

Towards development of Ontology-Based Context-aware Persuasive Applications Promoting Physical Activity

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Abstract

Modern lifestyle is becoming more sedentary. As a consequence, many ubiquitous computing and mobile technologies have been designed to motivate people towards more active lifestyles. The concept of context-awareness is one important aspect of ubiquitous computing technologies. Context-aware applications and devices can deliver relevantly specific information and services with respect to users' needs and well adapt to their constantly changing environment. Therefore, context-awareness is now becoming critical in the development of ubiquitous and mobile technologies encouraging physical fitness.

However, appropriately exploiting, representing and managing contextual information poses a serious challenge. There is a need for a formal context model facilitating context sharing, knowledge reasoning, and interoperability among diverse systems. Ontology-based context modeling can address these issues. Therefore, the present thesis proposes as a solution, the concept of context ontology, called Extensible Context Ontology for Physical Activity (ECOPA), and the architecture, abbreviated as CAPPa, to facilitate the development of Context-Aware Persuasive applications promoting Physical Activity. Furthermore, an application prototype called ExePeEnhancer, has been built and verified through experimentations to demonstrate the effectiveness of development of applications based on the proposed architecture and ontology. The evaluation results have shown that ExePeEnhancer as a persuasive application that accounts for different contexts, exhibits more effectiveness than a persuasive application that does not take those contextual information into consideration.

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1 Introduction

According to the World Health Organization (WHO), there has been a dramatic decline in daily physical activity among individuals [1]. While a large proportion of the population worldwide is leading a sedentary lifestyle, technologies can promote a healthier lifestyle by encouraging people to take part in physical activity [43, 8, 46]. Such technologies are generally referred to as persuasive technologies [22]. The effectiveness of persuasive application can be improved by being context-aware, as they can deliver more relevant services according to the user's needs, and therefore these applications can lead to a healthier lifestyle. However, appropriately exploiting and managing context information is an issue. There is a need for a formal context model that facilitates context sharing and knowledge reasoning. Ontology as a context model shows great promise. It can address the problem of interoperability between diverse systems and support context reasoning. This thesis presents a context ontology and an infrastructure based on that ontology to support the development of persuasive applications promoting physical activity.

1.1 Motivation

Lack of physical activity is becoming one of the most pressing health issues worldwide [2]. Throughout the last decade, people have been adopting a sedentary lifestyle which is

characterized by being more engaged in activities such as sitting, watching TV, playing video games, etc., and remaining inactive for most of the day. According to the WHO, 60-85% of the world's population lead a sedentary lifestyle [1]. Moreover, it has been reported that approximately two-thirds of children and more than 80% of adolescents are not sufficiently active, which has a dramatic impact on their future health [1].

The lack of physical activity is contributing to many health issues, including obesity, cardiovascular diseases, diabetes, and high blood pressure [3-5]. This prompted the WHO to issue a warning that the number of obese or overweight individuals has doubled since 1980, and in 2008 over 1.4 billion adults were globally recorded as suffering from obesity and being overweight [6]. Moreover, the WHO says a sedentary lifestyle is among the 10 causes of death and disability in the world; almost 2 million of the deaths around the world are attributed to inactivity [1]. Furthermore, a reduction in regular exercise results in a weakening of the immune system [7].

However, technologies present new methods for the reduction or prevention of the health problems previously described. Many research studies have contributed new techniques and technologies that motivate people to take part in daily physical activity [8-10]. They are known as persuasive technologies. The number of ubiquitous mobile devices employed in persuasive systems is increasing quickly [6, 11, 12]. As a result, persuasive technology is progressing towards becoming ubiquitous and pervasive. This trend is part of a bigger pervasive computing movement where ubiquitous devices are seamlessly being integrated into users' everyday lives by providing information and services in an "anywhere, anytime" fashion [13].

One important aspect of ubiquitous and pervasive computing, called context-awareness, imply that applications and services should have the ability to be aware of the changing contexts and react accordingly without the user's explicit interventions [7, 14]. The effectiveness of context-aware applications will increase, as they can adapt their behaviour to changing situations [15] and deliver more relevant information and services with respect to user needs [16]. Therefore, it can be argued that ubiquitous persuasive technologies promoting physical activity can benefit from being context-aware as it enables them to deliver useful persuasive services. As such, the use of context-awareness for persuasive applications can help increase the effectiveness, functionality, and adaptability of such applications by affording them to take different contexts into account to deliver more suitable services according to user needs and status. However, efficiently gathering, modelling and managing context data is still challenging. These challenges will be explored in section 1.2.

1.2 Problem Statement

Context-aware applications and services use contextual information about a user's state and surroundings and proactively offer usable operations and content relevant to the user's tasks [15]. To provide the proper and relevant services and information, context-aware systems should capture, organize, store, and represent contexts from different resources; this is known as context modelling [17]. We use the definition given by Dey and Abowd [15] that refer to context as *“any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves”*.

In ubiquitous and pervasive computing environments, contextual information such as user status,

devices' features and computational capabilities, ad-hoc networks properties, and other environmental characteristics come from diverse sources. Context-aware systems model information collected from heterogeneous and ubiquitous sensors and devices. Many of them use informal models such as programming strings, java objects, or other programming language objects to represent contextual knowledge [18].

Conversely, to deliver the most appropriate services and information, context-aware systems should cooperate and exchange context knowledge between each other [19]. Therefore, there should be a shared understanding about context among diverse computing entities. However, systems using implementation dependent concepts for modelling context can only communicate and exchange data with systems strictly abiding to the same concepts. To provide interoperability between heterogeneous systems, there is a need for a context model that semantically represents knowledge which is independent of any programming language or low-level implementation agreement to facilitate knowledge sharing. Moreover, programming and application dependent context modelling don't allow context reasoning which may be required for analyzing the low level context acquired from ubiquitous sensors, such as the GPS location, and for creating high level context, such as user activity. Furthermore, there is a lack of appropriate infrastructures that facilitates developing context-aware systems. Consequently, the development of context-aware systems is complex and time-consuming [20].

Since context-aware persuasive applications designed for ubiquitous and pervasive computing devices are a subset of context-aware systems, many of them are subject to the same challenges, namely the lack of a context model that supports semantic knowledge representation, context reasoning, and improves interoperability between different systems [21]. Similarly, the same general issue exists for context-aware persuasive applications that promote physical activity, as

aforementioned applications belong to of context-aware persuasive applications designed for ubiquitous and pervasive computing devices domain.

1.3 The Proposed Solution

We believe that providing an ontology-based context model for persuasive systems that motivates physical activity can address the critical issues discussed in section 1.2. Ontologies model information with explicit semantic representation and support knowledge sharing as well as knowledge reasoning [21]. As a result, they improve interoperability between various systems. By developing a context ontology as a reusable model, we can help developers of physical activity encouraging systems by putting less effort into designing relevant ontologies and being more concentrated on the implementation and development of other aspects of their system. Moreover, the availability of a dedicated ontology-based infrastructure can help and accelerate the building of the so-called applications.

1.4 Contribution

In this thesis, we propose an extensible context ontology to support the building of context-aware persuasive applications that promote physical activity. Moreover, using this context ontology, we propose an ontology-based architecture to facilitate the development process of those systems. Furthermore, according to the architecture, we have designed a context-aware persuasive application called ExePeEnhancer, which is aimed at improving exercise performance by helping users to achieve their goals. Finally, we have developed a prototype of ExePeEnhancer and have conducted a user study to evaluate the users' efficiency in achieving their predefined workout goals.

