Chapter 3
Diagnostic and Accessibility Based User Modelling

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Abstract This chapter discusses application driven user modelling by dividing user model applications into two broad categories: to provide access for the user with a device and to derive conclusions about the user. Both imply different requirements and different algorithms. The chapter starts by reviewing user modelling literature. Next, the chapter focuses on a discussion of design work in providing accessible documents to deliver accessible educational materials to students, matched to their needs and the capabilities of the device that they are using, so modelling components need to be considered. Next is a presentation of user models supporting the diagnosis of cognitive states, employing a user model that is expressed as fusion of sensor data. With a baseline created, the system captures sensor data over time and compares it with 'normal' pattern, to identify indications of Mild Cognitive Impairment (MCI). Finally, a novel framework for User Models design is shown, dividing user data into static and dynamic types.

3.1 Introduction

Our chapter will discuss application driven user modelling. Here we will discuss application based modelling in contrast to generic user modelling[23]. Context and location dependent applications, typically, will require the sort of specialized partitioning of the user models discussed here; however much that is said in application based user modelling can be applied to generic user modelling systems.

In this chapter we will look at user models as task driven systems, driven by the pull of the application and the availability of content. Because these models are used as terms of selection or as the source for classification their structure is pre-determined rather than emergent and any inferences should be drawn solely from the user data itself.

We will discuss user model applications in two broad categories: User models used to provide access for the user with a device and user models used to derive

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conclusions about the user. Each of these has different requirements and uses different algorithms to accomplish their goals. We will discuss each of these approaches in terms of a worked out example.

Finally the chapter will close with a novel way to approach user models from the perspective of changing user attributes. This is driven by a relational database approach to users and contexts, and inspired by several experiences with projects and models where the two were conflated. By keeping data that never changed in the same 'table' as attribute values that change frequently, the system is forced to either keep multiple copes of a user model for a single person, or to constantly change the model as the context of use changes. In the chapter we will discuss the ramifications of these approaches.

3.2 Theoretical Background

User models have been used as diagnostic tools when combined with reasoning engines in expert systems[23], as configuration aids in systems with stereotype patterns [12, 31], as recommender systems in collaborative filters[27], and as tools for properly fitting assistive technology to real users needs[20]. User models that provide support for interface presentation, in terms of what, how, and when information is presented [12] are well suited to presentation of educational materials as discussed in section 3 below.

The initial uses of user models supported simple lists of attribute value pairs and some kind of logic formalism. Stereotypes made user modelling possible by limiting the vocabulary that the user was described with thus allowing inferences and contradiction detection [25]. Some user models did consider the difference between static and dynamic user model attributes[19], but from the perspective of the user as a solitary unit, not part of a dynamic system. There has been a great amount of work done on user model servers, along with the architecture of the system to modularise the functions as well as supporting reuse[24]. The great advantages of these systems, abstraction and generality, is a shortcoming in designing systems that are context and history sensitive, because they typically do not retain the changing states of the users interactional and current context. In general, user modelling systems [22] need to:

- Store information about users in a non-redundant manner.
- Provide support for classification of users as belonging to one or more of these subgroups, and the integration of the typical characteristics of these subgroups into the current individual user model;
- Support recording of users' behaviour, particularly their past interaction with the system.

Additionally, user modelling systems often have these characteristics (from [11]):

- Expressiveness and strong inferential capabilities
- Support for quick adaptation.
- Extensibility.
- Import of external user-related information.
- Management of distributed information.
- Support for open standards.
- Load balancing.
- Failover strategies.
- Transactional consistency.
- Privacy support.

There are several kinds of architecture that support novel kinds of user modelling, particularly in the field of ubiquitous and mobile computing where numerous environmental and usage history data drive the systems output to the user. In some cases having a central server provides too much reliance on robust network connection, on the other hand local devices may not have computational resources to provide real-time system response. At times, in response to security concerns, using a local desktop computer for specific data processing is the only (secure) way to guarantee the privacy and intimacy of personal information, so the decision of what/how to protect this critical information must be tackled *ad hoc* and agreed to by the end user and legal stakeholders.

User models can also be a support for interface presentation, in terms of what, how, and when information is presented [12]. This approach is well suited to presentation of educational materials as discussed in section 3.

The World Wide Web Consortium [28, 49, 50] has provided several useful frameworks for integrating user, device and content. Substantial thought and prototyping effort has been done to produce systems [46-48] that 1) are standards based and 2) use robust technologies (RDF, existing device metadata) that formed a basis for much of the thought in section 3, below.

Probably one of the most complex fields for user modelling is related to the daily activity user profiling. To tackle this challenge several projects were started on the second half of last decade: MavHome project [53], the Gator Tech Smart House [15] the iDorm [8], the Georgia Tech Aware Home[2], and the University of Colorado Adaptive Home [33]. This type of user modelling is based on sets of sensors of various types deployed across an unconstrained environment where the person performs his or her daily activity, which allows knowing what the person is doing at any moment, specially regarding activities of daily living (ADL [21]). The environment consists of various smart objects and a human being and the interactions amongst which constitute different events. The sequence of these events can tell us the when, what with and how, i.e. the person is cooking, taking breakfast, personal care, tiding the house or just sleeping. Events may have strong dependence on preceding events over multiple durations [34], and this really compounds the daily routine. A majority of previous approaches for activity representation requires explicit modelling of activity structure [32, 40]. Because such models are not at a hand or existing *a priori,* representations that can encode activity structure with minimal supervision are needed[14]. To this end, there has been recent interest in extracting activity structure simply by computing their local event-statistics (see e.g. [41], using Vector Space Model [37, 54]; using Latent Semantic Analysis [7], and [13]; using n-grams [29] respectively), but there the concept of activity is closely related to automatic document processing, natural language processing or video imaging processing, which are most times far from the peculiarities that human activities of daily living might show. Also, by adapting Latent Dirichlet Allocation graphic models [4] and Author-Topic Models from document interpretation to outdoor human activity analysis, some authors have generated plausible explanations for the similarity of some parts of the data (topics) obtained from cell phones and Bluetooth devices [10, 42]. More complex but also more accurate for human activity recognition for this kind of user modelling is the use of Markov models which can better accomplish the successful detection of ADL initiation and completion. While this method is effective at distinguishing between simple tasks, handling real-world task recognition is more challenging [39]. The CASAS project [38] added some temporal information to the models to make the models more robust. Based on Markov Models and Finite State Machines, Aztiria et al. developed an algorithm to obtain frequent behaviours by means of learning user's patterns taking into account the special features of intelligent environments [3]. Based on this algorithm, Aztiria et al. propose in [1] a process to discover sequences of user actions in a system based on speech recognition. In this approach, patterns are used not only to automate actions or devices, but also to understand users' behaviour and act in accordance with it. The speech recognition system allows user to interact with the patterns in order to use his/her acceptance to automate actions. This learning machine for frequent behaviours while performing activities of daily living is a common topic in both Aztiria's research and BEDMOND project [30] but with a different interpretation focus on the user model created: Aztiria's work deals with automated assistance for implementing personal preferences (frequent activities), while BEDMOND project looks for changes in those personal preferences to be interpreted with neurology criteria. Due to those important similarities and the ability of Markov Models for ticketing and activity classification (in general) the BEDMOND project decided to follow this technique for user modelling in regard to activities of daily living.

