Computer-Supported Assessment for Tailoring Assistive Technology

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ABSTRACT

The main purpose of assistive technology is to support an individual's daily activities, in order to increase ability, autonomy, relatedness and quality of life. The aim for the work presented in this article is to develop automated methods to tailor the behavior of the assistive technology for the purpose to provide just-in-time, adaptive interventions targeting multiple domains. This requires methods for representing and updating the user model, including goals, preferences, abilities, activity and its situation. We focus the assessment and intervention tasks typically performed by therapists and provide knowledge-based technology for supporting the process. A formative evaluation study was conducted as a part of a participatory action research process, involving two rehabilitation experts, two young individuals and one senior individual as end-user participants, in addition to knowledge engineers. The main contribution of this work is a theory-based method for assessing the individual's goals, preferences, abilities and motives, which is used for building a holistic user model. The user model is continuously updated and functions as the base for tailoring the system's assistive behavior during intervention and follow-up.

Keywords

Knowledge-based systems; User modeling; Personalization; Assistive technology; End-user development; Ambient assisted living; Multi-agent systems; Mental health; Behavior change systems; Participatory action research

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1. INTRODUCTION

People in the modern IT-society are supported in an increasing number of tasks by computational resources, sometimes embedded in the everyday living environments. Moreover, the border between tasks, which are expected to be performed by skilled professionals and by laypersons is becoming more and more diffuse. For instance, health relates to a large extent to everyday activities and not only to healthcare tasks performed by healthcare professionals. Individuals are increasingly being expected to take care of their health and prevent illness in order to avoid becoming subjects to healthcare. Moreover, in case individuals are subjected to healthcare, it is desired, mainly for economic reasons, that large part of the care is conducted without admitting the person into a care facility, i.e., in a home environment and as part of everyday life (e.g. [30]).

If health is expected to be monitored and maintained as a part of everyday life by the individuals, then it is also desired that the instruments for being able to do so are being developed by the individuals who take interest in the outcome and have use of the new instruments (e.g., [6]). The co-design, co-creation and maker concepts are examples of this trend.

Both these developments provide challenges. The first challenges the existing healthcare system, which is built on the patient-healthcare expert and the customer-producer dichotomies. The roles change when the patient acts the healthcare professional, and the customer produces new technology innovations. The second development challenges the view that end-users are useful at best in the phase when requirements are specified, but during the development, programmers and software developers are building the new instruments and innovations. The Living Lab design concept has evolved to meet these challenges.

The main research question of our work is how can a dynamic and holistic user modeling be accomplished, which takes the individual's preferences, goals, motives, ability, motivation and context sufficiently into consideration for promoting behavior change?

The focus of this article is the knowledge-based therapeutic assessment and intervention procedure, which we aim to augment with tailored computer-based support to an individual through assistive technology. The therapist's procedure typically consists of the following. An initial assessment is conducted, a holistic understanding of the client is established (*i.e.*, a *client*, or *user model*), a plan of (multi-) interventions is made, implemented and followed up with adjustments of both the user model and interventions according to detected changes in needs, ability, health and preferences over time. Key in these tasks is the dynamic user model, which motivates the behavior of the *active* assistive technology. In this work the definition of *active* assistive technology used by Kennedy and co-workers [16] is applied to distinguish systems, which includes automated processing of health information during a human's interaction with the system and which may output tailored responses to the human in the process. To distinguish the active, knowledge-based and adaptive components of the system, we hereafter denote these intelligent and social software agents, or in short, agents.

The article is organized as follows. The following section gives an overview of the methods applied, the theories underpinning our work and the technology used and developed as part of this work. A case study was conducted for the purpose to investigate how the needs, preferences and motivational structures are captured by the user model, giving the user the opportunity to define and prioritize their goals for improving their situation. The results from the development and case study are presented in Section 3. The results are discussed in Section 4 in the context of related work and in relation to challenges when using computer-based support for promoting and supporting a persistent behavior change, before the contributions are summarized in Section 5.

