	PersonAAL	

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Techniques for Adaptation, Customisation and Persuasion (Initial)

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1 INTRODUCTION

The goal of the PersonAAL project is to extend the time elders people can live autonomously at their home. The project aims to achieve this by defining a personalization tool and an underlying platform in order to support caregivers and elderly themselves in personalising applications for the elderly people, taking into account their behaviour depending on the context of use. For this purpose, applications are able to receive personalized and context-dependent assistance, which enhances their functionalities and let the caregivers and the relatives to be informed in case of sudden illness or anomalous behaviour.

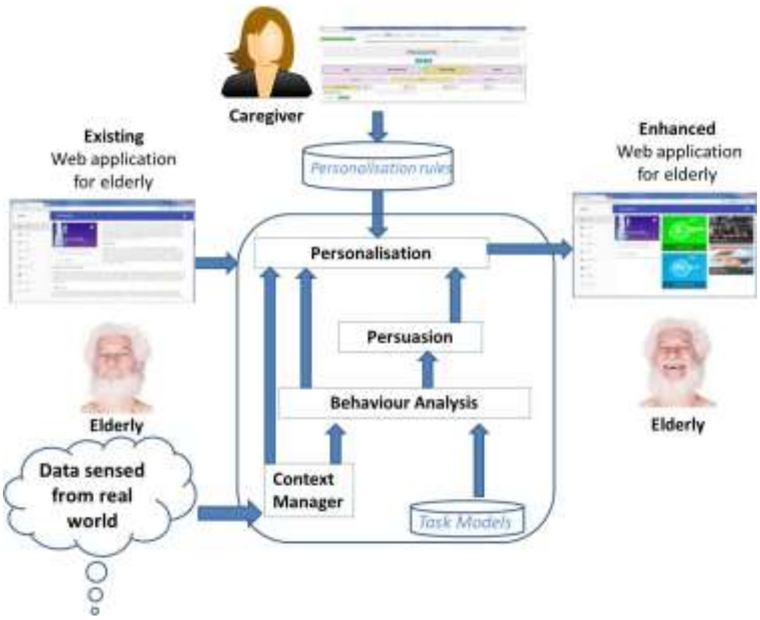

Figure 1: PersonAAL Platform Architecture

As showed in Figure 1, Existing Web applications for elderly people can be enhanced through the PersonaALL platform. First of all, caregivers or relatives can define a set of personalisation rules that describe how the application should change depending on the data sensed from the real world. The rules are specified in a "trigger-action" format. Triggers indicate events and conditions that should activate the execution of the specified action(s). Such triggers define which context entities the platform has to monitor.
The context manager is the platform component in charge to gather such information. It has a client-server architecture. It is composed of a number of *context delegates*, running on one or more devices located in the environment where the elder lives. Context delegates take information from sensors and pass it on to the *context server*, which organises the data into a common vocabulary that is used for communication with other platform components. The context server then notifies the *adaptation engine* when one or more rules are satisfied. The

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Adaptation Engine module receives the personalisation rules defined through the PersonAAL Rule Editor; those rules are associated with a specific user and application. The application name and the username of the user currently logged into the application are used by the application to subscribe to the platform, in order to be notified when there are actions that the application has to carry out to react to some events occurring in the surrounding user context. In particular, the application subscribes to the Adaptation Engine, which is the module that sends out to the application the actions extracted by the personalisation rules.Thus, when the Adaptation Engine receives the application subscription , it loads the corresponding rules and it subscribes to the context manager specifying the context entities involved in the events or conditions which compose the rules. When the adaptation engine is notified about the trigger of a rule, it retrieves the actions defined within the rule and it sends them to the adaptive application, which interprets and applies them.
For this purpose, the application is enriched with some scripts (written in the Javascript language), which are responsible for subscribing the application to the Adaptation Engine in order to inform this module that the application wants to be adapted, and then are able to interpret and execute the actions corresponding to the relevant triggers fired.

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2 ADAPTATION AND CUSTOMIZATION TECNIQUES

In order to describe the possible adaptation and customization techniques in a general manner, we have to consider possible triggers and action types. Triggers are events and/or conditions that occur in the context of use. Events are associated with the change of some contextual attributes at a specific point of time. Conditions are constraints on the state of some contextual attributes that are verified for some time. For example, when the senior enters home is an event. If the senior is at home is a condition. The event is instantaneous, while conditions are prolungued over time. In order to better discuss and manage contextual attributes, we have defined an abstract context model that classifies the possible attributes according to four main dimensions, which can then be refined in order to describe the specific contexts of use addressed in the project.

2.1 Contextual Dimensions

The context model is structured along four main dimensions (user, environment, technology, and social relationships) with the aim to describe the relevant aspects that can affect interactive context-dependent applications. In the following, we detail the refinement of each contextual dimension.

The **user** dimension includes personal data, physical and mental state, activity, personal social connections.

- Personal data concern some static information about the user (name, surname, age, gender, education) and preferences: the latter are further refined into sleeping and eating preferences.
- Physical and mental state concern data associated with physical characteristics, emotional aspects, cognitive aspects.
  - Physical aspects are categorised into: walking ability, balance, heart rate, daily steps, body temperature, respiration rate, posture.
  - Emotional aspects are divided into: happiness, anxiety, stress, serenity.
  - Cognitive aspects are categorised into: perception, attention, planning, reasoning, memory, language.
- Activity is categorised into: position, behaviour and motivation.
  - Position can be specified in relative or absolute terms: relative position can be expressed in terms of proximity type (e.g. in_front_of | beside | below | …) and point of interest (e.g. device| thing| environment). Absolute position can be specified in terms of latitude, longitude and altitude.
  - Behaviour refers to relevant aspects of the user behaviour. For instance, if we are interested to monitor the user behaviour as far as a correct medication intake is concerned, in this case behaviour is further categorised into: medication and task. Medication is further categorised into medication planned and medication occurred. Medication planned is further categorised into: notification timestamp, notification time, medication and dosage. Medication occurred is categorised into: registration timestamp, registration time, medication, dosage. Task is an elementary node that identifies the task that the user is expected to do.

  - Motivation is an elementary node, which can be specified in terms of the main concerned aspect. For instance, in case of a remote assistance application the main motivations could regard wellness, health, social, and fitness.
- Social connections refer to the users' social relationships. For each of them it is possible to indicate: the type of communication and relevant social events.

The **environment** dimension is further conceptualised into: date and time, characteristics, ambient attributes.

- Date and time is further refined into: time, date, and GMT offset.
- Characteristics provide general information on the surroundings. It can include information concerning: type (e.g. indoor/outdoor); name; and environment size, which is further categorised into: base shape, base area, base width, base height.
- Ambient attributes is further refined into: light level, noise level, temperature, humidity, presence, motion.

With **technology** we consider information related to any relevant technology available, e.g. devices, smart things/ appliances, network connectivity. In particular, technology is further subdivided into:

- devices, which has a number of attributes, e.g., name, category (e.g. tablet, TV, smartphone), owner, battery level, plus an additional sub-category (relative position, which is refined as described above)
- physical objects which has some attributes (name, type, state, power consumption, description) and an additional sub-category (relative position, which is refined as described above)
- connectivity, which describes the different types of network capabilities of the context (e.g. Wi-Fi, infrared, Bluetooth).

The last dimension concerns **social relationships**. Under this category we consider information related to characterising the context in terms of relevant social aspects, which could be specified according to the following information: type of network (for instance if the network is virtual or physical); type of relationship (the relationship shared by the members of the network e.g. family, hobby); users (the list of members of the network).

