Requirements for a Behaviour Pattern Based Assistant for Early Detection and Management of Neurodegenerative Diseases

Andreas Hochgatterer*, Lukas Roedl*, Alberto Martínez†, Igone Etxeberria‡, Erkuden Aldaz‡, Bernhard Wöckl§ and Jürgen Bund¶

*Health & Environment Department, AIT Austrian Institute of Technology GmbH, Wiener Neustadt, Austria
Email: {andreas.hochgatterer, lukas.roedl}@ait.ac.at
†Health & Quality of Life, TECNALIA Research and Innovation, Zamudio, Spain
‡INGEMA, Instituto Gerontológico Matia, San Sebastián, Spain
§CURE, Center for Usability Research & Engineering, Vienna, Austria
¶Meticube-Software, Coimbra, Portugal

***Abstract*—This paper describes the various aspects of the BEDMOND AAL Joint Programme project, which aims at the development of an ICT-based system for the early detection of Alzheimer's disease and other neurodegenerative diseases, with focus on the identified applied reasoning layers. First the requirements of such a behaviour pattern based assistant are discussed, then the used system architecture is introduced and finally the applied reasoning layers for the situation recognition, interpretation and data representation layers are also detailed.**

I. Motivation & Background

The motivation of the activities and the work presented here are mainly driven by the demographic changes and the related increasing prevalence of neurodegenerative diseases.

A. Ageing and Neurodegenerative Diseases

The ageing European population will have as a consequence an increased number of people at risk of needing care. Indeed, studies estimate a duplication of the number of people with dementia (one of the age related diseases) every 20 years, if today's age-specific prevalence rates persist [1]). As the prevalence of dementia increases with age, it is estimated that the risk for dementia doubles every five years after the age of 65 and that nearly 50% of people aged 85 and older suffer from Alzheimer's Disease [2].

Currently, international estimations come from 30 million people in the world suffering from dementia, most of them living in developing countries (66%). Moreover, 4.6 million new cases are expected to occur every year and in 2050 people suffering from dementia will reach a number of 100 million. According to the European Community Concerted Action on the Epidemiology and Prevention of Dementia Group [3], there are 5.5 million people estimated with dementia living in Europe.

There is considerable interest in the ability to diagnose dementia of the Alzheimer type in the earliest possible stage of the disease. The earliest diagnosis is critical for families and clinicians for a planning and management of the disease in terms of drug treatment and behavioural interventions. It is known that people with Mild Cognitive Impairment (MCI) have a higher risk of developing Alzheimer's disease compared with older persons without discernable cognitive impairment. However, the detection of Alzheimer in an early stage is difficult [4] and still remains one of the major challenges in developed countries. An early diagnosis allows an early treatment, aiming on slowing the course of the Alzheimer's disease, and therewith supporting an autonomous and independent living of the patients in the privacy of one's home. Diverse studies suggest that first indicators, that raise suspicions of a possible neurodegenerative disease, are subtly manifested in patients' daily behaviour patterns. Thus, an interest emerged for developing a technological system that can record and code behavioural changes occurring in the daily life of elderly persons applying low level sensors in the home. The challenges of the ongoing project are:

- to determine the requirements and acceptance aspects of such a monitoring system for caregivers and health care professionals
- the specification of the behaviours that are essential for the diagnosis of the Alzheimer's disease that can be interpreted from recorded sensor data
- the technical implementation and validation of the system

B. Related Work

Most of the related work and projects found follow a different scope than BEDMOND and are designed to prevent or/and manage elderly individuals chronic diseases through an increase in physical activity and monitoring, resulting in better physical and mental health and qualified information for the doctors, ultimately improving the quality of life of its users. The MATCH Project [5] is focused on the development of integrated home care technologies and does not take into consideration to provide this information to the physician about daily behaviour for an early diagnosis. The CARE Project [6] aims to realise an intelligent monitoring and alarming system for independent living of elderly persons by applying a visual sensor and is therefore not as unobtrusive as often preferred by end users. The HERA [7] aims to provide a platform with cost-effective specialised assisted living services for the elderly people suffering from mild Alzheimer with identified risk factors and stresses cognitive and physical reinforcement services. ROSETTA [8] objective is to help community dwelling people with progressive chronic disabilities to retain their autonomy and provides an ICT system that offers activity guidance and awareness services for independent living. It is based on EMERGE [9] and applies video surveillance and a wearable wireless localization system. Finally the CCE Project [10] aims at an European platform to deliver connected ICT-based assistive living solutions for the elderly, building on initiatives at the national level and, taking account of different funding mechanisms in EU member states and to develop and assess business models to support the mainstream provision of assistive solutions.