2. METHODS

The main goal and starting point for our work is to disseminate evidence-based medical and health knowledge and best practice knowledge to an individual in a context where it is useful, and tailored to the individual. The reason for using established domain knowledge is for optimizing quality in the health services provided the user. Consequently, a knowledge-based user modeling approach is required, which is combined with methods for identifying specific individual features [19]. Our work that aims to identify specific individual features is based on two main theories: Cultural-Historical Activity Theory (e.g. [15]), which provides systemic models for describing and explaining humans' purposeful behavior in a context, and the Self-Determination Theory (SDT) [32] regarding development of motivation in humans. In particular, we apply the activity-theoretical model of purposeful activity, which is oriented towards an *objective* serving *needs*, where the needs are specified by SDT (*autonomy*, *relatedness* and *competence*). Moreover, we apply the SDT concepts *intrinsic* and *extrinsic* motivation, meaning internally motivated or externally motivated activities respectively.

A case study was conducted as a part of a participatory action research process (e.g. [26]). This means that the participants in the case study were considered stakeholders, representing future users of the system, and were thereby

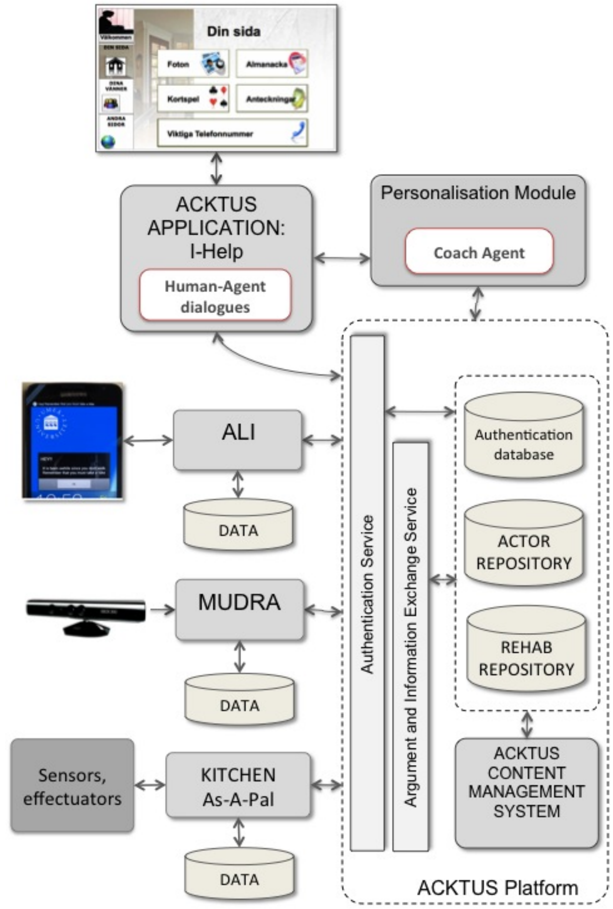

Figure 1: As-A-Pal architecture with the modules used in the study.

directly involved in the formative evaluation study and indirectly in the development of the software. The study involved two experts in the rehabilitation domain, two young individuals and one senior individual as end-user participants, in addition to knowledge engineers.

2.1 Instruments and software

The domain knowledge was modeled and integrated by domain professionals in an end-user development process using the ACKTUS content management system [21, 25] (Figure 1). ACKTUS (Activity-Centered Knowledge and interaction modeling Tailored to USers) is a semantic web application that is designed to allow domain experts who are typically not familiar with knowledge engineering to author and model the knowledge content of, and design the interaction with, knowledge-based applications [25, 24]. The platform allows the user to model the knowledge into knowledge bases (Rehab Repository in Figure 1) by extending the ACKTUS core ontology. The core ontology was developed for representing the knowledge about the domain, the user and the context [25]. The ontology was created based on models of human occupation (e.g., [15, 32]), the International Classification of Disability, Functioning and Health (ICF) provided by the World Health Organization[1], and other medical ter-

[1]http://www.who.int/classifications/icf/en/

minologies such as Snomed CT [23]. The person-specific information is associated to items in the knowledge base, and stored in the Actor Repository, which is structured as an event ontology (Figure 1).

The content of the ontologies is used for reasoning about diagnoses, treatment and advice to be given. Formal argumentation is used for the purpose to capture uncertainty, ambiguities and inconsistencies in the fusion of heterogeneous sources of data, in our study the sensor-based sources and the self-assessment information [12, 18]. The reasoning using heterogenous sources of information is enabled through a common language, the conceptual model for argument and information exchange based on an adaptation of the Argument Interchange Format (AIF) [8] accessed as a service (Figure 1). The arguments and information are instances of classes in the ACKTUS ontologies, which provide the semantics of the observation of, e.g., the human actor performing activities in a home environment. Consequently, interoperability is achieved among the systems which conforms to this common vocabulary.