The creation of a domain-oriented context model from the generic context model is performed with the support of domain experts. There is no limit to the definition of new classes in the domain-dependent context model, neither in terms of number nor in terms of names or connections among them. For each class, an arbitrary number of attributes can be defined as well, without any naming restrictions.

It is worth pointing out that this distinction between generic and domain-specific context model facilitates the reusability of the context-dependent platform in different domains. For example, the User class can be modelled differently in different applications, each one with an associated domain-specific context model, which refers to the same generic context model. In the Ambient assisted living domain considered in PersonAAL, the generic User is modelled as Patient. Aspects such as Disabilities (e.g. motor impairment, blindness) and Diseases (e.g. diabetes, hypertension) are included in the specific context model. All the user's physiological parameters

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(e.g. hearth rate, blood pressure) are also included for monitoring purposes. Other ones, such as Education Level or Work, are not particularly relevant for the domain, thus they are not included in the specific model. However, in the smart retail domain, the generic User is modelled as Customer. Most of the original data structures with their detail level are maintained. Personal Data, including Nutritional Preferences, Age, Education Level, Work, are kept since they are relevant for the domain. Such contextual aspects are useful for taking into account the actual needs of the customer and provide them with tailored commercial recommendations.

2.2 Actions categories

We have also carried out a classification of the possible actions that can be associated with the personalisation rules.
In particular, we have identified six types of actions that can be carried out for personalisation purposes. These not only can affect (e.g. change) the user interface of the application itself, but also use different means to implement a reaction to a specific contextual event or state, for instance by communicating with appliances available in the current environment to change their status in order to modify the current conditions of the environment. In the customization phase such actions need to be tailored in order to address the specific services, devices, and appliances that are available in the target context of use. The categories identified are the following six ones:

- those performed by **appliances** (to change the state of some actuator);
- **user interface modifications** (to change the presentation, content or navigation of the personalised application user interface);
- **user interface distribution** (how the application user interface should be distributed across multiple devices);
- **functionalities** (some external service that is accessed);
- **alarms** (to highlight some potentially dangerous situations);
- and **reminders** (to indicate some task that should be accomplished).

Now we will better elaborate on each of the six categories identified above, in order to show how each category is further refined and structured. It is worth noting that such conceptualisation of events and actions described in this section are actually supported in the Personalisation Rule Editor developed in the project,which allows users to specify bith the triggers and the action sub-categories. Examples of use of the described categories in concrete rules specified through the support of this tool will be provided later on in this document.

User interface modifications can affect various aspects of the user interface (UI):

- The *presentation*. When adapting the presentation, the content of the UI remains the same but the way in which such content is presented changes. Various options are available for changing the presentation of a UI. One way is changing graphical attributes of the presentation e.g. increasing/decreasing font size, change background color, change font color. Using different layouts is another possibility (responsive web design is a well-known technique allowing the same web page to be suitably viewed onto a variety of devices by fluidly changing its layout). In addition, the same information can be rendered by using different media types (e.g. a textual description instead of an image)

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- The *content* of the information that is presented (by e.g. showing or hiding some specific portion of the content). Various types of content can be rendered in a UI e.g. audio and video files, images, textual elements as well as other UI elements like tables, forms. The goal of adapting the content of a UI is to increase the user's understandability of the content. Techniques for adapting the content include: automatic generation of additional information according to the current level of user's interest or knowledge, comparison of information (by analogy or contrast), varying explanations, summarisations. In addition, depending on the type of the content, further, specific techniques can be used for adaptation. For instance, there are specific adaptation techniques for textual elements like e.g. conditional texts (content within a document that is meant to appear in some situations but not others), Stretchtext (which expands or contracts the content)
- The *dynamic behaviour* of the UI (by varying the choice of the possible navigations, by enabling or disabling some interaction elements). The goal of adapting the navigation of a Web UI is to increase the efficiency and satisfaction in navigating it. In this perspective there are various techniques: hiding, removing or disabling links; changing the order in which the links appear, annotating links, dynamically generating links.
- In addition, another way of adapting the UI is using some combinations of the above mentioned techniques (e.g. combining the adaptation of the content and the adaptation of the dynamic behaviour of the UI)

UI distribution concerns the distributions of the UI elements across multiple devices. It can be performed in two ways duplicate the entire user interface onto two (or more) different devices, or partially distribute the UI onto different devices. In the first case the user interface is completely duplicated in the devices, while in the second case the UI is partially distributed among them so as to reduce (or even remove) the overlapping in terms of UI elements in the devices. For instance, one device can be only dedicated to control the content which is shown only the second device.

One further customisation type involves the dynamic activation of application *functionalities*. For instance, for a remote assistance application, relevant functionalities can be those concerning showing home energy consumption, temperature, or the state of alarms.

The specification of *alarms* and *reminders* is mostly the same, even if they have different meanings: they can be customised in terms of the text to be provided, the channel used for the notification (e.g.: sms, mail), the pattern of repetition, and the receiver of the message.

When a rule is triggered, the corresponding actions are received by the application which is in charge of interpreting them, and applying the corresponding modifications to the elements of the application according to the constructs available in the language. We have developed a XML-based language for specifying trigger-action rules. Thus, also for the action parts, which are those that implement the adaptation and customization techniques, it provides a general format that can be used across different applications. In this general description, there is a part with application-dependent content, which indicates the specific elements that need to be modified or deleted or created or activate, whose identifiers are defined within the considered application.

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Thus, the language specifies which contextual events should be considered and the consequent modifications that should be performed on the interactive applications. An initial version of this language has been described in Section 5 of deliverable D1.1.a (further updates will be provided in a next version of that deliverable). As you can see from D1.1.a, in that language all the six types of actions described above can be specified by using: i)elementary actions like create, read, update, delete; ii)well-known constructs to combine actions such as if, while, for each, for; iii)an additional construct -'invoke function' - to access an existing service which might be connected to available appliances.

2.2.1 Appliances Examples

In order to see an example of personalization technique that involves the use f some appliances, we can cosnider a responsive Web Home Application we developed that allows users to customize, control and check the status of appliances and sensors installed in an elderly home.

Figure 2: The initial version of the Web Home Application

When a user logs in to the application, the back-end subscribes to the Adaptation Engine. In this way, the application is ready to receive and apply the actions once a rule triggers. Figure 2 shows the initial version of the Web Home Application; the top right panel lists the initial rules associated with the application.

In the CNR lab an Arduino board provided with an ethernet interface to connect it to a router was installed, so that Arduino is connected to the internet network and the application can ask the current values of the installed sensors.

We also connected several sensors to the Arduino board; the installed sensors are: gas, smoke, motion, light, temperature and humidity sensors.

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The application is also able to connect to a Philips HUE bridge placed in the lab and connected to the internet network. The bridge exposes some RESTful services which allows to change the light state and colour.
Considering the available sensors, we can write a rule which is triggered when the motion sensor detects a movement and the corresponding action lights on the Philips HUE bulb and changes its colour.
The natural language of the rule describe in the previous paragraph is:
"WHEN the entrance motion sensor value is true then DO turn on and set the entrance light colour to blue."
The keyword *when* indicates the event, thus the rule should be triggered in the precise moment when the motion sensor value becomes equal to true.
Figure 3 shows the sensors connected to the arduino board, the Philips HUE bridge, the light is on and its colour is blue as an effect of the triggered rule.

