware Environments

C-LAB Publication

Herausgegeben von
Published by

Dr. Wolfgang Kern, Siemens AG
Prof. Dr. Franz-Josef Rammig, Universität Paderborn

Das C-LAB - Cooperative Computing & Communication Laboratory - leistet Forschungs- und Entwicklungsarbeiten und gewährleistet deren Transfer an den Markt. Es wurde 1985 von den Partnern Nixdorf Computer AG (nun Siemens AG) und der Universität Paderborn im Einvernehmen mit dem Land Nordrhein-Westfalen gegründet.

Die Vision, die dem C-LAB zugrunde liegt, geht davon aus, daß die gewaltigen Herausforderungen beim Übergang in die kommende Informations- und Wissensgesellschaft nur durch globale Kooperation und in tiefer Verzahnung von Theorie und Praxis gelöst werden können. Im C-LAB arbeiten deshalb Mitarbeiter von Hochschule und Industrie unter einem Dach in einer gemeinsamen Organisation an gemeinsamen Projekten mit internationalen Partnern eng zusammen.

C-LAB - the Cooperative Computing & Cooperation Laboratory - works in the area of research and development and safeguards its transfer into the market. It was founded in 1985 by Nixdorf Computer AG (now Siemens AG) and the University of Paderborn under the auspices of the State of North-Rhine Westphalia.

C-LAB's vision is based on the fundamental premise that the gargantuan challenges thrown up by the transition to a future information and knowledge society can only be met through global cooperation and deep interworking of theory and practice. This is why, under one roof, staff from the university and from industry cooperate closely on joint projects within a common research and development organization together with international partners. In doing so, C-LAB concentrates on those innovative subject areas in which cooperation is expected to bear particular fruit for the partners and their general well-being.

C-LAB Publication

Band 25

Robbie Schäfer

Model-Based Development of Multimodal and Multi-Device User Interfaces in Context-Aware Environments

D 466 (Diss. Universität Paderborn)

Shaker Verlag
Aachen 2007

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Zugl.: Paderborn, Univ., Diss., 2007

Copyright Shaker Verlag 2007
All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the publishers.

Printed in Germany.

ISBN 978-3-8322-6528-1
ISSN 1438-3527

Shaker Verlag GmbH • P.O. BOX 101818 • D-52018 Aachen
Phone: 0049/2407/9596-0 • Telefax: 0049/2407/9596-9
Internet: www.shaker.de • e-mail: info@shaker.de

Model-Based Development of Multimodal and Multi-Device User Interfaces in Context-Aware Environments

Dissertation

A thesis submitted to the
Faculty of Computer Science, Electrical Engineering and Mathematics
of the Universität Paderborn in partial fulfillment
of the requirements for the degree of Dr. rer. nat.

by
Robbie Schäfer

Paderborn, July 2007

Supervisors:

1. Prof. Dr. Gerd Szwillus, Universität Paderborn
2. Prof. Dr. Franz J. Rammig, Universität Paderborn
3. Prof. Dr. Jean Vanderdonckt, Université Catholique de Louvain

Date of public examination: July 3, 2007

Acknowledgements

I would like to express my gratitude to a number of people who had a significant impact on my work.

First of all I would like to thank my supervisors Prof. Dr. Gerd Szwillus, Prof. Dr. Franz J. Rammig and Prof. Dr. Jean Vanderdonckt for the support of my research. In addition, I would also like to thank Prof. Dr. Gitta Domik and Dr. Wolfgang Müller for taking part in the board of examinators.

I am especially grateful to Dr. Wolfgang Müller for helping me to find my research directions in the beginning and for the continuous support of my work.

Part of this work has been conducted in two international research projects: "Middleware for Virtual Home Environments" (ITEA-VHE) and "Security in Ubiquitous Computing" (IST-UBISEC). The work in these projects was very beneficial for me, and I would like to thank in this context Johan Plomp, Dr. Andres Marín López, Dr. Stephan Flake and Dr. Jürgen Tacken for the excellent cooperation.

The same also goes for my colleagues Dr. Chris Loeser, Tim Schattkowsky, Dr. Heinz-Josef Eikerling, Frank Berger, Jurgen Görlich, Dr. Brigitte Oesterdieckhoff, Henning Zabel, Dr. Achim Rettberg, Alexander Krupp, Kay Klobedanz and Tao Xie.

I am also in debt to the following (former) students whose work I supervised, and I believe the benefit was mutual: Steffen Bleul, Tobias Schumacher, Max Ziegler, Stefan Gildner, Dirk Hopmann, Roman Deimann and Serge Rittscher.

Many thanks go to the following members of the OASIS UIML Technical Committee: James Helms, Dr. Marc Abrams, Dr. Kris Luyten, Prof. Dr. Jean Vanderdonckt and Jo Vermeulen. Our continuous discussions on a very professional level have been a valuable addition to my research.

I would also like to thank Hannelore Schlott and Kai Mun Liu for proofreading my manuscript.

Last but not least I would like to thank my family for their support and especially my wife Wang Yan Liu for her continuous encouragement.

Abstract

Nowadays, the vision of "Ubiquitous Computing" is partly put into practice, as users have many networked interaction devices at hand such as mobile phones, PDAs, Laptops etc. To allow unobtrusive and natural interaction with the devices in the user's environment remains a major challenge, as many different platforms, modalities and even contexts of use have to be supported. Traditional approaches in developing tailored user interfaces for each platform, device and modality are bound to fail since they neither take the dynamic usage context into account nor are they adaptable to the user's preferences and capabilities.