1.5 Thesis Organization

The remainder of this thesis is organized as follows:

- Chapter 2 provides the background and related works for the topics that the research deals with, including persuasive technology, pervasive technology, context-awareness, and ontologies.
- Chapter 3 details the context ontology proposed in this research. Moreover, it presents two use case scenarios to show the usability of the ontology. Given the use cases, it provides examples of context reasoning based on the ontology.
- Chapter 4 introduces the ontology-based architecture for building context-aware persuasive applications aimed at encouraging physical activity with details, and later presents a context-aware persuasive application, called ExePeEnhancer, which is built based on the architecture.
- Chapter 5 describes the details of the conducted user study, using the prototyped ExePeEnhancer, presents the evaluation results along with a discussion of these results.
- Chapter 6 provides a conclusion and an outlook on future works.

2 Background and Related Work

This research touches several topics including persuasive technologies, pervasive technologies, context-awareness, and ontologies. The purpose of this chapter is to provide some backgrounds on these topics which are essential for comprehending the rest of the work. In section 2.1, we give an overview about persuasive technologies and then present a number of related persuasive applications that improve physical activity. Since pervasive computing and ubiquitous mobile devices are widely adopted for persuasive technologies, in section 2.2, we give a short overview on this research area. Section 2.3 presents a brief description on context-awareness and discusses some of its applications and challenges. Later in this section, we survey the available method for context modelling, as it is the case for our proposed work. Section 2.4 provides an overview and required backgrounds on ontologies needed for readers who are not familiar with. Importantly, in section 2.4 we briefly review existing context ontologies and ontology-based infrastructures. Finally, in the section 2.5, we show the shortcomings and weaknesses of existing context ontologies in terms of employing them in context-aware persuasive systems promoting physical activity. These findings will motivate the introduction of our proposed context ontology.

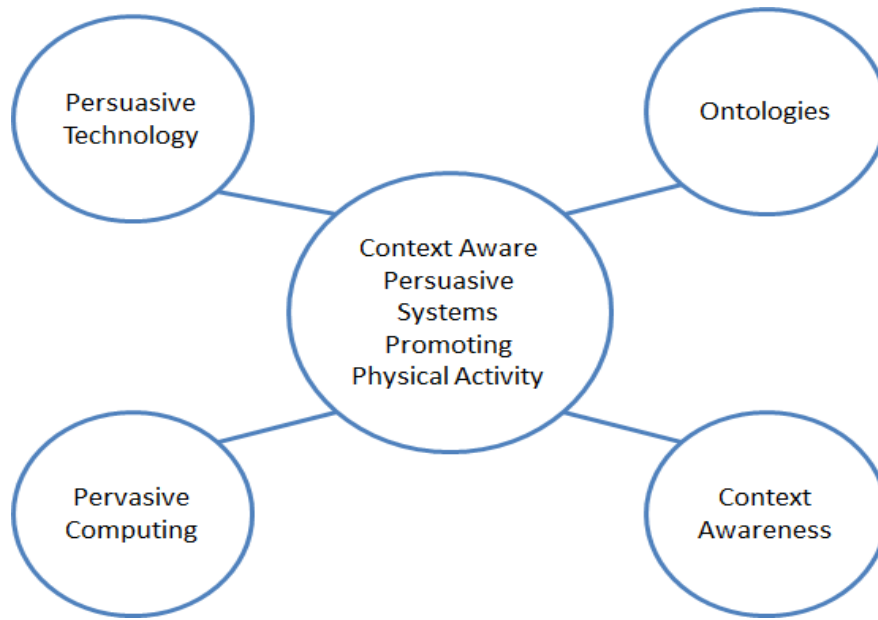


Figure 2.1 Context Aware Persuasive System's Associated Domains

2.1 Persuasive Technology

New technologies can be used to help people pursue a healthier lifestyle. Initially, the idea of utilizing technology to motivate desirable attitude changes was introduced by Fogg [22]. He mentioned that interactive computing technologies can impact people's attitudes and behaviours. He called them persuasive technologies. He also pointed out the notion of Captology which refers to the study of computers as persuasive technologies. In past years, persuasive technology has been a focus of research and commercial communities. Many persuasive technologies in the forms of Web sites, software applications, and mobile computing devices have been developed in various domains such as marketing, health, safety, and the environment [23, 24].

One of the most promising areas of persuasive technologies is marketing and ecommerce [24]. Persuasive information systems in this domain encourage people to buy products or services [25-

27]. Safety is another application domain for persuasive technologies. For instance, to promote safety and prevent accidents, a persuasive mobile application is designed to change the speeding behaviour of young drivers [28]. It persuades drivers by various incentives to reduce their speed. The environment is potentially the next domain for the application of persuasive technologies. Such applications attempt to encourage people to protect the natural environment [24].

Health is one of the most important application domains of persuasive systems. In this area, persuasive systems motivate people towards healthy behaviours by encouraging the adoption of healthy good habits or by breaking unhealthy bad habits. Such technologies assist people to lose weight [29] or to have more active lifestyles by improving daily physical activity levels or by maintaining an exercise routine [30]. For instance, a mobile coaching application encourages people to eat more vegetable and fruits [31]. Similarly, pmEB is a mobile application that attempts to help its users to monitor their caloric balances in real-time [32]. Many persuasive mobile applications have been developed to motivate physical activity, such as Chick Clique [33] and AcitivMon [34], or to avoid sedentary activities, such as BreakAway [35]. BreakAway motivates individuals who have sedentary jobs to take breaks when sitting for a while. Furthermore, some of the persuasive applications in this area have been developed for influencing people to get out of a bad and unhealthy habit, such as smoking [36] or alcohol abuse [37].

To persuade people, these systems employ various persuasion techniques, including self-monitoring, social influence, praise, and reward to persuade their users. Self-monitoring is one of the common techniques used by such systems [8]. It enables people to track their behaviour over a period, so they can properly evaluate their behaviours. Social support [38], cooperation [39], comparison [40], and competition [41] are among the influential persuasive strategies. Social

components pressure people to either work together or against each other to achieve a goal. Moreover, Praise and reward are other persuasive techniques which are used in persuasive applications [33, 42]. Praise boosts users when they reach their target goals. Reward is a common technique in persuasive games which it gives credits or virtual reward to users after getting to a target goal [10].

2.1.1 Persuasive Technology to Promote Physical Activity

During the last decade, we have observed an increase in the number of technologies encouraging healthy lifestyles. One target of health care software applications is increasing physical activity and/or reducing sedentary activities. Due to dramatic changes in lifestyles over the past three decades, nowadays, we are more engaged in sedentary activities such as watching TV or performing office work, while being less involved in physical activities. Therefore, some technologies have been developed to maintain healthy lifestyles by encouraging individuals to engage in physical exercises. In the following sub-sections, a couple of these technologies are introduced.