C. The BEDMOND Project

The BEDMOND AAL Joint Progamme Project [11], [12] aims at developing an ICT-based system for an early detection of Alzheimer's disease and other neurodegenerative diseases, focused on elderly people while living at home. With such an early detection health professionals can apply also an early treatment later on which will help the elder to live longer in an independent way at home by delaying Alzheimer's disease appearance as long as possible. The project has started in June 2009, is now in its implementation phase and will last until May 2012.

BEDMOND is based on a constant monitoring of the elders' behaviour during their daily living so it can be continuously matched against a user profile set up within a training period. The results of this periodical matching can provide relevant information to the health experts to evaluate whether an Alzheimer's disease at early stage could appear to start. So, all the data gathered by the BEDMOND system are initially taken from a home sensor network, processed to daily activities recognition patterns and finally interpreted through a rule-based engine (where health professionals knowledge is the key). The interpreted results will be periodically presented to the medical expert to determine whether, activity by activity, the behaviour changes shown may mean the beginning of a cognitive decline or just a casual deviation. After detection, health experts will very likely apply a pharmacological treatment to the elderly person and the BEDMOND system will keep on monitoring user's behaviour in order to assure that the supported treatment takes effect on the delay of Alzheimer's disease appearance.

Figure 1 shows the general concept of BEDMOND and the stakeholders addressed.

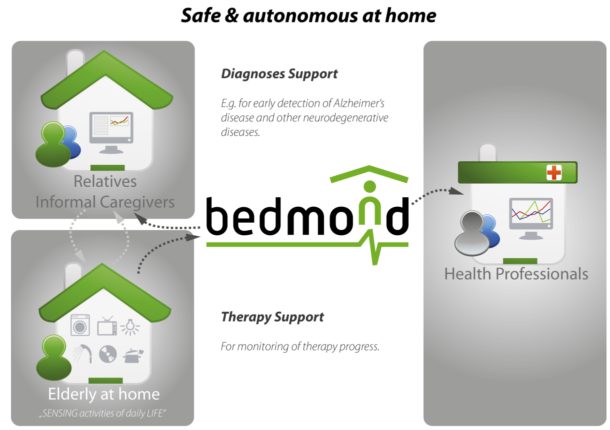

Fig. 1. The BEDMOND concept

II. Requirements of a Behaviour Pattern Based Assistant

In order to gather the needs and requirements of both, caregivers and health professionals, a mix of quantitative (questionnaires) and qualitative (focus groups) methods was applied in two European countries (Spain and Austria). A total number of 13 caregivers and 10 health professionals participated in the focus groups. Additionally, in both countries 21 questionnaires were applied to caregivers and 20 to health professionals.

Results from focus groups could show that there are several observable changes that indicate the beginning of the disease such as: personality changes (e.g. sadness, apathy), cognitive deterioration (e.g. forgetting appointments or taking medication) and behavioural changes (e.g. personal hygiene, abandonment of activities). Based on these results a questionnaire was designed in order to collect detailed information about the frequency and severity of the behaviours indicating the start of the Alzheimer's disease. The questionnaire structure included the following sections:

- Socio demographic data
- Symptoms in people with neurodegenerative diseases
- Possible benefits of BEDMOND system
- BEDMOND system acceptance and functions

A. Results: Caregivers

The data analysis of focus groups and questionnaires with caregivers resulted in a list of more than 90 behaviours that occur during daily life of Alzheimer patients. The following table (Table I) shows in the first column the most frequent behaviours specified by caregivers. The second column highlights the level of burden that is caused by the behaviour to the caregiver. The third column displays the rated level of help caregivers consider that the BEDMOND system can provide. The most common symptoms derive from cognitive abilities (e.g. memory loss, executive functioning), behaviour (e.g. change in eating habits) and personality changes.