3.3 User models for Content Accessibility

A current topic in European research is systems supporting universal access to distance learning [2][3][4], the specifics described here came out of initial design work in

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[2] http://www.aegis-project.eu

the EU4ALL project [9].These projects emphasise the use of content fitted to stereotypical sensory, and to a lesser degree, cognitive disabilities. Adding to the complexity of the problem is the rising popularity of mobile platforms, where previously a reasonable assumption was that the material would be accessed through 'typical' PCs, now material may be presented on screens as small as a smartphone and in the pad format. The rise of ubiquitous and embodied computational services adds to the complexity of delivery of the right content, in the right way, and via the right medium [12].

This kind of personalization is a special case of a broad range of applications and systems that will be tailored to a user's needs and capabilities and with respect to the context at the time and place of use. Scenarios of use may include searching and accessing schedules and real-time location of buses in transit services non-visually on a smartphone[43]; reading medical records on a wall display closest to the users current location and printing them on the nearby printer; locating a friend in a crowded shopping district, locating a film centre nearby and purchasing tickets, and using a mobile pad to present a text version of a lecture given as part of a distance learning university course.

This kind of deep personalization is dependent on three things: the end user, the context (which includes the device used for input and output) and the content. Each end-user presents a unique set of abilities and needs; sometimes this may be as broad as a preferred language or as deep as sensory and motoric disabilities with preferred alterative presentation mode (e.g. low visual acuity & synthesized text) and preferred input mode (i.e. voice commands, scan and select input). The context of the application has two dimensions: the actual environment, including the history of the users interactions with the computer (in general) and earlier sessions with this application; and the device with which the user interacts with the system, including the device constraints (i.e. small screened smartphones) and the device capabilities (i.e. speakers, text synthesiser). The third part of the personalization is the content that is presented to the user; this may be one of a set of identical 'content' expressed in different modalities, or a server that adapts the content to the needs and capabilities of the user/device.

Although this chapter and book is focused on user models, it is difficult to discuss a system that uses user models without considering the context in which the user models provide leverage. Here we will start with considering the user herself, the User Model (UM). While the specifics discussed here are concerned with the needs and abilities that differ from 'typically' abled users, looking at the problem with this lens makes it easier to highlight the salient issues for all users. Each person brings to the problem space a unique set of abilities and needs, and it is important to consider both the disability *and* the preferred mode of adaptation that this user has. Because of the unique set of attributes that the user brings to the application the use of simple stereotypes, while initially appealing, may cause a poor

[3] http://adenu.ia.uned.es/alpe/index.tcl
[4] http://www.eu4all-project.eu/

fit (due to the too large granularity of the stereotype) between document, applications and user. For these reason these user models have attributes that describe discretely individuals to the adaptation system. Examples of these discrete attributes may include various levels of visual disability, where describing their visual sense with a binary blind/not blind may not capture the large percentage of partially sighted persons who could gain some advantage from a custom form of visual interface. Similarly motoric and cognitive disabilities both require a wide range of attribute-value pairs to describe them. Further, a given person may have a *combination* of sensory/motoric/cognitive abilities that makes them unique. Ontologies and hierarchical description schemas may be useful, both as a support for attribute names but also in that nodes that are not leafs may also provide goals for places to base accessibility support. Finally, this part of the user modelling system should only concern itself with those attributed to the user which never change, or change very slowly monotonically down an axis of ability. By this we mean that if a user condition pertinent to the application waxes and wanes, in contrast to only decreasing over time, this should be captured as a part of the context /device model as described below.

The next element in this user modelling system is the device model (DM), which in a larger sense is the context. By this we mean several things: 1) the actual context which includes the current time and place and various other details that constitute the environment 2) the device used to access the material and 3) the changing attributes of the user. To describe the actual physical context existing ontologies and frameworks may prove both useful and a way to access existing data sources. Part of the captured context includes resources as well as static descriptions, i.e. network accessibility, temperature, light. Chapter 2 of this text nicely lays out the advantages of device modelling in discussion the problems of interoperability.

Device as context makes sense if you talk about context as everything on the outside of the user that affects, or is pertinent to, the user. In the case of the users device this provides an inventory of capabilities to the system. The inventory of device abilities can include local availability of resources (i.e. printers, Java, browser) I/O capabilities such as a list of compatible mime types [16] and input affordances (touch screen, speech synthesiser and verbal recognition). These qualities can be represented in existing schemas (frameworks or ontologies) such as UAProf and CC/PP [35, 49]. A more dynamic approach for device description can be taken with systems like the examples of V2 [44] and URC[45], or the aria initiative [51] where the device can self configure to match the needs of the applications user controls.

Finally context can be considered as the history of the user and application. History as context can be built from system history, application history, and users history (as captured for example in bookmarks and previous preferred configurations). The user modelling system can use these as both local support for making inferences, i.e. he is doing this task and has just finished this subtask, and as a basis for inferring conditions of importance to the successful completion of the goalat-hand. An example of this could come from a task support application [5] where the user may have paused for a long time at this point in previous trials (and might trigger additional help from the system) or where the user is going over the sub task prompts very rapidly, from which the application may infer that the user has these sub-tasks memorised in a chunk and therefore might flag compression of many prompts for a set of sub-tasks into one single prompt for a larger sub-task.

The last part of this user modelling system is the content itself. It may be easier to think of the content as a participant in the accessibility process to talk about it in process terms. In this case we could use the term Digital Resource Description (DRD), a set of metadata associated with documents. In the educational example we are discussing every document or 'chunk' of digital material in an educational process has a DRD record. This approach comes out of the work that has been done in learning object metadata (LOM - IEEE 1484.12.1-2002 Standard for Learning Object Metadata) [17]. A LOM is a data model, usually encoded in XML, used to describe a learning object (a chunk of content).

The provision of appropriate material results from this set of attributes and values fitting together with the needs of the user as expressed in her user model and the capabilities of the user current device as express in the DM. This approach can take two forms: selection and delivery, and adaption. Both of these have network bandwidth requirements for successful use, which are part of the information on the DRD record. The selection and delivery approach finds the existing right content based on the user and device/context and presents this to the user. The adaption approach takes a meta document representing the content and creates the accessible content on the fly.

Select and deliver requires the system to create and store different versions of the same material, and this leads to authoring and on-going revision problems. The advantage of replacement it that it is relatively easy to implement, after the matching infrastructure in the UM and DM are in place. The problem with this approach is that content authors have the burden of many adaptations and later modifications of material will make sets of the same content out of synch. Adaptation forces the author to write in a kind of markup language, which may be mitigated by authoring support tools. Adaptation also requires another layer of software to take the marked up content as input and produce the appropriate content; this may either be done on the server or at the client. Also adaptation may support interface adaptation like ARIA [51] and URC/V2[18], taking motoric issues in accessibility into account.