2.1.1.1 Persuasive Applications Providing Personal Awareness

One commonly used technological approach towards promoting physical activity is self-monitoring and providing personal awareness. Applications such as Houston [43] and UbiFit [8] encourage exercising by monitoring individuals' daily physical activity and representing it with a stylized display. Houston is a fitness mobile application that tracks daily step count and shares the results with the application user's friends. It encourages physical activity by self-monitoring and social interaction among friends. The application prototype has been tested on thirteen

female participants. Importantly, in this research, four essential requirements for designing technologies motivating physical activity were suggested, which are widely used as guidelines for developing persuasive technologies [34, 42, 44]. The key requirements consist of “*Give users proper credit for activities*”, “*Provide personal awareness of activity level*”, “*Support social influence*”, and “*Consider the practical constraints of users’ lifestyles*”.

In a similar way, UbiFit is another mobile application that increases personal awareness through an “at-a-glance” display. UbiFit consists of a virtual garden representing physical activity behaviour. The users grow their gardens by achieving their fitness goals. When they meet their goals, virtual flowers or butterflies appear on the display, serving as rewards. To frequently provide awareness about the fitness goals and achievements, the virtual garden resides on the background of the mobile device to remind them whenever the user uses her device. The application was evaluated with 12 participants for three weeks and the results showed great promise.

2.1.1.2 Persuasive Applications Improving Physical Activity during Use

Some persuasive applications enhance physical activity during fitness workouts. They assist people in achieving their physical activity goals. For example, MOPET [45] is a mobile personal trainer in an outdoor fitness trail. Given the GPS position of the user, MOPET provides users with navigational directions through a visual map with specified icons, guides them along the trail, and tells her/him the speed she/he has at different trail points. It also has a virtual 3D personal trainer which demonstrates to the user the correct way of performing some exercise

movements with rings.

Besides MOPET, MPTrain [46] is another mobile personal trainer application that helps the users to achieve their defined goal by playing the proper music. It constantly tracks user performance based on her heart rate. In order to attain the predefined goal, when MPTrain wants to play the next song, it recognizes whether the user needs to speed up, slow down, or keep exercising with the same speed based on the monitored performance, and then selects the next music accordingly. Similarly, TripleBeat [47] is a persuasive mobile application that provides musical feedback during exercise like MPTrain.

2.1.1.3 Persuasive Game Applications for Physical Fitness

In addition, many computer games are designed by persuasive technology researchers to motivate physical activity. As games provide entertaining environments and facilitate social interactions, they can be very promising motivators for healthy behaviour changes. Fish'n'Steps [48] is a persuasive desktop game designed to increase daily footsteps. The application displays an animated fish tank consisting of a virtual fish. The virtual fish grows and moves to reflect the user's step count. Also, other fish representing other users' physical activity can enter the user's tank, which encourages the user to compete or cooperate with them by comparing her fish with other fish in the tank. The prototype application was tested on 19 participants for a period of three weeks. The results of the pilot test demonstrated that it promoted healthy behaviour changes in users' daily routines. PLAY, MATE! [49] is another game offering virtual rewards corresponding to the physical activity that the player performs in the real world. Monster and Gold [50] is also a mobile fitness game that motivates its user to gain their fitness goal while taking her physiological information. Last but not least, iFitQuest [51] is a persuasive game

targeted at children at school. [52]

2.2 Pervasive Technologies

Due to the widespread use of mobile devices, several persuasive applications are designed for ubiquitous pervasive devices [46, 43, 8]. These emerging technologies are very desirable due to their availability in many places and accessibility at any time. Since the advent and growth of smartphones, wearable devices, and notebooks, devices are shrinking in size while their computing power is increasing. Moreover, wireless network technologies are advancing rapidly and they can cover many locations. The presence of wireless networks at many places along with advancements in mobile devices enables access to computers in an “everywhere, anytime” style, and leads to a new field of research called pervasive computing.

2.2.1 Pervasive Persuasive Technologies

Persuasive technologies designed for ubiquitous devices fall under the umbrella of pervasive computing technologies. For example, RunWithUs [53] is a persuasive application designed for a smart city called “Ubiquitous Oulu”. It motivates users to engage in moderate intensity exercises through social interactions. Correspondingly, Feeding Yushi [52] is a location-based ubiquitous computing game that encourages its users to move in their cities. Persuasive applications developed for mobile phones are arguably pervasive computing technologies [54]. These applications employ various persuasion methods, such as providing awareness and social pressure to encourage their users [8, 47]. Shakra is an example of a location-based mobile application that persuades users by augmenting their daily activity and sharing the results with friends. The application estimates daily movement of users by monitoring the GSM cell signal

strength on their mobile phone.

2.3 Background on Context-Awareness

2.3.1 Context Definition

Many definitions of “context” and what it actually refers to, have been given in the area of computing. However, defining “context” is very challenging and there is no universal definition for this term. Initially, Schilit and Theimer [55] introduced the notion of “context-aware” and attempted to clarify the term by its various aspects. They described context as location, nearby people and objects, in addition to the changes in those objects. They divided context into three categories, which include computing, physical, and user context [56]. Computing context contains network connectivity, communication cost and bandwidth, as well as computing device descriptions such as CPU speed, display attributes, and memory capacity. Physical context includes lighting conditions, temperature, noise level, and traffic conditions. Finally, User context consists of user profile, social situation, and friends.

Moreover, Chen and Kotz [20] identified time as the fourth category of context due to its importance in many context-aware applications. Ryan et al [57] gave another definition that includes the logical and physical aspects of context and consists of a user’s location, environment, time, states of sensors, and computers. Brown [58] provided a generalized definition of context, referring to context as elements of the environment that the user’s computer is aware of and can include location, states of computers, people, temperature, and time.

Dey and Abowd [15] proposed another definition for context. They referred to context as “*any information that can be used to characterize the situation of entities (i.e., whether a person, place or object) that are considered relevant to the interaction between a user and an application, including the user and the application themselves.*” They classified context into the four categories of location, identity, activity, and time. They noticed that these primary context classes in practice are more important than others and can generally specify the situation of entities.

2.3.2 Context-Aware Applications

As mentioned in section 2.3.1, the term “context-aware computing” was coined by Schilit and Theimer [55] for the first time. From their perspective, context-aware systems are systems that continuously analyze environmental factors such as location, nearby people, and devices, and adjust themselves accordingly by responding to environmental changes. Context-aware systems are brought up with several characteristics such as being adaptive, reactive, responsive, situated, context-sensitive and environment directed [15]. Dey and Abowd [15] refer to a context-aware system as “*A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user’s task.*”

Since context-awareness improves system adaptability and usability, context-aware systems have many applications. One of the initial and well-known examples of context-aware systems is the Active Badge Location System [59]. It identifies the location of users in office environments and automatically forwards their calls to the phone closest to the user location. For instance, when a user is in a meeting and receives a call, based on location, the system detects that he is in a meeting, and forwards the incoming call to his voice mailbox. Another example of a context-

aware system is Shopping Assistant, which helps the user to obtain information about products while navigating in a store. With the Shopping Assistant, the user can find the location of items, see their prices, and look for items on sale. Moreover, when a user enters the store, the Shopping Assistant can suggest particular store items by considering his personal profile.

2.3.3 Sensing the Context

One of the essential steps to building a context-aware application is sensing the context. Sensing the context is the process of capturing context from sensors and delivering it to the application. Sensor is a general term for any source of data providing context to the application and can be hardware- or software-based. Hardware sensors are the most common type of sensors which measure physical properties including temperature, location, motion, audio, acceleration, etc. On the other hand, software sensors are type of programs that collect data such as personal information from information systems or other software resources [60]. Context data collected by sensors is called low level context.