Additional information was gathered referring to the

TABLE I
SELECTED BEHAVIOURS THAT OCCUR DURING DAILY LIFE OF ALZHEIMER PATIENTS (CAREGIVERS)

Problem Behaviour	**Frequency (%)**	**Burden in the caregiver (%)**	**BEDMOND system can help (%)**
Changed eating habits	90.5	14.3	29.4
Forgets what day it is	66.7	4.8	42.8
Forgets medical appointments, important dates or taking medication	66.6	28.6	57.2
Difficulty organizing or planning steps to carry out an activity	66.6	38.1	38.1
Takes the medication regularly	61.9	23.8	61.1
Disability for a simple management of money	61.9	19.1	38.0
Lack of interest in things and abandonment of activities	57.1	33.3	28.6
Start but not finish things	52.4	28.5	40.0
Sleep problems	52.4	33.3	26.3
Having problems with complex devices	52.4	14.3	40.0

TABLE II
SELECTED BEHAVIOURS THAT OCCUR DURING DAILY LIFE OF ALZHEIMER PATIENTS (HEALTH PROFESSIONALS)

Problem Behaviour	**Frequency (%)**	**BEDMOND system can help (%)**
Forgets what day it is	57.9	31.6
Reduction of attention	52.6	15.8
Loses, misplaces or hides things	47.4	36.9
Forgets medical appointments, important dates or taking medication	47.4	57.9
Reiterative behaviour (ask the same question continuously, to do the same action repeatedly,...)	47.3	26.3
Increased strategies to conceal the errors (self-justification)	47.3	10.6
Difficulty with coordination and organization (Problems to do the cooking, shopping,...)	47.3	36.9
Difficulties in coming up with the correct word so they use words like: “give me that” instead of “give me the plate”	42.2	10.6
Lack of interest in things and abandonment of profitable activities	42.1	15.8
Changes in personal hygiene (showering bad or refused, not wanting to shave...)	42.1	26.3

BEDMOND system acceptance aspects and functionality. Results indicate that caregivers consider the system to be:

1) secure and reliable
2) not being harmful (especially personal relationships)
3) not recording and storing the same data for all users
4) respecting privacy
5) distinguishing between patients, informal and formal caregivers, related health professionals and unrelated healthcare professionals
6) not only tracking mild cognitive impairment (MCI) and its development but also supporting the patient and the caregiver during this process
7) supporting in organizing and representing recorded data in a way that users can understand how to deal with the gathered information

B. Results: Health Professionals

Health professionals specified the same behavioural changes, as indicated by caregivers (personality changes, cognitive decline and behaviour changes) but added a new category: biomedical changes. As well as in the case of the caregivers, feedback from health professionals resulted in a long list of behaviours that are indicating Alzheimer’s disease. The most frequent rated behaviours can be seen below in table II.

The health professionals categorize the BEDMOND system acceptance and functional aspects the same as the caregivers above (see section II-A).

C. Results: Elderly Persons

In the initial phase the BEDMOND system was planned to be as unobtrusive as possible to not disturb the elder person living at home during daily life activities. In contrast, results from focus groups with caregivers and health professionals during the requirements phase highlight that such systems must have some added value/benefit for the user at home to raise their acceptance. Consequently, it is planned to integrate an interface at the patient’s home with limited interaction options not only for interacting with the system itself (e.g. reminder and alarm functions) but also with the vision for

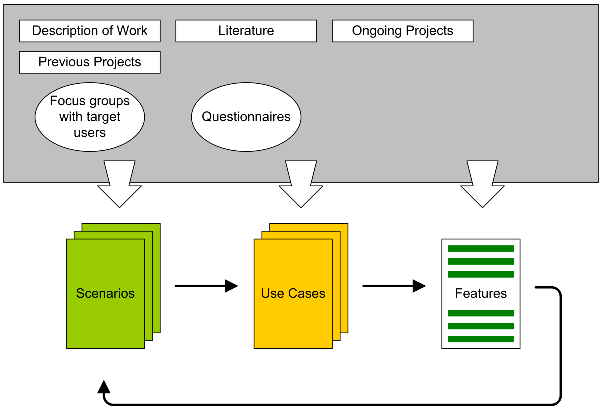

Fig. 2. The iterative approach: Developing Scenarios, Use Cases and Features

adding additional care services or modern communication services next to the monitoring function.

