



UNIVERSIDAD DE DEUSTO

DYNAMIC USER INTERFACES ADAPTATION ENGINE THROUGH SEMANTIC MODELLING AND REASONING IN MOBILE DEVICES.

Tesis doctoral presentada por Eduardo Castillejo
dentro del Programa de Doctorado en Doctorado en Informática y
Telecomunicaciones

Dirigida por Dr. Diego López-de-Ipiña
y Dr. Aitor Almeida



UNIVERSIDAD DE DEUSTO

DYNAMIC USER INTERFACES ADAPTATION ENGINE THROUGH SEMANTIC MODELLING AND REASONING IN MOBILE DEVICES.

Tesis doctoral presentada por Eduardo Castillejo
dentro del Programa de Doctorado en Doctorado en Informática y
Telecomunicaciones

Dirigida por Dr. Diego López-de-Ipiña
y Dr. Aitor Almeida

El doctorando

El director

El director

Bilbao, Month de 2014

Dissertation Title

Author: Name

Advisor: Name

Advisor: Name

The following web-page address contains up to date information about this dissertation and related topics:

<http://paginaspersonales.deusto.es/Name/>

Text printed in Bilbao

First edition, August 2014

Zuk nahi duzuna.

Abstract

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut ultrices egestas nunc, venenatis rhoncus elit fermentum non. Pellentesque gravida nulla vitae ipsum lobortis ullamcorper. Ut adipiscing, tellus in egestas mattis, enim metus pretium erat, ac tempor dolor neque placerat nulla. Nullam nec ligula eu ipsum pharetra semper a in magna. Integer ut tortor quis nisi fringilla euismod eu ac ipsum. Pellentesque sodales consectetur erat eget rutrum. Proin ornare dolor ut arcu aliquet vestibulum. Pellentesque laoreet tincidunt sem eget semper.

Integer interdum mattis magna ullamcorper tristique. Nullam commodo nulla eget ipsum vulputate tincidunt auctor leo aliquet. Fusce euismod sagittis ante, eu vulputate eros dictum at. Cras non euismod nunc. Nullam velit diam, consectetur sed eleifend vitae, blandit at arcu. Maecenas ut urna nec turpis lobortis commodo. Aliquam aliquet turpis id massa viverra id sollicitudin est cursus. Sed a tortor non mauris cursus imperdiet.

Integer fermentum rutrum urna at vestibulum. Vivamus ullamcorper erat in sapien dignissim pellentesque. Integer convallis fringilla dictum. In bibendum lectus eu nulla pretium volutpat. Morbi hendrerit fringilla tortor, sed gravida neque lacinia a. In risus magna, hendrerit vitae cursus ac, vehicula at eros. Aenean quis ipsum sit amet leo vestibulum cursus.

Cras placerat mattis dui quis vehicula. Nulla sit amet metus nibh, at auctor enim. Quisque congue ultricies sapien in suscipit. Fusce vitae placerat ante. Praesent aliquet urna ac elit consequat nec mattis

augue faucibus. Nunc et sapien vel felis mollis sodales. Aenean molestie nulla vestibulum nisi fringilla vel euismod dolor tristique. Aenean fermentum, dolor eget tincidunt faucibus, risus lorem feugiat elit, sagittis malesuada eros ligula in odio. Pellentesque ac libero lobortis justo bibendum laoreet. Cras egestas lorem eget ligula dignissim sollicitudin. Vestibulum sit amet augue ultrices erat faucibus vestibulum. Aenean tincidunt faucibus leo, nec auctor diam bibendum a. Sed varius, mauris in pellentesque scelerisque, nisl ligula viverra erat, in eleifend tellus enim ac magna. Pellentesque quis est risus. Cras mollis feugiat auctor. Proin ac eros vitae nulla gravida varius.

Morbi at augue sapien. Duis tempus quam vitae velit interdum ultricies. Vivamus laoreet lacinia elit sit amet vehicula. Ut congue diam ac magna hendrerit sed fermentum justo lacinia. Curabitur vel odio neque, quis consequat mi. Proin lobortis justo quis enim fermentum accumsan sagittis ipsum imperdiet. Proin sem felis, laoreet placerat egestas id, fringilla id mauris. Pellentesque a nisi sit amet leo consectetur gravida nec et dui. Curabitur quis hendrerit augue. Etiam sed dui nec tortor convallis fringilla. Proin tempor mattis diam nec egestas. Quisque condimentum elementum lacus ac porta. Vivamus congue, odio eu ullamcorper elementum, leo turpis tempus sem, at condimentum dolor quam eu nunc. Pellentesque eget risus ac velit aliquam sollicitudin sed et ipsum.

Resumen

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut ultrices egestas nunc, venenatis rhoncus elit fermentum non. Pellentesque gravida nulla vitae ipsum lobortis ullamcorper. Ut adipiscing, tellus in egestas mattis, enim metus pretium erat, ac tempor dolor neque placerat nulla. Nullam nec ligula eu ipsum pharetra semper a in magna. Integer ut tortor quis nisi fringilla euismod eu ac ipsum. Pellentesque sodales consectetur erat eget rutrum. Proin ornare dolor ut arcu aliquet vestibulum. Pellentesque laoreet tincidunt sem eget semper.

Integer interdum mattis magna ullamcorper tristique. Nullam commodo nulla eget ipsum vulputate tincidunt auctor leo aliquet. Fusce euismod sagittis ante, eu vulputate eros dictum at. Cras non euismod nunc. Nullam velit diam, consectetur sed eleifend vitae, blandit at arcu. Maecenas ut urna nec turpis lobortis commodo. Aliquam aliquet turpis id massa viverra id sollicitudin est cursus. Sed a tortor non mauris cursus imperdiet.

Integer fermentum rutrum urna at vestibulum. Vivamus ullamcorper erat in sapien dignissim pellentesque. Integer convallis fringilla dictum. In bibendum lectus eu nulla pretium volutpat. Morbi hendrerit fringilla tortor, sed gravida neque lacinia a. In risus magna, hendrerit vitae cursus ac, vehicula at eros. Aenean quis ipsum sit amet leo vestibulum cursus.

Cras placerat mattis dui quis vehicula. Nulla sit amet metus nibh, at auctor enim. Quisque congue ultricies sapien in suscipit. Fusce vitae placerat ante. Praesent aliquet urna ac elit consequat nec mattis

augue faucibus. Nunc et sapien vel felis mollis sodales. Aenean molestie nulla vestibulum nisi fringilla vel euismod dolor tristique. Aenean fermentum, dolor eget tincidunt faucibus, risus lorem feugiat elit, sagittis malesuada eros ligula in odio. Pellentesque ac libero lobortis justo bibendum laoreet. Cras egestas lorem eget ligula dignissim sollicitudin. Vestibulum sit amet augue ultrices erat faucibus vestibulum. Aenean tincidunt faucibus leo, nec auctor diam bibendum a. Sed varius, mauris in pellentesque scelerisque, nisl ligula viverra erat, in eleifend tellus enim ac magna. Pellentesque quis est risus. Cras mollis feugiat auctor. Proin ac eros vitae nulla gravida varius.

Morbi at augue sapien. Duis tempus quam vitae velit interdum ultricies. Vivamus laoreet lacinia elit sit amet vehicula. Ut congue diam ac magna hendrerit sed fermentum justo lacinia. Curabitur vel odio neque, quis consequat mi. Proin lobortis justo quis enim fermentum accumsan sagittis ipsum imperdiet. Proin sem felis, laoreet placerat egestas id, fringilla id mauris. Pellentesque a nisi sit amet leo consectetur gravida nec et dui. Curabitur quis hendrerit augue. Etiam sed dui nec tortor convallis fringilla. Proin tempor mattis diam nec egestas. Quisque condimentum elementum lacus ac porta. Vivamus congue, odio eu ullamcorper elementum, leo turpis tempus sem, at condimentum dolor quam eu nunc. Pellentesque eget risus ac velit aliquam sollicitudin sed et ipsum.

Laburpena

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut ultrices egestas nunc, venenatis rhoncus elit fermentum non. Pellentesque gravida nulla vitae ipsum lobortis ullamcorper. Ut adipiscing, tellus in egestas mattis, enim metus pretium erat, ac tempor dolor neque placerat nulla. Nullam nec ligula eu ipsum pharetra semper a in magna. Integer ut tortor quis nisi fringilla euismod eu ac ipsum. Pellentesque sodales consectetur erat eget rutrum. Proin ornare dolor ut arcu aliquet vestibulum. Pellentesque laoreet tincidunt sem eget semper.

Integer interdum mattis magna ullamcorper tristique. Nullam commodo nulla eget ipsum vulputate tincidunt auctor leo aliquet. Fusce euismod sagittis ante, eu vulputate eros dictum at. Cras non euismod nunc. Nullam velit diam, consectetur sed eleifend vitae, blandit at arcu. Maecenas ut urna nec turpis lobortis commodo. Aliquam aliquet turpis id massa viverra id sollicitudin est cursus. Sed a tortor non mauris cursus imperdiet.

Integer fermentum rutrum urna at vestibulum. Vivamus ullamcorper erat in sapien dignissim pellentesque. Integer convallis fringilla dictum. In bibendum lectus eu nulla pretium volutpat. Morbi hendrerit fringilla tortor, sed gravida neque lacinia a. In risus magna, hendrerit vitae cursus ac, vehicula at eros. Aenean quis ipsum sit amet leo vestibulum cursus.

Cras placerat mattis dui quis vehicula. Nulla sit amet metus nibh, at auctor enim. Quisque congue ultricies sapien in suscipit. Fusce vitae placerat ante. Praesent aliquet urna ac elit consequat nec mattis

augue faucibus. Nunc et sapien vel felis mollis sodales. Aenean molestie nulla vestibulum nisi fringilla vel euismod dolor tristique. Aenean fermentum, dolor eget tincidunt faucibus, risus lorem feugiat elit, sagittis malesuada eros ligula in odio. Pellentesque ac libero lobortis justo bibendum laoreet. Cras egestas lorem eget ligula dignissim sollicitudin. Vestibulum sit amet augue ultrices erat faucibus vestibulum. Aenean tincidunt faucibus leo, nec auctor diam bibendum a. Sed varius, mauris in pellentesque scelerisque, nisl ligula viverra erat, in eleifend tellus enim ac magna. Pellentesque quis est risus. Cras mollis feugiat auctor. Proin ac eros vitae nulla gravida varius.

Morbi at augue sapien. Duis tempus quam vitae velit interdum ultricies. Vivamus laoreet lacinia elit sit amet vehicula. Ut congue diam ac magna hendrerit sed fermentum justo lacinia. Curabitur vel odio neque, quis consequat mi. Proin lobortis justo quis enim fermentum accumsan sagittis ipsum imperdiet. Proin sem felis, laoreet placerat egestas id, fringilla id mauris. Pellentesque a nisi sit amet leo consectetur gravida nec et dui. Curabitur quis hendrerit augue. Etiam sed dui nec tortor convallis fringilla. Proin tempor mattis diam nec egestas. Quisque condimentum elementum lacus ac porta. Vivamus congue, odio eu ullamcorper elementum, leo turpis tempus sem, at condimentum dolor quam eu nunc. Pellentesque eget risus ac velit aliquam sollicitudin sed et ipsum.

Acknowledgements

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut ultrices egestas nunc, venenatis rhoncus elit fermentum non. Pellentesque gravida nulla vitae ipsum lobortis ullamcorper. Ut adipiscing, tellus in egestas mattis, enim metus pretium erat, ac tempor dolor neque placerat nulla. Nullam nec ligula eu ipsum pharetra semper a in magna. Integer ut tortor quis nisi fringilla euismod eu ac ipsum. Pellentesque sodales consectetur erat eget rutrum. Proin ornare dolor ut arcu aliquet vestibulum. Pellentesque laoreet tincidunt sem eget semper.

Integer interdum mattis magna ullamcorper tristique. Nullam commodo nulla eget ipsum vulputate tincidunt auctor leo aliquet. Fusce euismod sagittis ante, eu vulputate eros dictum at. Cras non euismod nunc. Nullam velit diam, consectetur sed eleifend vitae, blandit at arcu. Maecenas ut urna nec turpis lobortis commodo. Aliquam aliquet turpis id massa viverra id sollicitudin est cursus. Sed a tortor non mauris cursus imperdiet.

Integer fermentum rutrum urna at vestibulum. Vivamus ullamcorper erat in sapien dignissim pellentesque. Integer convallis fringilla dictum. In bibendum lectus eu nulla pretium volutpat. Morbi hendrerit fringilla tortor, sed gravida neque lacinia a. In risus magna, hendrerit vitae cursus ac, vehicula at eros. Aenean quis ipsum sit amet leo vestibulum cursus.

Cras placerat mattis dui quis vehicula. Nulla sit amet metus nibh, at auctor enim. Quisque congue ultricies sapien in suscipit. Fusce vitae placerat ante. Praesent aliquet urna ac elit consequat nec mattis

augue faucibus. Nunc et sapien vel felis mollis sodales. Aenean molestie nulla vestibulum nisi fringilla vel euismod dolor tristique. Aenean fermentum, dolor eget tincidunt faucibus, risus lorem feugiat elit, sagittis malesuada eros ligula in odio. Pellentesque ac libero lobortis justo bibendum laoreet. Cras egetas lorem eget ligula dignissim sollicitudin. Vestibulum sit amet augue ultrices erat faucibus vestibulum. Aenean tincidunt faucibus leo, nec auctor diam bibendum a. Sed varius, mauris in pellentesque scelerisque, nisl ligula viverra erat, in eleifend tellus enim ac magna. Pellentesque quis est risus. Cras mollis feugiat auctor. Proin ac eros vitae nulla gravida varius.

Morbi at augue sapien. Duis tempus quam vitae velit interdum ultricies. Vivamus laoreet lacinia elit sit amet vehicula. Ut congue diam ac magna hendrerit sed fermentum justo lacinia. Curabitur vel odio neque, quis consequat mi. Proin lobortis justo quis enim fermentum accumsan sagittis ipsum imperdiet. Proin sem felis, laoreet placerat egetas id, fringilla id mauris. Pellentesque a nisi sit amet leo consectetur gravida nec et dui. Curabitur quis hendrerit augue. Etiam sed dui nec tortor convallis fringilla. Proin tempor mattis diam nec egetas. Quisque condimentum elementum lacus ac porta. Vivamus congue, odio eu ullamcorper elementum, leo turpis tempus sem, at condimentum dolor quam eu nunc. Pellentesque eget risus ac velit aliquam sollicitudin sed et ipsum.

Donec nulla enim, scelerisque quis dignissim ut, vehicula sit amet felis. Ut tristique pulvinar aliquet. Proin vitae odio nibh. Sed est dolor, malesuada et lobortis vitae, tempor quis tellus. Proin mollis lacus eget arcu tempor vitae bibendum nisi adipiscing. In sollicitudin pretium dapibus. Sed accumsan imperdiet diam quis pellentesque.

