PHD THESIS PROPOSAL: A User-Adaptive and Context-Aware Architecture for Mobile and Desktop Training Applications

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1 Introduction

Since the late 1970's, artificial intelligence, user modeling, and human-computer interaction communities have been researching on user-adaptive systems, i.e. interactive systems that adapt their behavior to individual users on the basis of processes of user model acquisition and application that involve some form of learning, inference, or decision making [28]. Research efforts led to compelling and diverse results meant, for example, to tailor information presentation, recommend products or other objects, give help, adapt an interface, and support learning. The latter goal was on the basis of a class of user-adaptive systems called intelligent tutoring systems, i.e. computer-based instructional systems with models of instructional content that specify what to teach, and teaching strategies that specify how to teach [37, 49]. These systems have been widely employed in the e-learning and work training domains, while other training domains (e.g., fitness training) are scarcely explored. Moreover, current solutions mostly rely on user and domain models as well as traditional mouse and keyboard input, while other kinds of inputs are only occasionally employed to identify particular work training actions or to estimate user's attention and motivation.

Complementary, in the middle 1990's, the ubiquitous computing and the human-computer interaction communities started researching on context-aware systems, i.e. software that adapts according to the location of use, the collection of nearby people, hosts, and accessible devices, as well as to changes to such things over time [40]. The notion of context on the basis of these systems was then extended in [41] to cover a wider variety of aspects, such as environmental conditions (e.g., light, temperature), infrastructure (e.g., available networks, computational resources), and human factors (e.g., tasks, users). This has recently led to a partial merge of the two research topics of user-adaptive and context-aware systems as well as to a the first proposal to distribute user and context information among different web-based, desktop, and mobile applications [21]. However, further research is needed to tailor user-adaptive techniques for context-aware systems, expecially for mobile and ubiquitous ones, and to integrate a richer context-awareness in user-adaptive systems.

Therefore, the aim of the thesis is to analyze proposals from the different research areas of user modeling, ubiquitous computing, artificial intelligence, and human-computer interaction and research on how these proposals can be adapted and merged together with new ones in a user-adaptive and context-aware architecture for mobile and desktop training applications. A distinguishing feature of the architecture will be the exploitation of virtual humans, i.e. three-dimensional simulations of human beings, which seem to be promising to improve effectiveness and motivation, since they can attract users' attention and convey conversational and emotional cues [2, 33]. To evaluate the effectiveness and the scalability of the architecture, it will be employed in desktop as well as mobile training applications for the fitness and the e-learning domains.

This PhD thesis proposal is organized as follows. Section 2 covers thesis background and related work in three subsections devoted to user-adaptive systems, context-aware systems, and virtual humans. Section 3 introduces a proposal for the architecture and poses the related research questions. Section 4 presents the results achieved so far, i.e. two early and partial designs of the architecture, two pilot applications, and a tool to simplify and speed-up the modeling of virtual human animations. Section 5 concludes the PhD thesis proposal planning future work.

2 Background and related work

2.1 User-adaptive systems

To behave differently for different users, user-adaptive systems rely onto two key components, namely user models and adaptation strategies. A *user model* is a representation of information about an individual user [4]. To design a user model, three fundamental questions should be addressed [42]: what is being modeled (i.e. the nature of the information)? how it is modeled (i.e. the structure of the model)? how models are built and maintained (i.e. the approaches to handle the model)? Considering the nature, a user model can deal with information about users' conceptual knowledge (i.e. facts and relationships), procedural knowledge (i.e. problem solving skills), interests (i.e. items the user likes), immediate purpose (i.e. goals and tasks), background (i.e. experience outside the core domain), and individual traits (i.e. personality traits, cognitive styles, cognitive factors, learning styles).