III. System Architecture

The findings of the requirements phase of the BEDMOND project have been fed into scenario writing. The scenarios describing the future use and impact of the system from a stakeholders view have been used to identify actors, use cases and features which were modelled with Enterprise Architect in Unified Modelling Language (UML; [13]) and lead to the first iterations of the system architecture and the database model. It was a major challenge to define and develop the use cases out of the given scenarios and therefore it was important to use both an iterative approach for developing the solution as well as developing use cases on basis of scenarios and features for understanding the user needs. The related work gave the input to the creation of Use Cases and Features. BEDMOND follows an iterative process and Use Cases and Features were created in parallel and they all give input to each other (figure 2).

A. *Overall Architecture*

The overall architecture is based on the identified stakeholders of the BEDMOND concept. The main stakeholders are elderly people living at home, caregivers (being the ones providing daily care and feeling responsible for the elderly) and remote health professionals. The BEDMOND system is meant to be a platform and a hub exchanging information between these stakeholders and a tool to fulfil the BEMOND goals of supporting diagnosis and treatment.

Because of the involvement of different local and remote stakeholders the architecture is split into a home and a server side. To achieve a maximum of data security and a minimum amount of data transfer the raw data is stored on the home side and only pre-processed data is transferred to the server side. Main components of the server side are - besides the server interface and the server side database - the caregiver and health professional interfaces. Low level sensor data will only be stored in the home side database which is important for privacy reasons as well.

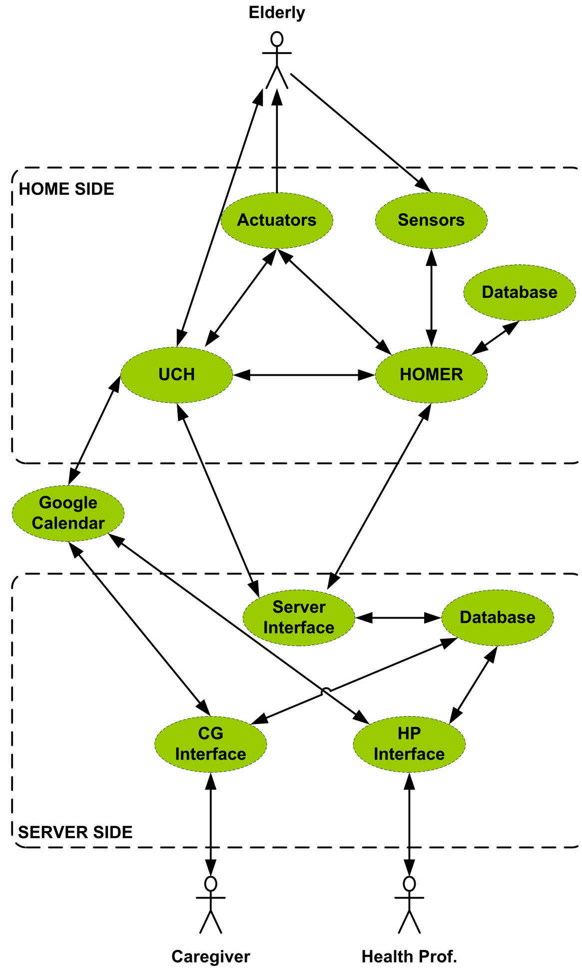

Fig. 3. The BEDMOND system architecture

At the elderly's home the core components URC/UCH [14] and HOMER [15] are used and integrated smart sensors are installed. The sensors are integrated by HOMER, which furthermore handles the client-side database access. Only pre-processed data is transferred over safe and secure connections to a server where higher level processing, back-ups, user registration and management etc. take place. The needed components to achieve alarm generation are all put on the client side, so that they can also work offline for safety and security reasons.

Finally Google Calendar is used to store appointments and create reminders. Figure 3 shows the current architecture of BEDMOND system.

B. *The Universal Remote Console / Universal Control Hub (URC/UCH)*

The integration of the URC/UCH as applied in BEDMOND allows the integration of devices and services by using just one communication protocol towards the user interfaces and not using the several different communication protocols that the different devices and services use.

The usage of the URC/UCH technology also brings scalability and adaptability to the BEDMOND system, allowing its future expansion by the development of APIs with “plug and play” capabilities based on the URC/UCHs Target Adapter and Target Discovery Module concept. This expandability allows an efficient and seamless integration of new home automation devices, new sensors, actuators and new services, such as new social networks applications, or any other type of applications.