Sed in lacinia lectus. Nullam ac magna in erat blandit posuere nec nec ante. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egetas. Maecenas ipsum neque, fringilla sed sodales id, scelerisque et erat. Morbi placerat mauris vel elit ultricies sed molestie ipsum faucibus. Nunc vel sem orci, ac placerat justo. Nulla

varius nisi mauris. Vivamus sed ligula felis, ac mattis purus. Vivamus felis nibh, bibendum et aliquam sed, feugiat a elit. Morbi imperdiet libero vitae lacus viverra tempus. Praesent ultricies fermentum urna eget varius. Nunc blandit, augue eget vehicula venenatis, ligula eros posuere tellus, non sollicitudin tortor velit quis augue. Nulla rhoncus fringilla dolor, vel cursus ligula varius id. Vestibulum et eros eros, ut euismod elit. Praesent placerat libero sed lorem mollis sed cursus erat laoreet.

Suspendisse in fermentum nulla. Donec blandit ultricies felis, non suscipit turpis sagittis eget. Donec eget enim in erat auctor lobortis eu sagittis mauris. Aliquam vitae nibh nisi. Integer nulla erat, feugiat quis vulputate vel, vulputate id erat. Morbi dolor dui, volutpat congue fermentum tempus, rutrum et quam. Vivamus aliquam, sapien in ultrices dictum, tortor tellus dictum justo, eu viverra velit tellus congue nibh. Suspendisse potenti. Nullam at massa id leo sollicitudin ultricies ut et nibh. Vivamus fermentum pellentesque ante et lobortis. Etiam eros justo, rutrum at varius et, porttitor ac lorem. Aenean viverra, mauris eget imperdiet aliquet, risus quam tincidunt risus, quis elementum enim diam a ipsum. Ut et arcu nunc, a viverra mi. Nullam egestas lectus vel ipsum sodales eget consectetur metus facilisis. Proin egestas magna sed felis mattis ultrices.

Morbi a lectus vitae lacus malesuada tincidunt. Vestibulum eu quam justo. Integer hendrerit posuere augue, in fringilla nulla feugiat ut. Fusce vel libero sed tellus posuere molestie in sed justo. Nunc orci magna, aliquam id dictum sit amet, bibendum vestibulum augue. Maecenas luctus ultricies elit, et aliquet justo rutrum sed. Proin mauris dui, cursus quis tempus non, rhoncus nec ante. Lorem ipsum dolor sit amet, consectetur adipiscing elit.

Fusce ac nunc non felis fermentum ultrices. Curabitur nibh felis, convallis id consequat rhoncus, elementum sodales ipsum. In hac habitasse platea dictumst. In quis nulla eu sapien mattis cursus nec semper leo.

Maecenas sagittis viverra quam, vel sodales elit placerat et. Sed condimentum ultricies mattis. Pellentesque scelerisque convallis lobortis. In tempus lorem nec lorem blandit sodales.

Eskerrik asko,

Your name

August 2014

Contents

List of Figures	xvii
List of Tables	xix
1 State of the Art	1
1.1 Adaptation models	2
1.1.1 Physical adaptive systems	7
1.2 User	9
1.2.1 A Chronological Review of the Evolution of User Models	9
1.2.2 User models	10
1.2.2.1 1991: Jon Orwan and the Doppelgänger system	10
1.2.2.2 2001: Gerhard Fischer	11
1.2.2.3 2002: Gregor et al.	12
1.2.2.4 2003: Gauch et al.	13
1.2.2.5 2005: Hatala and Wakary and the Ec(h)o system	14
1.2.2.6 2003: Razmerita et al.: The OntobUM Ontology	15
1.2.2.7 2005: Fernando Pereira	15
1.2.2.8 2007: Persad et al.	16
1.2.2.9 2007: Heckmann et al.	17
1.2.2.10 2008: Casas et al.	18
1.2.2.11 2007: Golemati et al.	19
1.2.2.12 2012: Evers et al.	19
1.2.2.13 2012: Skillen et al.	19
1.2.2.14 Generic User Modelling Systems	20

CONTENTS

1.2.3	Users Models Comparison	21
1.3	Context	24
1.3.1	What is context?	24
1.3.2	A Chronological Review of the Evolution of Context Management	25
1.3.3	Context models	25
1.3.3.1	2000: Chen and Kotz	26
1.3.3.2	2001: Anthony Jameson	27
1.3.3.3	2002: Henricksen et al.	27
1.3.3.4	2002: Held et al.	28
1.3.3.5	2004: Gu et al.: The SOCAM Ontology	29
1.3.3.6	2005: Chen et al.: The CoBrA Ontology	30
1.3.3.7	2005: Yamabe et al.: The Citron Framework	31
1.3.3.8	2008: Wood et al. and the AlarmNet system	31
1.3.3.9	2011: Baltrunas et al.: InCarMusic	32
1.3.3.10	2012: McAvoy et al.	32
1.3.3.11	2013: Almeida and López-de-Ipiña: The AMBI2ONT Ontology	33
1.3.3.12	Context Models Comparison	33
1.3.3.13	Modelling Techniques	36
1.3.3.13.1	Key-value	36
1.3.3.13.2	Markup scheme	37
1.3.3.13.3	Graphic models	38
1.3.3.13.4	Object oriented models	38
1.3.3.13.5	Ontology based models	38
1.4	Device Models	39
1.4.0.14	Composite Capabilities/Preference Profiles	39
1.4.0.15	UAProf	40
1.4.0.16	Device Description Repository	41
1.4.0.16.1	WURFL	42
1.4.0.16.2	OpenDDR	42
1.4.0.16.3	51Degrees.mobi	43
1.4.0.17	DDR Solution Comparison	43

CONTENTS

1.4.0.18	Ontologies	44
1.4.0.19	Device Discussion	44
1.4.1	Related Standardization Work	45
1.4.1.0.1	The Web Accessibility Initiative . . .	45
1.4.1.0.2	The Uncertainty Reasoning for the World Wide Web Incubator Group	45
1.4.1.0.3	The Video in the Web Activity	46
1.4.1.0.4	The Provenance Working Group . . .	48
1.4.1.0.5	The Moving Picture Experts Group . .	49
1.4.1.0.6	The Internet Engineering Task Force .	50
1.5	Attentive computing	50
Bibliography		51

List of Figures

1.1	Several iOS accessibility tools [1]. On the left, VoiceOver [2]. On the right, Siri [3]	3
1.2	Buttons during the flat state (up) and during the raised state (down) [4].	8
1.3	Message from a sensor to the server [5]	10
1.4	Orwant user model [5]	11
1.5	The DOPPELGÄNGER user modelling system gathers data about users from sensors, makes inferences on those data, and makes the results available to applications. [6]	11
1.6	The human-computer interaction channel [7]	12
1.7	Adaptable browsing interface [8]	13
1.8	Several user model property dimensions [9]	17

List of Tables

1.1	Fischer comparison between adaptable and adaptive systems [7] .	2
1.2	Related work for the user modelling approaches. Under the user characteristics heading <u>A</u> ctivities or behaviour, <u>C</u> apabilities, <u>E</u> xperience, <u>I</u> nterests, <u>E</u> motions, <u>P</u> ersonal, <u>S</u> tress and <u>L</u> ocation information are presented	24
1.3	Related work for context modelling approaches. Under the domain heading <u>C</u> ontext <u>A</u> wareness, <u>C</u> ontext <u>M</u> odelling, <u>P</u> ervasive <u>C</u> omputing, <u>S</u> mart <u>E</u> nvironments, <u>M</u> obile <u>C</u> omputing and <u>R</u> ecommender <u>S</u> ystems. Under the context parameters heading <u>L</u> ocation, <u>T</u> ime, <u>A</u> ctivity, <u>N</u> earby <u>R</u> esources, <u>N</u> earby <u>P</u> eople, <u>P</u> hysical <u>E</u> nvironment, <u>S</u> ocial environment, <u>I</u> nfrastructure, <u>U</u> ser's parameters and <u>H</u> igh level information are presented	37
1.4	CC/PP: several advantages and drawbacks	40
1.5	Analysed DDRs comparison [10]	44
1.6	W3C standards and specifications for user and device modelling .	47
1.7	PROV documents description. Document type (Recommendation or Note) is also shown	49
1.8	Active IETF Working Groups	50

Listings

Personally, I think it does help, that it makes a beneficial difference, but the scientific literature on the subject is very messy.

Jeanne Petrek

CHAPTER

1

State of the Art

This chapter introduces several significant models and techniques related to adaptive user interfaces and systems during the past 20 years. Besides, user-oriented, context-aware and device models and solutions are reviewed. Once the general domain in which this dissertation **fits** has been analysed during this chapter, the specific approaches that are close to this proposal are examined. This way, **it will be analysed the way in which each proposal addresses the aspects related to this dissertation.**

First, in Section 1.1 several important adaptation models are introduced. The performed methodology and modelled parameters are analysed in detail. Next, Section 1.2 **focus** its attention in the models that have been used during the past 20 years for characterizing the user and his/her capabilities. Section 1.3 analyses the most significant context-aware systems and the way these approaches model the context and its characteristics. Devices are also one of the main entities that are taken into account in this dissertation for the adaptation process. Therefore, Section 1.4 examines several modelling techniques and the devices' capabilities in different domains.

Besides, a chronological review of the evolution of the presented models will be depicted in each section.

1. STATE OF THE ART

Table 1.1: Fischer comparison between adaptable and adaptive systems [7]

	Adaptive	Adaptable
Definition	Dynamic adaptation by the system itself to current tasks and current user	User changes (with substantial system support) the functionality of the system
Knowledge	Contained in the system; projected in different ways	Knowledge is extended
Strengths	Little (or no) effort by the user; no special knowledge of the user is required	User is in control; user knows her/his task best; system knowledge will fit better; success model exists
Weaknesses	User has difficulty developing a coherent model of the system; loss of control; few (if any) success models exist (except humans)	Systems become incompatible; user must do substantial work; complexity is increased (user needs to learn the adaptation component)
Mechanisms required	Models of users, tasks, and dialogs; knowledge base of goals and plans; powerful matching capabilities; incremental update of models	Layered architecture; domain models and domain-orientation; “back-talk” from the system; design rationale
Application domains	Active help systems, critiquing systems, differential descriptions, user interface customization, information retrieval	Information retrieval, end-user modifiability, tailorability, filtering, design in use

1.1 Adaptation models

Before starting to introduce the analysed adaptation models, a distinction between what adaptable and adaptive mean is needed. In 2001 Gerhard Fischer defined both principles through 6 different concepts: definition, knowledge, strengths, weaknesses, required mechanisms, and application domains. Table 1.1 is a representation of these concepts.

The main principle that defines the difference between both concepts lays within the definitions themselves. As it is shown in Table 1.1, an adaptive system is able to dynamically change due to certain situation. On the contrary, an adaptable system will require the user intervention. For example, current smartphones have several accessibility capabilities that allow users with certain disabilities to interact with them in a better way than with other devices. Font sizes, colour combinations, screen magnification ¹, dictation, etc. are just a few examples of the functionalities

¹Android, for instance, allows the user to make screen zooms by using a triple-tap gesture [11]

available in such devices [12] [1]. Figure 1.1 shows an example of several iOS accessibility tools.



Figure 1.1: Several iOS accessibility tools [1]. On the left, VoiceOver [2]. On the right, Siri [3]

Now that we have defined what adaptivity means, several significant adaptive systems are presented in the following lines.

User interface adaptation has evolved through HCI history. First, and dealing with the concept of adaptability (and not adaptivity), user interfaces start to be malleable. Colour palettes and screen resolution tools were given to the user. Nowadays, regarding our portable devices, even automatic brightness control systems are available (dealing with adaptivity). Since many years, developers have attempted to offer customization tools to the end user. These tools have grown in complexity, covering a wider range of functionalities and also users. What is more, a few years ago the context was taken into account as the set of characteristics that define a situation.

1. STATE OF THE ART

Systems personalization and environment components adaptation has been demonstrated to benefit both users and service providers [13]. However, for achieving a satisfactory adaptation it is necessary to have several inputs, for example, a user characteristics model. This way, the service provider will be able to apply the corresponding adaptations for the corresponding user. Besides, we believe that current context conditions [14] and user's device capabilities are also crucial within this domain. In Section ?? we dig in this idea.

Nevertheless, before starting to analyse most popular user interface adaptive approaches, it is important to distinguish between *adaptivity* and *adaptability*. On the one hand, adaptivity is related to the fact that a system or a service is able to learn somehow to change itself to increase the user satisfaction in the interaction process. On the other hand, adaptability deals with the property of the system or service to be customized by the user [14].

Nilsson et al. considered that designing user interfaces for mobile devices tends to be problematic for several reasons, e.g., screen size is small and interaction mechanisms are very different from a desktop system [15]. Besides, these devices are usually used in dynamic environments (i.e., variations in the context).

In the literature several context based user interface adaptation solutions can be found, but first we need to know what context is. According to Weerawarana et al. and Anind K. Dey context is defined as any situation that can be used to characterize the situation of an entity, taking an entity as a person, a place, or an object that is considered relevant to the interaction between the user and the application (see Section 1.3). The definition of *use context* inherits from the context definition itself as the set of variables values which models the used device, so as the physical and social environment where the interaction is being performed [16][17].

Calvary et al. stated in 2002 that a user interface is *plastic* if it is capable of adapting itself taking into account context changes keeping the usability [18]. They presented a process and a dynamic software mechanism which supports context variability. This work was supported by the idea that context changes may provoke the triggering of several reactions under a *prologue-action-epilogue* paradigm. In addition, to enhance the performance they introduced a *historical of contexts*. By selecting pre-known configurations the adaptation process resulted faster. This historical database stores several context situations and the corresponding computed

reactions. Besides, the "*Plasticity Threshold*" and "*Context Coverage*" novel concepts help to set the boundaries of a still valid user interface [19].

Using another paradigm, Lehtonen et al. detailed a tool to perform dynamic adaptation on documents based on several user parameters (language, document type, etc.) [20]. The presented approach is based on several *configuration files* (Product Configuration Files) which describe the current user interface and store the user preferences. The user interfaces are designed with Bean Markup Language [16] (a language focused on user interfaces) and Java Beans.

Repo introduced in 2004 a model that allows the use of Web-based user interfaces (as well as the creation of new ones) that covers the environment adaptability requirements and context in the best possible way [21]. The main problem is given by the range of devices that users typically employ, which have different capabilities and run different platforms. This situation causes the need of more flexible applications and devices. Repo identified a lack of attention in the initial adaptation process, e.g., when the capabilities of the mobile device are identified. This approach was based on a *middleware* architecture, and it was capable of detecting new devices in the current environment (context changes). His solution allowed services to query for devices' capabilities through this middleware architecture. Once a service identified a certain device, it sent the corresponding user interface. Another *middleware* approach was introduced by Nilsson et al. [15]. Their model was able to build auto-adaptable systems. In this case, the middleware leads the adaptation process dynamically. This adaptation middleware is a framework component which provides several mechanisms to: (1) detect changes in the application context, (2) reason about these changes and (3) adapt to them by a dynamic reconfiguration of the current application. Hallsteinsen et al. presented another context *middleware* approach [22]. Based on the same architecture introduced by Nilsson et al. [15] the system reacts to context changes recommending alternative configurations in each case.