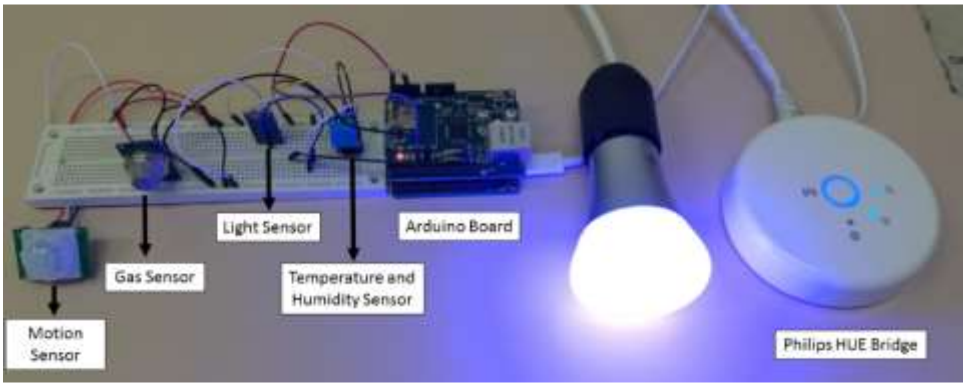

Figure 3: Sensors connected to Arduino and Philips HUE bridge

2.2.2 Functionality Activation Example

The same application described in the previous section can be used to show an example of functionality activation implemented by invoke function actions (in Section 2.2. the meaning of the invoke function has been described)
The user interface is designed as a dashboard, thus the user can immediately interact with the home devices and visualize the data from the installed sensors that are represented through some widgets. The application can be enriched through widgets showing the data retrieved by invoking external services or internal functions; to this end it is possible to define an action of type "invoke function" which, when applied, causes the invocation of the specified function.
The invoke function actions work only if in the target application the accessed functionality are implemented as global functions (which means accessible from external modules), and having the same signature (input/output parameters) of the function name specified in the action .

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Figure 4: "IF tomorrow weather forecast is raining, DO invoke BBC Weather Widget"

Figures 4 and 5 show two examples of the Invoke Function action: Figure 4 shows the effect of the rule "IF tomorrow weather forecast is raining, DO invoke BBC Weather Widget", while Figure 5 shows the user interface after the following rule has been applied: "WHEN power consumption is more then 3KW/h, DO invoke Power Consumption Widget".

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Figure 5: WHEN power consumption is more then 3KW/h, DO invoke Power Consumption Widget

2.2.3 UI Modification Examples

In order to demonstrate how this kind of action works, we consider the application called "Remote Assistance Application" developed by Reply. This application should enable elderly users to receive remote assistance and support by both family and care providers directly in their own homes. The user's physiological parameters will be collected by sensors on peripheral devices (ECG, Accelerometer, etc), the data are evaluated for potential problems (e.g. fall), and caregivers and health providers can be immediately alerted if a problem is detected in order to ensure timely support.

The goal of the first rule related to the Remote Assistance Application is to improve exercise motivation. Knowledge about personal factors influencing physical activity behaviour can be used to tailor physical activity interventions to the individual and to improve long-term adherence to regular physical activity. Depending on the personal main motivation factor and on the age of the user, an appropriate exercise suggestion can be presented in the Remote Assistant Application, according to4 main motivation factors:

- Wellness: enjoy the activity itself, relax, satisfaction in reaching personal objectives.
- Health: desire to keep good health conditions or to improve them.
- Social: enjoy spending time with others, do something with friends, compare with others.
- Fitness: desire to lose weight, look better, feel stronger.

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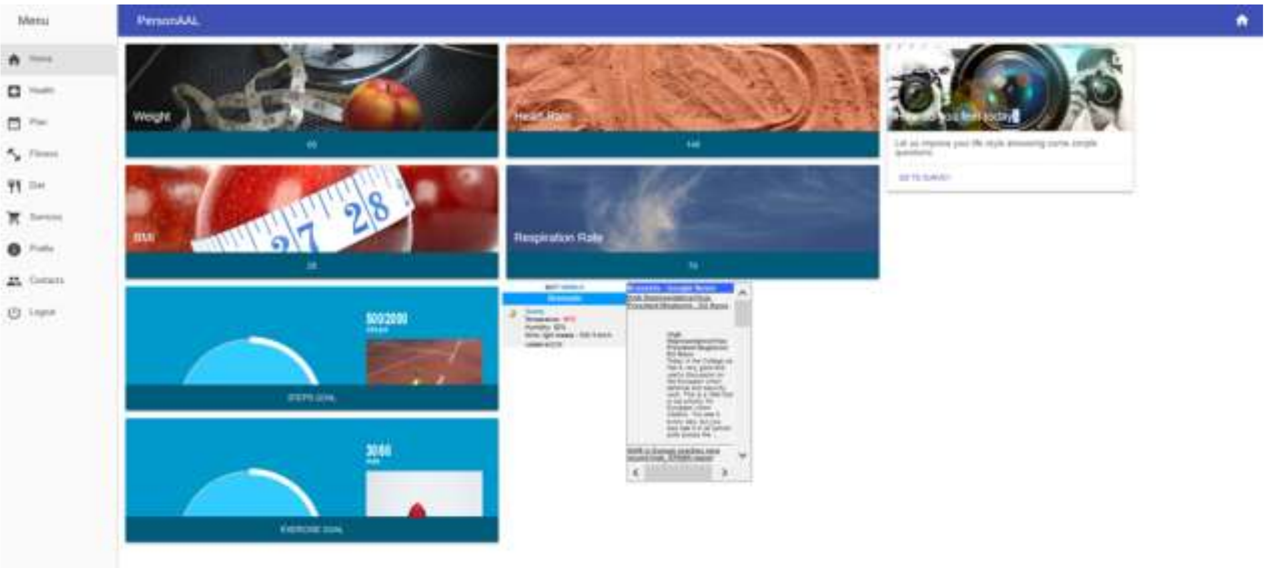

Figure 6: Initial version of the Remote Assistance application

Figure 6 shows the initial version of the Remote Assistance application, while Figure 7 shows the effect of a rule which takes into account the motivation factor of the elder user: "IF Motivation is health, DO Show Health Element, Hide Goal Element, Show questionnaire, Hide Fitness Element, Hide News Element"

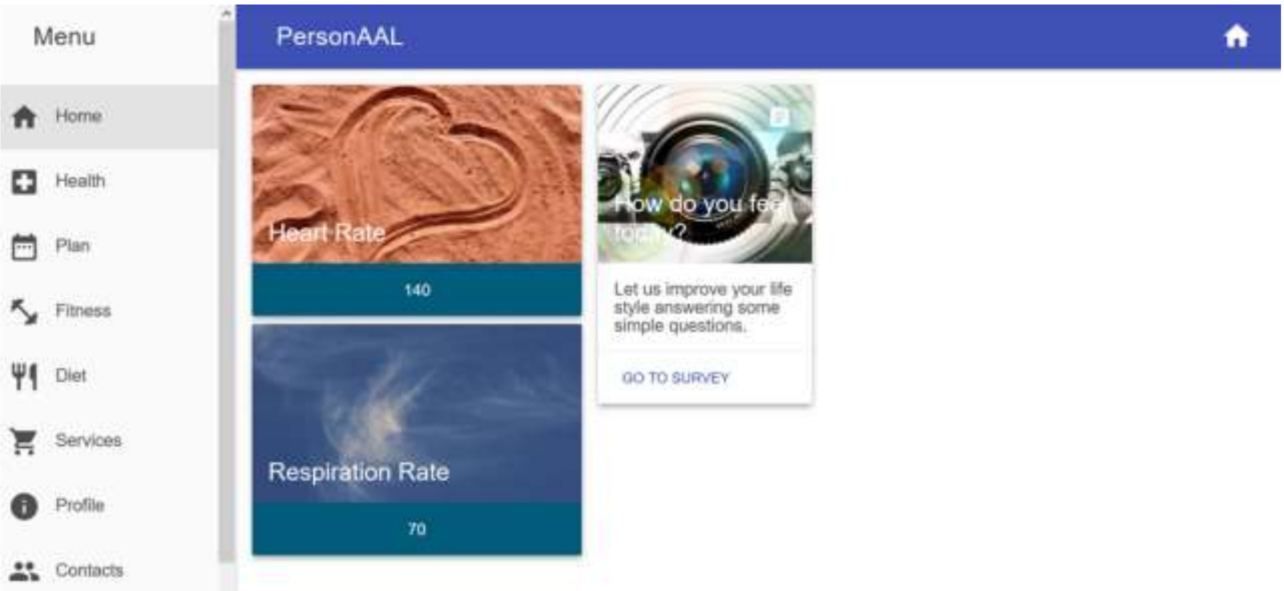

Figure 7: Example of rule triggered by Motivation Factor

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This rule modifies the aspect of the user interface showing the health and the questionnaire cards and hiding the elements which are not related to the current motivation factor.
The effect of the activation of another rule is shown in Figure 8 (right part); also this rule takes into account the motivation factor (in this case motivation factor is fitness) and the age of the user; the action part shows only the exercise that are appropriate for the user.