Also on the area of user interfaces, the usage of the UCH allows a high degree of freedom on the choice of the technology and protocols used in the User Interfaces. For instance it is possible to have web based interfaces, TV based interfaces, speech driven UIs, screen readers for visually impaired and even BCI systems as being pursued in FP7 sibling project “BrainAble”, just to name a few.

By using this technology the BEDMOND system will get compliant with ISO/IEC standard 24752 for Universal Remote Consoles which supports the openURC consortium’s mission and raises its success significantly [14].

C. The HOMe Event Recognition System (HOMER)

The HOMe Event Recognition System (HOMER) will integrate the local (off-the-shelf) sensors and perform preprocessing. This open source plattform [16] is based on an Apache Felix OSGi framework and encapsulates its functionalities in terms of OSGi bundles which enables modularity. The bundles are executed on the Java Runtime Environment (JRE), which can be installed on various operating systems, what offers hardware independency. The usage of an OSGi framework provides remote maintenance and individual adaptability of the system. The components, coming in the form of bundles for deployment, can be remotely installed, started, stopped, updated and uninstalled without requiring a reboot of the system. Thus the framework is flexible in terms of expanding its functionality and updating single modules during runtime. The interactions and dependencies between bundles are handled by the framework itself. It manages searching and binding of required services, which are exposed functionalities within OSGi bundles, even when the service is activated at later time. Fine grained configuration options allow detailed access to functionalities in each OSGi bundle. Along with OSGi several supporting technologies, like Apache Maven [17] and Spring Dynamic Modules (SpringDM; [18]), are used. Standards for medical device communication and home automation networks are integrated to enable communication to appropriate devices. All of these technologies are used to realize important aspects for an AAL service platform: namely security, modularity, extendibility and interoperability.

Furthermore HOMER makes use of several standards, namely:

- Independent Living Activity Hub specialization ISO/IEEE 11073-10471.
- ISO/IEC 14543-3: KNX is a standardized OSI-based network communications protocol for intelligent buildings [19].

In the laboratory prototype typical off-the-shelf home automation sensors, e.g. motion detectors, contact closure sen-

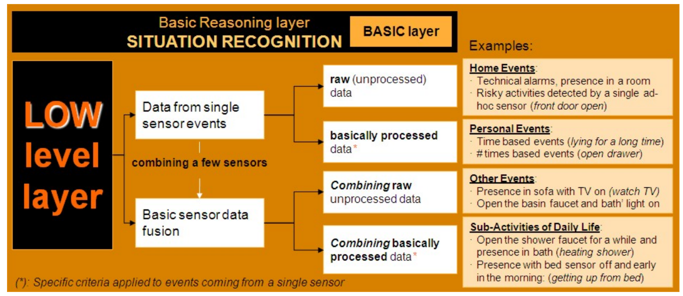

Fig. 4. Basic reasoning layer in BEDMOND system (Situation Recognition)

sors and energy consumption sensors are used.

IV. From Sensors to Behaviours and Trend Analysis

A. Sensors integrated

The sensors used for behaviour detection are off-the-shelf and low-cost and - besides a phone and a bed sensor from the commercial partner IBERNEX - conventional KNX home automation sensors and wireless xComfort sensors from EATON [20], which use a proprietary protocol, are applied and connected to HOMER. All three sensor types have been integrated in the platform and are working in parallel due to the harmonization of data packets in a hardware abstraction bundle provided by HOMER. The passive infrared sensors (PIR) for motion detection and person tracking have been slightly adapted to decrease their detection area. Communication is established via RF-link to a gateway, which is USB-connected to a PC. All the sensors are battery powered and therefore do not need any cables, which eases the positioning and mounting in the home.

For ethical and acceptance reasons the project will not use video cameras and microphones and concentrate on unobtrusive sensor technology.

Table III lists the sensors integrated in the current BEDMOND prototype.

B. Mapping Sensors to Behaviours and Rules: Reasoning Layers for Situation Recognition and Interpretation

The reasoning layer deepens into several levels, regarding the different sensors involved and the information provided by them. A 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.

Low level layer is related to information retrieved directly from sensor events or a basic data fusion. It is what BEDMOND calls the “Situation Recognition” phase. Figure 4 depicts a scheme of this basic reasoning layer.