Adaption, while a complete solution, requires standardizing and built-in functionality like cascading Style sheets (CSS), which have been used in this fashion with some success. Select and deliver can use existing systems but adaptation requires a whole new infrastructure, and more relevantly, the adoption of this infrastructure by all content developers.

Having described all the parts of the user modelling for accessibility system we can now describe it in short hand as:

$$UM + DM + DRD = CP$$

which we will call the Content Personalization formula.

Where UM is the user model. DM refers here to the Device Model, remembering that we have included context and history in the DM. The DRD refers to the metadata that describes the content that we have, which may take many different forms pointing to the same concepts. Finally the CP stands for content personalized for the user and context. In order for this to work we must have a tightly controlled vocabulary which is often domain specific, so that UM and DM and DRD must have matching attributes and ranges of values. It is important to ensure adoption of such systems by building on existing standards such as shown in **Table 3.1.**

Table 3.1 Existing Personalized Distance Learning Standards

LOM (IEEE)
Dublin Core (DC-education extensions)
IMS
ACCLIP
ACCMD
ISO 24751-1,2,3
DRD, PNP

Here are existing standards that we use in the following example:

- User Modelling (UM): PNP (personal needs and preferences from part 2 ISO 24751 draft 2007)
- Device modelling (DM): CC/PP (from W3C Composite Capabilities / Preference Profiles: Structure and Vocabularies 2.0 (CC/PP 2.0)
- Content Metadata: DRD (from Part 3: Access for All ISO 24751 draft 2007))

So the content personalization formula then becomes:

$$PNP + CC/PP + DRD = CP$$

Here is an example of the process, in our prototypical remote learning accessibility system (**Fig. 3.1**). First there is a request for content object (CO) in learning process, to do this the user agent (browser) uses a proxy that inserts device model ID into the header of http request containing the request for a CO in the form of the device identifier. Then the virtual learning environment (VLE) passes these (the content ID, the UM-ID and the DM-ID) to a content personalization module (using web service calls from here to the return to the VLE). Content personalization module then gets:

1. User profile from user modelling subsystem
2. Device profile from device modelling system
3. CO accessibility metadata -digital resource description (DRD) from Learning Object Metadata Repository
4. It matches them and returns the right one (if there is one)

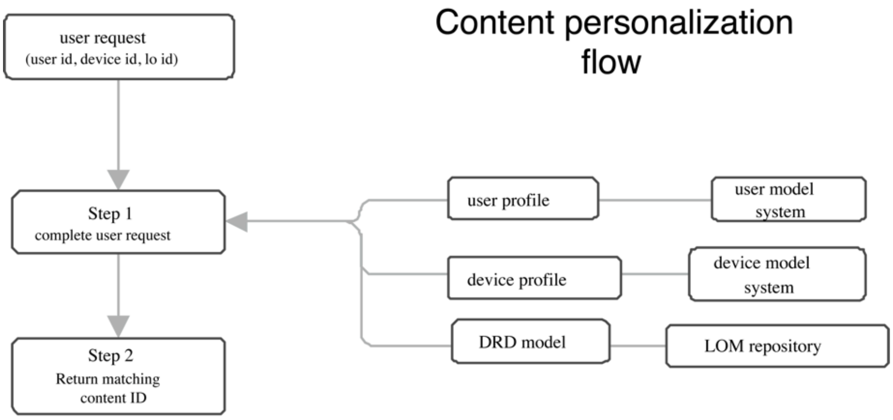

Fig. 3.1 Content Personalization Flow in Select and Deliver Model

An alternative process flow, using the adaptation model is below (**Fig. 3.2**).

Following that are examples of both the select and deliver approach and the adapt approach; to deliver accessible educational materials to students, matched to their needs and the capabilities of the device that they are using. To effect this the three parts of the CP equation need to be considered. This can be expressed as shown in **Table 3.2**.

This process is further broken down in tables 3.3 to 3.10. **Table 3.3** showing the Adaption Preference from PNP; Table **3.4** containing Preferences from PNP; **Table 3.5** giving an example of DM Attributes from CC/PP; **Table 3.6** laying out the pars of a Media Meta Record from DRM; **Table 3.7** explicating how table 3.6 is comprised of the Access Mode Record Template; **Table 3.8** expand on 3.7 into an Adaptation Template; **Table 3.9** illustrates the use of the Adaptation Template; and finally **Table 3.10** showing the whole process in the Content Selection Matrix.