Figure 8: (Left) the initial version, (Right) the user interface modified after that the actions have been applied.

2.2.4 Alarm Example

In order to shown an example of the possibility to obtain alarms, we consider another application that when potentially dangerous deviations occur in the elderly behavior then it provides this feature. Here, a rule example can be: IF the user takes pill before breakfast DO send alarm with text "user should take diuretics pill after the breakfast".

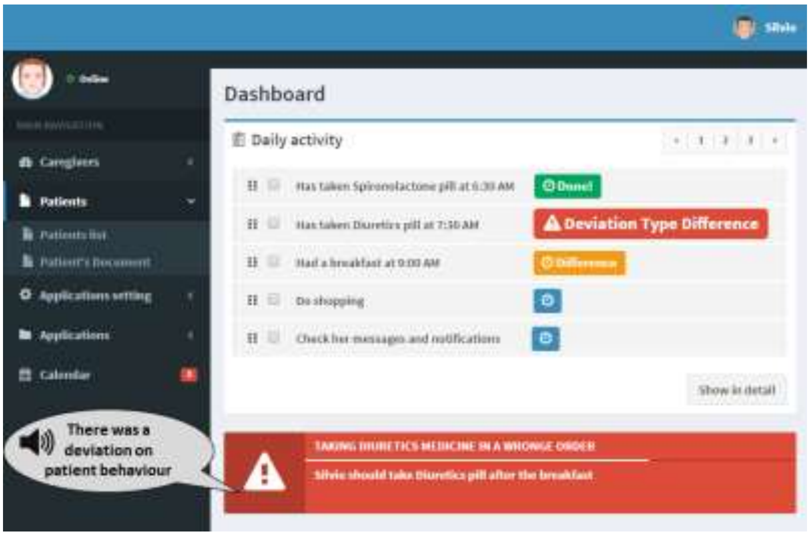

Figure 9: The user interface with the alarm.

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2.2.5 Reminder Example

Through the Remote Assistance application, it is also possible to set a daily steps goal. The Bitalino device is able to detect the steps carried out by the user in an interval of time. The step values are received by the application and then sent to the context manager in order to store them.
For elderly users it is important to have a walk daily, thus a care giver can define a rule such as: "IF the daily steps are less than the steps goal, DO send a reminder to the user with the text: 'Today you did not do many steps, I suggest you go outside for a walk'"

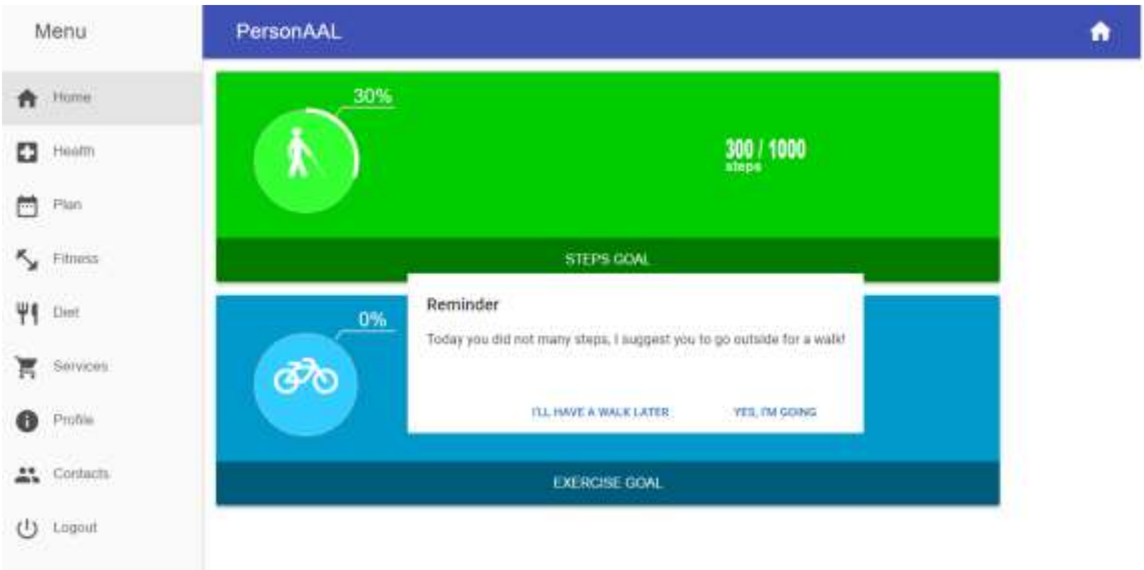

Figure 10: Rule to remind the user to have a walk

Figure 10 shows an example of reminder related to the execution of the rule described before.

2.2.6 UI Distribution

If we consider the example described in Figure 8, elders may have problems while exercising because these are shown on the PC and this can create difficulties in understanding the correct movements that should be performed. To solve such potential problems, we can write a contextual rule which exploits the distribution action provided by the PersonAAL platform.
Through an indoor localization service, which uses e.g. Bluetooth low energy beacons, we are able to know where the elder is located and thus we can define a rule like this: "IF the user motivation is fitness AND age is more than 65 AND the location is near the Living Room Smart TV, DO distribute the fitness page into the Living Room Smart TV".

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In this way the elder can follow the exercise recommendations looking at the TV (Figure 11) and not at the personal device which has a smaller screen.