Location is one of the main context types. As location has a very dynamic nature and changes whenever a user moves, various techniques and sensors are used to acquire this context accurately. Location sensors can be divided into three groups: physical, virtual, and logical. Physical sensors are hardware sensors such as a GPS positioning system. Virtual sensors are software processes that detect location through applications and services. Applications that record events can be used for location detection. Events in such applications are used to detect the location of people or equipment. For example, an electronic calendar can be used for detecting a person's location. Virtual sensors detect location by analysis of the information collected from both physical and virtual sensors along with other information sources including

databases. For example, a person's location can be inferred from his calendar data and the position of his cell phone.

2.3.4 Context Modelling

After obtaining contextual data through sensors, context-aware applications model the context information in order to fuse the various pieces of information together into a unified view. For instance, a call forwarding system uses the context information taken from sensors such as the user being located in the bathroom, the bathroom light being on, and the bathroom tab being open, to infer that the home resident is taking a shower and when it detects the home resident is taking a shower, it forwards incoming calls to his voicemail. As context is collected from distinct and heterogeneous sources, the system first needs to unify it into a model, and then use it to conclude that he is taking a shower.

Each application uses its own context model to express data coming from various sources and sensors. According to Strang et al. [61], the most distinctive context modelling approaches for data representation and exchange with respect to data structure can be divided into six categories as follows:

- **Key-Value Model:** The key-value approach is one of the most common methods used for context modelling. In this model, there are key-value pairs to represent the context in which keys are environmental variables such as "location" and values are the actual context information sensed from the environment, such as "bedroom".
- **Markup Schema Model:** Markup schema models have a hierarchical data structure in which the value of one markup is recursively defined in another markup tags. All markup

scheme models are composed of markup tags followed by attributes and values. The most common usage of these models is to represent profile. User Agent Profile (UAProf) [62] and Comprehensive Structured Context Profiles (CSCP) [63] are two examples of markup schema models for expressing profiles.

- **Graphical Modelling:** Graphic oriented context modelling approaches use and extend general purpose graphical modelling languages. Unified Modelling Language (UML) is a language used for representing and expressing contextual information. UML is a general purpose graphical modelling language with strong graphical expressiveness. For instance, Henriksen et al. [64] model context in the air traffic management domain by UML extension. Object-Role Modelling (ORM) is another well-known graphical modelling language used for modelling contextual aspects [65]. Such models are very suitable for context management architecture using relational databases, as the ER models can be simply derived from the context model.
- **Object-Oriented Modelling:** Modelling context with object-oriented methods offer the advantages of object-oriented design principals including encapsulation, information hiding, and reusability. Cues [66] is a project that models contextual information with an object-oriented paradigm. In this project, the concept of cue is introduced. A cue is an object that takes data from physical and logical sensors as input and provides symbolic or sub-symbolic output. The cues model the context and encapsulate the details of context processing and representation.
- **Logic[67]-Based Modelling:** Logic-based context models express context with a set of rules. In such models, rules, facts, and expressions model the information with a high degree of formality. In this model, contextual information can be changed by directly

adding new facts, or indirectly by inferring from the available rules. One of the initial attempts for modelling context with logic has been done by MacCarthy [67]. He defined context as mathematical and formalized entities. Sensed Context Model [68] is another project which represents context with first order logic predicates. Furthermore, multimedia System by Bacon [69] modelled location with a set of facts encoded by Prolog.

- **Ontology-Based Modelling:** Ontologies provide a formal representation of knowledge in a domain. They are very promising for modelling contextual information since they allow context reasoning. As ontology has a high degree of formality, it can support logic reasoning techniques such as first order logic. Many context-aware architectures and frameworks exist that use ontology for context modelling. These ontologies will be discussed in the next section.

Strang evaluated the introduced models based on different requirements such as incompleteness and ambiguity, richness and quality of information, and level of formality. He concluded that ontologies are the most appropriate instrument for context modelling according to the counted requirements. Specifically, ontology can be used for modelling context in pervasive computing environments. In these environments, context-aware systems cooperate and communicate with other systems to deliver appropriate services by exchanging context information. For instance, one system informs another one that it senses the context has changed and the latter system reacts based on the context sensed by the former system. In order for systems to exchange information, they need to have the same representation of context. However, many systems use their own method for context modelling, and therefore it makes the exchange of information very challenging. On the other hand, ontologies provide shared specification of knowledge so they are

very useful for modelling contextual knowledge of pervasive context-aware systems that cooperate and negotiate with each other.

2.3.5 Context-Aware Pervasive Technologies

Pervasive computing technologies are being developed in a way so as to be used everywhere, at any time. Since these technologies are ultimately integrating into users' daily lives, developing them to be context-aware is highly demanding. Context-awareness is one of the active research areas in pervasive computing. In this field, context-aware systems are able to adapt themselves to the changing situations without explicit user intervention. They have the flexibility of changing their behaviours accordingly in order to respond with respect to the users' needs. As a consequence, building context-aware application is an asset, due to its essential role in pervasive computing.

2.3.6 Context-Aware Pervasive Persuasive Technologies

Many persuasive pervasive applications such as RunWithUs, Feeding Yushi, and Shakra can be considered context-aware, since they take contextual information into account while persuading users to exercise. However, they consider only one or two types of context such as location and physical activity while ignoring other contextual data such as user context. For example Feeding Yushi only considers the context type of location. Similarly, users' personalities which are types of context are ignored by several applications in providing persuasion. Persuasive applications employ several persuasion techniques to motivate people promote a healthier lifestyle. However, a large amount of research performed in the area of persuasive technologies widely acknowledges that some of these persuasion methods effect reversely some users [70, 71]. For

example, competition as a kind of persuasion technique cannot motivate a broad range of people and that lose their appeal after a short period of time [48]. By taking into account the personality of users, persuasive applications can tailor persuasion methods and therefore achieve more success.

2.4 Background on Ontologies

2.4.1 Ontology Definition

The term “ontology” originally comes from philosophy. It refers to the science of being, deals with existence and the structure of reality [72]. This term was introduced into computer science by Gruber [73] in 1993. He defined ontology as “an explicit specification of a conceptualization”. Afterward, Borst [74] gave another definition of ontology by adding two certain characteristics to Gruber’s definition. He defined ontology as “a formal specification of a shared conceptualization”. The first characteristic requires ontologies to be represented in a machine readable format. Secondly, the conceptualization, the perception of the real world, has to be shared among all parties using the conceptualization. In other words, all parties must have consensual knowledge about the world and there must be a commitment about all aspects of the world intended to be modelled in ontology.

Studer [75] provided a more complementary and comprehensive definition based on the previous ones. It states that ontology is “a formal, explicit specification of a shared conceptualization”. This definition contains all characteristics of the previous definitions. He also clarified the meaning of conceptualization. Conceptualization is an abstract view of an interesting area in the world that a system wants to represent [75]. The interesting area is represented in the form of

some entities and objects and the relevant interrelation among them.