Stuerzlinger et al. focused their work on desktop applications adaptations and on the adaptation, reconfiguration and combination of user interfaces using a *User Interface Facades* system [23]. Based on the definitions laid down by Marmolin et al. [24], where differences between superficial personalization (which allows users to select different options between some predefined) and deep customization

1. STATE OF THE ART

(which allows customizing deeper aspects of the system) were introduced, authors stated the following criteria for adaptive interfaces:

- Fast, simple, or just-in-time customization: users are able to customize their interfaces without advanced planning, whenever they need it, and they will be able to do it in a simple way.
- Not only big personalization, also local ones (at minor scale).
- Deep personalization: users can define new customization rules.
- Cross-application personalization: interfaces customization must enable different applications to be combined.

A *framework* based approach is presented by Almeida et al. in 2011 [25]. Imhotep is a framework for user interface adaptation based on inserting preprocessor primitives within the source code. This way, at compilation time different versions of the final application are generated due to the corresponding user and device parameters. WURFL [26] database was used for modelling devices and their capabilities. WURFL is a DDR (Device Description Repository), a catalogue of mobile device information and a framework for adaptation of mobile. By using it, authors ensure to have the latest devices with their capabilities. As configuration files, the platform checks both user and device capabilities and use them to compile the corresponding solution. This approach has the limitation of being static. This means that each change in the user interface needs a new compilation of the whole application.

A work in progress by Evers et al. tackles the problem of the need of user interaction in the adaptation process [27]. Their work, centred in users, discusses about adaptation versus usability defining different types of adaptation (i.e., forward and backward) and different user ways of interaction (i.e., implicit versus explicit). This perspective helps developers to take into account not only technical characteristics (users models, devices capabilities, context parameters, adaptation engines...) but also some psychology to be aware of user mood or stress. In stressful situations users may not be comfortable with an adaptation engine which asks questions about the process.

Several ideas of this work are taken into account for the proposed user model in combination with the Casas et al. research [28]. For instance, the visual handicap metrics in the sensory layer gives an idea of modelling not the user disability but the minimum needed configuration for a view component in the screen. This issue is deeply discusses in Chapter ??.

1.1.1 Physical adaptive systems

Although it is out of the scope of this dissertation, there is a research pathway dealing with physical adaptive systems. In Tactus [4], a company which aims to redefine redefining devices and user experiences by combining the modern and traditional interfaces and on-demand buttons on touch screens for a tactile experience [29], a novel adaptive technology has been developed. This technology allow screens to dynamically "build" physical buttons into a flat touch screen, depending on the current task. For example, if the user needs to send an email, the keyboard will "emerge" from the screen as a physical interface. This interface is supported by the combination of small fluid channels which are routed throughout the Tactile Layer. This layer enables fluid to expand the top polymer layer to create the physical buttons (see Figure 1.2).

Nowadays, this technology might be surprising for the reader. Nevertheless, there are examples of physical user interfaces adaptation all around us. One of the most common and spread example is shown in cars. The cars companies deal with adaptivity for the current driver not just inside the car, but also outside. Some models adapt the driving wheel in depth and height depending on the driver who unlocks the door. Displays and controller brightness, even radio volume can be also adapted considering context light or noise. Even the car lights system adapts to the road conditions.

Again, these are just a few examples of what adaptation technologies might be pointing at for the near future.

1. STATE OF THE ART

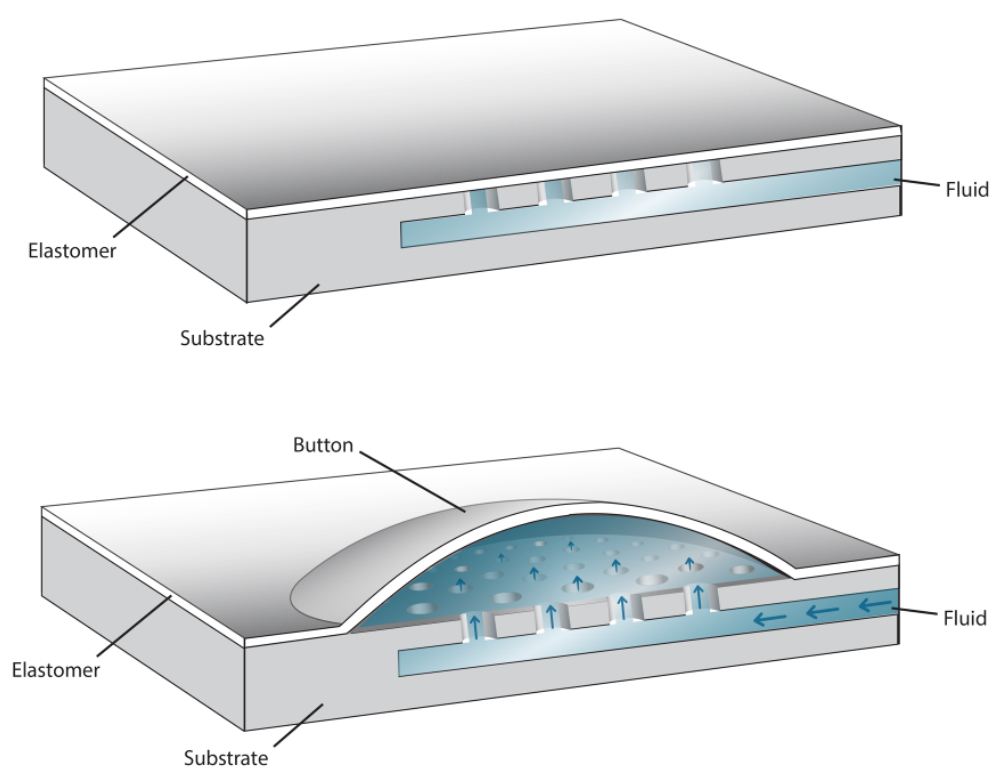
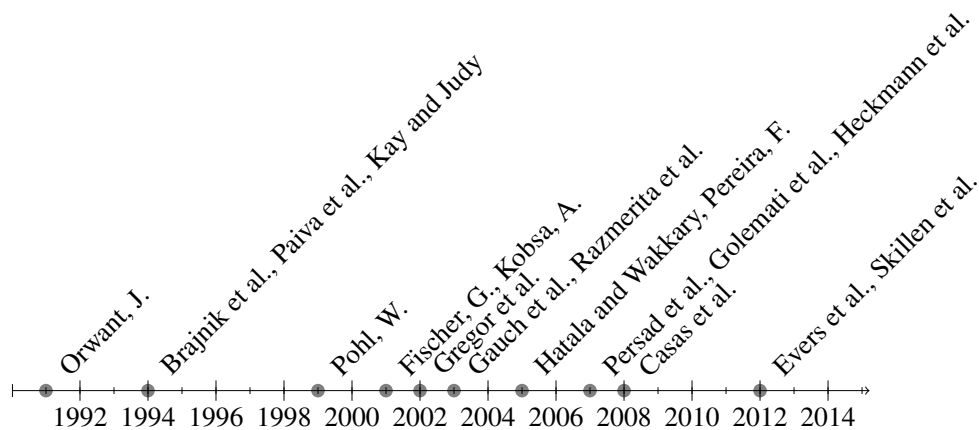


Figure 1.2: Buttons during the flat state (up) and during the raised state (down) [4].

1.2 User

1.2.1 A Chronological Review of the Evolution of User Models

The following figure illustrates the evolution and different solutions by chronological order for the last 15 years. During these years different user characteristics have been taken into account considering the final purpose of the designed system.



First user modelling systems started in the late eighties. Allen [30], Cohen and Perrault [31] [32] and Elaine Rich [33] [34] are examples of researchers whose works inspired next user modelling approaches. From there several authors started collecting different types of information about the users and exhibiting, for example, different kinds of adaptations to them [35].

But first, what is user modelling? There are at least two different perspectives which might answer this question. One of these is related to the Artificial Intelligence research area, and it considers user modelling as the process through which systems gather information and knowledge about users and their individual characteristics. Therefore, a user model is considered a source of information about the user of the system which contains several assumptions about several relevant behaviour or adaptation data. However, in this paper the Human-Computer Interaction research perspective is taken, which is defined by Wolfgang Pohl as follows:

Definition 1 *It refers to an a-priori model of the users of a computer system that the system designer has in mind, or to the assumed models that users will probably develop of the system and the tasks they can perform using the system [36].*

1. STATE OF THE ART

Nevertheless, this definition and the AI perspective coincide in the idea that every system must use information about the user to be able to see and react to their different problems and needs and improve the system purpose. This section analyses the most significant user models in the past 15 years.

1.2.2 User models

1.2.2.1 1991: Jon Orwan and the Doppelgänger system

Doppelgänger is a user modelling system that performs inferences upon user data and makes this information available to applications. The system allows users to modify their models, it makes implicit generalizations about the data (which is gathered through different channels) and provides an extensible architecture [37].

Users' data is gathered through a continuously operative sensor network which senses users' everyday activities (see Figure 1.3). This way, both long-term and short-term information about the user are stored. Sensors are integrated in users' activities. However, Doppelgänger acknowledges the imperfection of real world data. Data streams are usually incomplete or erroneous. The main objective of the Doppelgänger system is to recover from these imperfections through several learning techniques:

- The Beta distribution [38], which is used to determine the preference strength, probability of accuracy and the confidence of an estimation.
- Linear prediction, to predict a possible next event.
- Markov models, which represents user's behaviour through several states and all possible transitions between them with the corresponding probability.

The system maintains an accuracy estimation for each sensor, which helps the system to decide a confidence metric for the gathered data.

```
(object orwant location (place 344) (time 779562701) (id active-badge))
```

Figure 1.3: Message from a sensor to the server [5]

```
(object orwant location (place 344) (time 779562701) (id active-badge))
```

The user models are **modeled** in SPONGE, a LISP based data structure manipulated with C and Pearl programs [5] (see Figure 1.4). Models are stored as Unix directories consisting of domain submodels and conditional submodels. The first **one contain** information about the user behaviour (i.e., location, preferences, etc.); the second group **contain** triggering information for deciding actions when certain situations are met. Besides, each user model is conceptually represented as a point in a high dimensional space in which the dimensions are determined by the number of sensors in the network.

```
(object orwant primary
  (object biographical_data
    (string_binding "true name" "Jon Orwant")
    (string_binding "e-mail address" orwant@media.mit.edu)
    ...)
  (object control
    (int_binding "doppelganger ID" 4))
  ...)
```

Figure 1.4: Orwant user model [5]

```
(object orwant primary
  (object biographical_data
    (string_binding "true name" "Jon Orwant")
    (string_binding "e-mail address" orwant@media.mit.edu)
    ...)
  (object control
    (int_binding "doppelganger ID" 4))
  ...)
```

Figure 1.5: The DOPPELGÄNGER user modelling system gathers data about users from sensors, makes inferences on those data, and makes the results available to applications. [6]

1.2.2.2 2001: Gerhard Fischer

In 2001 Gerhard Fischer reviews the user models of the past 10 years. He describes how using computers in Human-Computer Interaction (HCI) environments has been always modelled as a user-computer couple [7]. These elements are modelled as an explicit connection which represents the communication between them.

1. STATE OF THE ART

New and modern interfaces such as windows, menus, pointers, colours, sound and touch screens have “enlarged” this communication line thanks to their capabilities. Furthermore, in addition to the possibilities of new design approaches, knowledge-based architectures in HCI explore the possibility of implicit communication channel. The required knowledge considers the problem domain, communication processes and the communication agent. Users are part of the communication agent group. Fischer defends the idea that there are many types of users. Besides, their needs change with the experience and through time. This way, a simple user classifications (e.g., “novel”, “intermediate” and “expert”) is not enough to characterize users in complex environments. Nevertheless, despite Fischer remarks the significance of each agent, he does not establish which agent capabilities are important to face the problem of modelling a user.

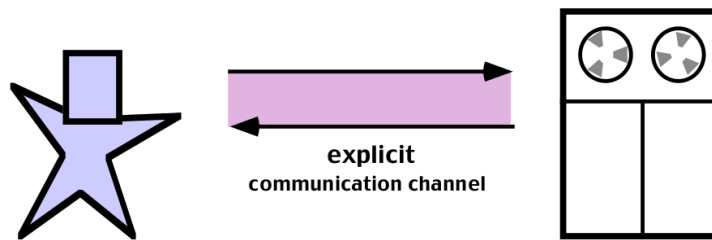


Figure 1.6: The human-computer interaction channel [7]

1.2.2.3 2002: Gregor et al.

In 2002, Gregor et al. focus their approach on a certain groups of users: the elderly [8]. A three group classification is presented. In the first group there are the fit older people, who are not considered **disabled**. The second group is formed by older fragile people who have one or more disabilities. Finally, the last group encompasses the older and people with disabilities whose capabilities to function depend on other **faculties**. In this case, the authors identify several user capabilities:

- Physical, sensory and cognitive capabilities.
- The ability to learn new techniques (cognitive).
- Memory problems (cognitive).

- The environment can affect several elderly capabilities.
- Elderly experience (as a positive fact).

On the other hand, Gregor et al. consider that, as people grow older, their capabilities change. This process encompasses a reduction of cognitive, physical and sensory functions depending on the individual. This “dynamic diversity” is a significant issue for modelling users and designing computing systems.

Figure 1.7 shows an adaptable user interface which takes into account these capabilities.

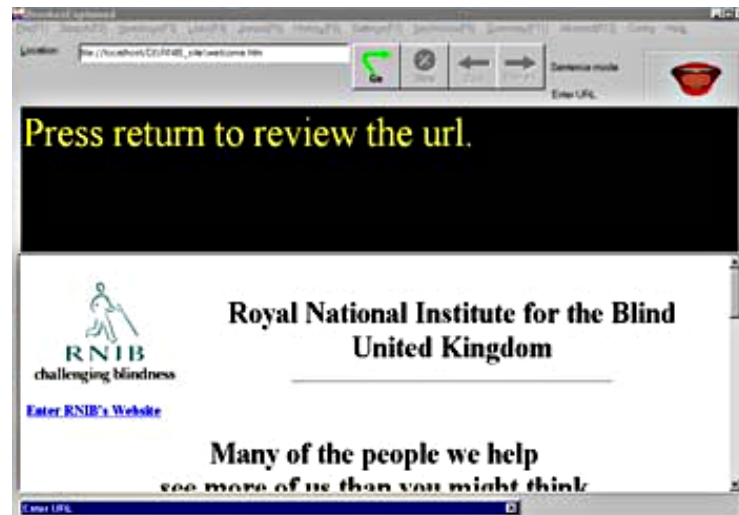


Figure 1.7: Adaptable browsing interface [8]

1.2.2.4 2003: Gauch et al.