The As-A-Pal architecture was initially presented in [22] and is an expansion of the ACKTUS architecture (Figure 1). The architecture has in this work been further developed and implemented with embedded modules for activity recognition and activity interpretation in ambient environments. The Rehab Repository was extended with content that is used for assessing goals and priorities. This information is used for building the user model by the personalization module developed for this study (Figure 1). The following functionalities and services of As-A-Pal were combined in the assessments and management of personalized assistive services in our pilot study:

1. An *(self-)assessment instrument* contained in the application I-Help, which in our study was used by the participant during the baseline assessment interview with the therapist, and in the followup assessments,

2. *Activity recognition* and updates based on the information obtained through different sensor-based systems,

3. *Agent-Based Reasoning* In this work the concept of a *Coach Agent* is implemented in the personalization module [22, 4] and the human-agent interaction is mediated through the I-Help application [5]. The added value of applying the agent approach is to utilize autonomous and realtime reasoning based on the different sources of information in a smart environment, and for management of the assistive services. In addition to the Coach Agent, the concept of an *Activity Agent* is deployed in a mobile application, which assesses the physical activities and monitors the tailored messages provided the participant [12].

Different methods for capturing ambient information and for refining the information are being developed for the following three approaches, which was used in the pilot study:

1. A *sensor network* integrated in a kitchen environment (Kitchen As-A-Pal), which detects state transitions for common objects, human presence, and object manipulations (Figure 2) [34, 28],

2. *3D sensor-based*, which is a lightweight solution for detecting body posture, gestures, objects and object manipulations (MUDRA) [3],

3. *Mobile device and its sensors*, to be carried around in and outside a home and/or work environment, detecting different types of movements and activity patterns (ALI) [10, 12].

Figure 2: The As-A-Pal kitchen environment.

For tailoring the support for the targeted activities the two young adult participants modeled personalized recommendations which they preferred to be given, and under what conditions they should be presented. These recommendations were integrated into the system before they used ALI during the baseline assessment.

2.2 Pilot study

We conducted a pilot study targeting the initial phases of the therapeutic assessment and intervention procedure: i) initial assessment - the establishment of a holistic understanding of the client (i.e., the *user model*) and a plan of interventions, ii) the implementation of the plan and iii) an initial followup on the implementation, where our study targets revision of the user model and plan of interventions. A summary of the workflow of the study is shown in Figure 3.

We limited our scope regarding assessment and multi-intervention to the domains *physical* regarding balance, strength and pain; *social* activities and support; and *mental* including worries, cognition and wellbeing. This scope was regarded as broad enough to function as an holistic assessment, since it includes aspects, which taken together relate to all needs specified by Self-Determination Theory (SDT) (autonomy, relatedness and competence). Also, these domains are very commonly and to an increasing extent causing impairments in both the older and younger populations [38, 37, 36, 1, 27]. Extensions to additional domains will be in the near future to address incontinence, which affects social participation negatively in all ages where it occurs. Chronic obstructive lung disorder (COPD) will be another domain to consider in our future work.

Our main goal with the pilot study was to explore in a formative manner, the potentials of including active (semi-autonomous) assistive technology in the therapeutic procedure and explore barriers, which need to be bridged through design choices or technology development. This was done by executing the therapeutic procedure as done in clinical practice with prototypes included as instruments in three case