Information about knowledge (both conceptual and procedural) can be structured in scalar models that uses quantitative or qualitative values. For example, MetaDoc [3] represents user knowledge of Unix as a qualitative scalar value (novice to expert) and then adapts content proposed to the user by using stretchtext, i.e. a collection of text boxes which are expanded or collapsed if their content is, respectively, more or less suited to the user. Other representations to handle knowledge information are structural models, which divide knowledge into independent fragments. The most popular type of structural model is the overlay overlay model where individual knowledge is seen as a subset of the domain model. This last model can be a set of unrelated concepts, an hierarchy of concepts (from high-level to elementary), a network model (with many different relationships), or even a formal domain ontology. For each fragment of the domain model, the overlay model stores a binary value (boolean), a weighted value (qualitative, numeric, or uncertainty-based), or layered values (separate pieces of information from different sources), which represent user's knowledge about that fragment. An example of tutoring system which exploits an overlay model of students' knowledge to select content and recommend links is AHA! [14].

Users' interests are structured as a weighted vector of keywords or as a weighted overlay of a concept-level domain model with semantic links. An adaptive museum system which models users' interests in designer, style, and origin of jewelery items is presented in [36]. Goals are organized in an overlay-like goal catalog or in a more structured goal hierarchy. For example, the PUSH system [25] has a catalog of goals, deduces current one by observing user's actions, and uses stretchtext to adapt content presented to the user.

Background is usually structured in a simple stereotype model, i.e. each user is fit to a particular class of users. For example, [47] distinguishes users of a medical adaptive system by their profession and selects medical terms or everyday language accordingly. Individual traits are modeled following Witkin's field-dependent / independent [50] or Pask's holistic / serialist [39] guidelines. AES-CS [46] is an example of adaptive system for the e-learning domain where field-independent users can control navigation, while the other users proceed sequentially and have orientation support tools.

Considering user modeling approaches, Kobsa [30] has recently provided an exhaustive state of the art from the origins to current proposals. The first applications exploiting user models handled them inside the application itself, but, as user model complexity grew, the General User Modeling System (GUMS) [16] and user modeling shell systems [29] started to be designed as a separate and dedicated component. User modeling servers shared among applications and platforms are now a widely employed solution, while agent-based user modeling, where each user has its own agent, is a recent research trend. User modeling approaches can be also divided in those which collect information explicitly asking the user, those which implicitly elicit it by observing the user, and those which combine both the previous strategies.

While user modeling is devoted to the collection, the organization, and the storage of user information, the *adaptation strategies* exploit it to achieve the following goals [31]:

- *Adaptation of content*: the relevant content should be selected and adapted in accordance with user, usage and environment data (e.g., a novice user of a training system will be provided with explanations for basic tasks, while an expert user will be provided with advanced information).

- *Adaptation of presentation and modality*: presentation and media format as well as interaction elements (e.g., buttons, text fields) should be changed considering user needs (e.g., a blind user will require vocal descriptions instead of images).

- *Adaptation of structure*: the presentation of links should be personalized (e.g., some links can be suggested with a particular annotation or putting them first in a list of links).

Focusing on content adaptation, earlier solutions simply selected a page of content from a set (page variants), while later proposals (e.g., AHA! [14]) dynamically compose a page of content combining different fragments (fragments variants). Content presentation strategies [5] mainly consist in relevance-based techniques such as the previously mentioned stretchtext and coloring, sorting, or scaling fragments, and techniques for media adaptation such as using different types of media for different user-specific features or technical resources.

While commonly applied in the e-learning domain, user-adaptive systems have been scarcely employed in the fitness domain. One of the few applications which exploit some user information is the commercial Eye Toy: Kinetic fitness training system [43] for Playstation 2. However, unfortunately, the system only considers a few demographic information to choose a game level and updates it once a week by considering session results (i.e. the scores achieved in the proposed games).