Towards the goal of personalized navigation of online information Gauch et al. [39] provide a user ontology for dynamically modelling the user browsing. The ontology is formed by several concepts which are weighted indicating the user's perceived interest in the corresponding concept. These concepts are related with surfing experience (i.e., the content, length and time spent) on each Web page and classified into the reference ontology. This way the user profile is created automatically. This means that the user profile information is collected implicitly without

1. STATE OF THE ART

user feedback, as the ontology's concepts are automatically weighted considering the amount of related information from the user browsing.

1.2.2.5 2005: Hatala and Wakkary and the Ec(h)o system

Ec(h)o is an ontology-based augmented audio reality system for museums which aims to maintain rich and adaptive output information. The main purpose of this work is to address the problem of supporting experience design and functionality related to museum visits through user models combined with augmented reality and tangible user interface system. Hatala and Wakkary [40] find several challenges for capturing rich information about the context. For the presented museum scenario, social, cultural, historical and psychological factors are significant for the user experience. In this field the argumentation made by Dourish[41] [42] is remarked as relevant. Dourish states that activities and context are directly and dynamically linked. This concept is called “embodied interaction”.

The core of the ec(h)o's reasoning module is a dynamically updated user model [43]. The ruled-based model changes as the user moves through the museum and selects several audio objects. This models enables developers to consider which inputs influence user interests. In the ec(h)o system there are two ways of updating the model: the user movement and a selection of an audio object. These actions have different effects on the model of the user interests, i.e., influence of initial interest selection, of object selection on user interest and of location change.

As it occurs with recommender systems, user's interest are vital for the concept ontology. These concepts are weighted in the ontology as concepts which represent the user's likes within the environment. Besides, an interaction history is maintained recording the way the user interacts with the museum. In addition to these characteristics the user type is also considered. This way the system is allowed to characterize the user experience with the environment. It classifies users into three different categories:

- The avaricious visitor, who wants to see as much as possible in a sequentially way.
- The selective visitor, who is more selective with the concepts he/she is interested in.

- The busy visitor, who prefers to not spend much time and get a general vision of the exhibition.

1.2.2.6 2003: Razmerita et al.: The OntobUM Ontology

Focused in the context of Knowledge Management Systems (KMS) Razmerita et al. present OntobUM, a generic ontology-based architecture for user modelling [44]. The model is generated through two different ways:

- Explicitly, using a user profile editor. This way the user has to provide some information.
- Implicitly, information maintained by several intelligent services which 1) maintain and update the information about the user considering the user's behaviour with the services and 2) provide adapted services based on user's preferences.

The architecture of the presented ontology is composed of the following ones:

- The User Ontology, which structures the different characteristics and preferences of the user.
- The Domain Ontology, which defines several concepts about the domain.
- The Log Ontology, which manages the semantics of the interaction between the user and the whole system.

Authors identify several users' characteristics that are relevant for a KMS under the Behaviour concept. Nevertheless, most of the user ontology is generic and it is available to be used in other application domains.

1.2.2.7 2005: Fernando Pereira

Within a video adaptation and quality of experience evaluation scenario, Fernando Pereira studies a user characterization through three different dimensions: sensorial, perceptual and emotional [45]. First of all, Pereira establishes the difference between sensations and perceptions as follows:

1. STATE OF THE ART

- Sensations are monomodal, more low-level, physical and less related to the real world composition than perceptions. They regard the simple conscious experience for the corresponding physical stimulus (e.g., light variation and eyes reaction to this change). They are related to the first contact between a human and the surrounding environment.
- Perceptions are multimodal, and they are part of the cognition process (knowing and learning) and regard the conscious experience and identification of objects.

On the other hand, emotions are considered as central in a communication and entertainment process. Therefore, Pereira proposes a triple layered sensation-perception-emotion (SPE) user model for the evaluation of the quality of experience in the consumption of multimedia content.

1.2.2.8 2007: Persad et al.

Persad et al. relate user capabilities and product demands as a tool to evaluate the product design [46] [47]. Inclusive design is defined as follows [48]:

Definition 2 *The design of mainstream products and/or services that are accessible to, and usable by, people with the widest range of abilities within the widest range of situations without the need for special adaptation or design.*

In a particular toaster case study, the sensory, cognitive and motor product demands are compared with different users capability levels. Authors remark four main components to consider when it comes to interaction between people and technology: (1) the user, (2) the product, (3) the environment or context and (4) the set of activities or tasks that define the interaction [47]. They try to assess an adaptation degree between users and the designed products using different compatibility measures. These measures can be assessed on different levels of human capabilities, including sensory, cognitive and motor. The concepts of user capability and product demand provide a useful framework for analysing the user-device compatibility. The product demand levels are considered multidimensional and they are set by the interface attributes of the product itself. For example, a product's text display will be designed with a certain text size, font, and colour contrast.

The combination of these attributes define the visual demand level within the user visual capabilities. Similarly, other combinations of product attributes command several cognitive and motor demands. Authors also reviewed functional classifications and experimental studies to identify the most relevant low-level skills for designing products within the cognitive, motor and sensory domain [47].

1.2.2.9 2007: Heckmann et al.

A different approach is implemented by Heckmann et al. Divided into four main groups (emotional state, personality, characteristics and physiological state), the authors present GUMO, an ontology model to characterize users capabilities [9] within adaptive environments. A significant user aspect that is taken into account in this work is the stress. In the adaptive interfaces domain it is needed to pay special attention to the consequences of each adaptation. But the stress is not only determined by this process. It is also derived from several user experiences, as the current context state, e.g. traffic, noise, surrounding people, etc. [49].

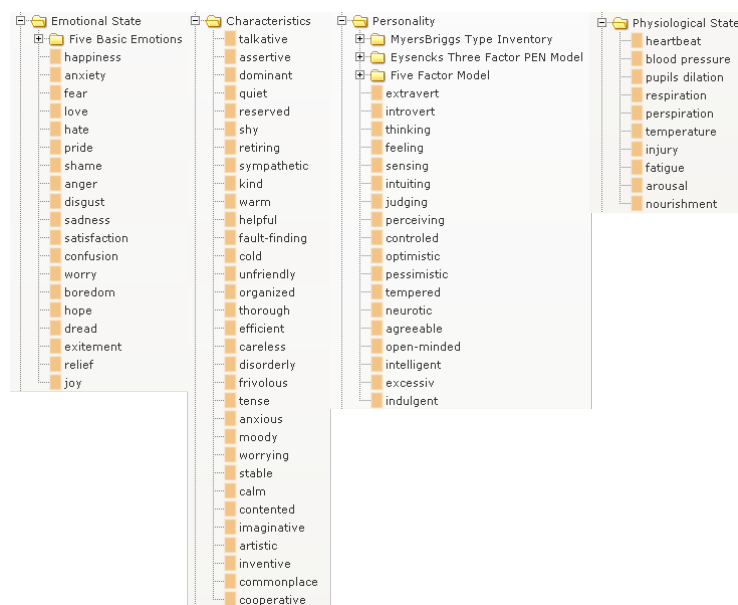


Figure 1.8: Several user model property dimensions [9]

1. STATE OF THE ART

1.2.2.10 2008: Casas et al.

Another approach is the one presented by Casas et al. In this case the authors work under the “Persona” concept which is introduced to distinguish between different user groups within an adaptive user interfaces domain [28]. Originally this concept was introduced by Alan Cooper in 1999 by the following definition:

Definition 3 *“Personas” are not real people, but they represent them through a design process. They are hypothetical archetypes of real users [50].*

Casas et al. distinguish between two categories of people:

- Primary: those who represent the main group and use primary interfaces.
- Secondary: those who can use primary interfaces, but with several extra needs.

By assigning random values to several characteristics (e.g., age, education, profession, family conditions, disabilities and technological experience) authors are capable of covering a wide range of potential users. However, the most significant contribution is that, instead of being focused on users capabilities, they consider **on the** users needs. To that end they build a user profile supported by four main bases:

- The user level, which indicates the ability of the user to face the system.
- Interface, for the interaction mechanism to be used by the user.
- Audio, to indicate the audio volume levels.
- Display, which includes usual display controls (contrast, colours, brightness...).

This approach is focused on the solution, on the adaptation itself. It is a perspective which allows users to configure the interaction based on their capabilities. This helps applications designers because user capabilities are not directly taken into account in the model as medical or technical aspects. This way there is no need to be experts or have any medical knowledge about users disabilities. Another advantage is that each user can manage his/her own profile. This way, they can configure their preferences and capabilities on their own.

1.2.2.11 2007: Golemati et al.

Golemati et al. present an ontology which considering past literature solutions aims to reduce the intrinsic problems of user modelling: ad-hoc modelling processes, the required amount of work to model users and the possibility of errors by omitting several user's characteristics [51]. To this end, the authors present an extensible, comprehensive and general ontology which design is addressed through a top-down approach by firstly collecting static information about the user. Next, the ontology designers analyses the semantics of the profile models and suggest concepts that would adequately model them. It is remarkable that this work is focused on static user characteristics, although they consider the possibility of incorporating dynamic and temporal characteristics.

1.2.2.12 2012: Evers et al.

Several studies, as the research presented by Evers et al. [27], recognize that it is complex to perform interfaces adaptations without bothering the user. On the one hand, adapting an interface without the participation of the user might lead to an unsatisfactory result. On the other hand, asking too much for participation might bother the user. From this work we assume that if the user has high stress levels the corresponding application should not ask for interaction. This way, the application should operate as "automatic" and "self-sufficient" as possible. Following this stress perspective Liao et al. [52] present an unified probabilistic decision model based on Influence Diagrams for modelling user stress levels. These levels were inferred by probabilistic inferences of several sources data (e.g., heart rate, mouth openness, head movements, pupils monitoring, etc).

1.2.2.13 2012: Skillen et al.

Within an application personalization within mobile environments Skillen et al. present a User Profile Ontology which is able of modelling dynamic components [53]. The ontology considers both static and dynamic aspects of the user mainly focused on his/her behaviour changes. In this work user capabilities are also taken into account for the user profile. Capabilities are defined as the extent to which the user has an ability (i.e., physical, emotional or cognitive) to carry out some activities. User's interests and several context parameters are also considered in the

1. STATE OF THE ART

ontology to cover context-aware environments.

1.2.2.14 Generic User Modelling Systems

Apart from the analysed models there is another generic approach for modelling users known as Shell Systems. More focused in the field of Artificial Intelligence, these solutions consider the user model as a source of information which are built on assumptions about relevant user aspects or behaviour [36].

Heckmann differentiates between the model, which is where the user data is collected, and the modelling system, which is the module that manages the model [54]. Besides, he **remark** the following two definitions from Wahlster and Kobsa previous work [43]:

User model

A user model is a knowledge source in a system which contains explicit assumptions on all aspects of the user that may be relevant to the behaviour of the system. These assumptions must be separable by the system from the rest of the system's knowledge.

User modelling component

A user modelling component is that part of a system whose function is to incrementally construct a user model; to store, update and delete entries; to maintain the consistency of the model; and to supply other components of the system with assumptions about the user.

Assumptions are deeply studied and depicted in [36]. In this section, a quick overview of how these systems behave is performed to just take into account the difference between generic user modelling approach (user modelling shells) and the approach followed in this dissertation, which is related to Human-Computer Interaction.

In 1986 GUMS, a General User Modelling System, is presented. This software allowed developers to make user-adaptive applications by defining several stereotypes, facts and rules to reason with [55]. GUMS supports the addition of new facts in runtime, manages facts inconsistencies and answers the application about

assumptions about the user [13]. The following systems are several examples of generic user systems developed in the following years (chronological ordered):

- DOPPELGÄNGER, which uses several learning techniques for generalizing and extrapolating sensor data for the development of the user model [37].
- UMT, which supports the definition of hierarchically ordered stereotypes about the user, rules for user model inferences and contradiction detection [56].
- TAGUS, which uses first-order formulas to represent assumptions about the user [57].
- **um**, which models not only assumptions but beliefs, preferences and other user characteristics in attribute-value pairs [58].
- BGP-MS, which permits user and groups of users assumptions [59].

1.2.3 Users Models Comparison

In this section **we emphasize** our user modelling perspective. There are several points of view regarding the user modelling requirements. Here the HCI perspective is taken. This means, (as Pohl states in [36]) that the user model refers to user characteristics using a certain system (see Section 1.3.2). In the AI perspective the works by Alfred Kobsa and Wolfgang Pohl are significant. The authors design generic user model systems (known as shell systems) under this viewpoint [35] [59].

Now that the HCI viewpoint has **been remarked**, we emphasize the amount of different domains that are addressed in the literature considering user modelling. From product design to multimedia and user interfaces adaptation, every approach follows the same purpose: to consider several user characteristics to improve the system and user's satisfaction and product or service usability. However, although these solutions share the same objectives, the considered characteristics differ a lot. For ubiquitous and more context-aware domains, activities are taken into account. For example, Razmerita [44] et al. discuss **about** an ontology based architecture, which aims to be generic **through collecting user data by two** different ways (explicitly and implicitly). Golemati [51] et al. also take an ontological point of view

1. STATE OF THE ART

to avoid the problem of domain dependency (among others) by designing a more general, comprehensive and extensible ontology.

Gauch et al. [39] remark in the presented ontology the importance of time. Regarding the studied domain (web browsing) time is significant because it might help characterizing the user considering the spent time reading an article or visiting a website. Well known and popular recommendation systems, as Youtube, utilise this information combined with different explicit and implicit sources from the user interaction to make proper recommendations [60].

User activities have also been considered as relevant for many authors in the literature. The first example is the Doppelgänger system [37] (1991), which uses activities for sharing relevant user information to different applications. In the same way, Persad et al. [46], Heckmann et al. [9] and Skillen et al. [53] modelled activities to take user's behaviour and interaction into account for the proposed classifications and systems. For Hatala and Wakkary [40] activities are also vital within context-aware environments.

As occurs with context modelling (see Section 1.3.3.12) many different techniques are available for the model representation. This usually depends either on the developer, because of his/her experience, or in the system's technical characteristics. For example, if the system is able to perform inference with the user data an ontology based representation could be more helpful than an object based one. Strang and Linnhoff-Popien [61] demonstrate that ontological modelling is more appropriate for ubiquitous computing environments.

It is also common to model medical related characteristics of the user. For example, the works by Gregor et al. [8] and Persad et al. [46] consider physical, cognitive and sensory capabilities. Skillen et al. [53] also model several user abilities for performing different tasks and activities. The problem is that being aware of these capabilities is difficult and, in some cases, poorly practical. For example, measuring the sight capability of one individual requires medical experience or advice. Besides, people with the same affection do not respond in the same way. A person who was born blind would interact differently with the environment than another who has been losing sight during his/her life. The precise same disability, e.g., tunnel vision, might affect different people in many different ways depending on their personal skills, e.g., adaptability, orientation, etc. This leaves an open issue which leads us to an idea. What if, instead of modelling medical skills (disabili-

ties), we were able to model user's capabilities? The first approximation for this is found in Casas et al. [28] work. They present a user profile which abstracts from physiological aspects and let users to manage and configure their own profile. Just in the opposite, Skillen et al. [53] model user capabilities as a set of abilities which allow users to perform some task or activities.