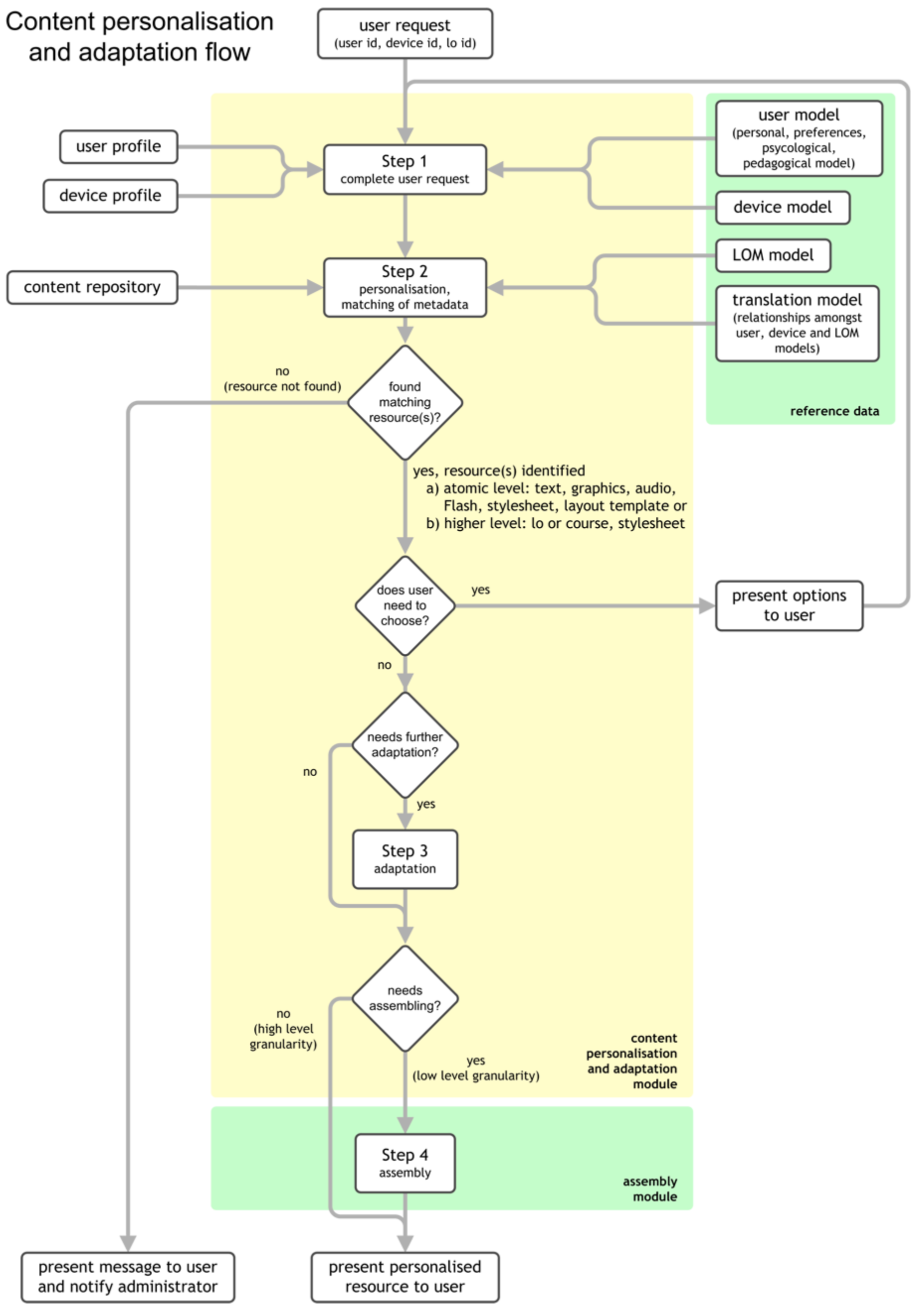

Fig. 3.2 Content Personalization Flow in Adaptation Process

Table 3.2 Three Parts of CP Equation

No.	Table	Example	Orig. access mode (s)	Adaptation type
1a	Aud-itory	Tape of talk	Audio	Transcription
1b	Visual	Text of lesson	Text	Audio tape
2	Visual	Physics lecture on vid-eo tape	Visual and Auditory -Two entries in metadata pointing at the same original content object: Visual and Auditory	
2_{visual}	Visual	Demonstration part of above	Visual part	Audio Description
$2_{auditory}$	Visual	Lecture part of video	Auditory part	<none> NOTE: this is an *.avi
3	Visual	Photo caption	Visual	OCR
4	Visual	Text (a book)	Visual	Text to audio DM transformation

The PNP record in the user model stores the users preferences of content presentation. The index into the preferences table:

Table 3.3 Adaption Preference from PNP

Attribute	Allowed Occurrences	Datatype
Adaptation pref.	Zero or more per Content	Adaptation_Preference

The preferences table:

Table 3.4 Preferences from PNP

Attribute	Allowed Occurrences	Datatype
usage	Zero or one per Adaptation Prefer-ence	Usage_vocabulary Pg. 80
adaptation type	Zero or one per Adaptation Prefer-ence	Adaptation_type_vocabulary Pg. 64
original access mode	One per Adaptation Preference	access_mode_vocabulary pg. 63
Adaptation_preference _ranking = not DM or DRD	Zero or more per Adaptation Prefer-ence (i.e. multiple adaptation types for the same original access mode could exist)	Integer – the preference rank of the possible adaptation

Having gotten the user needs from the above, the personalizing process con-tinues with the Device Model (in this simple case there are no context or historical data, but this is where they would go). Here the DM is based on the CC/PP record from UAProf **[52]**):

Table 3.5 DM Attributes from CC/PP

Attribute	Description	Sample Values
Mime_Type	List of the IANA mime type(s) that can be 'played' on this device	"Audio.MP3" See IANA mime type listings for vocabulary
AT-Transformation type	a bag of literal each literal represents a given transformation (scenarios)	Could be integers could be audio-to-text

where the mime types are:

- .aif audio/aiff
- .aos application/x-nokia-9000
- .asm text/x-asm
- .eps application/postscript
- .gif image/gif
- .html text/html
- .java text/plain
- .jpg image/jpeg

and the transformation type could be:

- Text -> audio
- Audio-> text
- HTML-> correct colour contrast

Finally we have the metadata attached to each chunk of content. This is taken from the ISO 24751 part 3, the DRD record template. The media META record:

Table 3.6 Media Meta Record from DRM

Attribute	Allowed Occurrences	Datatype
Media_Object _ID	One time per Access For All Resource	EU4ALL Identifier
access mode statement	Zero or more per Access For All Resource	Access_Mode_Statement
has adaptation	Zero or more per Access For All Resource	EU4ALL Identifier
is adaptation	Zero or one per Access For All Resource	Is_Adaptation
adaptation statement	Zero or more per Access For All Resource	Adaptation_Statement
Mime_type – DM	Zero or more per Access Mode Statement	IANA Mime type

An Access Mode Record:

Table 3.7 Access Mode Record Template

Attribute	Allowed Occurrences	Datatype
original access	One per Access Mode Statement	access_mode_vocabulary
access mode usage	Zero or one per Access Mode Statement	access_mode_usage_vocabulary

An ‘is adaptation’ record:

Table 3.8 Is Adaptation Template

Attribute	Allowed Occurrences	Datatype
is adaptation of	One per Is Adaptation	EU4ALL Identifier
extent	One per Is Adaptation –	extent_vocabulary

And finally, the Adaptation Statement (AS):

Table 3.9 Adaptation Template

Attribute	Allowed Occurrences	Datatype
adaptation type	Zero or one per AS	adaptation_type_vocabulary
original access mode	One per AS	access_mode_vocabulary
extent	Zero or one per AS	extent_vocabulary
Mime_type	Zero or more per AS	Mime type vocabulary from IANA site –

Putting them altogether we have:

Table 3.10 Content Selection Matrix

Disability	Original access mode	Adaptation type	PNP attribute / values	DRD Attribute / values	DM Attribute / values
Needs replacement for auditory	Audio	Transcription	Orig. access. Mode = Auditory Adaptation type = Text representation // Adaptation_ preference _ranking = 1	Adaptation stanza: Orig. access. Mode = Auditory // Adaptation type = Text representation // Mime_type = Text.plain	Mime-type = text.plain
Needs replacement for visual	Text	Audio tape	Orig. access. Mode = Text Adaptation type = Audio representation //Adaptation_ preference _ranking = 1	Orig. access. Mode = Text Adaptation type = Audio representation Mime_type = Audio.MP3	Mime_ type = Audio .MP3

Here is a more complex example requiring multiple adaptations. In this example there is a video of a physics lecture and a demonstration (**Fig. 3.3**). The video has two parts: audio and visual:

Disability	Example	Orig. access mode (s)	Adaptation type	PNP attribute / values	DRD Attribute / values	DM Attribute / values
Visual impairment	Physics lecture on video	Visual and Auditory Two entries in metadata pointing at the same original content object: Visual and Auditory				
Demonstration part of above		Visual part	Audio Description	Orig. access. Mode = Visual Adaptation type = Audio_Description Adaptation_ preference _ranking = 1	In the adaptation stanza Orig. access. Mode = Visual Adaptation type = Audio description Mime_type = audio.mp3	Mime_type = audio.mp3
Lecture part of video		Auditory part	<none> NOTE: this is an *.avi	Orig. access. Mode = Auditory Adaptation type = <no entry>	Mime_type = video.avi (we are only dealing with the audio side of the avi)	Mime_type = video.avi

Fig. 3.3 A More Complex Example of Selecting Content

Finally, an example using device based transformation:

Table 3.10 Content Transformation Example

Disability	Visually Impaired
Example	Text (a book etc.)
Orig. access mode	Screen reader
Adaptation type	Orig. access. Mode = Text Adaptation type = Audio representation Adaptation_ preference _ranking = 1
PNP attribute / values	In the adaptation stanza Orig. access. Mode = Text No matching Adaptation type
DRD Attribute / values	In the adaptation stanza Orig. access. Mode = Text No matching Adaptation type
DM Attribute / values	DM has transformation attribute that maps from text to audio (i.e. has jaws or the like)

The above brief introduction to the complex domain of personalized content delivery is but one of many possible implementations of the UM + DM + DRD = CP formula. In this authors opinion the content selection and delivery approach is seriously flawed due to the authoring and updating requirement. By this I mean that although a given 'chunk' of content may exist in many different media, covering most possible needs and disabilities, any updating of the content requires simultaneous updating of all variations, a condition that has a very low probability of happening. On the other hand the adaptation approach, while complete, requires the adoption of a meta-language and adaption engines across the domain, which requires an integrated system to be designed, implemented and widely adopted. Because of the difficulty of doing this current efforts are typically focused on the select and deliver approach.

3.4 User Modelling for Diagnosis (the BEDMOND Project)

3.4.1 Project Background

The BEDMOND project uses user modelling with a very specific focus: how to early detect neurodegenerative diseases on the basis of human behavioural changes.

Despite controversies in neuro-cognitive and neuropsychological research, there is a general consensus that cognitive decline (CD) occurs in a high proportion of the older population (10–20%) causing discomfort in their daily performance and influencing negatively their quality of life. Though this CD can be considered a normal consequence of ageing process, it sometimes manifests in a pathological manner, progressing beyond the MCI state, which is considered to be a boundary stage between ageing and dementia. Persons with MCI have a higher risk of developing Alzheimer's Disease (AD) compared with older persons without discernable cognitive impairment [36]. When CD becomes pathological and transforms into a neuro-generative disease, it produces very high expenses to our Public Health Systems and Services, expenses that could be vastly diminished if the disease were detected at its earliest stage.

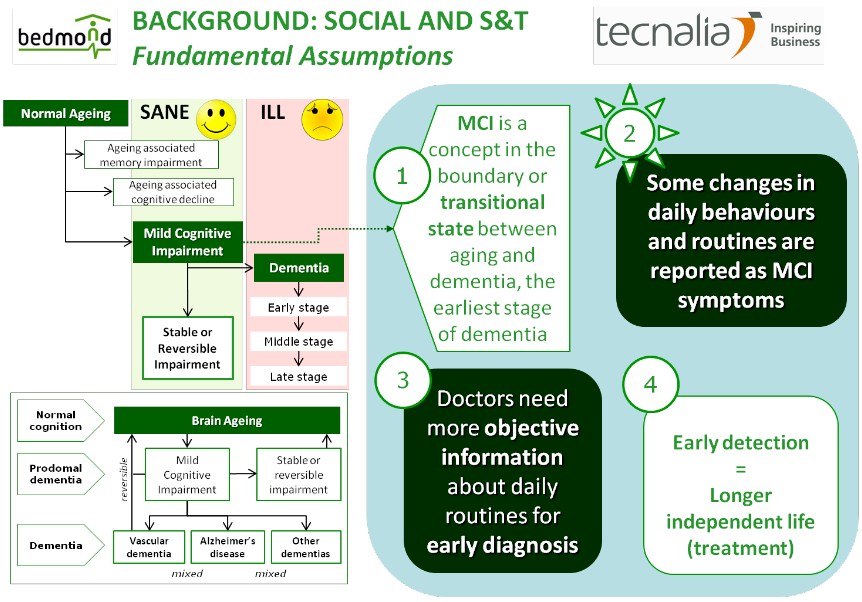

Fig. 3.4 Early Stage Of Neurodegenerative Diseases (MCI) Can Be Detected Through Behaviour Pattern Changes

The study of the early detection of neurodegenerative diseases is being widely carried out by investigating the root and causes of the brain degeneration, through several biomedical brain-centred fields, namely through genomic and proteomic fields and modern ICT-based equipment for neuro-imaging. These fields of scientific research are still in initial phases and quite far from providing useful diagnostic tools efficacious in the short term. On the other hand, much less has been done in the detection and analysis of different early symptoms (prodromes) that can show externally, through behavioural changes in the person, the consequences of its affect on the cognitive domains of executive function (memory, disorientation, in-home activity, social affairs, etc.). These symptoms are related to specific mood changes and behaviours that strongly influence the performance of the activities of daily living. The severity of these symptoms are fairly well classified and range across several international scales for CD screening, running from a typical elder profile up to a pattern with very severe CD.

Using user models to diagnose medical/cognitive states is in its infancy, but consequently, if we are able to build a behavioural pattern for the person while being at home and still cognitively intact, which afterwards we can use in monitoring daily activity and matching it against the baseline pattern –and it is at that time user modelling becomes be crucial. In this way a system would be able to track the divergence from the original pattern. Then, these deviations are classified into different levels of danger and this classifying of the severity of the changes detected may be used to inform the doctor periodically with intelligent warnings (the intelligence must be provided by the health professional expertise to correctly interpret detected changes and deviations). This way, the doctor can get real-time objective information about the possible appearance of a neurodegenerative disease at its earliest stage.

A complete set of symptomatic behaviours, detailed by health professionals as to appear at MCI stage, where collected at the requirements specification phase of BEDMOND. Some of those symptomatic behaviours are related to activities of daily living and others to specific moods and behaviours not closely concerned with daily living (oversights, disorientation issues, etc.). For both groups of symptomatic behaviours, some of them, where feasible, can be detected through a home sensor network, taking into account that these sensors had to be necessarily low-cost and unobtrusive devices.

BEDMOND platform intelligence progresses through three main sequential steps before the last level, machine based intelligent inferences. Following is a presentation of this 3-step processed information for quick understanding and easy interaction, and consequently for real usefulness and acceptance. These three steps proceed through layers of raw and derived data for knowledge processing before an early diagnostic result can be produced: (1) **data acquisition**, (2) **situation recognition** and (3) **situation interpretation**. All three steps rely on user modelling for daily activities.

This process uses a user model that is expressed as sets of sensor data. With a baseline created, the system captures sensor data over time and compares it with ‘normal’ events expressed as sensor data sets and uses them to classify indications of MCI.

In this first step the user model is made of a sequence of daily activities which all together build the daily routine pattern of the person. It is built from sensor events information, so this is the first step. Algorithms for user modelling and deviation calculation have been developed, pending of adjusting and optimizing the daily activity pattern for some relevant activities (meals taking, personal care). Also algorithms for deviation interpretation and user interface for presenting information to the doctor are tested and ready to be used. Four sheltered houses for field trials have been equipped with the complete infrastructure. They will serve for real testing of BEDMOND platform for about six months.

3.4.2 Modelling and Intelligence

Here we will describe in detail the process for creating and using user modelling in BEDMOND.