2.4.2 Types of Ontologies

Ontologies represent a conceptualization of reality. The perspective of the user perceiving the reality specifies the conceptualization and it depends on how and what he is interested in observing in the world. Therefore, the level of generality and the scope of ontologies depend on the conceptualization view and are not specified in the definition of ontology [76]. According to the level of generality, ontologies are classified into two categories of generic and specific ontologies [76]:

- **Generic Ontologies:** Generic ontologies are also known as general, upper, top-level, common or core ontologies. They represent general and reusable concepts such as events, time, and space, which are independent of a specific domain. Suggested Upper Merged Ontology (SUMO) [77], Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) [78] are three distinctive generic ontologies.
- **Specific Ontologies:** These ontologies express the terms and relevant relationships in a particular context such as a domain, application, task, activity, or method. Specific ontologies are divided into particular classes with respect to their application areas, such as knowledge engineering, natural language processing, etc.

In addition, Guarino [79] proposed a taxonomic ontology classification, including top level, domain, task and application ontologies (Figure 2). Top level ontology represents basic notions. Domain ontologies describe particular domain concepts, while task ontology contains concepts for achieving a task in the relevant domain. Application ontology is a specialized type of task

and domain ontology, with more details.

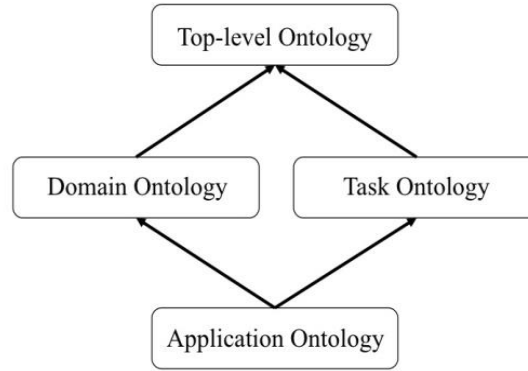


Figure 2.2 Hierarchy of Related Types of Ontologies [77]

Furthermore, ontologies can be classified into two classes of lightweight and heavyweight ontologies in terms of the level of expressiveness [80]. Lightweight ontologies consist of concepts, relationships, and their properties [81]. Heavyweight ontologies model the entities and relationships along with the axioms and constraints that exist in that domain [82].

2.4.3 Ontology Development Technologies

2.4.3.1 Ontology Languages

According to the ontology definition, ontologies are expressed in a formal and explicit way. To fulfil these requirements, ontologies must be encoded by formal languages. Formal languages support logic reasoning, and therefore make ontologies very powerful components for knowledge representation. Some initial ontology languages developed to provide formal semantics and knowledge reasoning are Ontology Interchange Language (OIL), DARPA Agent

Markup Language (DAML) based on XML(S), RDF(S), and DAML+OIL based on OIL and DAML.

Ontology Web Language (OWL) [83] is one of the distinctive ontology languages for defining ontologies proposed by the World Wide Web Consortium (WC3) [84]. It has been developed based on DAML+OIL. OWL provides strong expressiveness, semantic interoperability for knowledge exchange, and enables automatic knowledge reasoning. OWL is classified into the three subcategories of OWL Lite, OWL DL, and OWL Full. OWL Lite supports hierarchical classification and basic constraints such as cardinality with values of 0 and 1. OWL DL has maximum expressiveness while it has the problem of decidability and completeness. OWL Full is developed based on OWL DL and OWL Lite and keeps some compatibility with RDF Schema to have maximum expressiveness, though there is no completeness guarantee. OWL DL is the most frequently used ontological language in different applications compared with the other options [80].

2.4.3.2 Ontology Tools and Methods

There are three approaches to create ontologies: manual, semi-automatic, and automatic. In the manual approach, ontologies are developed using dedicated software applications and tools supporting the ontology development process. Protégé [81] is one of the most popular ontology editors, developed at Stanford University. It is a free and open source knowledge modelling tool that allows ontology developers to create, visualize, and modify ontologies in various formats including CLIPS, RDF, XML, UML and relational databases. In the automatic approach, an ontology is generated from existing information resources such as web resources [85], text documents [86], and multimedia contents [87]. The semi-automatic method applies both manual

and automatic ontology generation approaches. In this method, usually the ontology is learned from various resources and then refined manually.

2.4.4 Ontology Reasoning

As ontology is a formal and explicit specification, it must be expressed with knowledge representation formalisms which prevent ambiguity, inconsistency, and incompleteness. Therefore, they must be expressed by formal languages. Ontology languages represent entities and relationships with formal semantics to allow reasoning through a set of rules and axioms. Reasoning essentially provides the possibility of checking the correctness, minimal redundancy, and consistency of knowledge in ontology specification [76]. Ontology languages such as OWL use different types of logic-based knowledge representation formalisms, including description logic and first order logic, to enable reasoning.

Description logic is a knowledge representation formalism for modelling ontology [88]. It is based on some formal semantics with a set of First Order Logic decidable fragments. It describes a domain by three which correspond to classes: roles which present the properties, relationships among concepts, and individuals which represent class instances.

Description logic models a situation with a set of statements called axioms. Each axiom captures a specific bit of knowledge about a situation. In description logic, there are two types of axioms: ABox and TBox. TBox consists of a set of terminological axioms and facts about individuals, while ABox contains assertional axioms about classes and their properties. For example, the fact “Female is a Gender” is asserted in TBox, since ‘Female’ and ‘Gender’ are two classes. In contrast, “a banana is a Fruit” is asserted in ABox, which means ‘banana’ is an instance of the class ‘Fruit’.

OWL is one of the ontology languages built based on the foundation of description logic. Computational decidability is a key challenge in designing logic based languages. First order logic has the issue of decidability, while description logic addresses this problem by taking a decidable fragment of first order logic and providing ABox, TBox and tableau procedures[88].

By providing the possibility of knowledge reasoning with the aid of logic-based languages, semantic reasoners or inference engines perform reasoning to create logical deduction based on a set of assertions. They are software tools that are essential for creating and maintaining high quality ontologies. Pellet [89], RacerPro [90], and FaCT++ [91] are among the most important and commercialized semantic reasoners.

2.4.5 Ontology Use and Applications

Since ontologies facilitate knowledge sharing and logic reasoning, they are applied in various areas such as knowledge management, bio-informatics, semantic web, natural language processing, media content annotations, and pervasive computing. Knowledge management is one of the major fields in which ontology has been widely used [92]. Knowledge management refers to the process of knowledge acquisition, organization, representation, refinement and distribution [93]. In this area, ontologies can provide reusable and effective knowledge models for managing content [94]. Specifically, in bioinformatics, many knowledge management systems use ontology-based models for representing and structuring biomedical data [95].

Ontologies play an important role in the semantic web, and constitute one of the vital building blocks of it. The idea of the semantic web was first introduced by Tim Berners-Lee [96] as “an extension of the current web in which information is given well-defined meaning, better enabling

computers and people to work in cooperation”. Natural language processing and media content annotation are other areas of ontology applications. In natural language processing, ontologies provide the meanings of the words in the text, so they are very useful for perceiving the semantics of text and creating meaningful results. For example Mikroskosmos [97] is a system which develops a meaningful representation of a text resource by analysing the text with ontology. Ontologies are used for text annotations [98], translation [99], and summarization [100]. Moreover, the application of ontology for annotation is not only restricted to text, but has also been used to annotate other mediums, such as video [101].