2.2 Context-aware systems

When context-awareness was defined in 1994 [40], the early research efforts was spent on location-based applications such as the first mobile tour guides [1]. However, in 1999, Schmidt et al. [41] claimed that there is more to context than location and demonstrate their thesis by designing and developing two demonstrators. The first was a light-sensitive display obtained by integrating a light sensor in a Palm Pilot PDA which allowed users to have display backlight automatically adapted as light conditions changed. The second demonstrator was an orientation-sensitive user interface: by adding two mercury switches the PDA became aware of the orientation, so that the user interfaces could adapt their elements accordingly. Besides describing the two demonstrators, the article proposed a working model for context and a four-layered architecture for sensor fusion, i.e. the combination of several different sensors to obtain more information than the sum of each sensor one. At the first layer of the architecture, each physical or logical sensor is regarded as a time dependent function that returns a scalar, a vector, or a symbolic value. At the second layer, cues, regarded as a function taking the values of a single sensor up to a certain time as input and providing a symbolic output, provide an abstraction from sensors. The third layer regards contexts as descriptions of the current situation on an abstract level, derived from the cues that are available. The fourth layer, the scripting one, provides mechanisms to include context information in application, supporting semantics “entering a context”, “leaving a context”, and “while in a context”.

Since the notion of context has been extended in the ubiquitous computing community to include information about the user, and user modeling community has begun considering context information beyond user, user-adaptive systems and context-aware ones has started merging together. Figure 1 provides context views from the perspective of user modeling and ubiquitous computing communities [4]. In general, a thumb rule to split information into user and context models is considering how long the information keeps its validity [4]: user models usually contain information (e.g., birth date, user interests) that lasts longer than context information (e.g., heart rate, temperature).

A recent proposal which handles both user and context models has been the object of the research discussed in [21]. This PhD thesis presents the user model

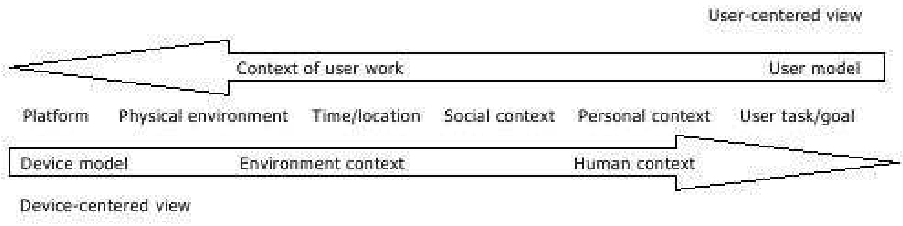

Figure 1: Context from user-centered (user modeling) and device-centered (ubiquitous computing) views [4].

ontology GUMO [24], UbisWorld ontology [22] to model context information, and a service to distribute user and context models among different web-based, desktop, and mobile applications by means of the UserML user modeling markup language for ubiquitous computing [23].

An important class of context-aware systems are adaptive mobile guides. An updated state of the art about adaptive mobile guide proposals, including those which exploit both context and user information, has been summarized in [32]. A proposal particularly relevant for this thesis is PEACH museum guide [44], which exploits both mobile and stationary devices in real time and on site. PEACH provides the users with automatic content adaptations based on technical restrictions, user preferences and knowledge (e.g., it uses large images on stationary devices, while it uses videos on PDAs). A particular feature of PEACH is the use of comic-like 2D virtual characters which act as tour guides. Characters may easily transit from one device to another and the different available characters have different roles or present the same information under different perspectives.

Considering applications in the fitness training domain, only a few context-aware solutions have been proposed. Philips Virtual Coach [27] provides motivation while cycling on a stationary bike by considering user's heart rate. Masuko and Hoshino [34] exploit the same information to dynamically change the difficulty of a fitness game, i.e. a videogame where users play by performing physical exercises. Finally, MPTrain [38] is a mobile and personal system that users wear while exercising. MPTrain's software allows the user to enter a desired workout in terms of desired heart rate stress over time, constantly monitors user's heart rate and movements, and selects music with specific features that will guide the user towards achieving the desired workout goals.

2.3 Virtual humans

Virtual humans are increasingly attracting the attention of computer graphics researchers as well as companies, which are exploiting them in several domains such as training, medicine, ergonomics, and entertainment. To deal with the different aspects of virtual human animation, Funge et al. [18] proposed the modeling hierarchy shown in Figure 2.