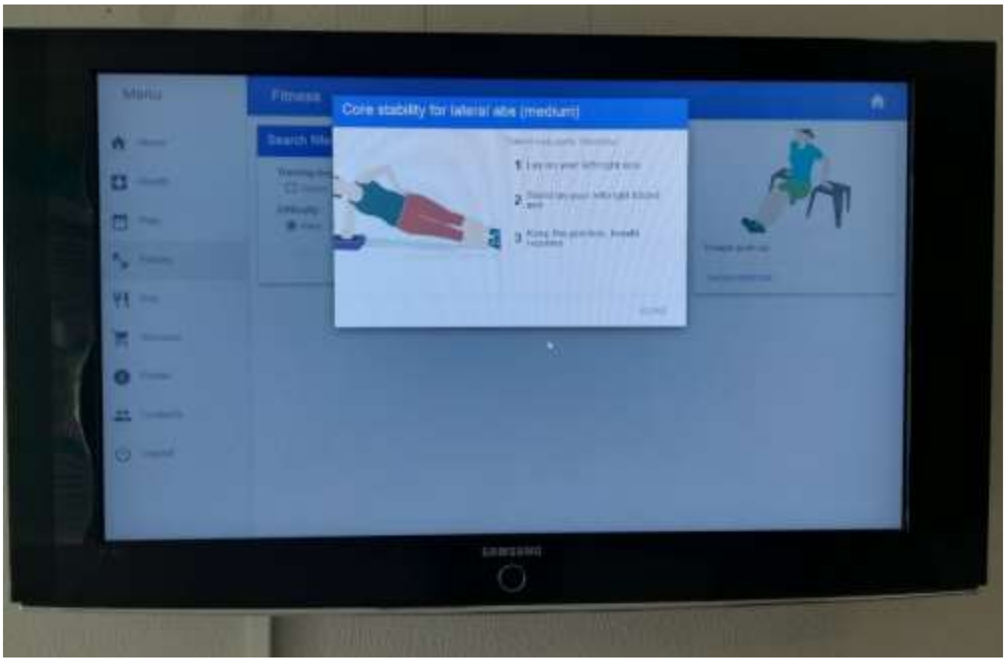

Figure 11: The fitness page fully duplicated on the Living Room Smart TV

2.3 The Action Editor

The action categories (Appliances, UI Modification, Functionalities, Alarm, Reminders) can be considered useful for the classification of the various possible actions. They are generic and common for all applications. However, the actions can not be the same for all the application.
The *Appliances* category is characterised in terms of the environments in which the appliances are available, while the *UI Modification/UI Distribution* actions specify the UI elements and their attributes which should be modified/distributed when the rule is triggered. The *Functionality* category involves the dynamic activation of functionalities implemented in the target application. The *Alarm* and *Reminder* category are more general, they are composed of a text, the number of repetition and the target of the action (phone number, e-mail address, etc.), finally there is the notification mode (SMS, Push Notification, E-Mail, Call
Thus, it is clear that the actions have some aspects that ate dependent on the target application which will receive the actions (such as the identifiers of the user interface elements to manipulate or the functionalities to activate): thus it should be able to interpret them in the right way.
Within the Authoring Tool for editing the personalisation rules we have added an Action Editor (Figure 12), which is a visual tool to allow users to specify the information needed to fully specify the actions to perform. For instance, for the "Appliance" action category users need to specify e.g. the unique ID of the concerned appliance, and the attribute for specifying the

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appliance state to properly define an action (e.g. "set the appliance state to OFF"). The defined actions for a specific target application are saved in the Rule Editor, which will then made them available when users specify the personalisation rules. For this purpose, in the Setting section of the tool it is possible to specify the target application in such a way that the corresponding customized actions are made available for the rule editing.

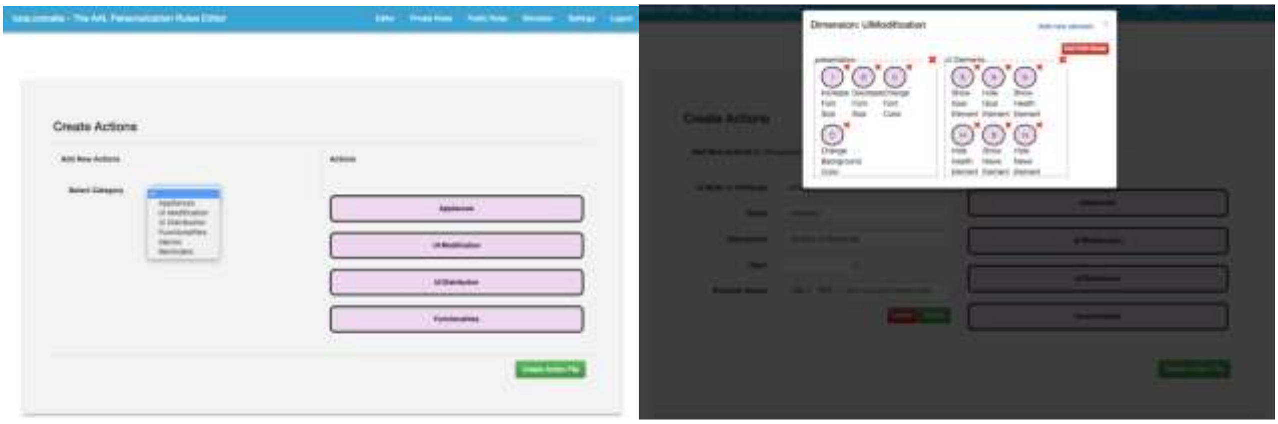

Figure 12: The Action Editor

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3 PERSUASION MODULE

The PersonAAL Persuasion Module aims to motivate older adults to adopt behaviours that improve their well-being and, ultimately, increase the time they can live independently at home. The Persuasion Module uses the data collected by the PersonAAL framework to reason about the current behaviour of the user and decide about the motivation techniques that can be applied to try to reinforce or change the behaviour. In the context of the project, we have focused on behaviours related to and promoting physical activity and social activity.

3.1 Conceptual Framework

The persuasion process comprises understanding current behaviours, detecting when the older adult is deviating from the intended target, and, if so, deciding the best course of action to nudge the older adult towards the target behaviour. For this to be possible, the Persuasion Module must model the older adult behaviour using an existing Behavioural Model and must apply one or more Behavioural Changing Techniques to promote changes.

3.1.1 Behavioural Models

A Behavioural Model aims to model factors that can be used to explain behaviour changes in an individual. Several Behavioural Models have been created and are being used to explain individual behaviours. In PersonAAL, we have considered 4 Behavioural Models: Fogg's Behavior Model[1], the Health Belief Model[2], the HAPA – Health Action Process Approach[3] and COM-B[4].

We ultimately selected the COM-B model due to its more abstract and simpler nature. COM-B (Figure 23) explains Behaviours based on 3 factors: capability, opportunity and motivation. *Capability* is defined as the individual's psychological and physical capacity to engage in the activity concerned. It includes having the necessary knowledge and skills. *Motivation* is defined as all those brain processes that energize and direct behaviour, not just goals and conscious decision-making. It includes habitual processes, emotional responding, as well as analytical decision-making. *Opportunity* is defined as all the factors that lie outside the individual that make the behaviour possible or prompt it. The model not only considers that the 3 factors can individually influence the behaviour, but also that there can be an influence between components of the system. For example, opportunity can influence motivation as can capability; enacting a behaviour can alter capability, motivation, and opportunity.

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[1] Fogg, B. J. (2009, April). A behavior model for persuasive design. In Proceedings of the 4th international Conference on Persuasive Technology (p. 40). ACM.

[2] Rosenstock, I. M. (1974). The health belief model and preventive health behavior. Health education monographs, 2(4), 354-386.

[3] Schwarzer, R., Lippke, S., & Luszczynska, A. (2011). Mechanisms of health behavior change in persons with chronic illness or disability: the Health Action Process Approach (HAPA). Rehabilitation psychology, 56(3), 161.

[4] Michie, S., van Stralen, M. M., & West, R. (2011). The behaviour change wheel: a new method for characterising and designing behaviour change interventions. Implementation science, 6(1), 42.