Within this thesis, the aforementioned challenges are addressed by a model-based approach, which allows the specification of device- and modality-independent context-aware user interfaces by a combination of dialogue and presentation models, profiles describing users, devices, modalities and context, as well as transformations between models and target user interfaces. The work carried out in this thesis is divided into three major topics: modeling the user interfaces, modeling and managing context information, and the adaptation of user interfaces based on the previous two concepts.

For the user interface modeling part, the Dialogue and Interface Specification Language (DISL) has been developed, which is an XML-based UI description language, closely related to the User Interface Markup Language (UIML). DISL incorporates a powerful dialogue model and a modality-independent presentation model. Some properties of DISL are now included in the upcoming OASIS-standard UIML 4.0. Together with DISL, a rendering architecture is presented, which allows interaction with different devices and modalities.

Concepts for context modeling have been established by using sets of interrelated profiles that are used to describe different aspects of users, devices and environments they are in. Furthermore, means for acquiring and processing contextual information, while maintaining the user's privacy, have been addressed.

The glue between the user interface models and the final user interfaces is provided through transformations which take the contextual information into account. As a transformation tool, the development of the Rule Description Language for Tree Transformation (RDL/TT) proved to be useful for many tasks provided in the scope of this thesis.

The contributions of this thesis have been validated by proof-of-concept implementations, a set of case studies that combine these implementations and examinations of requirements for the domains addressed.

Contents

Acknowledgements iii

Abstract v

1 Introduction 1
- 1.1 Motivating Scenario . . . 2
- 1.2 Research Questions . . . 4
- 1.3 Statement . . . 5
- 1.4 Architectural Overview . . . 6

2 User Interface Modeling 9
- 2.1 Introduction . . . 9
- 2.2 Related Work . . . 11
  - 2.2.1 User Interface Models . . . 11
  - 2.2.2 XML-based User Interface Description Languages . . . 23
- 2.3 Dialogue and Interface Specification Language . . . 30
  - 2.3.1 Issues for Developing Multimodal Dialogues . . . 31
  - 2.3.2 UIML for Multimodal and Multi-Device Interfaces . . . 34
  - 2.3.3 Generic Widgets . . . 35
  - 2.3.4 Dialogue Specification Notation . . . 36
  - 2.3.5 Dialogue and Interface Specification Language . . . 39
  - 2.3.6 Control Flow for Multimodal and Multi-Device Interfaces . . . 42
  - 2.3.7 A Small Proof of Turing Completeness . . . 48
- 2.4 Dealing with Limited Devices: SDISL . . . 52
- 2.5 Multi (Device and Modality) Interaction Rendering System . . . 55
- 2.6 Towards Object-Orientation: ODISL . . . 57

3 Context-Dependent User Interfaces 63
- 3.1 Introduction . . . 63
- 3.2 Modeling Users and their Context with Profiles . . . 64
  - 3.2.1 Data Classification . . . 64
  - 3.2.2 Requirements for Profiles . . . 70
- 3.3 Profile Acquisition . . . 74
  - 3.3.1 Acquiring Device and user Data . . . 74
  - 3.3.2 Acquiring Context . . . 75

3.4 Persistence and Security . . . 78
3.5 Processing and Decision Making . . . 84
3.5.1 Fuzzy Decision Making . . . 85
3.5.2 Profile Evolution . . . 87

4 User Interface Adaptation 97
4.1 Introduction . . . 97
4.2 Rule Description Language for Tree Transformation (RDL/TT) . . . 98
4.2.1 Overview of the Transcoding System . . . 99
4.2.2 General Structure of RDL/TT . . . 100
4.2.3 Functions . . . 102
4.2.4 Control Structures . . . 102
4.2.5 Paths in RDL/TT . . . 104
4.3 A Survey on Transformation Tools . . . 105
4.3.1 Selection and Comparison Criteria . . . 105
4.3.2 Selected Transformation Approaches . . . 106
4.3.3 General Language Comparison . . . 110
4.3.4 Discussion . . . 111
4.4 Detailed Comparison of RDL/TT, UIML-Peers and XSLT . . . 112
4.4.1 Transcoding Example . . . 113
4.4.2 Implementation Experience with the Transcoding Languages . 116
4.4.3 Feature Comparison and Discussion . . . 121

5 Implementation, Integration and Validation 127
5.1 Prototypes . . . 127
5.2 The AC-LAB Environment . . . 130
5.3 Applications and Case Studies . . . 132
5.3.1 Context-Aware Applications . . . 132
5.3.2 Profile and Security Handling Applications . . . 134
5.3.3 Information Access with Different Devices . . . 134
5.3.4 Multimodal Remote Control . . . 137
5.4 Validation . . . 139
5.4.1 Validation Against the DISL Requirements . . . 139
5.4.2 Improvements on UIML . . . 143
5.4.3 Discussion of Multimodal Support . . . 143
5.4.4 Assessment of Profile Requirements . . . 145
5.4.5 Supported Design Options . . . 146

6 Conclusions 149
6.1 Summary . . . 149
6.2 Scientific Contributions . . . 150
6.3 Further Impact . . . 154
6.4 Future Prospects . . . 155

A Examples of improved UIML **157**
A.1 Implementing a Simple State Machine . . . 157
A.2 Implementing a More Complex State Machine . . . 160
A.3 Validating Input . . . 164

B Examples of ODISL **171**
B.1 Overview . . . 171
B.2 The Display class . . . 172
B.3 The Editable Display Class . . . 175
B.4 A Concrete Instance: The Speedometer Class . . . 177
B.5 Inheritance and Extension of Behavior . . . 180
B.6 Instantiating Classes . . . 181

C DISL DTD **185**

D Example of the RDL/TT-based Profile Evolution **193**