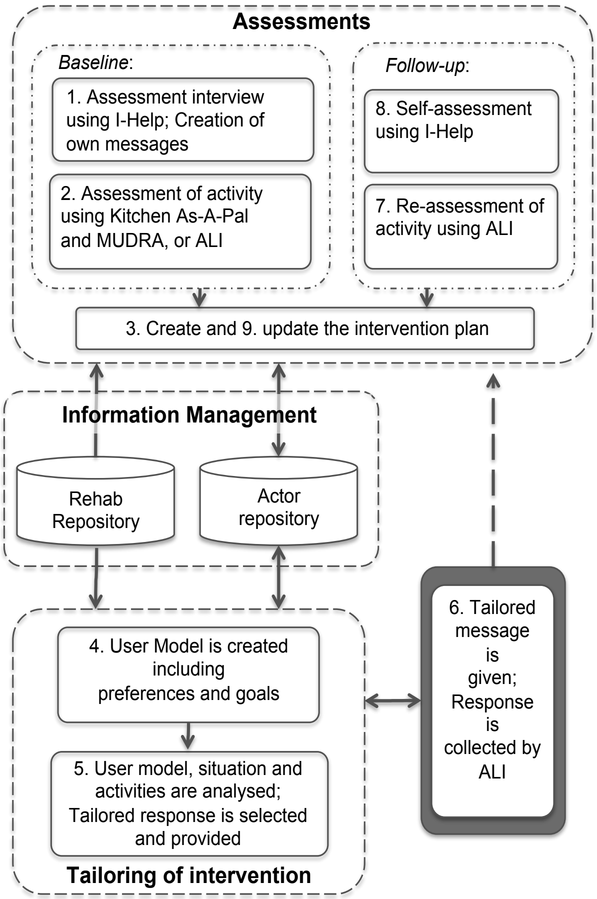

Figure 3: The workflow of the study.

studies, and with particular focus on the holistic approach to creating and managing the user model (Figure 3).

We were also interested in exploring how the participating clients approach the task of defining own arguments, which may increase the actor's compliance with agents' suggestions about changed behavior.

We selected a convenient sample of three subjects for our study who matched the age categories young adults (18-24) or older adults (older than 65 years). The participants were two young female adults (18 years old), who we call Anna and Sara, and an older female adult (67 years old), who we call Sabina. Written informed consent was obtained by the participants.

In addition to these three participants, two occupational therapists were participating for conducting the assessments and forming plans for interventions. The two therapists also participated in knowledge engineering of the I-Help application.

Our pilot study was organized in the following way, following the typical routine by which rehabilitative interventions are formed, deployed and followed up.

Each of the three participants was at an initial occasion interviewed and assessed by an occupational therapist (Figure 3). In this process they used the web-based I-Help application. Depending upon the participant's needs, goals and priorities, activities considered as important to the individual were identified by the individual and the therapist together, which were to be supported. A corresponding assessment was done in parallel by the Coach Agent (CA) based on the information, forming a baseline for the user model.

At a second occasion the participants were observed and assessed, while conducting one or more selected and prioritized activities that they wanted to be able to accomplish. These two assessments formed a baseline for the computer-based interventions. At the second occasion functionalities of the smart environment was applied, selected based on the individual's preferences and goals, and partly to form a baseline also for the system. The older adult performed her breakfast routine in a controlled smart kitchen environment partially shown in Figure 2, and the two young adults used the ALI smart phone application during two days for assessing mobile activities. The therapist and the participant formed based on the assessments a plan containing what interventions would be suitable to implement for the purpose to improve their situation.

After this, the two young participants followed the plan during a period of two weeks, during and after which the interventions were followed up and adjusted. The older adult did not continue using the technology during an intervention period due to primarily technical reasons.

3. RESULTS

The main results of the knowledge engineering tasks performed by the therapists were the development and digitalization of a set of assessment instruments, which they modified and connected using functionalities of the platform. By applying these assessment instruments, the system can generate a user model incorporating priorities and preferences regarding the individual's goals and behavior of the assistive technology.

One such contribution is a protocol for the assessment of priorities and goals. This protocol highlights a set of key activities, which the therapists selected for a baseline assessment. During the baseline assessment conducted using (computer-supported) interviews, the client specifies for each activity the following:

1. the degree of importance to the client following a five item scale ranging from *not important* to *most important* (*Importance* in Table 1),
2. to which extent the activity is currently being performed in a satisfactory way. The categories of degrees relate to satisfactory or not satisfactory, here distinguished between too extensively, or too little (*Satisfaction* in Table 1),
3. whether or not the client want to have support from assistive technology to manage the activity, and thereby define a goal relating to this activity (*Intervention* and *Desired goal* in Table 1).

The therapists also modeled and developed protocols for tailoring exercise, assessing risk for falling down, pain conditions, sleep disorder and worries.

This information can be used for generating a *personalized model of each activity*, which can be related to the basic needs specified in the Self-Determination Theory (SDT) *autonomy*, *competence* and *relatedness*. Autonomy and competence are dependent on the individual, and are therefore taken into consideration in the activity models illustrated in

Table 1: Nine different potential models of the same activity (A_i), depending on how the character is valued by the individual. In our study the the activities forming the models A_4 to A_7 were targeted for intervention following the person's wishes.