2.4.6 Ontology-Based Context Modelling

Ontology has been employed for modelling contextual information in pervasive computing environments. Various context aware infrastructures in pervasive computing environments exist that benefit from ontology for representing and managing contextual knowledge. In the following, ontologies developed for pervasive computing environments are reviewed.

SOUPA [102]: This ontology is one of the primary ontologies that attempted to model context in pervasive computing environments. It was developed by UbiComp Special Interest Group as a standard context ontology for developing ontology-driven pervasive and ubiquitous applications. The ontology developers defined a set of use cases and designed the ontology based on the key vocabularies driven from the use cases. They realized that some of the SOUPA vocabularies could be found in other well-defined ontologies, and consequently adopted part of the SOUPA vocabularies from those ontologies consisting of Friend-Of-A-Friend ontology (FOAF), DAML-Time, Spatial ontologies in OpenCyc, Regional Connection Calculus, COBRA-ONT, MoGATU BDI ontology, and Rei policy ontology. SOUPA comprises two distinct ontologies: SOUPA

Core which defines the general terms in common domains of pervasive computing, and SOUPA extensions define additional concepts for supporting specific applications. SOUPA core represents nine distinctive ontologies related to person, agent, belief-desire-intention (BDI), action, policy, time, space, and event.

COBRA-ONT [103]: This ontology was developed for supporting context-aware pervasive computing. The ontology consists of a set of ontologies for modeling context in smart environments. It is designed to be used in broker-centric agent architecture (CoBrA) in smart spaces. CoBrA is an agent-based architecture that enables knowledge sharing and context reasoning. The central part of CoBrA is an agent called a context broker which uses CORBA-ONT to maintain a shared model and provide contextual reasoning. COBA-ONT is expressed by OWL and consists of four major concepts: Place, agent, and events. The place concept describes physical locations and extends to two concepts of AtomicPlace as room and CompoundPlace as campus. Agent is another top level concept which is divided into two specific concepts: Person and SoftwareAgent. Each agent can have different roles in an event.

CONON [104]: CONON is also an ontology that attempts to model contextual information in pervasive environments. This ontology is described by OWL. CONON provides a formal context model for semantic representation of contextual information. The ontology is divided into two ontologies: upper ontology and domain ontology. Upper ontology describes primary and universal entities which are general in pervasive computing domains. It has the flexibility of extending into domain ontologies. Domain ontologies define details of general concepts in sub-domains and describe their domains with specific information. This separation encourages reusability of general concepts. One of the fundamental obstacles behind developing context-aware systems is the lack of context-aware infrastructure. The presence of a context model is

essential for context-aware infrastructures. CONON was developed to address this issue. Some context-aware infrastructures use CONON as their context model. Service-Oriented Context-Aware Middleware (SOCAM) [105] uses CONON as a formal context model. SOCAM is an infrastructure for generating context-aware services. Similarly, CONON as a shared context model is applied in the OSGi Infrastructure [106]. OSGi is a context-aware infrastructure for rapidly building context-aware applications in smart home environments.

Extendible Context Ontology [107]: This ontology was developed for modeling context in ambient intelligent environment. The designers of the ontology identified some requirements for ambient intelligent computing infrastructures, including: application adaptively, resource awareness, mobile services, semantic service discovery, code generation, and context-aware user interfaces. The context-aware software or service must be able to serve the requirements. With respect to the requirements, four main concepts are identified: user, device, environment, and service. The ontology describes these four concepts with details and represents their relationships to each other.

2.5 Conclusion

With discussing several persuasive systems motivating physical activity such as Houston, UbiFit, and Fish'n'Steps, it can be inferred that such persuasive systems do not exhibit an effective support for knowledge sharing and context reasoning. Many of the context-aware persuasive systems motivating physical are designed for specific problems and are non-generalizable, as a result, it is difficult for them to obtain and process different context information since they are highly depending on the underlying hardware and operating system. In the other words, in these persuasive systems that promote physical activity, knowledge representation is application and

programming-dependant. Although context-aware persuasive systems promoting physical activity, similar to the other context-aware systems, may require cooperating and exchanging data with other devices and applications to deliver appropriate persuasive services without users interventions, they can only communicate with those systems having the same implementation specification.

This issue can be addressed by providing a common and shared ontology-based context model for developing context-aware persuasive applications promoting physical activity. The model can improve context representation, knowledge sharing and semantic interoperability between heterogeneous systems. Ontology as a formal context model can provide a shared semantic that decouples representation of contextual knowledge from implementation. In addition to knowledge sharing, ontology allows context reasoning. As a result, it is possible to infer high-level context from low-level contextual information including raw data.

However, there is a lack of standard context ontology and specific ontology-based architecture for developing context-aware persuasive application promoting physical activity. To the best of our knowledge there is no ontology that can be particularly used for this purpose and the existing context ontologies are very general to serve it. Most of the context ontology we surveyed such as SOUPA and CONON are general purpose context ontology. Such ontologies only model the core context entities that are common between different domains and do not provide enough details about the context with specific details. Recalling the example in section 3.2.1, location is a core context entity. However, it can be model with different details in each domain. Therefore, they do not model context with details required for context-aware persuasive application promoting physical activity. As a result, ontology-based application developers required to spend time and energy to extend these ontologies for developing physical activity motivating applications. By

defining a context ontology and architecture facilitates system developers to reduce their efforts in creating the relevant ontologies and to be more focused on the actual system implementations.

3 Towards an Extensible Context Ontology for Applications Promoting Physical Activity

Context-aware persuasive systems that promote physical activity aim at adapting their persuasion methods by taking into account the context without an explicit user intervention. Therefore, they need to consider the changing context while delivering relevant persuasive services to users in an “everywhere, anytime” fashion. To achieve this goal, they require cooperating and sharing context knowledge with other computing entities in the pervasive computing environment. Context sharing is an important aspect of this domain, so that all entities can “understand” context in the same way. Therefore, the establishment of a common context model which can be shared by all computing entities is essential. Ontology shows great promise for context modelling [104] as it facilitates context representation and supports context sharing, context reasoning and interoperability in ubiquitous computing environments. A context ontology can provide a reusable model to avoid repeatedly developing context model for individual applications. Therefore, we developed an ontological context model for applications promoting

physical fitness. In this chapter, we present our proposed Extensible Context Ontology for supporting pervasive and ubiquitous applications promoting Physical Activity (ECOPA). Moreover, we demonstrate some use case scenarios to show the usefulness of the ECOPA. Finally, we represent some examples to show the reasoning support of ECOPA.

3.1 Ontology-Based Context Model for Applications Promoting Physical Activity

An ontology-based context model represents knowledge semantically, which is independent of programming language, underlying operating system, or middleware. We developed our context model based on ontology encoded with OWL. We chose OWL for several reasons. Firstly, this language is recommended by W3C and it uses web standards for knowledge representation such as RDF and XML schemas [84]. Secondly, it is much more expressive in comparison to other ontology languages such as RDFS [108]. Moreover, OWL provides formal semantics to support a high degree of inference and automated reasoning. Many available semantic reasoners or rule engines are based on it, such as Pellet [109] and HermiT [110]. Figure 3.1 shows a part of our proposed ontology expressed with OWL. We used protégé 3.2, a free and open-source knowledge management tool, for encoding our ontology in OWL.