Considering the geometric layer, a virtual human consists of different 3D surfaces and materials, while at the kinematic layer a virtual human is usually represented a set of rigid bodies, called *segments* (e.g., upper and lower arms, tight, skull), hierarchically organized and connected by *joints* (e.g., knees, shoul-

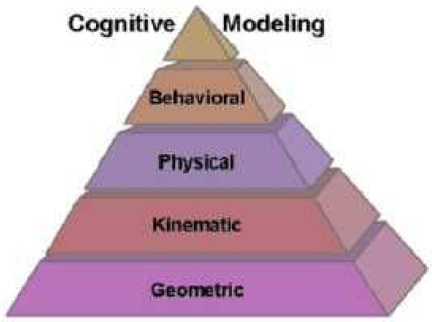

Figure 2: The modeling hierarchy proposed by [18].

ders, elbows), as proposed in the ISO H-Anim standard [26]. Following this model, an animation consists in a timed series of rotations applied to one or more joints. To determine these joint rotations, different methods have been proposed:

- *Direct kinematics.* This method requires the modeler to set all the rotation values of the involved joints for particular time instants, called *keyframes*. Rotation values for time instants between two keyframes are derived by interpolation.

- *Stream based animation.* This method uses a stream of rotation values acquired by motion capture, i.e. using sensors which record the movements of a real human.

- *Inverse kinematics.* This method derives the rotation values for all the involved joints by considering the required position for the end effectors (e.g., hands, feet) and conditions of constraint (e.g., degree of freedom, range of movement). This method requires less data from the modeler, but needs more computational resources, since a nonlinear system should be solved to obtain the required rotation values. A well-known set of inverse kinematics algorithms for anthropomorphic arms and legs is IKAN [45].

A further classification of motion editing methods, which considers how they enforce temporal constraints, can be found in [19]. At the physical layer, physical laws are applied to compute, for example, cloth [13] and hair [20] animation, while the behavioral layer deals with virtual human personality, moods and emotions [15]. The highest layer, the cognitive one, deals with what the virtual human knows, how that knowledge is acquired, and how it can be used to plan actions. Main research results concerning this layer are about conversational agents, i.e. virtual humans that have the same properties as humans in face-to-face conversation [11].

3 Proposal and research questions

As introduced in Section 1, the thesis will deal with user-modeling, ubiquitous computing, artificial intelligence, and human-computer interaction issues. The goal is designing and developing a user-adaptive and context-aware architecture for mobile and desktop training applications by adapting existing solutions and proposing innovative ones. A preliminary version of the architecture with its subsystems, modules, and databases is illustrated in Figure 3:

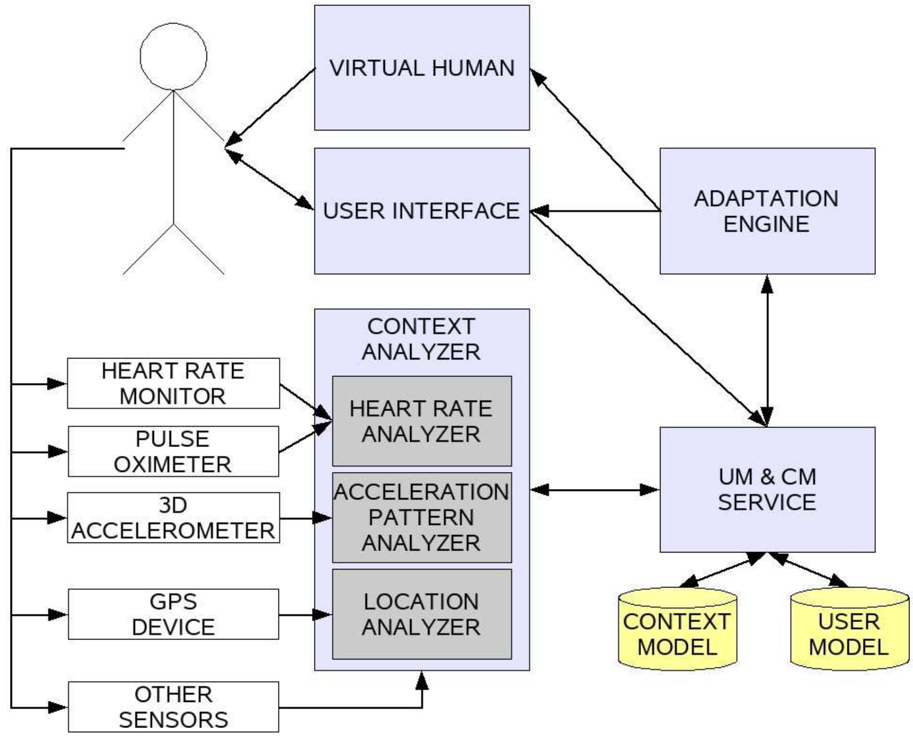

Figure 3: A preliminary version of the intended architecture.

- The *Context Analyzer* subsystem acquires raw data from available sensors, analyzes it to derive higher level information on the user's physiological state and movements, such as burnt calories and speed, and provides the UM & CM Service with all those pieces of information. In particular, the *Heart Rate Analyzer* module processes ECG data provided by an heart rate monitor and pulse data provided by a pulse oximeter to derive user's current heart rate and percentage of oxygen in the blood. The *Acceleration Pattern Analyzer* module processes acceleration data provided by 3D accelerometers and recognizes patterns that correspond to specific user's movements (e.g., a side-jump). The *Location Analyzer* module deals with GPS data to determine user's position, speed, and burnt calories by exploiting also information about the user (e.g., weight), available through the UM & CM Service.
- The *UM & CM Service* subsystem receives information about the user from the Adaptation Engine and the User Interface as well as information about the context from the Context Analyzer. The UM & CM Service stores this information in the User Model and in the Context Model databases and provides the Context Analyzer and the Adaptation Engine

with the information they require. Moreover, the UM & CM Service is meant for sharing user and context information among different instances of the architecture, e.g., to exchange performance information from a desktop fitness training application to a mobile one and viceversa.

- The *User Model* database stores personal information explicitely provided by the user (e.g., age, gender, weight, height) as well as implicit information acquired during the use (e.g., for the fitness domain, the number of times the user completed a particular exercise, the maximum volume of oxygen she can consume in a minute, the amount of time spent for a particular training goal). This information is available to the different subsystems through the UM & CM Service.

- The *Context Model* databases stores information acquired or derived from the sensors. This information is again available through the UM & CM Service.

- The *Adaptation Engine* subsystem considers the user and context information provided by the UM & CM Service and applies inference rules to decide if (and which) adaptations (e.g., for the fitness domain, an increase in the difficulty of a particular exercise) or advice (e.g., for the fitness domain, suggestions to avoid overexertion) are needed. Required adaptations and advice are asked to the User Interface and to the Virtual Human subsystems which are responsible for their actualization.

- The *User Interface* subsystem implements the Adaptation Engine requests providing the user with proper textual (e.g., written instructions), graphical (e.g., visualizations of particular values), and audio (e.g., a vocal advice) feedback. Moreover, the User Interface provides the user with interaction elements (e.g., buttons, text fields) and sends user inputs to the UM & CM Service.

- The *Virtual Human* subsystem is responsible for providing the user with advice and demonstrations by means of 3D virtual human animations. Following the Adaptation Engine instructions, the animations are adapted to both the user and the context.

The design and development of the proposed architecture requires to address the following research questions:

- *How can training efficiency and motivation be enhanced?* Achieving results from training usually requires not only an efficient and individually tuned training program, but also lots of motivation. Therefore, the thesis will explore different user-adaptive and context-aware techniques to improve training efficiency. Moreover, the thesis will investigate on the use of virtual humans and interactive activities (e.g., for the fitness domain, proper exercises and games) to enhance motivation.