Character	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
Importance	Yes	No	No	Yes	No	Yes	No	No	Yes
Satisfaction	Satisfied	Satisfied	Too little	Too little	Too little	Too much	Too much	Too much	Too much
Desired goal	No	No	No	Yes	Yes	Yes	Yes	No	No
Autonomy	Yes	Yes	Yes	No	No	No	No	No	No
Competence	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Motivation	Int	Ext	Ext	Int	Ext	Int	Ext	Ext	Int
Intervention	No	No	No	Yes	Yes	Yes	Yes	No	No

Table 1. The fulfillment of relatedness is dependent on the settings of a particular activity. Consequently, a subset of the activities selected by the individual is expected to fulfill the need for relatedness, e.g., spending time with family members.

The information can also be interpreted using the SDT concepts of activities motivated *internally* or *externally.* While internally motivated activities are more likely to be conducted, the externally motivated may become transformed into internally motivated activities by time and engagement. We interpret an activity as externally motivated when the client value its importance low and vice versa (Table 1).

The Coach Agent forms a *preference model* of the client's prioritized goals based on the level of importance that the client specifies for each activity (Table 2 and 3). This part of the user model is used by the Coach Agent when selecting among supportive actions and initiating dialogues. As will be exemplified, this model needs to be updated when the client's situation changes.

The case studies of the three clients illustrate the broad range of individual preferences and goals. Conflicting goals were also identified, both within the individual, and between the individual and the environment. This could be due to changing priorities in the individual due to changing circumstances, or "avoidance behavior", where the client prefers to avoid challenging situations, which the therapist encourages the client to become engaged in for improving function, competence and autonomy. This illuminates also the importance that a semi-autonomous system should be continuously adapting to changing goals and preferences, and be built on a knowledge base, which can aid the system in distinguishing when a certain behavior is healthy and when it is not. The following examples from the case studies illustrate such situations.

3.1 Perception of Generated Advices

The advices provided Sara through the cellphone were perceived appropriate, but not timely, which was due to that the system was unaware of what activities Sara had ongoing in different situations other than those that the system was designed to recognize.

The advices provided Anna were also perceived appropriate, and also timely. Timely in the sense that she could have complied with the advices, if she had been "a bit more motivated". When Anna was shown a summary of her activities detected during the days she had been using the ALI application, her interest became triggered. The reason was likely because she received an overview of her accomplishments in the form of walks through the forests with her dog and the maps were familiar. However, since the evaluation study did not continue during a longer period of time, the potential impact such feedback could have on her motivation remains to be investigated.

3.2 Same Activity and Goal, Different Preference Levels, Different Recommendations

The two young adults had different priorities and goals. Sara assessed highest importance to all social activities, and wanted support for finding and maintaining a healthy level of activity and exercise routines. Anna rated generally the importance of social activities low, even grading being in public contexts as occurring far too often (Table 3). This difference mirrors the actual time each of them spent among people. Consequently, both reach their goals regarding social contacts and networks.

Anna was aware of that she needed support for routines regarding school and work, however, to receive support for this was not prioritized by Anna (corresponding to A_3 in Table 1). Anna's plan of interventions targeted meal, exercise and sleep routines (Table 2), with reminders created by Anna particularly about medication (A_4), exercise (A_5) and visiting her grandmother (A_4). After some consideration, she chose to also include support for school routines knowing that she was expected by her environment to perform the tasks, although they were ranked low in importance (A_3 changed to A_5). This is an example of externally motivated activity. Our system ranks the individual's goals both by their assigned importance level, and by the level of satisfaction is associated with the conduction of the activity. If an activity is ranked low, but the individual still selects it to be supported due to the dissatisfaction, the system assumes it to be an externally motivated activity (corresponding to A_3 in Table 1). Consequently, the system may tailor the encouragement messages differently, depending on which type of motivation is behind the goal. One example of an own-formulated motivational message to be delivered Anna in the externally motivated activity was: "Now you have spent enough time school-working, now you deserve to sleep!". More energy and emphasis was put in creating messages confirming her own attitude towards the activity, which was also well received, than arguments that were externally motivated.

The contrary was seen in Sara, who formulated arguments, which in rough terms ordered her to stop being lazy and get her ass out to do some exercise. This was an activity that was internally motivated in her case, corresponding to A_4 in Table 1.