On the other hand, Gerard Fischer comments in [7] that it not only is difficult to model users because of the wide range of different types of people that exist. He also considers that each individual changes with experience and through time. For example, old people's capabilities decrease with ageing. This idea is shared with Gregor et al. [8], whose work is centred around the elderly. Heckmann [54] not only considers that users might evolve (from an AI perspective), but he also takes new context information from the inference process. This also opens a new point of view that we address in Section ?? and it takes context as a significant user's environment entity that might directly influence the user's capabilities. In other words, users change through experience, time and, in concrete situations, due to the current context characteristics. For example, an individual might not suffer from any mobility disability, but in a crowded street would be difficult to perform several daily activities (just walking could be difficult). Razmerita [44] et al. also address this issue when they talk about the implicit user information collecting process. This, of course, deals with the concept of dynamism.

Evers et al. [27] consider that respecting user's interactive behaviour with applications needs to be taken into account. On the other hand, Pereira [45] analyses the differences between emotional and perceptual user characteristics.

Table 1.2 summarizes the analysed approaches for user modelling emphasizing the modelled user characteristics and domains. Besides, although in a first version every used technique was remarked, for this paper we have focused on emphasizing just those which follow an ontology-based approach. This is because many of the cited works are more theoretical or surveys, or they just give some advices about important context data when facing a context modelling task. Besides, Strang and Linnhoff-Popien [61] demonstrate that using ontologies is more appropriate for modelling context-aware systems.

JUSTIFICAR DISCAPACIDAD CONTEXTUAL CON LA IDEA DE HECKMANN DE SU TESIS, PÁGINA 15 (dibujo) y compararlo con el approach de inferencia de modelos de usuario en IA.

1. STATE OF THE ART

Table 1.2: Related work for the user modelling approaches. Under the user characteristics heading Activities or behaviour, Capabilities, Experience, Interests, Emotions, Personal, Stress and Location information are presented

Solution	Domain	Ontologies	User characteristics							
			A	C	Ex	I	E	P	S	L
2002, Gregor et al. [8]	Inclusive design			✓	✓					
2003, Gauch et al. [39]	Automatic profiling	✓				✓				
2003, Razmerita et al. [44]	KMS	✓	✓			✓		✓		
2005, Hatala and Wakkary [40]	Tangible interfaces	✓				✓		✓		✓
2005, Fernando Pereira [45]	Multimedia adaptation						✓			
2007, Persad et al. [46]	Product design demands		✓	✓						
2007, Golemati et al. [51]	User profiling	✓	✓		✓	✓		✓		
2007, Heckmann et al. [9]	Ubiquitous applications	✓	✓				✓	✓	✓	
2008, Casas et al. [28]	Adaptive user interfaces			✓	✓					
2012, Evers et al. [27]	Adaptive applications								✓	
2012, Skillen et al. [53]	Mobile environments	✓	✓	✓		✓				✓

1.3 Context

1.3.1 What is context?

Context is mostly defined by the definition by Anind K. Dey as follows:

“Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves” [17].

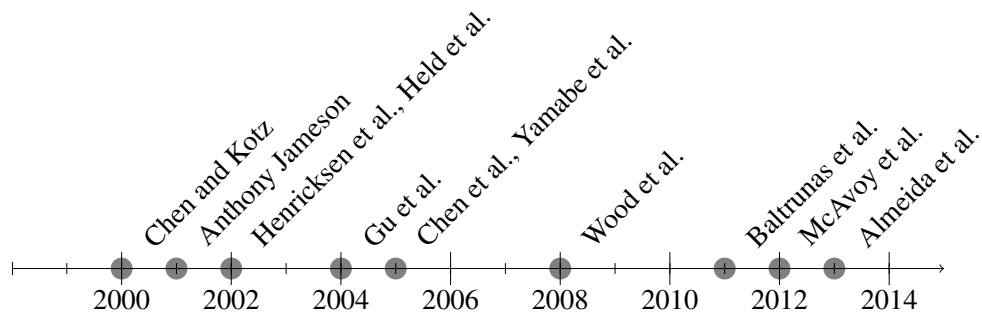
In the past decades there were many definitions of context [62]. Nevertheless, the one stated by Anind K. Dey is one of the most popular and extended definitions. Dey’s definition enables developers to easily enumerate those elements which take part in the context for a certain application domain. He stated that *“if a piece of information can be used to characterize the situation of a participant in an interaction, then that information is context”* [17]. A proposed example explains this

definition: “Take the canonical context-aware application, an indoor mobile tour guide. The obvious entities in this example are the user, the application and the tour sites. We will look at two pieces of information – weather and the presence of other people – and use the definition to determine whether either one is context. The weather does not affect the application because it is being used indoors. Therefore, it is not context. The presence of other people, however, can be used to characterize the user’s situation. If a user is travelling with other people, then the sites they visit may be of particular interest to her. Hence the presence of other people is context because it can be used to characterize the user’s situation” [17].

By this example it is seen how different pieces of information are analysed to determine if they belong to what Dey states context is. These definitions are based on research experience. Section 1.3.3 shows how modelling and defining context has evolved in the past 20 years.

1.3.2 A Chronological Review of the Evolution of Context Management

The following figure shows the evolution for context modelling by chronological order for the last 15 years.



1.3.3 Context models

Dey also defines *context-aware systems* as those systems which, using context data, provide significant information and/or services to the user where the relevancy of the given information depends on the user task [17]. Schmidt et al. consider several issues about context modelling. Authors emphasize the excess of abstraction about context-aware systems and environments which causes a lack of models to

1. STATE OF THE ART

be compared [63]. Therefore they present a working model for context-aware systems categorized into human and physical environment factors. In 2001 Anthony Jameson studies how context-aware computing represents a challenging frontier for researchers [14]. In this work, information about the environment, the user current state, longer term user properties and the user behaviour are compared in order to take the correct adaptation decision. Several works focused on user interface adaptation area base their processes on context changes as triggers. However, they lack of a common model of context in their platforms [18] [15].

In the following subsections a review of the most popular context-aware systems is presented, mainly focusing on the modelled context parameters, techniques, domains and dependencies. Besides, several authors define context and context-awareness through their own experience. All these models and definitions have been considered for the context model proposed in Section ???. In Section ?? Table 1.3 shows several significant features of each approach, and a comparing analysis is performed.

1.3.3.1 2000: Chen and Kotz

Chen and Kotz [64] define context as follows: *Context is the set of environmental states and settings that either determines an application's behaviour or in which an application event occurs and is interesting to the user.* Besides, **an active and passive definitions of context-aware computing** are also given:

- Active context awareness: *“an application automatically adapts to discovered context, by the changing in the application's behaviour”.*
- Passive context awareness: *“an application presents the new or updated context to an interested user or makes the context persistent for the user to retrieve later” .*

Based on the work by Schilit et al. [65], Chen and Kotz consider time as an important and natural context feature for many applications. Besides, they introduce the term *“context history”*, which is an extension of the time feature recorded across a time span.

A significant problem remarked in this work is the impossibility to exchange context information between the studied context-aware systems due to the way

they model the environment. Furthermore, as location is one of the most modelled context features, Chen and Kotz provide a study of several aspects that should be taken into account when researchers face the problem of modelling it.

1.3.3.2 2001: Anthony Jameson

Anthony Jameson [14] analyses in 2001 how context-aware computing represents a challenging frontier for researchers in the field of Adaptive User Interfaces. In this work information about the environment, the user's current state, longer term user properties and the user behaviour are compared in order to take the correct adaptation decision. The idea is to compare several scenarios. In the first one, only information about the environment is considered. In the following scenarios the user's current state, behaviour and long-term properties are taken into account. This way, the results conclude that considering a wider range of user information can help context-aware systems designers.

1.3.3.3 2002: Henricksen et al.

The approach followed by Henricksen et al. [66] makes the following notes about context in pervasive environments:

- Context information exhibits temporal characteristics. Context can be static (those characteristics that do not change over time, e.g., birthday) or dynamic, e.g., user location. Besides, the persistence of the dynamic information can easily change. This way, it is justified that the static context should be provided by the user, while the dynamic one should be gathered by sensors. Past historic and a possible future context are also taken into account as part of the description of the whole context description.
- A second property of the context information is its imperfection. Information can be useless if it cannot reflect a real world state. It also can be inconsistent if it contains contradictions, or incomplete if some context aspect are unknown. There are many causes to these situations. For example, information can change so fast that it may be invalid once it is collected. This is obviously because the dynamic nature of the environment. Besides, there is a strong dependency on software and hardware infrastructures, which can fail any time.

1. STATE OF THE ART

- Context has multiple alternative representations. Context information usually comes from sensors which “speak” different languages. For example, a location sensor can use latitude and longitude **metrics** while the involved application works with a street map.
- Context information is highly disassociated. There are obvious connections between some context aspects, e.g., users and devices. However, other connections need to be computed with the available information.

This work also indicates the dependency between context models, the scenarios and use cases of the application domains. Authors extract several context parameters to consider:

- User activity, distinguishing between the current one and the planned one.
- Device that is being used by the user.
- Available devices and resources.
- Current relationships between people.
- Available communication channels.

1.3.3.4 2002: Held et al.

In 2002 Held et al. [67] **discuss** about the necessity of content adaptation and representation formats for context information in dynamic environments. A significant perspective is the justification of modelling not only the user but the network status and device context information as well. The following parameters are considered as relevant context information:

- Device: basic hardware features, e.g., CPU power, memory..., user interface input, e.g., keyboard, voice recognition... and output, e.g., display and audio, and other particular specifications of the device, e.g., display resolution, colour capability....
- User: service selection preferences, content preferences and specific information about the user.

- Network connection: bandwidth, delay, and bit error rate.

Authors also present several requirements concerning the representation of context information. Accordingly, they defend that a context profile should be:

- Structured, to ease the management of the amount of gathered information and remark relevant data about the context.
- Interchangeable, for components to interchange context profiles.
- Composable/decomposable, to maintain context profiles in a distributed way.
- Uniform, to ease the interpretation of the information.
- Extensible, for supporting future new attributes.
- Standardized, for context profile exchanges between different entities in the system.

1.3.3.5 2004: Gu et al.: The SOCAM Ontology

In 2004 Gu et al. [68] design the SOCAM service-oriented context-aware middleware architecture for designing and prototyping applications in an Intelligent Environment. following components:

- Context providers, which abstract context information from heterogeneous sources and semantically annotate it according to the defined ontology.
- The context interpreter, which provides logic reasoning to process information about the context.
- The context database, which stores current and past context ontologies.
- Context-aware applications, which adapt their behaviour according to the current context situation.
- The service-locating service, which allows context providers and interpreters to advertise their presence for users and applications to locate them.

1. STATE OF THE ART

Gu et al. use OWL to describe their context ontologies in order to support several tasks in SOCAM. As the pervasive computing domain can be divided into smaller sub-domains, the authors also divided the designed ontology into two categories:

- An **upper ontology**, which captures high-level and general context knowledge about the physical environment.
- A **low-level ontology**, which is related to each sub-domain and can be plugged and unplugged from the upper ontology when the context changes.

As a result, the upper ontology considers person, location, computational entity and activity as context concepts.

Gu et al. [69] also present an OWL based model to represent, manipulate and access context information in smart environments. The model represents contexts and their classification, dependency and quality of information using OWL to support semantic interoperability, contextual information sharing, and context reasoning. The ontology allows to associate entities' properties with quality restrictions that indicate the contextual information quality.

1.3.3.6 2005: Chen et al.: The CoBrA Ontology

Another work under a similar approach is the one performed by Chen et al. [70]. Authors introduce the CoBrA ontology based system, which provides a set of semantic concepts for characterizing entities such as people, places or other objects within any context. The system provides support for context-aware platforms in runtime, specifically for Intelligent Meeting Rooms. The context broker is the central element of the architecture. This broker maintains and manages a shared context model between agents (applications, services, web services, etc.) within the community. In intelligent environments participating agents often have limited resources and capabilities for managing, reasoning and sharing context. The broker's role is to help these agents to reason about the context and share its knowledge. The presented ontology relies on:

- Concepts that define physical places and their spatial connections.
- Concepts that define agents (humans and not humans).

- Concepts that define the location of an agent.
- Concepts that describe an agent activity.

1.3.3.7 2005: Yamabe et al.: The Citron Framework

In 2005 Yamabe et al. [71] present a framework for personal devices which gathers context information about the user and his/her surrounding environment. Muffin, a personal sensor-equipped device is designed. Using it, several context parameters are gathered.

Sensor information is also considered for evaluating several user high-level context information. For example, accelerometer readings might recognize a walking or running activity, shaking and rotating, etc. The microphone is not only used to measure the ambient noise. It is also useful for detecting the place where the user is, e.g., meeting room, restaurant, street. . . .

The context acquisition is categorized in two different groups: the user and the environment. For the user several issues are analysed. For example, activities recognition requires the user to use the device in specific ways (it is not the same to use it with hands or waist-mounted). Another problem they encounter is about the time consuming process since an event is captured, then processed and finally validated. The last contextual issue deals with the intrinsic complexity and ambiguity of context information. For example, the meaning of what is loud might depend on the current situation, e.g., if the user is in a meeting room, if the user is in the street. . . . For the environment, Muffin suffer several heat problems due to the sensors sensitivity to environment temperature. This way, sometimes the gathered measures are invalid.

1.3.3.8 2008: Wood et al. and the AlarmNet system

AlarmNet is an AAL monitoring wireless sensor network system (WSN) for pervasive adaptive healthcare in assisted living residences for patients with special needs. In this work, Wood et al. [72] contribute with several novelties:

- An extensible heterogeneous network middleware.
- Novel context-aware protocols.

1. STATE OF THE ART

- SenQ, a query protocol for efficiently streaming sensor data.

The context-aware protocol uses a two-way network information flow. On the one hand, environmental, system and residents data flow. On the other hand, circadian activity rhythm (CAR) analysis goes back into the system to enable smart power management and dynamic alerts.

Several sensors are used for sensing environmental quality: light, temperature, dust, resident activities (motion sensors)... The devices' queries to the system are negotiated by the Query Manager.

1.3.3.9 2011: Baltrunas et al.: InCarMusic

Assuming that context-aware systems adapt to the specific user situation, Baltrunas et al. present a music recommendation system which takes into account the user's mood and the traffic conditions [73]. To this end, the authors design a methodology where users can be requested to judge several contextual factors, e.g., if current traffic conditions are relevant for a decision making task, and to rate an item when a certain contextual condition is met.

In order to take into account the user's music preference and the influence that context might have into them, context is modelled as several independent factors.

1.3.3.10 2012: McAvoy et al.

In this work the authors propose an ontology-based system for the managing of context within smart environments. One of the most significant contributions deals with the high-level information managed through the metadata and meaning which are collected by the sensor network [74]. The sensing devices within the smart environment have to be modelled in order to be semantically enriched. Data is formally represented as an ontology by using entities and the relationships which link them together. After the data is collected from the sensors it is passed to an enrichment module where it is made semantically rich. This new enriched data is stored in a semantic repository in the form of triples. The meaning of this information and the metadata are added to the data within this enrichment component.