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 enough to make the system react automatically to prevent a risky situation. A next level of processing could include a counting of the number of alarm

TABLE III
LIST OF SENSORS AND HOME LOCATION

Room	Furniture	Sensor
Bathroom		presence/motion sensor
	Cabinet	reed switch
	Drawer	reed switch
	Shower panel	reed switch
		temperature sensor
	Toilet (floor)	pressure sensor
	Toilet flush	reed switch
	Plug	power plug sensor
Kitchen		presence/motion sensor
	Refrigerator	reed switch
	Freezer	reed switch
	Microwave	power plug sensor
		reed switch
	Cooker	power consumption sensor
	Oven	power consumption sensor
	Toaster	power plug sensor
	Coffee machine	power plug sensor
	Washing Machine	power plug sensor
	Drawer (cutlery)	reed switch
	Cupboard (plates, glasses, cups,..)	reed switch
	Chair	pressure sensor
		smoke sensor
Bedroom		presence/motion sensor
	Bed	pressure sensor
	Wardrobe	reed switch
	Drawer	reed switch
Living room		presence/motion sensor
	TV, VCR, DVD, CD	power plug sensors
	sofa	pressure sensor
	phone	phone sensor
Hall		presence/motion sensor
	Drawer	reed switch
	Entrance door	reed switch

events registered; for example, if the system receives a certain number of alarms in a certain period of time, the system could reason in the way to detect a hazardous behaviour of the person living at home. This is what we call "basically processed data" in the aforementioned picture.

Another sub-level in this basic main block concerns the involvement of data provided from several sensors, also divided in other two sub-levels: raw data from the sensors or basically processed data form sensors. With a pressure sensor detecting the person in the sofa of the living room 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. This situation refers to raw data directly obtained gathering information from several sensors at the same time ("combining raw unprocessed data", figure 4). If those events are further processed, for example taking into account the moment of a day when they are

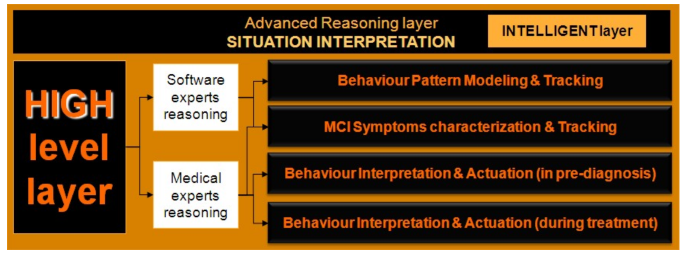

Fig. 5. Advanced reasoning layer in BEDMOND system (Situation Interpretation)

triggered and their repetition during several days of the week, a type of sub-activity of daily living being performed by the person ("combining basically processed data", figure 4) can be inferred.

But this is not enough to build a model or pattern of the daily activity of the person. In the BEDMOND scope a daily routine pattern - as much accurate and detailed as possible - is highly relevant and has to be built, because any single deviation might be important for the physician to early diagnose a neurodegenerative disease. And here it comes up the high level layer of reasoning, what BEDMOND calls the "Situation Interpretation" phase, mainly divided in two main blocks: on the one hand, the behaviour modelling and tracking and, on the other hand, the behaviour interpretation and actuation (as can be shown in figure 5). Rules regarding the first main block can be considered as "software developers" rules whilst the second one is obviously devoted to the health professional's knowledge and experience.

Both of them also include several sub-levels. Starting from the previous basic reasoning level, BEDMOND learns and sets up an activity of daily living (ADL) like, for instance, taking breakfast. This concrete ADL is made up of a sequence of several sub-activities previously registered: open the cabinet $\rightarrow$ take a cup $\rightarrow$ open the refrigerator $\rightarrow$ take the bottle of milk $\rightarrow$ open the microwaves $\rightarrow$ ... This reasoning level for ticketing the sub-activities and subsequent ADL is really relevant for the early detection of a neurodegenerative process because some changes on the sequence or the duration of certain sub-activities in such ADL may provide interesting information for the doctor. In a similar way it occurs to the next step of BEDMOND reasoning: there is a requirement for building the daily routine of the person, as a new sequence of ADL (sleep $\rightarrow$ get up $\rightarrow$ breakfast $\rightarrow$ personal care $\rightarrow$ home tiding $\rightarrow$ shopping $\rightarrow$ lunch $\rightarrow$ ...), taking into account that any deviation, change or even disappearance of an ADL in the daily routine sequence is once again a prodrome or early symptom of mild cognitive impairment (MCI).