Table 2: Example of results of a baseline assessment: Anna's priorities and goals, and the priority levels computed by the Coach Agent, which the Coach Agent uses for adapting its behavior in dialogues with Anna.

Priority level	Prioritized Topics	Valuation of Goals	Preferred support
1	Anna has *some difficulties* taking her medication	Anna thinks it is *important* to take her medication	Yes
1	Anna is *pretty* worried about what people think and about becoming ill	Anna thinks reducing worries is *important*	Yes
1	Anna is exercising *rarely*	Anna thinks it is *important* to maintain exercise routines	Yes
2	Anna sleeps *well*	Anna thinks it is *most important* to be satisfied with her sleep routines	Yes
2	Anna is able to begin with the things she needs to do to *a bit too little extent*	Anna thinks it is *important* to accomplish her duties in a satisfactory way	No
2	Anna is seeing close friends and family *enough*	Anna thinks meeting friends and family is *important*	Yes
3	Anna thinks that she keeps up with society to a bit too much extent	Anna thinks that it is *important* to keep up with society	No
4	Anna is participating in social activities *far too much extent*	Anna thinks that being in environments among a lot of people is *not important*	No
4	Anna has *no difficulties* preparing meals	Anna thinks that it *very important* to have at least one cooked meal each day	No

3.3 The Complexity of Multi-Intervention

Sabina, the client who was an older adult, had done part of the breakfast routine in the controlled kitchen environment a few days before the assessment, then for the purpose to explore which equipment and procedure was familiar to her, and for preparing the assessment. At this occasion an assessment was also done to inform the ambient system about the *perceivable* spaces, due to her visual impairment, and the *reachable* spaces, due to her need to use the walker for stability. This information would have been used at a later stage in case the study had included a longer period of testing. Then feedback and information would be given to Sabina about the environment, e.g., if she has lost some object due to her sight problem.

During the assessment, Sabina was moving around in the kitchen using her walker, which she also used as a tray for the objects, which she wanted to carry along, e.g., from the fridge to the preparation space, and to the kitchen table. She prepared porridge, boiled an egg on the stove, cooked the porridge in the microwave oven and toasted a piece of bread in the toaster after having seated by the table. While sitting by the table she read the news and had her breakfast.

The therapist observed that Sabina was able to carry out the breakfast routine as usual, organizing her things and procedure in an sufficiently efficient way. However, the mild memory dysfunction was observable in the forgetting of the coffee and pills (the therapist prompted Sabina about this), and a slow pace was also observed in thinking and acting. The observation confirmed the interview-based assessment done earlier.

Based on the initial assessments the following intervention plan was created. Sabina needed and desired support for managing medication, reminders about meals and social contacts, interventions for reducing worries, isolation and pain, and interventions for increasing balance and strength for reducing risk for falling down. At this stage, no further computer-based interventions were provided Sabina, partly due to the limitation of the technology. The installation of the smart home environment in her home was not practically feasible at the time of the study, and the mobile intervention for improving strength and balance would first be subjected to a feasibility study, in which Sabina was offered to participate in. However, the formative purpose of the pilot study was met, since requirements for further developing the technology supporting multi-intervention was identified. These included include extending ALI with qualifier measurements of physical activity, which has partly been achieved [11], As-A-Pal with a module for cognitive training and a social arena for performing intervention activities together with others. The smart home environment in the form of a sensor network deployed in a home environment is also further developed, feeding information into the multi-agent system for reasoning about activities and service provision in the multi-intervention perspective.

4. DISCUSSION

Other approaches also take a real world situation as starting point and frame the need for agent-based support [13]. SHARE-IT [9] (Supported human autonomy for recovery and enhancement of cognitive and motor abilities using information technologies) implements a combination of multi-agent system and other techniques to aid the elders based on user scenarios [2]. The agents hold information about all physical devices that exist in the environment to control daily living activities and the conceptual world's information. A difference in our work is that we integrate *assessment* into the context of use, and aim at using the professionals' instruments for continuing followup performed by software agents in the ubiquitous environment.

Table 3: Example of the results of a followup assessment: Anna's revised priorities and goals after the first followup assessment.