3.4.2.1 1st Step: Data Acquisition

The sensors used within the smart home network for activity detection are commercial-off-the-shelf and low-cost, namely conventional Konnex (KNX) home automation sensors[26] and other wireless sensors with a proprietary protocol.

Table 3.11 List of Sensors and Home Location

Room	Furniture	Sensor
Bathroom		presence / motion sensor
	Cabinets and drawers	reed switch
	Shower panel	reed switch / temperature sensor
	Toilet (floor)	pressure sensor
	Plug (shaver, hairdryer)	power plug sensor
Kitchen		Presence / motion sensor ; smoke sensor
	Refrigerator, freezer	reed switch
	Microwave and oven	power plug sensor /reed switch
	Cooker, Toaster, …	power plug sensor
	Washing Machine	power plug sensor
	Cupboard and drawers	reed switch
All	Chairs	pressure sensor
Bedroom		presence / motion sensor
	Bed	pressure sensor
	Wardrobes and drawers	reed switch
Living room		presence / motion sensor
	TV, VCR, DVD, CD	power plug sensors
	Sofa, chairs	pressure sensor
	phone	phone sensor
Hall		presence / motion sensor
	Drawers, Entrance door	reed switch

The system uses primarily low-cost and off-the-shelf sensors to monitor presence, pressure, furniture (open/close, reed switches), power consumptions (mainly for white and brown goods) and technical alarms (water, gas leak). A phone call detector for incoming and outgoing calls and a piezoelectric sensor for pressure detection which also allows tracking the heart and respiratory rates while resting in bed are examples of some new sensors developed and integrated within an off-the-shelf telecare system, are part of the platform. The acquisition of a base line, let's call it the *behavioural pattern for daily activities*, is a complex process, partially automatic and partially manual. First, a large amount of sensor event data must be produced and stored from a real user in a real environment. Then, a manual classification and ticketing process must be applied, just to gather those events related to each of daily activities, and finally the routine or 'standard' sequence of activities. With part of that event data, typically 60-70%, a first behavioural pattern for daily activities is generated. The rest of data are later used to confirm and adjust the behavioural pattern up to the moment we get an optimized pattern, what means that about 90% of real data (events) confirm the pattern designed.

Table 3.11 lists some of the inexpensive and non-invasive sensors integrated in the current BEDMOND acquisition system prototype.

3.4.2.2 2nd Step: Situation Recognition

The reasoning layer deepens into several levels, regarding the different sensors involved and the information provided by them. As shown in next **Figure 3.5**, first raw description divides the set of rules of the BEDMOND system into a couple of main blocks: low level and high level layers, two consecutive reasoning steps.

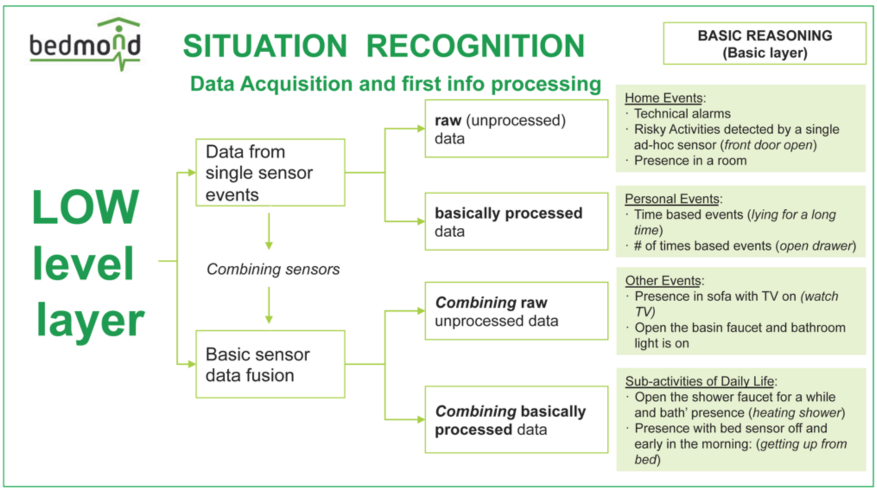

Fig. 3.5 Basic Level of Reasoning for Situation Recognition

Low level layer is related to information retrieved directly from sensor events or a basic data fusion. It is what BEDMOND calls the basic step in "Situation Recognition" phase. Some specific sensor events are able to provide relevant information by themselves; this is the case, for example, for the events triggered by the technical alarms (smoke and water leak). A single alarm event is informative enough to make the system react automatically to prevent the user about a potentially risky situation. A next level of processing could include counting of the number of alarm events registered; for example, if the system receives a certain number of alarms in a certain period of time, the system could reason in this way to detect a hazardous behaviour of the person living at home based on this "basically processed data". Another sub-level in this basic main block concerns the combination of data provided from several sensors. With a pressure sensor detecting the person in the sofa and a power consumption plug sensor activated by the TV set, the BEDMOND system can determine that the person is currently watching TV at that moment ("combining raw unprocessed data"). If those events are further processed, for example taking into account the moment of day when they are triggered and their repetition during several days of the week, a type of sub-activity of daily living being performed by the person can be inferred ("combining basically unprocessed data").

3.4.2.3 3rd Step: Situation Interpretation

The previous steps are not enough to build a model or pattern of the daily activity of the person. In BEDMOND's scope, a daily routine pattern is highly relevant and thus has to be built - any single deviation might be useful support for the physician to make an early diagnosis of a neurodegenerative disease.

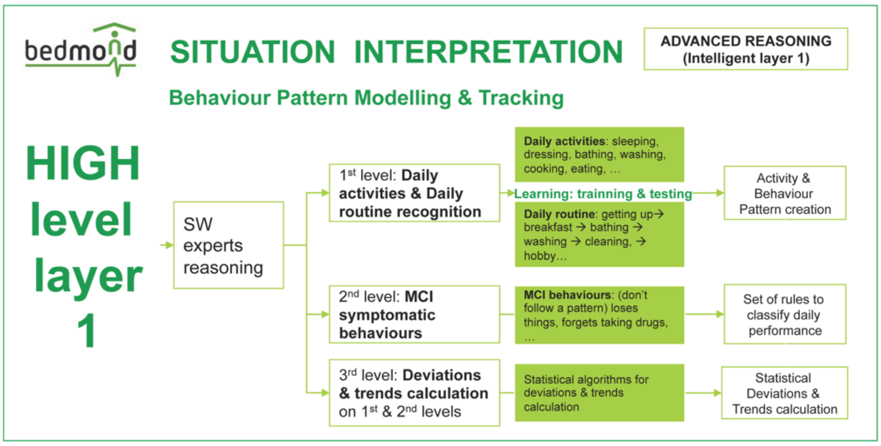

Fig. 3.6 Basic Level of Reasoning for Situation Recognition

This is implemented in the highest level layer of reasoning, which BEDMOND calls the "Situation Interpretation" layer. It is divided into two main blocks: on the one hand, **behaviour modelling and tracking** (layer 1, in **Figure**

3.6) and, on the other hand, **behaviour interpretation and actuation**. This latter main block supports generation of modules for both the pre-diagnosis assistance phase (layer 2, in **Figure 3.7**) and the treatment assistance phase(layer 3, in **Figure 3.8**).