1.3.3.11 2013: Almeida and López-de-Ipiña: The AMBI2ONT Ontology

Almeida and López-de-Ipiña [75] consider two common problems dealing with ambiguity in the area of context modelling: the uncertainty and the vagueness. The uncertainty models the likeness of certain fact, while the vagueness represents the degree of membership to a fuzzy set. The uncertainty is represented by a certainty factor.

Due to the nature of the process of collecting data from the environment, the proposed ontology has been designed to support two types of uncertainty:

- Uncertain data: This kind of uncertainty is generated from the capture of data from sensors due to the imperfect nature of the devices.
- Uncertain rules: It occurs in the execution of the rules.

To reason over the ambiguous information the JFuzzy Logic Open Source fuzzy reasoner has been adapted to support uncertainty information.

1.3.3.12 Context Models Comparison

The previous section has reviewed several significant context-aware systems and the followed approaches for modelling relevant context parameters of the environment depending on the application domain. In fact, this is one of the main problems in context modelling: the lack of model independence from similar domains and, also, the lack of models to be compared. Despite the fact that sometimes the “primary” domains are similar (context-aware computing, pervasive environments and ubiquitous computing) regarding the necessity of managing context knowledge, the concrete applications and approaches domains are different. Here, Henricksen et al. [66] realize about the lack of formality and expressiveness of previous context models.

However, to avoid this problem Gu et al. [69] present an ontology-based solution in which context information is modelled in two separated layers:

- In the upper layer there is an ontology which describes high-level knowledge about the current context and physical environment.
- Under it there is the possibility to add and remove ontologies which model low-level information of the current specific domain.

1. STATE OF THE ART

On the one hand, this approach allows developers to consider richer information, as activities, and abstract knowledge about the current global context. On the other hand, it makes possible to model specific knowledge of the current sub-domain. Besides, the possibility to plug and unplug these low-level ontologies makes this solution powerful. The solution provided by Gu et al. [68] is significant because of the following reasons:

- It considers high-level information on top of a more specific and domain dependent sub-model.
- Activities are modelled as a relevant concept for context in the upper ontology.
- The modelled entities are related. Persons are associated with locations and activities, each location is linked with indoor or outdoor entities, activities can be categorized into scheduled or deduced ones, etc.

As the work by Chen and Kotz [64] is a survey of context-aware computing the remarked context characteristics (location and time) are given more as an advice, since there is no model in their work. Nevertheless, they introduce several novelties like the term “context history”, which might be useful for future predictions about user’s behaviour and trends.

Modelling high-level information allows to perform deeper computations taking into account behavioural characteristics, trends information, inferred knowledge from small pieces of information combinations, etc. As can be seen in Table 1.3 many authors work with high-level data in their context-aware systems.

On the other hand, physical context parameters are frequently modelled in the analysed literature. Location, time and environment conditions, e.g., temperature, pressure, light, noise... are usually modelled to achieve final system’s goal, e.g., adapting the user interface, recommending items or services, filtering resources. . . . Besides, several approaches take user related characteristics to fulfil their purposes. For example, Schmidt et al. [63] consider not only physical environment as context information but also several human factors categorized as follows:

- User information, which gathers knowledge about user’s habits, emotional stated and bio-physiological conditions.

- Social environment, made up by **others users location**, social interactions of the current user and knowledge about the behaviour of groups of people.
- Task, taking into account spontaneous activities, engaged tasks and general goals.

A user modelling approach which considers emotional issues of the user is presented by Pereira [45]. As is remarked in Section 1.2.2.7 the author distinguishes between emotions and perceptions to separate both concepts for modelling processes. These approaches are found useful for recommending systems in which user mood and psychological state are relevant to filter multimedia content [73]. Following a similar perspective Evers et al. [27] analyse the user's participation in adaptive applications. Several concepts that should be taken into account regarding the user behaviour and interaction with the application are presented (see Section 1.2.2.12). Another similar approach regarding the user's more psychological aspects is presented by Liao et al. [52] Here the authors present a model for modelling user stress levels. This is related to the concept of Considerate Computing, term that it is explained in [76].

Schmidt et al. [63] also remark **social environment** as relevant for context modelling. More related to recommending environments, non explicit information about user's likes need to be computed. Similar approaches in these environments tend to avoid recommending systems intrinsic problems, like the so-called "cold start problem" [77] [78].

Another relevant point remarked by Schmidt et al. [63] are the user's tasks. Several authors consider activities relevant for modelling context [66] [68] [79]. Activities enrich context information about the user [44]. It is common to model user activities in the user model (see Table 1.2).

Finally, and as occurs with user information, sometimes the collected data might lead to misunderstandings or non-trustworthy data. Almeida and López-de-Ipiña [75] consider ambiguity and uncertainty in their work and **presents** an ontology-based process which allows to model them within a smart environment.

Table 1.3 shows the differences between each reviewed solution for modelling context. It is difficult to gather all the approaches in a unique table. Therefore, Table 1.3 just emphasizes several differences, although these solutions have more characteristics modelled. For example, the work by Almeida and López-de-Ipiña

1. STATE OF THE ART

[75] is focused on modelling context uncertainty and vagueness due to the nature of context data from sensors. Besides and as it is deeply discussed in [61], modelling the context with ontologies offers the following advantages:

- Ontologies are the most expressive approach to model context.
- Composition and management of the model can be done in a distributed manner.
- It is possible to partially validate the contextual knowledge.
- One of the main strengths of ontologies is the simplicity to enact the normalization and formality of the model.

Regarding the context-aware systems, we cannot go further without remarking the issues of gathering information from different sources or sensors. This information might sometimes be unreliable. Sensors can fail in the collecting process, they also can stop working due to several reasons, e.g., power or malfunction. What is more, every sensor “speaks” its language (this issue is addressed applying different **techniques**, like data fusion). Therefore, a process to evaluate the quality and trustworthiness of the collected information should be included in every context-based system as a method to avoid undesired results.

1.3.3.13 Modelling Techniques

Strang and Linnhoff-Popien reviewed the context modelling literature in 2004 [61]. They differentiate among several paradigms. Here we discuss **several approaches that followed these paradigms**.

1.3.3.13.1 Key-value

Maas et al. adopted a X.500 based solution to store location data [80]. This approach is also used in distributed searching systems. Although it is very easy to maintain and handle its main problem is that it makes difficult to build complex structures [61]. Similar solutions follow this key-value approach to identify

Table 1.3: Related work for context modelling approaches. Under the domain heading Context Awareness, Context Modelling, Pervasive Computing, Smart Environments, Mobile Computing and Recommender Systems. Under the context parameters heading Location, Time, Activity, Nearby Resources, Nearby People, Physical Environment, Social environment, Infrastructure, User's parameters and High level information are presented

	Domain	Ontologies	Context parameters									
			L	T	A	R	P	E	S	I	U	H
2000, Chen and Kotz [64]	CA		✓	✓								
2001, Anthony Jameson [14]	CM		✓		✓						✓	✓
2002, Henricksen et al. [66]	PC				✓	✓			✓	✓		✓
2002, Held et al. [67]	CA									✓	✓	
2004, Gu et al. [68]	SE	✓										✓
2005, Chen et al. [70]	PC	✓	✓	✓	✓	✓	✓	✓		✓	✓	
2005, Yamabe et al. [71]	MC		✓		✓			✓			✓	✓
2008, Wood et al. [72]	AAL				✓			✓			✓	
2011 Baltrunas et al. [73]	RS							✓			✓	
2012, McAvoy et al. [74]	SE	✓					✓					✓
2013, Almeida and López-de-Ipiña [75]	SE	✓	✓					✓				

a context element (key), like location, with an environment variable (value) [81] [82].

1.3.3.13.2 Markup scheme

Based on several derivative Generic Standard Markup Language (SGML), for example XML, marking schemes based models are widespread for modelling profiles. Some extensions are defined as Composite Capabilities/Preferences Profile (CC/PP)¹ standards and User Agent Profile (UAProf)², which have an achievable expressiveness by RDF and XML serialization. This kind of context modelling usually extends and completes the CC/PP and UAProf basic vocabularies. In [67] authors present an extension of this model, Comprehensive Structured Context Pro-

¹<http://www.w3.org/Mobile/CCPP/>

²<http://www.mobilemultimedia.be/en/uaprof/>

1. STATE OF THE ART

files (CSCP), which provides hierarchy to such schemes supporting the RDF flexibility to express natural structures of profile information.

1.3.3.13.3 Graphic models

While Bauer et al. used a UML tool to model the context in a air traffic domain [83], Henriksen et al. presented a graphic model (as an extension of Object-Role Modelling¹) [84]. UML (Unified Modelling Language) is a widespread general purpose modelling tool with a very powerful graphic component (graphic models): the UML diagram.

1.3.3.13.4 Object oriented models

Strang et al. presented an object oriented model in which context process details are embedded into object level [61]. Data is hidden from other components. This way the access to this context data is just allowed through several interfaces. This approach tries to use the object oriented programming benefits, as re-usability and encapsulation, to cover ubiquitous environment's problems about context. Another example of this approach is the one given by the GUIDE project by Cheverts et al., which is focused on location [85]. In this case the context information is also in the object as accessible states through those methods defined by the object itself and by modifying these states.

1.3.3.13.5 Ontology based models

As discussed in [61], modelling the context with ontologies offers the following advantages:

- Ontologies are the most expressive approach to model context.

¹<http://www.orm.net/>

- Composition and management of the model can be done in a distributed manner.
- It is possible to partially validate the contextual knowledge.
- One of the main strengths of ontologies is the simplicity to enact the normalization and formality of the model.

Multiple ontology based context models have been developed in the past. In the following section several ontology-based relevant models will be discussed.

1.4 Device Models

There are many and different approaches in the literature for devices modelling. Devices capabilities might determine the boundaries of an adaptation process or the consumable resources. Lemlouma and Layaïda **is considered** that an independent device model would probably reduce adaptation process efforts for different context situations [86]. In fact, the World Wide Web Consortium (W3C) reinforces this perspective by warning about the wide range of device capabilities and sizes [87] which define the boundaries of the content that each device can handle. Several techniques, like Device Descriptors, content transformation guides, devices APIs and CC/PP systems help developers to optimize the user experience. These modelling techniques are analysed in the following section.

1.4.0.14 Composite Capabilities/Preference Profiles

Composite Capabilities/Preference Profiles [88] (CC/PP) is a W3C standard system to express user and device capabilities. Using CC/PP a user will be able to show a specific preference or disability. For example, even though a user's device can display millions of colours, perhaps the user can just distinguish between a small set of colours. The necessity of this system stems from the wide range of web and ubiquitous devices available in the market. These devices have more and more multimedia and Web capabilities. This makes troublesome to Web content providers to service their content to these devices keeping usability and user satisfaction [86].

1. STATE OF THE ART

Table 1.4: CC/PP: several advantages and drawbacks

Advantages	Drawbacks
A good infrastructure for modelling devices Content negotiation flexibility	Device dependent It requires a more mature user preferences definition
Using CC/PP, Web based device developers and user agents can define accurate profiles for their products. Web servers and server proxies can use these profiles to perform the adaptation Open to new protocol proposals for profile exchanging	

However, managing a large number of devices is not a new problem. Many approaches have been proposed in the literature to tackle this situation. Most of them are based on content management. This approach considers different presentation alternatives. Depending on the client device, a presentation configuration is served. This way, in the content serving process there are two options: a) the server chooses which is the best configuration for the device, and b) the client decides what to do with the content. This approach is very easy to be performed since every device identifies itself against the server.

CC/PP is based on profiles. A profile contains components and attributes. Each component has, at least, one attribute, and each profile has at least one component. The main components are: the hardware platform, the software platform and single applications, e.g., a browser. Attributes can contain one or many values. For example, in case of the “hardware platform” component we can find the attributes *displayWidth* and *displayHeight*. These attributes have a single value. CC/PP uses RDF (Resource Description Language) as formal language to build these profiles. Table 1.4 shows several advantages and drawbacks of this approach.

1.4.0.15 UAPProf

User Agent Profile [89](UAPProf) is concerned with collecting wireless devices capabilities and preferences. This information is provided to content servers to easy the content format selection process.

UAProf is directly related to the W3C CC/PP specification and it is also based on RDF. This way, the document schema is extensible [90] [91]. These files, usually served as application/xml mimetype, describe several mobile devices capabilities, e.g., vendor, model, screen size, multimedia capabilities, etc. Most recent versions have also information about MMS, video streaming and more multimedia features. UAProf profiles are voluntarily built by the vendors, e.g., Nokia, Samsung, LG... for GSM devices, or by several telecommunications company for CDMA/BREW devices.

The system works as follows:

1. The device sends a header containing a URL and its UAProf within an HTTP request.
2. The server side analyses the received UAProf to adapt the content to the device's display size.
3. Finally, the server takes the decision and serves the corresponding items to the device.

However, this approach has several drawbacks:

- Not every device have a UAProf.
- Not every UAProf are available.
- UAProf data can contain schema or data errors.
- There is no industry-wide data quality standard for the data within each field in an UAProf.

1.4.0.16 Device Description Repository

The Device Description Repository (DDR) is a concept proposed by the Device Description Working Wroup (DDWG), an organization within the W3C. The DDR is supported by a standard interface and an initial vocabulary core about devices' properties. Web content authors will use these repositories to adapt their content to these devices. This way, the Web content interaction with different devices will be

1. STATE OF THE ART

easier. Screen size, input mechanisms, supported colour sets, known limitations, special features, etc. are stored in these repositories.

Here we present three of the most popular DDR systems:

1.4.0.16.1 WURFL

The Wireless Universal Resource FiLe (WURFL) is an XML based open source database which contains the characteristics and capabilities of a wide range of devices. These capabilities are classified into several groups. These groups are just a simple way to understand WURFL and its data. Its API is very easy to use and it has the advantage of providing a hierarchy able to *infer* several capabilities for devices which are still not present in the file.

The following are several capabilities used by Almeida et al. [25] for Imhotep, a framework which aims to ease the development of accessible and adaptable user interfaces:

- display: It contains information about the device screen, as the resolution, number of columns, orientation, etc.
- image_format: Supported image formats.
- playback: Supported video codec.
- streaming: Available streaming capabilities.
- sound_format: Supported audio formats.

WURFL has become the de-facto standard for mobile capabilities. Nevertheless, there are several free and open source alternatives that are growing within the community very fast.

1.4.0.16.2 OpenDDR

One of the previously cited open alternatives is OpenDDR¹. This DDR also provides an API to access DDRs about devices capabilities. It has two main advantages:

- The conviction that the application will work with any W3C DDR API implementation.
- Adopting the W3C standard the Copyright of the interfaces is protected by the W3C against any intellectual property and patent claims.