Priority level	Prioritized Topics	Valuation of Goals	Preferred support
1	Anna is *very* worried about what people think and about becoming ill	Anna thinks reducing worries is *most important*	Yes
1	Anna sleeps *badly*	Anna thinks it is *most important* to be satisfied with her sleep routines	Yes
2	Anna has *some difficulties* taking her medication	Anna thinks it is *important* to take her medication	Yes
2	Anna is exercising *rarely*	Anna thinks it is *important* to maintain exercise routines	Yes

To our knowledge, there is no other framework for assistive technology which utilizes a user model, which combines and synthesises theories of human occupation [15] and motivation [32] in combination with classifications and terminologies from the health domain. Moreover, we have not found any other research study, which combines these theories and terminologies in a formal and digital context for the purpose to achieve a continuous holistic assessment for automated generation of just-in-time, adaptive intervention to the individual.

Developing user models for ubiquitous computing environments possesses challenges [19, 7, 18], as well as developing assistive technology aimed at changing the behavior in a person, e.g. to adhere to an intervention [17, 32, 29]:

1. the lack of initial user information ("the cold start problem"),
2. heterogeneous sources of user modeling information with limited interoperability,
3. the need for continuous adaptation of a user model due to changing context,
4. changing attitudes and needs in the individual, and changing behavior.

If active and healthy living and aging is aimed to be promoted, the activities perceived as purposeful and desired by the individual need to be identified and supported [15, 31]. Moreover, this adaptivity should be provided on the basis of conditions defined and regulated by the individual [6]. We have presented a knowledge-based approach to meet these challenges.

4.1 The Cold Start Problem

The "cold start problem" is partially handled by the As-A-Pal architecture through the initial assessments done by therapists, which generate a minimal set of information about a person's health, abilities, motives and priorities. This minimal baseline set of information can be used by a system agent for creating a user model suitable for the purpose at hand, for instance, modeling the priorities and goals, which are used for tailoring interventions as shown in the article. The initial lack of the user information, which the ambient systems need, can also be partially handled by using the derived priority list of activities to be supported, for the purpose to make the initial data collection and refinements for creating a baseline model of typical activity trajectories for a particular user. Ongoing and future work includes the comparison of the trajectories obtained with the different ambient systems, and with professional assessments of motor and process skills. One purpose is to assess the reliability of the ambient systems' assessments of activity conduction and performance, to be included in the agent-based reasoning about contradictory information.

4.2 Handling Multiple Sources of Information

The actor and activity ontology is partly based on a holistic model of ability, dysfunction and health provided by the World Health Organization, which is familiar to health professionals. This differentiates our ontology from e.g., the semantic user model presented in [14], which separates the user ontology from the environment ontology, and matches the two for the purpose to identify handicap situations, mainly due to constraints in the physical environment. The ACKTUS core ontology is used as a common vocabulary for the different applications, which handle different sources of information.

4.3 Adapting Multi-Intervention

A challenge highlighted related to user modeling in smart environments is the need for continuous adaptation of a user model and consequently, the agent's behavior due to changing context [19, 7, 18], and attitudes and needs in the individual. While research on adaptive systems typically addresses physical limitations such as visual or mobility impairments, which are often stable over time (e.g., [14]), we address different kind of limitations including mental conditions in this article. This adds importance to the evidence-based health knowledge on which the interventions are based.

We recognize that mental conditions are common in all ages, both triggered and inhibited by circumstances in the social and cultural context and may affect anyone at some point in their lives (*e.g.*, [1]). Moreover, they are highly intertwined with activity performance and motivation, thus essential to take into consideration in reasoning about appropriate and tailored support to individuals. Consequently, "multi-intervention" is targeted as a natural effect of holistic assessments and user modeling, which means providing an individual a composition of tailored interventions targeting different areas, which need to be improved. This methodology has proved to give effect in recent studies [27].