Rules regarding the first main block can be considered as "software developers" rules whilst the second one is directed to the health professional's knowledge and experience. Both include several sub-levels. As shown in **Figure 3.6** and starting from the previous basic reasoning level, BEDMOND learns and sets up an activity of daily living (ADL) profile like, for instance, having breakfast. This concrete ADL is made up of a sequence of several sub-activities: open the cabinet and take a cup → open the refrigerator and take the bottle of milk → ... This reasoning level for ticketing the sub-activities and subsequent ADL is really relevant for the early detection of a neurodegenerative process because any change on the sequence or the duration of certain sub-activities in such ADL may provide salient information for the doctor. In a similar way the next step of BEDMOND reasoning is built up with a high level model of the daily routine of the person as a new sequence of ADLs (sleep → get up → breakfast → personal care → home tiding → lunch → ...), taking into account that any deviation, change or even disappearance of an ADL in the daily routine sequence is a *prodrome* or early symptom of MCI too.

After this level of information interpretation, the behavioural pattern is created. Then, the daily tracking starts, getting the whole set of daily events from sensors and once known how to classify them into daily activities integrated in the pattern. Deviations from the pattern and trends from the daily monitoring are obtained as a last step at layer 1.

However, a second level, a set of rules, is designed to support the goals to which this project is aimed: MCI detection as the indicator of the onset of a pathological cognitive decline. As shown in next **Figure 3.7**, this level will try to interpret the deviations amongst the patterns and daily performance.

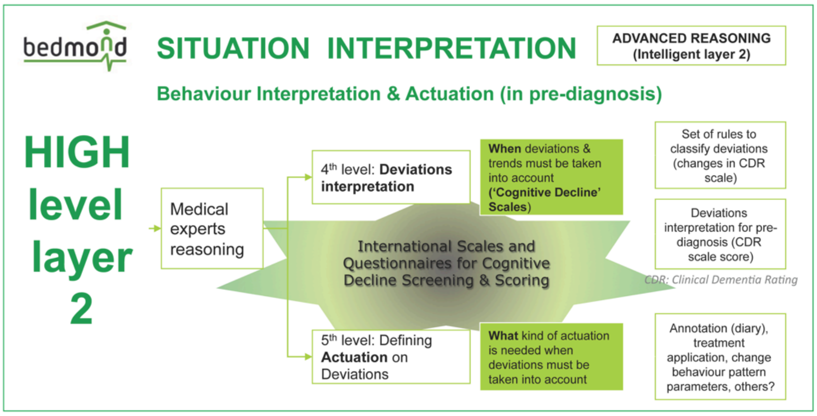

Fig. 3.7 Intelligent Layer for Situation Interpretation with Clinical Criteria during Pre-Diagnosis Stage

When matching the daily information obtained from the home sensor network against the pattern BEDMOND proceeds to the "situation interpretation" stage. This matching includes inferring the existence (or not) of each sub-activity and daily activity, the duration of each and the sequence. The intelligence to interpret parameters (when a sub-activity or activity is missing, when an activity duration is shorter or longer, or when the sequence is altered), is provided by the doctor and introduced in the platform through the configuration module for behaviour interpretation. Depending on the user model and the expertise of the health professional, any change or deviation that has appeared in any of these parameters can be relevant for the early diagnosis. For a timely interpretation, the doctor is provided with three ranges or severity indexes, to present the processed information using a traffic-light colour strategy: green meaning there's nothing of concern happening, yellow means a warning and a recommendation of investigation of a slight deviation and red indicates that a strong deviation has been detected.

Apart from some changes in the daily routine (the aforementioned deviations), some specific behaviours of the person are considered as potential MCI symptoms too. This detection is not directly correlated with deviations in a behaviour pattern, though some of them can be attributed, to a certain extent, to changes in the way that some ADL are performed. There is no behavioural pattern for reminding appointments, for example, but this kind of forgetfulness may allow an early detection of MCI. This level is linked to sensor data fusion and to an imaginative but reliable way of detection. For example, BEDMOND algorithms detect the "loses things" behaviour (memory and / or disorientation problem) by considering a kind of erratic or compulsive period of search: many room presence detectors triggered, joint to many drawers opening / closing actions, in a short period of time or prolonged for a long while. The third level of reasoning for this first main block deals with the deviation calculation when comparing the behavioural pattern versus the daily tracking, which is a statistical matter.

The next level occurs after measuring deviations over the pattern, initially regarding the interpretation of those deviations and finally the actuation required after such interpretation. Health professional criteria are now brought into the generation of rule settings. These rules define the domains of the personality related to the executive function where the changes or deviations should be included (memory, disorientation, social affairs, etc.) but comprise setting the limits for the deviations in order to be considered in a range from mild to critical. This is the most complicated but flexible reasoning layer in BEDMOND platform.

There is also another level of intelligence in BEDMOND platform - as shown in next **Figure 3.8**, which is related to consequences that could be automatically applied after deviation interpretation but it is not a matter of this chapter.

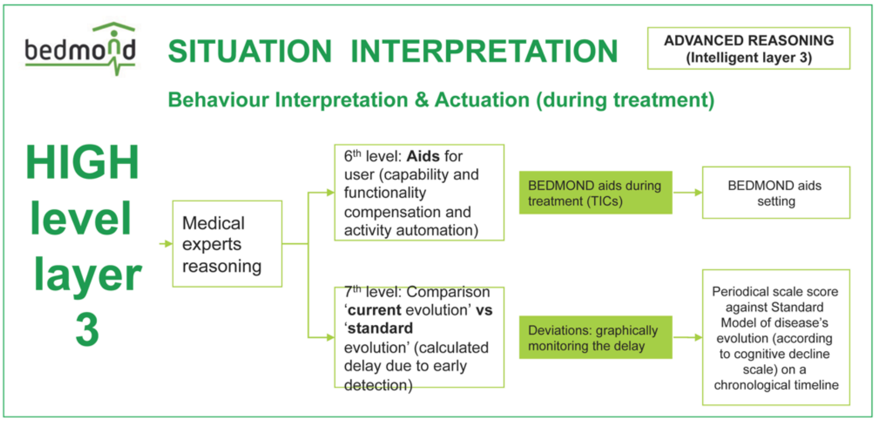

Fig. 3.8 Intelligent Layer for Situation Interpretation during Treatment Stage

Next **Figure 3.9** recapitulates the whole set of reasoning levels approached by BEDMOND platform.