Nevertheless, the OpenDDR API is complex. It does not provide an architecture approach like WURFL. This way, it assumes default values for unknown parameters, e.g., `displayWidth = 800` pixels.

1.4.0.16.3 51Degrees.mobi

It works similar to OpenDDR, with the difference that 51Degrees.mobi [92] has two versions. The first one (Lite) is free to use and it gathers several devices capabilities. The second one (Premium) is not free, but it has more data about devices and automatic updates for the stored information.

1.4.0.17 DDR Solution Comparison

The main problem with these solutions is their inability to provide all the information developers usually need. Many fields are empty (which means that default values are used) or with error data. Another disadvantage is that, for the interface adaptation domain, sometimes we may need dynamic information about the device. For example, the battery levels, or the available memory, can be crucial pieces of information before making any adaptation process. Table 1.5 depicts each solution's drawbacks and advantages.

¹<http://www.openddr.org/>

1. STATE OF THE ART

Table 1.5: Analysed DDRs comparison [10]

DDR	Advantages	Drawbacks
WURFL	Upgradeable to new versions	Errors in data
	A hierarchy which allows to infer values	Many empty values
	Many capabilities modelled	
	Very easy to configure	
	Powerful API	
OpenDDR	Free to use, even commercially	Limited number of capabilities
	Growing community	Default values for unknown data
51Degrees.mobi	A Lite version, free to use even commercially	Limited number of capabilities
	Easy to install and use	

1.4.0.18 Ontologies

There are other alternatives for modelling devices. As occurs with users and context ontologies allow us to give some meaning to the modelled concepts and the collected information. From the reviewed ontologies we remark the SOUPA ontology which, in addition to consider context information, it models many different aspects of static mobile capabilities and characteristics [93]. Another significant ontology is the one presented by Hervás, Bravo and Fontecha [94] as part of the PIVOn ontology. The Device Model Ontology describes not only the device's capabilities but its relationships with the service and user ontologies, dependencies and other features.

1.4.0.19 Device Discussion

Apart from all the cited techniques for considering devices and their capabilities, we need to remark how technology evolves in a way that makes difficult to predict how we will work with smart devices in the near future. A few years ago context was understood as the result of the mixture of every physical sensor deployed in the environment. Temperature, light, noise...all these context variables have been historically collected through several sensors located strategically. Now these sensors (and more) are also embedded in these smart devices. They have

become wearable, and using **their capabilities of the devices** they are embedded in they have improved their performance. Touchable screens, network capabilities, parallel computing resources and high storage space embedded in small devices have changed the way context and smart devices interact. This situation makes us contemplate how this interaction channel would be in the near future. Smart watches, glasses and other wearable devices are, undoubtedly, changing the way smart environments will sense, behave and react.

1.4.1 Related Standardization Work

ANEXO!!!!

Regarding the standardization, there are several initiatives (dealing with HCI) that, considering users and devices, are now presented.

1.4.1.0.1 The Web Accessibility Initiative

The Web Accessibility Initiative (WAI) [?] is focused on enabling people with disabilities to equally participate in the Web, e.g., **including** social inclusion, regarding not only their disabilities but the location and available infrastructure. On the other hand, there are also different approaches to standardise the content [?] and the presentation of the user interface, i.e., the Pennsylvania State University [95] studies how to deal with W3C's standards, accessibility and usability issues. Besides, several workshops are proposed to keep investigating under this issue (see [?]).

1.4.1.0.2 The Uncertainty Reasoning for the World Wide Web Incubator Group

Considering the uncertainty of the collected context information, the W3C's Uncertainty Reasoning for the World Wide Web Incubator Group (**URW3-XG**) [?] aims to define the challenge of reasoning with and representing uncertain infor-

1. STATE OF THE ART

mation through related WWW technologies. In 2008 the W3C Incubator Group released a report where there are many recommendations through different analysis to identify and describe not only potential uncertain situations but applicable methodologies and the fundamentals of a standardized representation to effectively use them.

Table 1.6 shows several W3C standards and different specifications considering users and devices. Besides, there are also many guidelines and discussion groups working on these issues.

The W3C remarks the lack of definition that makes the interoperability of user models difficult. In this context, they propose the following areas to work on:

- A standard interoperability model providing API's for different purposes and applications
- Common data storage format for user profiles
- Common calibration/validation technique
- Collaboration on ethical issues
- Ensuring sustainability by making them available within a standard
- Mechanisms for exchanging user profile data between sources
- Protection mechanisms for privacy issues
- Control mechanisms for user profile data exposure

1.4.1.0.3 The Video in the Web Activity

Promoting the use of the video in the Web, the Video in the Web Activity [?] aims to build a solid architecture to enable users to create, navigate, search, link and distribute video, effectively making video part of the Web. This activity group is formed by three different working groups:

Table 1.6: W3C standards and specifications for user and device modelling

Entity	Contribution	Type	
		Standard	Specification
User	UAProf	✓	
	Multimodal Architecture and Interfaces	✓	
	Extensible MultiModal Annotation markup language	✓	
	Ink Markup Language (InkML)	✓	
	Accessibility (All)		✓
	Web Content Accessibility Guidelines (WCAG)		✓
	Accessible Rich Internet Applications (WAI-ARIA)		✓
	User Agent Accessibility Guidelines (UAAG)		✓
	Authoring Tool Accessibility Guidelines (ATAG)		✓
	Evaluation and Report Language (EARL)		✓
	IndieUI		✓
Device	CC/PP	✓	
	Introduction to Model-Based User Interfaces		✓
	Model-Based User Interfaces Glossary		✓
	Guidelines for writing device independent tests		✓
	Delivery Context Overview for Device Independence		✓
	Authoring Techniques for Device Independence		✓
	Device Independence Principles		✓
	Authoring Challenges for Device Independence		✓
	Delivery Context Ontology		✓
	Delivery Context: Client Interfaces (DCCI)		✓

1. STATE OF THE ART

- The Timed Text Working Group [?], which mission is to provide a language that represents textual information that is associated with timing information. This group has released two versions of the Timed Text Markup Language (TTML). The first one was released in 2010. The last one during 2013.
- The Media Annotations Working Group [?], which main purpose is to provide an ontology and API to facilitate cross-community data integration of multimedia information in the Web. The group has published the following documents:
 - A second version of Use Cases and Requirements for Ontology and API for Media Resource 1.0 on January 2010, as an input for the development of “the Ontology and the API for Media Resource 1.0” Specification.
 - A W3C Recommendation version of the Ontology for Media Resource on February 2012.
 - The group is now about to publish a Proposed Recommendation of the API for Media Resources.
- The Media Fragments Working Group [?], which successfully aimed to address temporal and spatial media fragments in the Web using URIs. The group was closed on December 2013 having successfully published two versions (basic and advanced) of the Media Fragments URI 1.0 specification as a Recommendation.

The Video in the Web Activity members are still working over the issue of the video codec to be used in the W3C specifications (in particular HTML5).

1.4.1.0.4 The Provenance Working Group

Provenance is defined as the information about the involved entities in producing data which can be used to form assessments about its trustworthiness. In order to allow users to mark up web pages using the terms provided or by making available provenance information expressed as linked data the PROV specification [?]

Table 1.7: PROV documents description. Document type (Recommendation or Note) is also shown

Document	Type	Details
PROV-PRIMER [?]]	Note	The entry point to PROV offering an introduction to the provenance data model
PROV-XML [?]]	Note	Defines an XML schema for the provenance data model PROV data model
PROV-O [?]]	Rec.	PROV-O defines a light-weight OWL2 ontology for the provenance data model
PROV-DM [?]]	Rec.	Defines a conceptual data model for provenance including UML diagrams. PROV-O, PROV-XML and PROV-N are serializations of this conceptual model
PROV-N [?]]	Rec.	Defines a human-readable notation for the provenance model.
PROV-CONSTRAINTS [?]]	Rec.	Defines a set of constraints on the PROV data model that specifies a notion of valid provenance
PROV-AQ [?]]	Note	Defines how to use Web-based mechanisms to locate and retrieve provenance information
PROV-DC [?]]	Note	Defines a mapping between Dublin Core and PROV-O
PROV-DICTIONARY [?]]	Note	Defines constructs for expressing the provenance of dictionary style data structures
PROV-SEM [?]]	Note	Defines a declarative specification in terms of first-order logic of the PROV data model
PROV-LINKS [?]]	Note	Defines extensions to PROV to enable linking provenance information across bundles of provenance descriptions

provides a vocabulary to interchange this provenance information. This specification consists of 11 documents that define various necessary aspects to achieve the vision of inter-operable interchange of provenance information in heterogeneous environments such as the Web (we do not consider the Overview document). Table 1.7 shows the cited documents and their details. After the publication of the PROV Ontology [96] the PROV group was closed on June, 2013.

1.4.1.0.5 The Moving Picture Experts Group

The Moving Picture Experts Group (MPEG) is a working group of ISO/IEC with the mission to develop standards, e.g., MPEG-ACC, MPEG-H, MPEG-DASH, MPEG-4... for coded representation of digital audio and video. The group has produced several standards that help the industry offer end users an ever more enjoyable digital media experience. As this group keeps working on the cited objectives the 108 meeting is scheduled March 2014 in Valencia, Spain [97].

1. STATE OF THE ART

Table 1.8: Active IETF Working Groups

Working Group
Applications Area Working Group
Constrained RESTful Environments
Extensible Provisioning Protocol Extensions
Hypertext Transfer Protocol Bis
BiDirectional or Server-Initiated HTTP
JSON data formats for vCard and iCalendar
JavaScript Object Notation
Protocol to Access WS database
Preparation and Comparison of Internationalized Strings
IMAP QRESYNC Extension
System for Cross-domain Identity Management
SPF Update
Uniform Resource Names, Revised
Using TLS in Applications
Web Security
Web Extensible Internet Registration Data Service

1.4.1.0.6 The Internet Engineering Task Force

The mission of the Internet Engineering Task Force (IETF) is to produce high quality and relevant technical documents that influence people to design, use, and manage the Internet. IETF's standards development work is organized into 8 areas. Within each area there are multiple Working Groups. Each Working Group has one or more chairs who manage the work, and a written charter defining what the work is and when it is due. Table 1.8 shows the current active IETF Working Groups. The next meeting is scheduled for March, 2014 in London, England.

ctionUsability: Satisfaction metrics

ANEXO.

[45] metrics for quality experience

1.5 Attentive computing

ANEXO.

Personally, I think it does help, that it makes a beneficial difference, but the scientific literature on the subject is very messy.

Jeanne Petrek

Bibliography

- [1] Accessibility in ios. <https://www.apple.com/accessibility/ios/>. Accessed: 2014-08-06. xvii, 3
- [2] Voiceover for ios. <https://www.apple.com/accessibility/ios/voiceover/>. Accessed: 2014-08-06. xvii, 3
- [3] Siri for ios. <https://www.apple.com/ios/siri/>. Accessed: 2014-08-06. xvii, 3
- [4] Tactus. <http://tactustechology.com/>. Accessed: 2014-08-07. xvii, 7, 8
- [5] Jon Orwant. Heterogeneous learning in the doppelgänger user modeling system. *User Modeling and User-Adapted Interaction*, 4(2):107–130, 1994. xvii, 10, 11
- [6] Jon Orwant. For want of a bit the user was lost: Cheap user modeling. *IBM Systems Journal*, 35(3.4):398–416, 1996. xvii, 11
- [7] G. Fischer. User modeling in human–computer interaction. *User modeling and user-adapted interaction*, 11(1):65–86, 2001. xvii, xix, 2, 11, 12, 23
- [8] Peter Gregor, Alan F. Newell, and Mary Zajicek. Designing for dynamic diversity: interfaces for older people. In *Proceedings of the fifth international ACM conference on Assistive technologies*, page 151–156, 2002. xvii, 12, 13, 22, 23, 24

BIBLIOGRAPHY

- [9] D. Heckmann, E. Schwarzkopf, J. Mori, D. Dengler, and A. Kröner. The user model and context ontology GUMO revisited for future web 2.0 extensions. *Contexts and Ontologies: Representation and Reasoning (2007)*, page 37–46, 2007. xvii, 17, 22, 24
- [10] Comparing device description repositories. <http://www.samaxes.com/2012/10/comparing-device-description-repositories/>. Accessed: 2014-08-12. xix, 44
- [11] Android magnification gestures. <https://support.google.com/accessibility/android/answer/6006949?hl=en>. Accessed: 2014-08-06. 2
- [12] Accessibility in android. <http://developer.android.com/guide/topics/ui/accessibility/index.html>. Accessed: 2014-08-06. 3
- [13] Alfred Kobsa. Generic user modeling systems. *User modeling and user-adapted interaction*, 11(1-2):49–63, 2001. 4, 21
- [14] Anthony Jameson. Modelling both the context and the user. *Personal and Ubiquitous Computing*, 5(1):29–33, 2001. 4, 26, 27, 37
- [15] E.G. Nilsson, J. Floch, S. Hallsteinsen, and E. Stav. Model-based user interface adaptation. *Computers & Graphics*, 30(5):692–701, 2006. 4, 5, 26
- [16] S. Weerawarana, F. Curbera, M. J. Duftler, D. A. Epstein, and J. Kesselman. Bean markup language: A composition language for JavaBeans components. In *Proceedings of the 6th conference on USENIX Conference on Object-Oriented Technologies and Systems-Volume 6*, page 13–13, 2001. 4, 5
- [17] Anind K. Dey. Understanding and using context. *Personal and ubiquitous computing*, 5(1):4–7, 2001. 4, 24, 25
- [18] G. Calvary, J. Coutaz, D. Thevenin, Q. Limbourg, N. Souchon, L. Bouillon, M. Florins, J. Vanderdonckt, et al. Plasticity of user interfaces: A revisited reference framework. In *In Task Models and Diagrams for User Interface Design*, 2002. 4, 26

- [19] G. Calvary, J. Coutaz, and D. Thevenin. Supporting context changes for plastic user interfaces: a process and a mechanism. *People and Computers*, page 349–364, 2001. 5
- [20] M. Lehtonen, R. Petit, O. Heinonen, and G. Lindén. A dynamic user interface for document assembly. In *Proceedings of the 2002 ACM symposium on Document engineering*, page 134–141, 2002. 5
- [21] P. Repo. Facilitating user interface adaptation to mobile devices. In *Proceedings of the third Nordic conference on Human-computer interaction*, page 433–436, 2004. 5
- [22] S. Hallsteinsen, E. Stav, and J. Floch. Self-adaptation for everyday systems. In *Proceedings of the 1st ACM SIGSOFT workshop on Self-managed systems*, page 69–74, 2004. 5
- [23] W. Stuerzlinger, O. Chapuis, D. Phillips, and N. Roussel. User interface façades: towards fully adaptable user interfaces. In *Proceedings of the 19th annual ACM symposium on User interface software and technology*, page 309–318, 2006. 5
- [24] H. Marmolin, Y. Sundblad, K. Schmidt, et al. Medium versus mechanism: Supporting collaboration through customisation. In *ECSCW'95: proceedings of the Fourth European Conference on Computer-Supported Cooperative Work, 10-14 September 1995, Stockholm, Sweden*, volume 8, page 133, 1995. 5
- [25] A. Almeida, P. Orduña, E. Castillejo, D. Lopez-de Ipiña, and M. Sacristán. Imhotep: an approach to user and device conscious mobile applications. *Personal and Ubiquitous Computing*, 15(4):419–429, 2011. 6, 42
- [26] Wurfl - the mobile device database. <http://wurfl.sourceforge.net/>. Accessed: 2014-08-07. 6
- [27] Christoph Evers, Romy Kniewel, Kurt Geihs, and Ludger Schmidt. Achieving user participation for adaptive applications. In *Ubiquitous Computing and Ambient Intelligence*, Lecture Notes in Computer Science, pages 200–207. Springer Berlin Heidelberg, January 2012. 6, 19, 23, 24, 35