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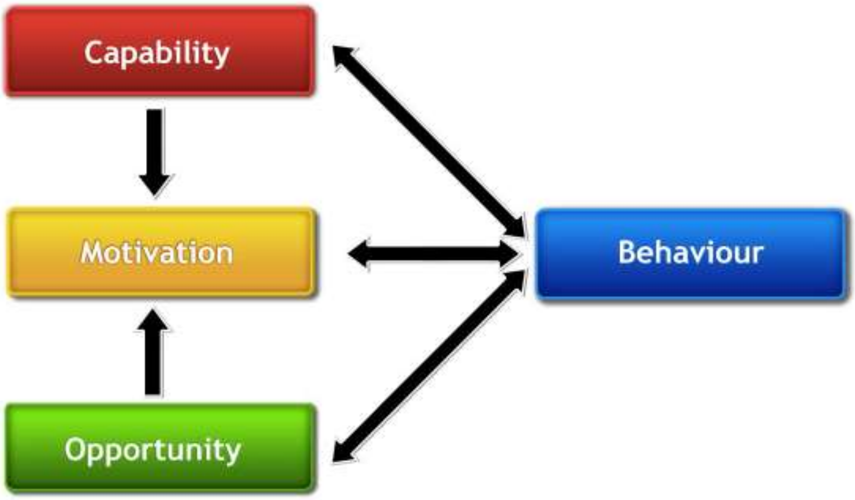

Figure 23 – The COM-B model (Michie et al., 2011)

The COM-B behavioural model is used in PersonAAL to model the factors that can be used to explain changes in behaviours. In PersonAAL we consider 2 types of activities: physical and social. For each activity, we compiled a list of factors for each of the 3 COM-B explaining constructs. When we detect deviations in that activity, a behaviour change intervention is initiated.

3.1.2 Behavioural Changing Techniques

The Behavioural Change Techniques are theory-driven methods that are used in behaviour change interventions. A Behavioural Change Technique is a process aiming to influence a psychological determinant (i.e., a variable in people's head). Typical examples of determinants are risk perception or self-efficacy.

Due to the large number of interventions described in the literature, there have been ongoing efforts to categorize interventions into taxonomies[5]. In PersonAAL, derived from the types of activities considered and the possible intervention contexts (technology supported), we use only a subset of the possible categories of techniques: Identity, Social, Rational, Positive Emotional Reinforcement, and Problem solving.

The Persuasion Module is responsible for selecting the most adequate techniques to apply, given the context and behavior of the older adult. Based on the behavioural modelling, the module decides on the most adequate categories to apply, and combines individual techniques in a computer supported intervention that can be realized via individual messages presented to the older adult, or changes in the information that is displayed in an application that the older adults use.

[5] Michie, S., Richardson, M., Johnston, M., Abraham, C., Francis, J., Hardeman, W., ... & Wood, C. E. (2013). The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. Annals of behavioral medicine, 46(1), 81-95.

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3.1.3 Conceptual Architecture

To meet the proposed objectives, the Persuasion Module is responsible for detecting changes in the older adult activities, modelling her or his behaviour, and implementing behaviour change interventions when required. The dependencies between these processes are presented in Figure 14.

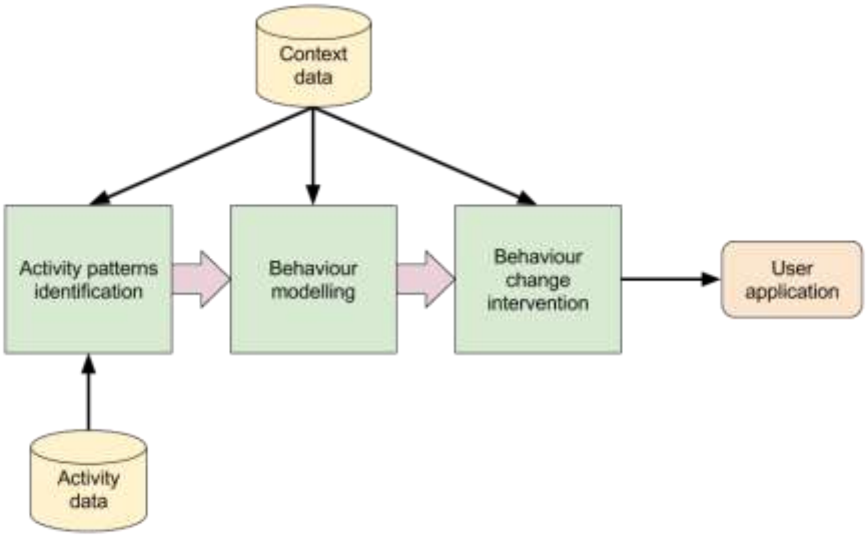

Figure 14 – Conceptual architecture of the persuasion module

The Activity Patterns Identification process identifies activity patterns for the user based on existing activity data (collected through PersonAAL sensors) and the context data that describes user and environmental properties. The process creates activity patterns for a given user and is also capable of identifying deviations from these patterns.
The Behaviour Modelling process models the user's behaviours for the specific activity that is being analysed based on the context information that characterized that activity. This process identifies the factors that can explain positive or negative changes in the user's behaviour.
The Behaviour Change Intervention process selects the techniques that are most adequate to try to reinforce or change a behaviour based on the factors that have been identified by the Behaviour Modelling process. The process subsequently prepares the intervention that is to be rendered in the user's application.

3.2 Implementation

This section describes how the Persuasion Module described in the previous section is implemented and integrated in the PersonAAL framework.

3.2.1 Architecture

The conceptual architecture presented in Figure 14 is implemented in 5 modules responsible for deploying the services required for the operation of the Persuasion Module. An API for accessing the different modules is under development. Figure 15 presents the different modules and their

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communication channels. The first two modules implement the first process in the conceptual architecture; the third module implements the second process; and the last two modules implement the final process. The last three modules query the data required for operation from PersonAAL's context manager. The output of the final module can either be rules to add to the Trigger-action rule base for a specific user if the interaction needs to be triggered based on an event or condition. If there is a need for an immediate interaction, module 5 can use the services of PersonAAL's adaptation engine to, for instance, send a message to the user.

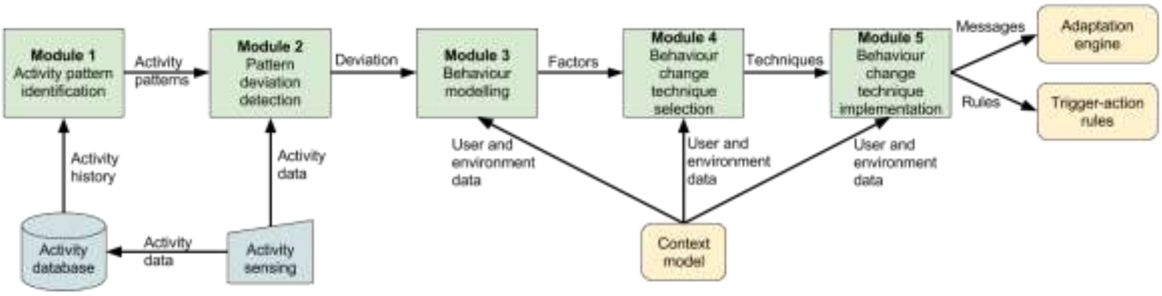

Figure 15 – Architecture of the persuasion module

3.2.2 Module 1 – Activity pattern identification

This module is responsible for identifying activity patterns in the user's data. In PersonAAL we consider two types of activity: physical and social. So far we have only addressed patterns for physical activity data, but we expect the process for social activity to be similar.

Physical activity of older adults can be inferred from step data[6]. To be able to develop this module we need data sets of step data for long periods of time. While there are data sets with step data of older adults for periods of about 7 seven days, there are no publicly available data sets of step data for older adults for longer periods. We used free data sources of step data from younger people covering two months. The step data was collected with a Fitbit sensor, and consists of the number of steps in 15 minute intervals.

The pattern identification is done through a clustering process. More specifically, we conduct unsupervised learning of *k* activity patterns. Based on our experiments with the data, we settled on *k=2*, allowing to distinguish 2 types of days: activity-heavy and activity-light days. The distance metric used for clustering compares the number of steps of all 15 minute intervals, allowing for the detection of different daily behaviours even if the total number of steps in the day is similar. The distance measure is calculated with a sliding window of 2 hours to find situations where the behaviour is the same but starts a bit earlier or later in the day. The clustering is done with the step data from the last 30 days.