- *How can virtual human animations be adapted?* A basic adaptation may simply choose a particular animation among different alternatives. However, more sophisticated adaptations (e.g., changing the duration, combining animations, altering rotations only for a part of the involved joints) might prove to be more effective. Therefore, the design and the implementation of such adaptations should be addressed and may require the extension of existing standards for virtual humans and their animations, such as ISO H-Anim [26].

- *How can training exercises be adapted?* In particular, the thesis has to identify and evaluate on users which elements of an exercise, a game, or a test can be altered to improve training efficiency and motivation.
- *Are the existing user modeling and adaptation proposals well suited for mobile devices or should they be adapted?* In particular, limited CPU performance and power consumption issues may require to simplify existing proposals or even design completely new ones aimed at the specific mobile needs and constraints.
- *Are existing user and context models well suited for the rather unexplored fitness domain?* In the fitness domain several information about the user and the context (e.g., current heart rate and speed) have a short term life. While the usual practice of storing information in persistent repositories, such as databases or ontologies, will allow to reason and perform adaptations on user's history and long-term information, short-term information that may even be life-critical in the fitness domain needs to gain priority and might be handled in a different way. Moreover, the relevant variables to evaluate user fitness and training efficiency have to be identified and organized in a user model.

4 State of the work

This section will introduce research carried out so far and provide references to the conference proceedings and the journal where results have been already published or accepted for publication. Results address the different research areas mentioned in Section 1 and consist in early and partial designs and implementations of the architecture proposed in Section 3 (Subsections 4.3 and 4.4), pilot applications (Subsections 4.2 and 4.5), and a tool to ease the authoring of virtual human animations (Subsection 4.1).

4.1 The H-Animator tool [9] and its integration in the MAge-AniM system [12]

Virtual human animation is a complex task which usually requires particular skills and training. To simplify this process we proposed a visual tool, called H-Animator, which aims to help animators (especially the novice ones) in modeling ISO X3D [48] animations for ISO H-Anim [26] virtual humans. Besides easiness of use, achieved through intuitive metaphors and interaction styles, our aim was providing an architecture to facilitate the reuse and sharing of X3D content, allowing animators to build a wide archive of material to be reused. The tool had also the immediate purpose of ease the implementation of subsequent works described in the following subsections. To display modeled animations on mobile devices, H-Animator has been integrated with the MobiX3D player [35] in the Mage-AniM system.

4.2 The MOPET fitness mobile guide [8]

Sports and fitness are increasingly attracting the interest of computer science researchers as well as companies. In particular, recent mobile devices with hardware graphics acceleration offer new, still unexplored possibilities. This work investigated the use of mobile guides in fitness activities, proposing the pilot application MOPET (an acronym for MObile PErsonal Trainer). MOPET uses a GPS device to monitor user's position during her physical activity in an outdoor fitness trail. It provides navigation assistance by using a fitness trail map and giving speech directions. Moreover, MOPET provides motivation support and exercise demonstrations by using an embodied virtual trainer, called Evita. Evita shows how to correctly perform the exercises along the trail with 3D animations and incites the user. To the best of our knowledge, our project was the first to employ a mobile guide for fitness activities. The effects of MOPET on motivation, as well as its navigational and training support, have been experimentally evaluated with 12 users. Evaluation results encourage the use of mobile guides and embodied virtual trainers in outdoor fitness applications.

4.3 The MOPET context-aware and user-adaptive wearable system [6]

Cardiovascular disease, obesity, and lack of physical fitness are increasingly common and can negatively affect people's health, requiring medical assistance and decreasing people's wellness and productivity. In the last years, researchers as well as companies have been increasingly investigating wearable devices for fitness applications with the aim of improving user's health, in terms of cardiovascular benefits, loss of weight or muscle strength. Dedicated GPS devices, accelerometers, step counters and heart rate monitors are already commercially available, but they are usually very limited in terms of user interaction and artificial intelligence capabilities. This significantly limits the training and motivation support provided by current systems, making them poorly suited for untrained people who are more interested in fitness for health rather than competitive purposes. To better train and motivate users, we proposed a new version of MOPET based on an early and partial version of the architecture proposed in Section 3. This version of MOPET is a wearable system that supervises a physical fitness activity based on alternating jogging and fitness exercises in outdoor environments. By exploiting real-time data coming from sensors, knowledge elicited from a sport physiologist and a professional trainer, and a user model that is built and periodically updated through a guided autotest, MOPET can provide motivation as well as safety and health advice, adapted to the user and the context. To better interact with the user, MOPET also displays a 3D embodied agent that speaks, suggests stretching or strengthening exercises according to user's current condition, and demonstrates how to correctly perform the chosen exercises with interactive 3D animations.