BIBLIOGRAPHY

- [28] R. Casas, R. Blasco Marín, A. Robinet, A. Delgado, A. Yarza, J. McGinn, R. Picking, and V. Grout. User modelling in ambient intelligence for elderly and disabled people. *Computers Helping People with Special Needs*, page 114–122, 2008. 7, 18, 23, 24
- [29] Tactus in linkedin. <https://www.linkedin.com/company/tactus-technology>. Accessed: 2014-08-07. 7
- [30] James Frederick Allen. A plan-based approach to speech act recognition. 1979. 9
- [31] C. Raymond Perrault, James F. Allen, and Philip R. Cohen. Speech acts as a basis for understanding dialogue coherence. In *Proceedings of the 1978 workshop on Theoretical issues in natural language processing*, page 125–132, 1978. 9
- [32] Philip R. Cohen and C. Raymond Perrault. Elements of a plan-based theory of speech acts. *Cognitive science*, 3(3):177–212, 1979. 9
- [33] Elaine Rich. Building and exploiting user models. In *Proceedings of the 6th international joint conference on Artificial intelligence-Volume 2*, page 720–722, 1979. 9
- [34] Elaine Rich. User modeling via stereotypes. *Cognitive science*, 3(4):329–354, 1979. 9
- [35] A. Kobsa. Generic user modeling systems. *User modeling and user-adapted interaction*, 11(1):49–63, 2001. 9, 21
- [36] Wolfgang Pohl. Logic-based representation and reasoning for user modeling shell systems. *User Modeling and User-Adapted Interaction*, 9(3):217–282, 1999. 9, 20, 21
- [37] Jon Orwant. *Doppelgänger—a user modeling system*. PhD thesis, Massachusetts Institute of Technology, 1991. 10, 21, 22
- [38] Alvin W. Drake. *Fundamentals of applied probability theory*. McGraw-Hill College, 1967. 10

- [39] Susan Gauch, Jason Chaffee, and Alexander Pretschner. Ontology-based personalized search and browsing. *Web Intelligence and Agent Systems*, 1(3):219–234, 2003. 13, 22, 24
- [40] Marek Hatala and Ron Wakkary. Ontology-based user modeling in an augmented audio reality system for museums. *User Modeling and User-Adapted Interaction*, 15(3-4):339–380, 2005. 14, 22, 24
- [41] Paul Dourish. What we talk about when we talk about context. *Personal and ubiquitous computing*, 8(1):19–30, 2004. 14
- [42] Paul Dourish. *Where the action is: the foundations of embodied interaction*. The MIT Press, 2004. 14
- [43] Wolfgang Wahlster and Alfred Kobsa. *User models in dialog systems*. Springer, 1989. 14, 20
- [44] Liana Razmerita, Albert Angehrn, and Alexander Maedche. Ontology-based user modeling for knowledge management systems. In *User Modeling 2003*, page 213–217. Springer, 2003. 15, 21, 23, 24, 35
- [45] Fernando Pereira. A triple user characterization model for video adaptation and quality of experience evaluation. In *Multimedia Signal Processing, 2005 IEEE 7th Workshop on*, page 1–4, 2005. 15, 23, 24, 35, 50
- [46] U. Persad, P. Langdon, and J. Clarkson. Characterising user capabilities to support inclusive design evaluation. *Universal Access in the Information Society*, 6(2):119–135, 2007. 16, 22, 24
- [47] U. Persad, P. Langdon, D. Brown, and P. J. Clarkson. Cognitive scales and mental models for inclusive design. In *Proceedings of the 4th international conference on Universal access in human computer interaction: coping with diversity*, page 776–785, 2007. 16, 17
- [48] *BS 7000-6:2005 Design management systems. Part 6: Managing inclusive design*. Guide. British Standards Institute, 2005. 16
- [49] W. Babisch. The noise/stress concept, risk assessment and research needs. *Noise and health*, 4(16):1, 2002. 17

BIBLIOGRAPHY

- [50] Alan Cooper and Paul Saffo. *The inmates are running the asylum*, volume 1. Sams, 2004. 18
- [51] M. Golemati, A. Katifori, C. Vassilakis, G. Lepouras, and C. Halatsis. Creating an ontology for the user profile: Method and applications. In *Proceedings of the First RCIS Conference*, page 407–412, 2007. 19, 21, 24
- [52] W. Liao, W. Zhang, Z. Zhu, and Q. Ji. A decision theoretic model for stress recognition and user assistance. In *PROCEEDINGS OF THE NATIONAL CONFERENCE ON ARTIFICIAL INTELIGENCE*, volume 20, page 529, 2005. 19, 35
- [53] Kerry-Louise Skillen, Liming Chen, Chris D. Nugent, Mark P. Donnelly, William Burns, and Ivar Solheim. Ontological user profile modeling for context-aware application personalization. In *Ubiquitous Computing and Ambient Intelligence*, page 261–268. Springer, 2012. 19, 22, 23, 24
- [54] Dominikus Heckmann. *Ubiquitous user modeling*, volume 297. IOS Press, 2005. 20, 23
- [55] Tim Finin and David Drager. GUMS: a general user modeling system. In *Proceedings of the workshop on Strategic computing natural language*, page 224–230, 1986. 20
- [56] Giorgio Brajnik and Carlo Tasso. A shell for developing non-monotonic user modeling systems. *International Journal of Human-Computer Studies*, 40(1):31–62, 1994. 21
- [57] Ana Paiva and John Self. Tagus—a user and learner modeling workbench. *User Modeling and User-Adapted Interaction*, 4(3):197–226, 1994. 21
- [58] Judy Kay. The um toolkit for cooperative user modelling. *User Modeling and User-Adapted Interaction*, 4(3):149–196, 1994. 21
- [59] Alfred Kobsa and Wolfgang Pohl. The user modeling shell system bgp-ms. *User Modeling and User-Adapted Interaction*, 4(2):59–106, 1994. 21

- [60] James Davidson, Benjamin Liebald, Junning Liu, Palash Nandy, Taylor Van Vleet, Ullas Gargi, Sujoy Gupta, Yu He, Mike Lambert, Blake Livingston, and others. The YouTube video recommendation system. In *Proceedings of the fourth ACM conference on Recommender systems*, page 293–296. ACM, 2010. 22
- [61] T. Strang and C. Linnhoff-Popien. A context modeling survey. In *Workshop Proceedings*, 2004. 22, 23, 36, 38
- [62] Gediminas Adomavicius and Alexander Tuzhilin. Context-aware recommender systems. In *Recommender systems handbook*, page 217–253. Springer, 2011. 24
- [63] A. Schmidt, M. Beigl, and H. W. Gellersen. There is more to context than location. *Computers & Graphics*, 23(6):893–901, 1999. 26, 34, 35
- [64] Guanling Chen and David Kotz. A survey of context-aware mobile computing research. Technical report, Technical Report TR2000-381, Dept. of Computer Science, Dartmouth College, 2000. 26, 34, 37
- [65] Bill Schilit, Norman Adams, and Roy Want. Context-aware computing applications. In *Mobile Computing Systems and Applications, 1994. WMCSA 1994. First Workshop on*, page 85–90, 1994. 26
- [66] K. Henriksen, J. Indulska, and A. Rakotonirainy. Modeling context information in pervasive computing systems. *Pervasive Computing*, page 79–117, 2002. 27, 33, 35, 37
- [67] A. Held, S. Buchholz, and A. Schill. Modeling of context information for pervasive computing applications. In *Proceeding of the World Multiconference on Systemics, Cybernetics and Informatics*, 2002. 28, 37
- [68] Tao Gu, Hung Keng Pung, and Da Qing Zhang. Toward an OSGi-based infrastructure for context-aware applications. *Pervasive Computing, IEEE*, 3(4):66–74, 2004. 29, 34, 35, 37
- [69] T. Gu, X. H Wang, H. K Pung, and D. Q Zhang. An ontology-based context model in intelligent environments. In *Proceedings of Communication Net-*

BIBLIOGRAPHY

- works and Distributed Systems Modeling and Simulation Conference*, volume 2004, page 270–275, 2004. 30, 33
- [70] Harry Chen, Tim Finin, and Anupam Joshi. Using OWL in a pervasive computing broker. Technical report, 2005. 30, 37
- [71] Tetsuo Yamabe, Ayako Takagi, and Tatsuo Nakajima. Citron: A context information acquisition framework for personal devices. In *Embedded and Real-Time Computing Systems and Applications, 2005. Proceedings. 11th IEEE International Conference on*, page 489–495, 2005. 31, 37
- [72] Anthony Wood, Jack Stankovic, Gilles Virone, Leo Selavo, Zhimin He, Qihua Cao, Thao Doan, Yafeng Wu, Lei Fang, and Radu Stoleru. Context-aware wireless sensor networks for assisted living and residential monitoring. *Network, IEEE*, 22(4):26–33, 2008. 31, 37
- [73] Linas Baltrunas, Marius Kaminskas, Bernd Ludwig, Omar Moling, Francesco Ricci, Aykan Aydin, Karl-Heinz Lüke, and Roland Schwaiger. Incarmusic: Context-aware music recommendations in a car. In *E-Commerce and Web Technologies*, page 89–100. Springer, 2011. 32, 35, 37
- [74] Laura M. McAvoy, Liming Chen, and Mark Donnelly. An ontology-based context management system for smart environments. In *UBICOMM 2012, The Sixth International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies*, page 18–23, 2012. 32, 37
- [75] Aitor Almeida and Diego López-de Ipiña. Assessing ambiguity of context data in intelligent environments: Towards a more reliable context managing system. *Sensors*, 12(4):4934–4951, 2012. 33, 35, 36, 37
- [76] W. Wayt Gibbs. Considerate computing. *Scientific American*, 292(1):54–61, 2005. 35
- [77] Eduardo Castillejo, Aitor Almeida, and Diego López-De-Ipiña. Alleviating cold-user start problem with users’ social network data in recommendation systems. August 2012. 35

- [78] Eduardo Castillejo, Aitor Almeida, and Diego López-de Ipiña. Social network analysis applied to recommendation systems: alleviating the cold-user problem. In *Ubiquitous Computing and Ambient Intelligence*, page 306–313. Springer, Vitoria-Gasteiz, Spain, 2012. 35
- [79] Gregory D. Abowd, Anind K. Dey, Peter J. Brown, Nigel Davies, Mark Smith, and Pete Steggles. Towards a better understanding of context and context-awareness. In Hans-W. Gellersen, editor, *Handheld and Ubiquitous Computing*, number 1707 in Lecture Notes in Computer Science, pages 304–307. Springer Berlin Heidelberg, January 1999. 35
- [80] H. Maass. Location-aware mobile applications based on directory services. *Mobile Networks and Applications*, 3(2):157–173, 1998. 36
- [81] B. N. Schilit, M. M. Theimer, and B. B. Welch. *Customizing mobile applications*. Citeseer, 1993. 37
- [82] G. M. Voelker and B. N. Bershad. Mobisaic: An information system for a mobile wireless computing environment. *Mobile Computing*, page 375–395, 1996. 37
- [83] J. Bauer, R. Kutsche, and R. Ehrmanntraut. Identification and modeling of contexts for different information scenarios in air traffic. *Technische Universität Berlin, Diplomarbeit*, 2003. 38
- [84] Karen Henricksen, Jadwiga Indulska, and Andry Rakotonirainy. Generating context management infrastructure from high-level context models. In *In 4th International Conference on Mobile Data Management (MDM) - Industrial Track*, page 1–6, 2003. 38
- [85] K. Cheverst, K. Mitchell, and N. Davies. Design of an object model for a context sensitive tourist GUIDE. *Computers & Graphics*, 23(6):883–891, 1999. 38
- [86] Tayeb Lemlouma and Nabil Layaïda. Context-aware adaptation for mobile devices. In *Mobile Data Management, 2004. Proceedings. 2004 IEEE International Conference on*, page 106–111, 2004. 39

BIBLIOGRAPHY

- [87] Device independence and content adaptation. <http://www.w3.org/standards/webofdevices/independence>. Accessed: 2014-08-08. 39
- [88] Cc/pp current status. <http://www.w3.org/standards/techs/ccpp>. Accessed: 2014-08-08. 39
- [89] Uaprofindex. <http://www.w3.org/wiki/UAProfIndex>. Accessed: 2014-08-08. 40
- [90] Mark H. Butler. Implementing content negotiation using CC/PP and WAP UAProf. *HP LABORATORIES TECHNICAL REPORT HPL*, (190), 2001. 41
- [91] Mark H. Butler. CC/PP and UAProf: issues, improvements and future directions. In *Proceedings of W3C Delivery Context Workshop (DIWS 2002)*, 2002. 41
- [92] 51degrees. <http://51degrees.com/>. Accessed: 2014-08-08. 43
- [93] Harry Chen, Filip Perich, Tim Finin, and Anupam Joshi. Soupa: Standard ontology for ubiquitous and pervasive applications. In *Mobile and Ubiquitous Systems: Networking and Services, 2004. MOBIQUITOUS 2004. The First Annual International Conference on*, page 258–267. IEEE, 2004. 44
- [94] Ramón Hervás, José Bravo, and Jesús Fontecha. A context model based on ontological languages: a proposal for information visualization. *J. UCS*, 16(12):1539–1555, 2010. 44
- [95] Accessibility vs. usability vs. w3c web "standards". <http://accessibility.psu.edu/usability>. Accessed: 2014-08-08. 45
- [96] Prov-o: The prov ontology. <http://www.w3.org/TR/2013/REC-prov-o-20130430/>. Accessed: 2014-08-08. 49
- [97] Mpeg 108 - valencia. <http://mpeg.chiariglione.org/meetings/108>. Accessed: 2014-08-08. 49

Declaration

I herewith declare that I have produced this work without the prohibited assistance of third parties and without making use of aids other than those specified; notions taken over directly or indirectly from other sources have been identified as such. This work has not previously been presented in identical or similar form to any examination board.

The dissertation work was conducted from 20XX to 2014 under the supervision of Name Surname and Name Surname at the University of Deusto.

Bilbao,

This dissertation was finished writing in Bilbao on Tuesday 12th August, 2014

This page is intentionally left blank