Figure 16 shows an example of the clustering process. The bars represent the step count over 15 minute intervals for the 30 days of the clustering process. The two clusters are represented by the red and blue solid lines. For this individual in the past 30 days, two patterns emerged: days with a constant level of activity across the daytime and almost no activity during the night

[6] Shephard, R. J., & Aoyagi, Y. (2010). Objective monitoring of physical activity in older adults: clinical and practical implications. Physical Therapy Reviews, 15(3), 170-182.

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time (red line); and days with some activity during the afternoon and almost no activity during night time and mornings (blue line).
The module's output is the description of the two clusters that characterize the individual's activity in the past 30 days. This module is executed for each individual with a weekly frequency, in order to make sure that the patterns represent recent activity data.
For social activity, we plan on collecting social interaction numbers from the user's mobile device. For instance, number of phone calls made or received, number of text messages exchanges, etc.

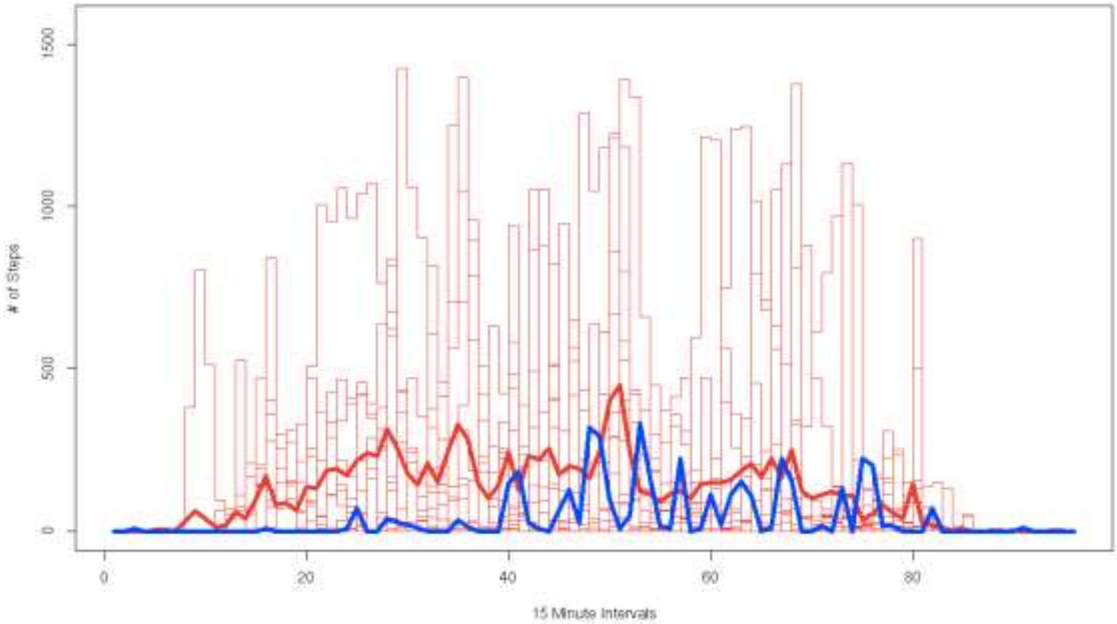

Figure 16 – Example patterns for one of the individuals in the step count data set. The red and blue lines illustrate the average step count across the day for the two identified patterns.

3.2.3 Module 2 – Pattern deviation detection

This module is responsible for detecting deviations from the patterns identified in module 1. The process begins with a classification of the activity data from the past day into one of the activity clusters. After deciding to which cluster it belongs, the module classifies the activity data as a regular day, as a slightly abnormal day or as a highly abnormal day. We explored 3 manual classification and 1 automatic classification approach.

3.2.3.1 Approach 1 (manual) – Based on the distance metric

This approach uses the same distance metric (D) that is used for clustering. Based on this metric, days are abnormal if they strongly deviate from the cluster center. We consider a new day as highly abnormal if it is further from the cluster center than the furthest day in the cluster, and as slightly abnormal if it is more than one standard deviation away from the average distance to the cluster center.
A day is considered highly abnormal if

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$$D(day) > D(furthest\ cluster\ day\ from\ the\ cluster\ center) \times \eta$$

where η is parameter used to fine tune the classification. A day is considered slightly abnormal if

$$D(day) > \overline{D(cluster\ days)} + std(D(cluster\ days))$$

A day is considered regular otherwise.

3.2.3.2 Approach 2 (manual) – Based on the day's energy

This approach is based on the day's energy (E). The energy of the day is defined as

$$E = \sum_{i=0}^{96} s_i$$

where s_i is the step count for the i^{th} interval in the day (a day has 96 15-minute intervals). A day is considered abnormal if his energy deviates more than a standard deviation (times a factor) from the average of the cluster days' energy.

A day is considered highly abnormal if

$$E(day) > \overline{E(cluster\ days)} + std\big(E(cluster\ days)\big) \times \Gamma$$

or

$$E(day) < \overline{E(cluster\ days)} - std\big(E(cluster\ days)\big) \times \Gamma$$

A day is considered slightly abnormal if

$$E(day) > \overline{E(cluster\ days)} + std\big(E(cluster\ days)\big) \times \gamma$$

or

$$E(day) < \overline{E(cluster\ days)} - std\big(E(cluster\ days)\big) \times \gamma$$

with $\gamma < \Gamma$ beign factors used to fine tune the classificaion. A day is considered regular otherwise.

3.2.3.3 Approach 3 (manual) – Based on outlier points

This approach is based on finding step counts that are above (A) or below (B) a step band. The band's top limit is defined as

$$\overline{s_i(cluster\ days)} + std(s_i(cluster\ days)) \times \varepsilon$$

The band's bottom limit is defined as

$$\overline{s_i(cluster\ days)} - std(s_i(cluster\ days)) \times \zeta$$

A is defined as the number of step intervals of the day being analysed that are above the top limit. B is defined as the number of step intervals that are below the bottom limit.

A day is considered highly abnormal if $A + B > \mu$ and slightly abnormal if $A + B > \nu$, with $\mu > \nu$. A day is considered regular otherwise. ε, ζ, μ and ν are factors used to optimize the classification accuracy.

3.2.3.4 Approach 4 (automatic) – Decision tree based

This approach trains a decision tree on the step data from each individual and then uses it to classify the deviation. The disadvantage of this approach is that the training process needs classified examples, which are not easily available. For the training process of our data sets, 3 researchers classified each day independently according to the 3 classes (regular, highly abnormal, slightly abnormal). The majority of votes was used to decide on the final classification of each day.

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For the decision tree we used the following features (based on the metrics presented in the 3 previous approaches): $D(day)$; $E(day)$; $D(furthest\ cluster\ day\ from\ the\ cluster\ center)$; $E(furthest\ cluster\ day\ from\ the\ cluster\ center)$; A; B.

3.2.3.5 Classification accuracy

We compared the performance of the 4 approaches in the data sets we had available. We started with a classification with only 2 classes: regular and abnormal (using the slightly abnormal decisions). Table 1 present the classification accuracy for the developed approaches when considering only 2 classes (regular and abnormal) instead of 3.

Table 1 – Classification accuracy of the proposed approaches with 2 classes

Approach	Classification accuracy
A1	55%
A2	76%
A3	85%
A4	91%

The automatic classification approach (A4) outperformed all the other classification approaches. A3 performance is still considered acceptable, and it is accurate enough in the situations where no supervised data is available to train the decision tree.
Table 2 presents the results when 3 classes, regular, slightly abnormal and highly abnormal, are considered.