4.4 A context-aware and user-adaptive fitness game architecture [10]

Since regular physical activity is recommended by physiologists to fight obesity and improve one's fitness, but usually requires considerable motivation, researchers as well as companies have recently proposed a few fitness games where game elements (such as graphics and gameplay) are used to encourage people to exercise regularly. This work proposes a fitness game system based on another early and partial version of the architecture proposed in Section 3. This fitness game system, meant for indoor use, aims at combining arcade-style game graphics, physiological sensors (e.g. heart rate monitor, 3D accelerometer), and an adaptation engine. The adaptation engine considers personal information provided by the user (e.g., age and gender), her current heart rate and movements, and information collected during previous game sessions to adjust the required intensity of physical exercises through context-aware and user-adaptive dynamic adaptations of graphics and gameplay. Besides designing the general system, we developed two games and carried out a preliminary user evaluation, which also led us to introduce in the system a 3D virtual human.

4.5 The 3DictSL international sign language dictionary [7]

3DictSL is our first pilot application for the e-learning domain. It does not exploit adaptive features, but helped us to explore the use of virtual humans on users having special needs (in this particular case, deaf people). Sign languages taught by this application are visual languages used by deaf people to communicate. As with spoken languages, sign languages vary among countries and have their own vocabulary and grammar. Therefore, the different deaf communities need a dictionary that associates signs to the words of the spoken language of their country as well as dictionaries to learn how to translate signs from a sign language to another. Several researchers proposed multimedia dictionaries for sign languages of specific countries, but there are only a few proposals of multilanguage dictionaries. Moreover, current multimedia dictionaries suffer from serious limitations. Most of them allow only for a word-to-sign search, while only a few of them exploit sign parameters (i.e., handshape, orientation, location, and movement) to allow for a sign-to-word search. Current solutions also commonly use pictures or videos to represent signs and their parameters, but 2D images are often misleading for a correct identification (e.g., recognizing an handshape can be very difficult due to occlusions). This work aimed at facing the above described issues, exploiting Web3D technologies such as X3D [48] and H-Anim [26] virtual humans to better understand signs and to simplify sign-to-word and sign-to-sign search, by proposing an online international sign language dictionary (3DictSL). We designed a client-server architecture for 3DictSL and authoring tools which allow deaf communities to extend the dictionary with their own language. As a practical case study, we focused on the Italian Sign Language (LIS).

5 Future work

Research work carried out so far partially answer to a subset of the questions posed in Section 3 and consequently covers only the design and the implementation of a partial and preliminary version of the proposed architecture. In particular, early user evaluations support the idea that virtual humans and interactive activities, such as fitness games, can boost user motivation in fitness training, while we have to carry out further evaluations to prove the long-term training efficiency of user-adaptive and context-aware techniques.

Considering adaptation, we have already proposed some animation and exercise adaptations, but further investigation is needed to achieve more sophisticated and possibly more effective results. Considering user and context modeling, current proposed solutions use ad hoc user and context models for the specific mobile or desktop needs and the particular application. Therefore, to gain flexibility, generality, and portability, we will separate modeling aspects from the particular applications by employing, adapting or inspiring from existing proposals such as GUMO [24] and UbisWorld [22] ontologies. Similarly, we aim at designing and developing a more general adaptation engine (e.g., using the rule engine Jess [17]). The main contribute will be adapting these solutions or designing new ones by considering mobile and fitness domain challenges. Finally, we would like to apply the proposed architecture also to the e-learning domain.

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