3.1.1 Related Ontologies

To build our ontology, we did not start from scratch. We have surveyed other developed ontologies related to our work and chose those that could be reused in our model. We adopted part of their vocabularies in terms of concepts and properties. However, instead of merging them

directly into our ontology, we only borrowed some of their terms.

```
<owl:Class rdf:ID="WeatherDescription"/>
  <owl:Class rdf:ID="Social_Purpose"/>
  <owl:Class rdf:ID="CPU_Resources">
    <rdfs:subClassOf>
      <owl:Class rdf:ID="Resource"/>
    </rdfs:subClassOf>
  </owl:Class>
  <owl:Class rdf:ID="GPS_Coordinates">
    <rdfs:subClassOf rdf:resource="#LocationEntity"/>
  </owl:Class>
  <owl:Class rdf:ID="DurationDescription"/>
  <owl:Class rdf:ID="Player_Type">
    <rdfs:subClassOf>
      <owl:Class rdf:ID="General_User_Charactristics"/>
    </rdfs:subClassOf>
  </owl:Class>
  <owl:Class rdf:ID="UserProfile"/>
```

Figure 3.1 Partial ECOPA Ontology Written in OWL

By using such an approach, the semantic reasoners will not have the overhead of importing ontologies which are not in the relevant domains [102]. In the following paragraphs, we will introduce the consensus ontologies used for developing our ontology.

CONON: We have already described this ontology in Chapter 2 section 2.4.6.

Extensible Context Ontology: We also have already described this ontology in Chapter 2 section 2.4.6.

GUMO [111]: General user model ontology defines a comprehensive set of vocabularies for

modelling a user in the semantic web in a unified way to facilitate sharing of user model data among various user-adaptive systems. User characteristics and dimensions are modelled in this ontology with entities such as physiological state, emotional state, characteristics and personality. In addition, user interests and preferences such as playing football can be represented by the ontology.

User Profile Ontology [112]: The vocabularies of this ontology are designed to model user profile. The ontology attempts to provide a general and extensible user profile that can be reused by various applications.

Physical Activity Ontology [113]: The ontology developed by Silvia et al for modelling physical activity and sedentary behaviour. Many factors can impact the level of physical activity, including environmental, physiological, cultural, as well as social aspects and constraints. This ontology describes the aforementioned aspects along with other features that influence physical activity. It provides a standard language to facilitate assessing of physical activity and sedentary behaviours.

3.1.2 General Overview of ECOPA

We propose an extensible and adaptable ontology for modelling the general contextual aspects of pervasive computing applications which enhance physical activity. The reason behind making the model extensible and adaptable is due to the fact that the pervasive computing field is always evolving, and providing a context specification that represents all contextual features is almost impossible. During the last few years, we have seen substantial progress in technologies, from the emergence of wearable and handheld devices to the spread of the internet and social media with the availability of and easy access to wireless networks. While the size of computers is

declining, their computing power is growing. Consequently, many aspects in the context of pervasive computing are rapidly changing -- from the emergence of computers in terms of software and hardware, to their applications in our daily lives. Therefore, by proposing an extensible and adaptable context model in the aforementioned domain, it is possible to capture the essential and common concepts and properties of context in the domain while having the flexibility and potential for future changes in the model.

By realizing the common context entities in our ontology, we develop our ontology in two levels: the upper context ontology, and the domain-specific ontology. The upper context ontology represents a basic specification with the common contextual entities that are universal for all pervasive computing environments. The domain-specific ontology extends the upper ontology. It models context for the domain of persuasive technologies that promote physical activity. It captures specific features about physical activity, the context it happens in and extending details about the general concepts by adding specific concepts and properties. The domain level ontology makes our ECOPA from the other context ontology. It contains more detail information about the context that is required to be modelled for persuasive applications promoting physical activity. The domain ontology can be extended into the application ontologies. The application ontologies are used in particular persuasive applications and are aimed at increasing physical activity. Figure 1 shows the general overview of our proposed ontology.

3.1.2.1 ECOPA at Upper Level

Context has some basic and generic entities in various pervasive computing domains; however, detailed features about these entities are considerably different in each domain [104]. For instance, consider location as one of the key context entities. Person, device, and location are

some important context types [114]. In all pervasive computing scenarios, there is always a person who uses a device, agent, or service, and this person has a location, so changes in any of these contexts may influence the provided context-aware service. However, location is an abstract term; any place can be called a location. Therefore, the details and features of identifying a location change from one domain to another. For example, for a context-aware smart home domain, kitchen, living room, and/or bedroom are location. Alternatively, in the context-aware vehicle domain, GPS position and coordinates are location. The Upper ontology identifies the core context entities that are shared in different domains. However, it does not provide detail information about these concepts. More details about context required for context-aware persuasive applications motivating physical activity is provided in the domain ontology.

The fundamental reason behind this approach is to improve interoperability of ontology-based pervasive applications which are developed based on our ontology and other pervasive computing applications using their own context ontologies. Since we define the generic context concepts in the upper-level ontology, they can be easily mapped to other context ontologies used by other applications. Generally, context ontologies such as CORBA, CONON, and SOUPA have some common context concepts, which can be mapped to our proposed upper ontology to increase interoperability.

3.1.2.2 ECOPA at Domain Level

ECOPA at the domain level models context for applications aimed at improving physical activity. After carefully surveying the domain, we realize that the **Person**, **Device**, **Activity**, and **PersuasiveService** concepts are the key concepts that play critical roles in modelling context for persuasive technologies that motivate physical activity.