The major reason for applying multi-intervention targeting also mental health is because the major causes of, and obstacles for changing unhealthy living patterns, are mental and neuropsychological conditions. In our case study the two young participants expressed two very different attitudes towards social activities. Consequently, both more or less reached their goals regarding social contacts and networks and if it were to be changed, it would have been more of the same, meaning that the socially very active Sara would be even more active, and the comparably socially inactive Anna would prefer to decrease this activity. However, if Sara would have been pushing her social activities together with all other activities to the border of exhaustion, and if Anna would have been isolating herself to the extent that it would affect her daily work, e.g. as a symptom of social phobia, anxiety or depression, their seemingly normal behavior would need to be addressed as symptoms of an underlying mental health disorder (e.g. [36, 38]). Consequently, encouraging the increase of social contacts based on the individual's own goals can be appropriate in one individual but not another, even appropriate to different extent in different time periods due to changing life situation for the same individual, and this difference a semi-autonomous system needs to have methods to assess. Based on this type of uncertainty and ambiguity, we argue that a careful and evidence-based initial assessment needs to be done, also when integrating semi-autonomous systems. These assessments should be supervised by a therapist in order to interpret the nature of an individual's behavior into a baseline user model, which can subsequently be enhanced, validated and adapted using agent-based methods.

4.4 Motivation and Behavior Change

Changing habits and coping strategies requires more mental effort and dedication than continuing with an internalized behavior pattern, which constitutes a part of the habitual system of an individual [17]. To be able to perform and engage in activities our interests, habits, routines, motivation and self-efficacy are important factors to consider [17]. For this purpose, we conducted a case study, where the potential end user representatives design their support systems, by means of arguments and motives as instruments for the agents, which they believe will have impact on their own behavior. These were interpreted addressing both internally and externally motivated activities, following the Self-Determination Theory (SDT) [32]. Consequently, our approach aims at evoking and reinforcing the individual's own capacity to change behavior, instead of primarily using external sources for imposing change, which the individual may object to.

However, the results regarding effects on motivation obtained in our case study were limited, partly due to the limited time during which the tailored applications were used. In one case, the limitation was due to that the context of use was not fully integrated for the arguments to be timely, and in the other case there were indications that the arguments should be augmented with partial visualizations of the user model for increasing motivation. The presentation of selected parts of the user model in relevant situations may contribute to motivating the user to comply with the chosen activity support, which will be investigated in future studies.

4.5 The Knowledge-Based Approach to User Adaptation

A limitation of the knowledge-based approach, is that the knowledge integrated into the systems is limited to the knowledge domains, which the domain experts represent. Moreover, the engineering of such systems is often the bottleneck of the development since it requires time and expertise [19, 33, 35]. We have addressed this problem by introducing ACKTUS, which allows the domain professionals to create knowledge-based web applications and design the content [24, 21, 20, 25]. It should be noted though, that in order to investigate the limitations of the knowledge content, user studies need to be conducted involving a larger number of participants of different age, gender, priorities and needs.

However, a user model is defined in terms of semantics models in our knowledge-based approach, which gives at least the following advantages:

1. agent-based reasoning mechanisms can be implemented by the architecture in order to support decision making related to diagnosis, choice of intervention and the behavior of the system;
2. data-interoperability can be managed between the different sub-systems of the architecture; and
3. since the semantic models captured by the ontologies can be extended, our user models are scalable.

In other words, the suggested user models and reasoning mechanisms can be extended to different user domains.

5. CONCLUSIONS

The major contribution of the presented work is a method for computer-supported assessment for tailoring agent-based assistive technology in a multi-intervention perspective.

For achieving the holistic perspective, the architecture integrates a generic core ontology based on medical and health terminologies, models of human occupation and motivation, and a model of egocentric interaction in ubiquitous environments. The core ontology is used for knowledge representation and reasoning, and for sharing information between systems. For interoperability between systems in the architecture, the systems utilize parts of the core ontology as a common vocabulary, and communicate information through a dedicated service.

The information used for creating the initial user model is collected by means of the routinely conducted clinical interviews and observations of activity, done by a healthcare professional as part of initial assessments of a client. Based on the information, the system agents create a baseline user model. In this work we investigated in particular how priorities, motives and goals are represented, adjusted and used for tailoring interventions to individuals' needs.

A pilot evaluation study was conducted, which demonstrated how the initial assessments formed a base for interventions, through user models capturing prioritized activities and corresponding needs and desire for support. The results showed limitations in how the context of use was integrated, and gave indications on the potentials in using visualizations of the information obtained by the ambient systems in combination with own-created arguments functioning as instruments for agents for increasing motivation in the user.

Future work includes an evaluation study conducted over a longer period of time, for the purpose to explore how the support needs to be adjusted to changing motives, goals and priorities in an individual. Further implementation work is being done, including improving the timing of feedback and support by integrating more contextual information, and improving the human-agent dialogues, partly by integrating dialogues for persuasion and negotiation.

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