Up to this stage, the situation interpretation planned in BEDMOND could be common to many other applications taking profit from human behaviour monitoring techniques. However, a second level (set of rules) concerns strictly the application field in which this project is aligned: the MCI detection. Apart from some changes in the daily routine, it appears that some specific behaviours of the person are

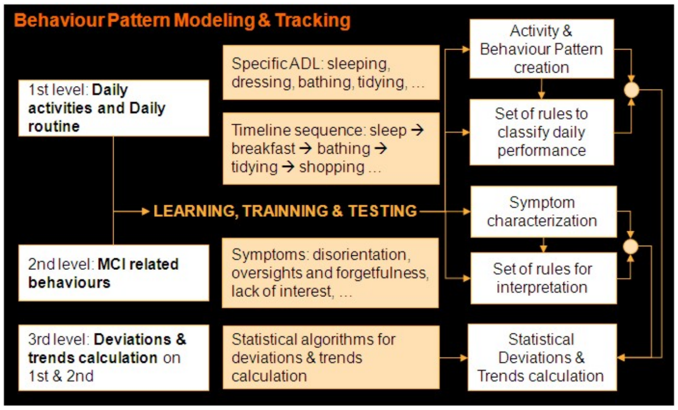

Fig. 6. Advanced reasoning for modelling and tracking

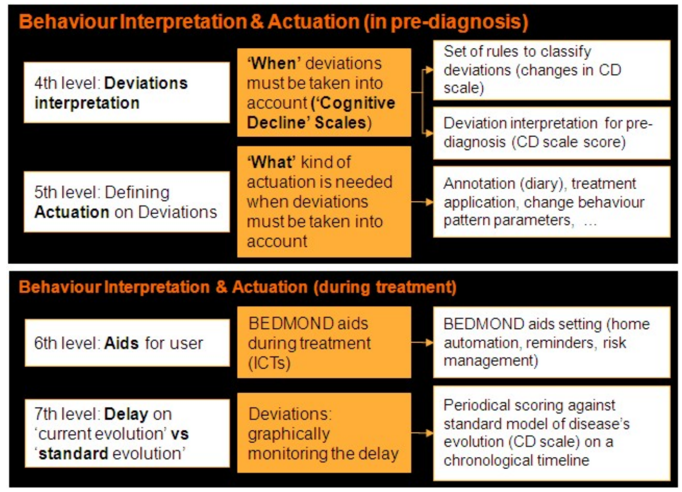

Fig. 7. Advanced reasoning for interpreting and acting

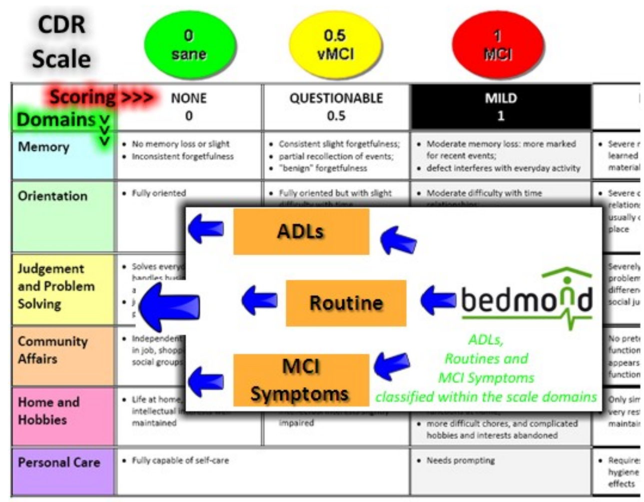

Fig. 8. Adapt & simplify: main approach in BEDMOND tools

considered as potential MCI symptoms, like those listed in table I and II. This detection is not directly correlated with deviations upon a behaviour pattern, though some of them can be assimilated, up 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 must be registered for an early detection of MCI. This level is much linked to sensor data fusion and to an imaginative but reliable way of detection. The third level of reasoning for this first main block deals with the deviation calculation when comparing the behavioural pattern versus the daily tracking. Figure 6 condenses these levels of rules implemented in the BEDMOND system.