Table 2 – Classification accuracy of the proposed approaches with 3 classes

Approach	Classification accuracy
A1	49%
A2	67%
A3	70%
A4	73%

The performance is substantially lower when 3 classes are considered. The decision tree is still the best approach. A3 is once again the best approach from the manual classification approaches.
Given these results, the current version of the Persuasion Module uses 2 class classification.

3.2.4 Module 3 – Behaviour modelling

This module is responsible for identifying the factors that can explain the detected behaviour changes. The initial step in the development of this module is the collection and classification of the different factors according to the COM-B model.
For physical activities, these factors were collected by the team at Sunnas Rehabilitation Hospital, together with the behavioural effect they can explain and how they can be measured. Table 3 presents factors associated with the Capability dimension of COM-B. Table 4 presents

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the factors associated the Opportunity dimension and Table 5 presents the factors associated with the Motivation dimension.

Based on this information, the module operates in the following fashion. Based on the deviation detected (positive or negative) the module identifies all the factors that could be responsible for it. Afterwards it queries the context manager to find which factors have new data that can explain the change. The list of factors with new data is passed onto the following module to select the ones that could trigger behavioural change interventions.

The selection of factor for social activity is ongoing. The operation of the module is independent of the type of activity, which means that we only need to add the new factors associated with social activity to have support for it.

3.2.5 Module 4 – Behavioural change technique selection

This module is responsible for selecting the Behavioural Change Techniques to apply to promote the desired behaviour, based on the factors identified by the previous module.

The module relies on a set of rules that define which are the appropriate techniques for each factor. The rule definition process begun with the identification of the categories of Behavioural Change Techniques that are appropriate for each factor. For instance, for the *Unfit* factor (from the Capability dimension) the following groups of techniques were considered appropriate: Social, Rational, Positive Emotional reinforcement, Problem solving. For the *Local Weather* factor (from the Opportunity dimension) the groups of techniques are: Social, Positive emotional reinforcement, Problem solving. For the *Below Step Goal* factor (from the Motivation dimension) the groups of techniques are: Social, Rational, Positive Emotional reinforcement, Problem solving.

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Table 3 – Factors associated with Capability for physical activity

CAPABILITY	Effect on behaviour	Measurement
High BMI (Body Mass Index)	Negative	Height/Weight
Hungry/not been eating	Negative	Schedule
Illnesses incl. cognitive impairment	Negative	Background
Injuries	Negative	Ask/Background
Low mood (Sadness/depression/loneliness)	Negative	Ask/Background
Pain	Negative	Ask/Background
Smoking	Negative	Background
Low Sleep Quality	Negative	Sensor
Unfit (number of steps and walking speed at baseline?)	Negative	Sensor/Background
Weak grip strength	Negative	Background
Fit (number of steps and walking speed at baseline?)	Positive	Sensor/Background
Happiness/positive mood	Positive	Ask/Background
Knows how to perform the activity	Positive	Background
Normal grip strength	Positive	Background
Self-efficacy	Positive	Background
Walking aids	Positive	Background
Normal BMI (Body Mass Index)	Positive	Height/Weight

The next step is defining the rules for each group of techniques for each factor (some rules will be identical for different factors). In the following we describe rules for the 3 factors exemplified above.
For the *Unfit* factor, we created the two following rules:

- If this week's **walking speed** is higher than last week and lower than **baseline**, then apply Positive emotional reinforcement and Rational techniques
- If this week's **walking speed** is lower than last week and lower than **baseline**, then apply Rational, Social and Positive emotional reinforcement techniques

For the *Local Weather* factor, we created also two rules:

- If the **weather** is good and **step count** is below goal then apply Social and Positive emotional reinforcement techniques

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- If the **weather** is bad and **step count** is below goal then apply Problem solving techniques

Table 4 – Factors associated with Opportunity for physical activity

OPPORTUNITY	Effect on behaviour	Measurement
Activity far away from home	Negative	Sensor
Activity nearby home	Positive	Sensor
Affordable activity	Positive	Background
Company (practical support)	Positive	Ask/Background
Got equipment needed for the activity	Positive	Ask
Local weather	Positive	Sensor
Free Agenda	Positive	Application
Schedule Activity	Positive	Application
Busy Agenda	Negative	Application
Need of transportation	Negative	Background

Table 5 – Factors associated with Motivation for physical activity

MOTIVATION	Effect on behaviour	Measurement
Below step goal	Negative	Sensor
Negative memories from activity	Negative	Background
Over step goal	Positive	Sensor
Company (social)	Positive	Application
Interested in the activity	Positive	Background/Ask
Perceived physical benefits	Positive	Background/Ask
Perceived psychological benefits (well-being)	Positive	Background/Ask
Perceived social benefits	Positive	Background/Ask
Positive feelings and memories about the activity	Positive	Background/Ask

For the *Below Step Goal* factor, we also have two rules:

- If **step count** is below one third of the goal then apply Social, Rational and Positive emotional reinforcement techniques

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- If **step count** is above one third of the goal, but below the goal then apply Rational and Positive emotional reinforcement techniques

For each factor received from the previous module the rules are evaluated. If triggered, the groups of behavioural change techniques that can be applied are collected and passed to the following module.
For evaluating the rules, this module queries the context manager to have the required information.

3.2.6 Module 5 – Behavioural change technique implementation

This module is responsible for implementing the behavioural change intervention in accordance with the groups of behaviour change techniques received from the previous module.
To support this module, a set of behavioural change techniques for each factor was created. Once more, we illustrate possible rules following the example started above.
For the *Unfit* factor, these are possible techniques for the different groups:

- Social
    - Suggest inviting someone (from the user's contact list) to walk with
    - Compare distance walked with the distance other users have walked
- Rational
    - Inform the user about the percentage of his goal that has already been completed
- Positive emotional reinforcement
    - Present congratulations message
    - Present encouraging message (e.g., "You've almost made it")
- Problem solving
    - Suggest calling a caretaker

For the *Local Weather* factor, some possible techniques are:

- Social
    - Suggest inviting someone (from the user's contact list) to walk with
- Positive emotional reinforcement
    - Inform the user that the weather is nice outside and encourage him to go for a walk
- Problem solving
    - Suggest the user to do some physical activity at home

For the *Below Step Goal* factor, possible technique include:

- Social
    - Suggest inviting someone (from the user's contact list) to walk with
- Rational
    - Inform the user about the percentage of his goal that has already been completed
- Positive emotional reinforcement
    - Present encouraging message (e.g., "If you go out for a walk you will feel better")
    - Motivate with gamification techniques (e.g., "This week you've earned 100 points already")

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- Show images of favourite places
- Problem solving
  - Inform the user about what he needs to reach his goal (e.g., "If you walk for 15 more minutes you will reach your goal"

For each factor, the module collects one technique for each group. If there is more than one group triggered for a factor, we attempt to combine the techniques. For example, for the *Below Step Goal* factor we could combine Rational and Problem solving techniques in the following manner: "You have completed 75% of your goal. If you walk 15 more minutes you will reach your goal".
The output of the examples above is mostly handled through messages to be rendered to the user. This could be achieved by sending an instruction to the PersonAAL Adaptation Engine with the content of the message. The Adaptation Engine is then responsible for rendering the message in the most appropriate fashion to the user. Other options include interfacing with PersonAAL supported applications, like the Remote Assistance Application that includes features like presenting achievement of current progress towards activity goals of the user. This could be achieved through the Trigger-Action rules, creating rules that enable or disable those features based on the results of the persuasion rules assessment.

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CONCLUSIONS

This deliverable reports on the techniques for adaptation, customization and persuasion considered in the project. It shows the components in charge of managing them within the PersonAAL platform and provides various example applications.
Future work will be dedicated to further extending such techniques, validating them from the users' viewpoint, and better integrating the persuasion component within the overall architecture.

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