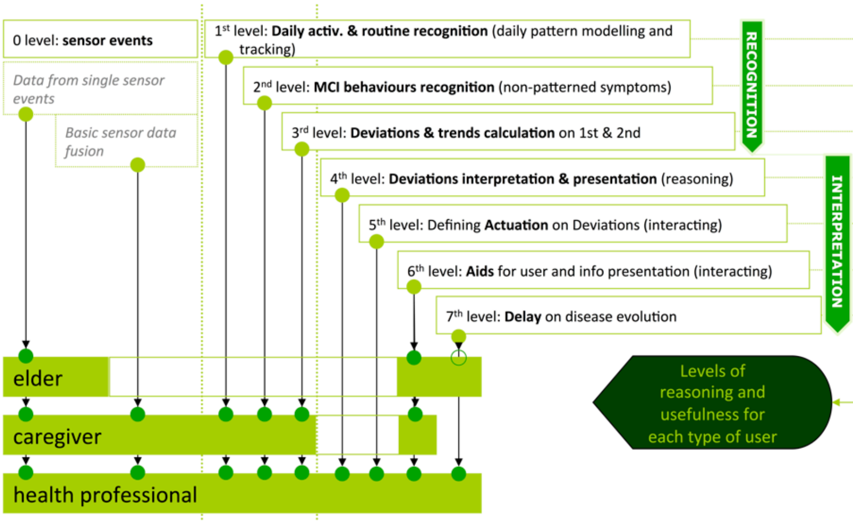

Fig.3.9 Whole Set of Reasoning Levels Addressed by BEDMOND Platform

Next steps are to take into account seasonal changes of patterns due to the relevance that this segmentation might provide. This means that new patterns in future work will not be represented as a simple mean value but as a curve or a graph with mean values per month. BEDMOND is just a first approach to check the importance of the information provided, but surely not as profound as it can be.

3.4.3 Algorithmic Approach

We decided to work on ruled-based coding due to the complexity of rules to apply for some daily activities. Perhaps one of the most interesting patterns to describe relates to the "having lunch" activity. First, we had to rule out similar activities like occasional snacking (taking a piece of fruit) and others with low levels of meal preparation. Basically, in terms of cognitive deterioration, we wanted to determine if the person is starting to eat with a lower level of planning, shortening preparation activities or just rejecting some of them. We consider as relevant nutrition activities those related to (1) taking and using cutlery, (2) getting food items, (3) heating a meal and (4) sitting on a chair to eat. All of these are sensorized, though not in a very precise manner. Algorithms take events from sensors when those four activities appear in a sequence over a certain period of time. We take into account the sequence, time of day, number of times, and duration of events. Additionally we also consider what we call 'confidence indicator' for each of those four activities. This confidence indicator reveals a likeliness of the activity appearance correlated with the "having lunch" activity and increases and decreases with triggers and time respectively, in a weighted way (not linear). Finally we apply a global confidence indicator for the whole group of partial indicators. All these indicators have been set up and validated through real experimentation. To detect deviations, the global indicator obtained at daily monitoring is compared with that one at the model. Then, each of the partial ones are considered to exist or not and compared with their correspondents in the general pattern. Certain ranges of deviations are interpreted as warnings for the doctor.

3.5 Ser and Estar Models

One common design problem encountered by user model systems is not distinguishing between user model attributes that represent the users 'being' and the users state. This leads to unnecessary data duplication and can migrate up to the user interface, causing confusion in the system's end-user. Looking at the whole of user modelling data, it basically falls into two kinds of models, which we will label as the *ser* and *estar* types of user models.

I have chosen to use two Spanish verbs that express to be as essential qualities and acquired qualities because their use roughly corresponds to the two kinds of data: one uses *Ser* to refer to the **essential characteristics** of things that you are, your name, your gender; *Estar* is used to refer to descriptive, potentially temporary attributes, the **condition,** like I am walking. The *Ser* user model contains the information about the users – these essential characteristics form the static user model. In *Ser* models changes occur very infrequently over time and they are typically independent of context. The *Estar* user models, in contrast, contain changing values that model the current condition of user; this dynamic user model may change over time, or there may be multiple copies that are linked one at a time to the ser model of the user. *Estar* models are often context dependent or reflect the different devices that are used at different times. *Estar* data type is used to keep histories of user actions.

This novel user model framework is driven by a relational database approach to users and contexts (i.e. normalization [6]), and inspired by several experiences with projects and models where the two were conflated, with problematic consequences. By keeping data that never changed in the same 'table' as attribute values that change frequently, the system is forced to either keep multiple copes of a user model for a single person, or to constantly change the model as the context of use changes. Also, conflation of the two types makes keeping histories complicated and causes redundant data to be stored. In the chapter we will discuss the ramifications of these approaches. This is not a 'new' approach *per se* (see the discussion of stable and temporary user characteristics in chapter 4 and also in the discussion of modelling users with disabilities in chapter 2 of this text), but by explicitly creating a framework that holds these two models design and performance advantages can be accrued.

Another advantage of discriminating between ser and estar models is that this provides a nice way to separate the actual data, so that applications with large amounts of sensor data can store it locally, making a mobile system less dependent on reliable high bandwidth connectivity.

3.6 Conclusion

Section four described a two part user model that comprises the ser user model for biographical modelling of the end-user and the estar part of the model stored with the device model. It is intended to be used by very many users simultaneously, and transparently deliver appropriate content in real-time. In contrast with this is the system in section three, which is designed to be used by only one person at a time (with the potential of multiple simultaneous systems in use). After a baseline is collected the application uses current and historical data form sensors to classify blocks of behaviour as normal, in need of a further look, and probably MCI. From this description the baseline data, which represents 'normal' sensor interaction, will be duplicated as long as the end-user remains cognitively in a normal range, is ser data. The tuples of sensor data that are the object of classification constitute estar data.

Why is it useful to make this discrimination in both applications? In the educational content delivery system the separation of the Device Model supports the end-user seamlessly utilizing different interface devices in differing conditions (e.g. network bandwidth). In the MCI diagnostic system the baseline ADL classified sensor signatures are conceptually easier to use to build up generic ADL signatures and *these* sets of sensor data (not just the attributes and values but also sequence of these tuples forming the classification of ADL sub-routine states) can then be used to create diagnostic systems for new individuals. As the classification model becomes more refined the generic model that instances the system always points to the latest, most accurate and representative set.

Another advantage of separating user and context/device models is the ability to have cross system reusability of the user model, speeding up the configuration and propagating the current user information across relevant applications.

3.7 Further work

As was discussed in section 3, further implementation of select and deliver architecture needs to be designed and used across several domains, starting with distance education and in those that rely on presentation of digital content. More challenging but in the end more important are the development of content adaptation systems, first as stand alone applications for narrow niche domains and then for generic use. Authoring tools for either the select and deliver or transform approaches need to be developed, with a focus on ease of use and adoptability. An associated problem, tied to the transformation problem is the design of meta data schemas for such a system.

In the case of the diagnostic system described in section 4, many things can be done beyond this first approach. Our first feeling is that we could incorporate more emerging (but non-low-cost) technologies that, on the on hand, better characterize activities of daily living, for example, sounds detection and interpretation. On the other hand, the personal health condition must be widely monitored to complement the activity performance. Beyond physical condition monitoring, emotional or affective computing is another important clue to learn about the real state and health condition of the person, and not only for specific mood detection but also to know how speech expression or postural movements are degrading. New learning processes for the automatic adjusting of the model must be implemented and some other intelligent elements can also be applied to learn about real clinician interpretation.

Finally, more thought and exploration of the ser and estar approach in user modelling would be most welcome.

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