Another couple of levels rise up after measuring deviations upon the pattern, regarding firstly the interpretation of those deviations and secondly the actuation required after such interpretation. Health professional criteria are now in the rule sets and, of course, both levels are to be applied in both stages of BEDMOND assistance: prior to the MCI detection and later on when in pharmacological treatment. 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 mainly and overall set the limits for the deviations in order to be considered as mild or critical.

C. High-level Data Representation for Caregivers and Health Professionals

The data representation level is also a high-level layer, probably the most important one since it can decide whether the tool is useful (friendly and usable) or not. In this paper the focus is on the data representation approach for the health professional as main end-user of the system. The main challenge was not about how to get the information to show but mainly about how to present the information to the end-user. This is also a relevant part of the reasoning machine behind the BEDMOND system, and it has been briefly introduced in the previous chapter.

The main objective to get a usable and friendly tool for the clinicians was doubled: adapt and simplify. Adaptation is basically done gathering the information retrieved and intelligently processed into one of the international scales that health professionals use to assess the cognitive decline (CD) status. Among these international scales for screening and scoring CD, the Clinical Dementia Rating (CDR) scale was selected. This scale presents two advantages over the rest: first, it scores CD in a range coming from the sane status (score "0") up to the severe cognitive impairment (score "3"), being MCI - the detection target - in the middle of the range (score "1"); besides, different behaviours to detect are classified into six domains (memory, orientation, judgement and problem solving, community affairs, home and hobbies and personal care), and each of these domains can also be scored, providing relevant information for the health professional.

Simplification is tackled through visual tools providing main conclusions at a glance. On a traffic-light interpretation basis, the information is quickly shown on green, yellow and red colours. A general vision of this meaning is shown in figure 8.

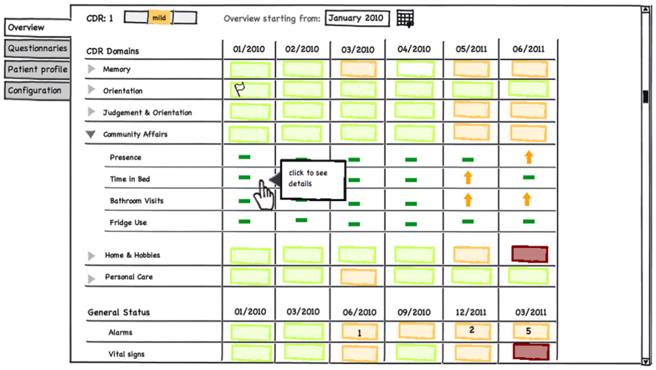

Fig. 9. An example of the health professional UI

Figure 9 shows a low-fi prototype of the overview (part of the main screen) of the health professional interface. The health professional is provided with abstract information about concrete sensor data related with this domain (Overall presence, Bed presence, Bathroom presence, Fridge use). Green colour indicates that no behaviour change occurred, yellow colour indicates a slight behaviour change and red colour a serious change. Arrows highlight the direction of the change. E.g. Here in this example yellow arrows up indicate: more overall presence, longer time in bed, more bathroom visits as compared with normal behaviour.

V. Conclusion and Outlook

Within the BEDMOND project the team has performed an extensive analysis of requirements for a behaviour based pattern assistant for the early detection and management of neurodegenerative diseases. Furthermore the system architecture applying the future-proof core components UCH/URC and HOMER has been specified and presented. The unobtrusive sensor technology for behaviour detection has been specified and integrated in the BEDMOND platform, which follows the requirements of modularity, interoperability, and extendibility. Currently the BEDMOND team is deeply engaged with the system final development and implementation activities of the first prototype. The current focus is on implementation of the rule-based engine and on high-level data representation for health professionals. That rule based engine distinguishes two steps: "situation recognition" as the first one, in order to model the daily behaviour pattern of the person and define the daily monitoring path. "Situation interpretation" as the second one, translating processed information at all the reasoning levels into the "medical language" of the health professional. Data representation is done under adapting and simplifying criteria for the health professional to get a quick conclusion about the information periodically reported. A laboratory prototype for technical validation and performance testing has already been set up. As a next step expert trials followed by first trial site installations in Spain and Austria are planned.

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