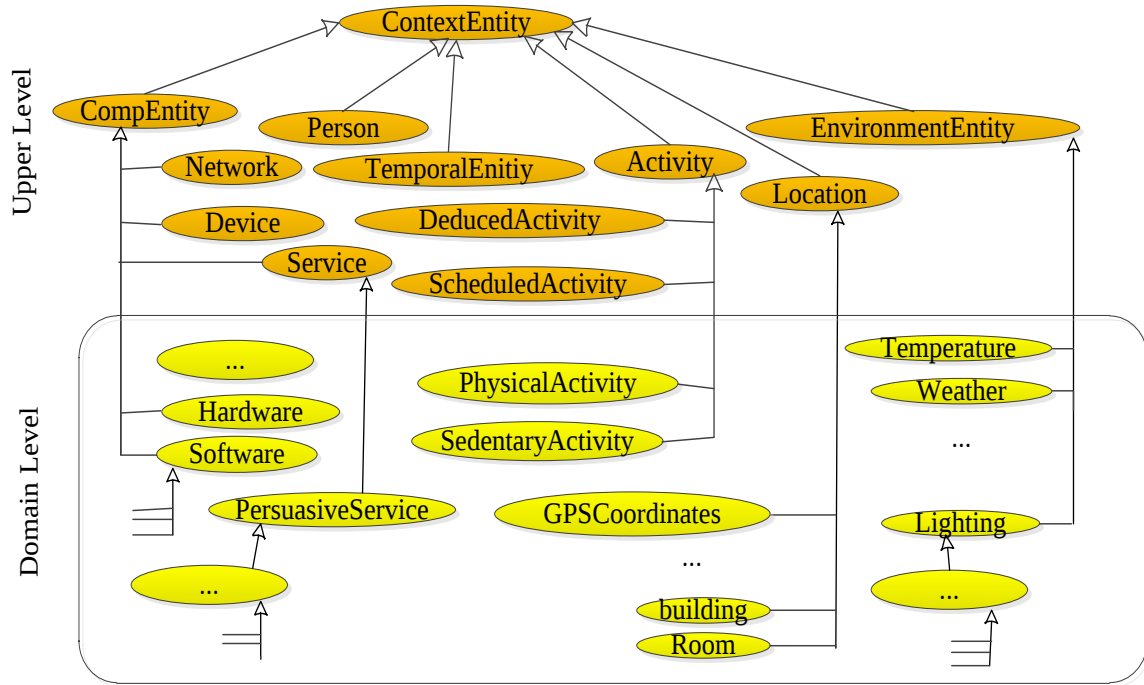


Figure 3.2 General Overview of ECOPA

In almost all of the scenarios we evaluated in this domain, we observed that context-aware applications deliver *Persuasive Service* to a *person* in regards to an *activity*. For example, using the *Persuasive Service*, *person* gets motivated to exercise more often. We model these four general concepts and then add other contextual details as concepts and properties which attempt to express them with more details. Figure 3.3 demonstrates an overview of the main concepts and their relationships.

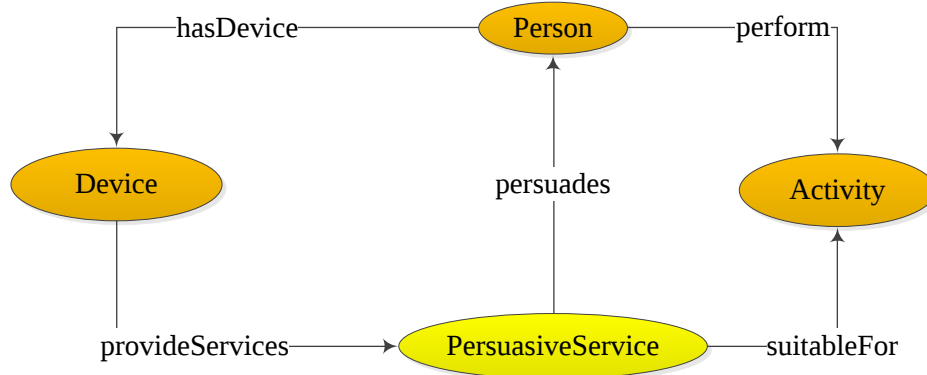


Figure 3.3 General Overview of ECOPA at Domain Level

3.1.3 Person Ontology

A person consumes persuasive services and applications. He/she is representative of a user in pervasive computing environments. In the context-awareness field, the essential effort is on delivering adaptable services and applications to the end user. Dey et al. [115] noticed that appropriate contextual data is what impacts a user's tasks. Moreover, according to Oinas-Kukkonen [116], to persuade a person with persuasive technology, information must be presented in a way that the person considers and comprehends it. That is why person has a central role in this domain. Therefore, the Person section of the ontology must model information that provides the possibility of analysing a person's context. Properties and information about a person that are represented by the ontology are called a user model, since he/she is the user of persuasive technologies enhancing physical activity.

A wide range of information and characteristics about a person -- from basic information such as

name to personality to physical states and activeness -- must be presented in the ontology. They can be divided into two groups, according to the rate of changes in their values. A large part of the information about a person is static. Static aspects of a person do not change over a long time, such as name or personality traits. However, some of a person's properties vary frequently or in a short amount of time, such as heart rate or blood pressure. It is very important to distinguish between these two categories of information from a ubiquitous systems perspective, as static data can be acquired once and remains constant, while, dynamic information has to be collected continuously through sensors as the system's behaviour depends on this data.

One of the primary categories of contextual knowledge that has to be captured in the model is personal information. Personal information consists of information such as age, gender, date of birth, contact information, and profession. The `BasicPersonalInformation` class in the model represents this category. Personal information does not alter over time and is static. However, availability and modelling of this information for the functionality of interactive systems is very important. The aforementioned aspects improve adaptability and usability of systems involving a high degree of human-computer interaction. For example, persuasive technologies that change their user interface according to gender and age are more usable.

Psychological characteristics are considerable aspects of a person that are represented in the model with the general concept of `PsychologicalCharacteristics`. These characteristics include personality traits, cognitive traits, emotional states, and behaviours. It is no wonder that people's personality and cognitive aspects play a key role in designing persuasive technologies, due to several reasons. Firstly, for generating effective persuasive messages, it is important to consider the personality factors and cognitive characteristics of the person using the technology. One substantial step towards motivating someone is analysing the persuasion strategy message[116].

For example, people with high cognition may be persuaded with direct messages, whereas people who are less thoughtful may be motivated through those strategies that use indirect messages [116]. Secondly, the persuasive strategies for people who have dominant characters should not have imperative content [117]. Moreover, several studies have confirmed the positive effects of personalizing the persuasion strategy by taking into consideration the personality of the user [70, 71, 117]. The CognitiveTrait and PersonalityTrait concepts in the model represent are provided by the model to represent personality and cognitive aspects of users. Persuasive systems aim at changing people's attitudes and behaviours, as a result by consequently providing a way for computers to analyze their behaviour and emotions, can influence the effectiveness of persuasive technologies. Behaviours are influenced by several factors such as emotions, beliefs, or past experiences and they might be consistent or ambivalent [116]. In the person ontology, the Behaviour, EmotionalState, and Belief concepts are used to model the psychological traits of a person.

Furthermore, physical characteristics and physiological attributes of individuals are two other groups of properties that are modelled with the PhysicalCharacteristics and PhysiologicalState concepts. This information is required for persuasive applications enhancing physical activity, including applications delivering health monitoring services and exercise motivating applications. For example, considering a personal trainer application that prescribes workouts which guide the person towards his/her weight loss goal, it requires the weight and height of the individual to suggest an appropriate workout. Generally, both physical characteristics and physiological states are dynamic contextual information and can be measured through various metrics. However, the rate of physiological attribute changes is very fast and might be less than a second, such as heart rate. On the other hand, physical characteristics such as weight take a

longer to change and are more stable than physiological ones.

Finally, individual Goals, Preferences, and Plans are other concepts pertaining to user that are represented in the model. We represent the Goal concept in our model since conscious goals can impact performance by having an effect on attention and effort [116], and therefore persuasive systems that help their users to set goals are promising [118, 119]. Similarly, including user preferences and interests in designing interactive persuasive systems can increase the chance of success in persuasion [120]. For example, considering the personal trainer application mentioned earlier, in order to schedule a workout, if it knows that the user prefers to exercise in the evening, it can set the time of workout to happen in the evening. Besides what has been mentioned, plans also lead to achieving goals. The person features that we represent in our user model are among the most useful and general that we believe should be captured. However, there might be other contextual information not represented in our model. As we attempt to provide an extendible and adaptable model, there is still room for defining new contextual concepts. Figure 3.4 represents the relevant person's concepts and relationships.

3.1.4 Activity Ontology

The Activity section of the ontology models information about an individual's activity and factors impacting it. According to Dey and Abowd [114], context consists of four primary types, of which activity is one of them. Activity is modelled by the Activity concept in the proposed ontology. Activity is a general term for anything people do to achieve a goal, such as eating breakfast, driving a car, taking a shower, etc.

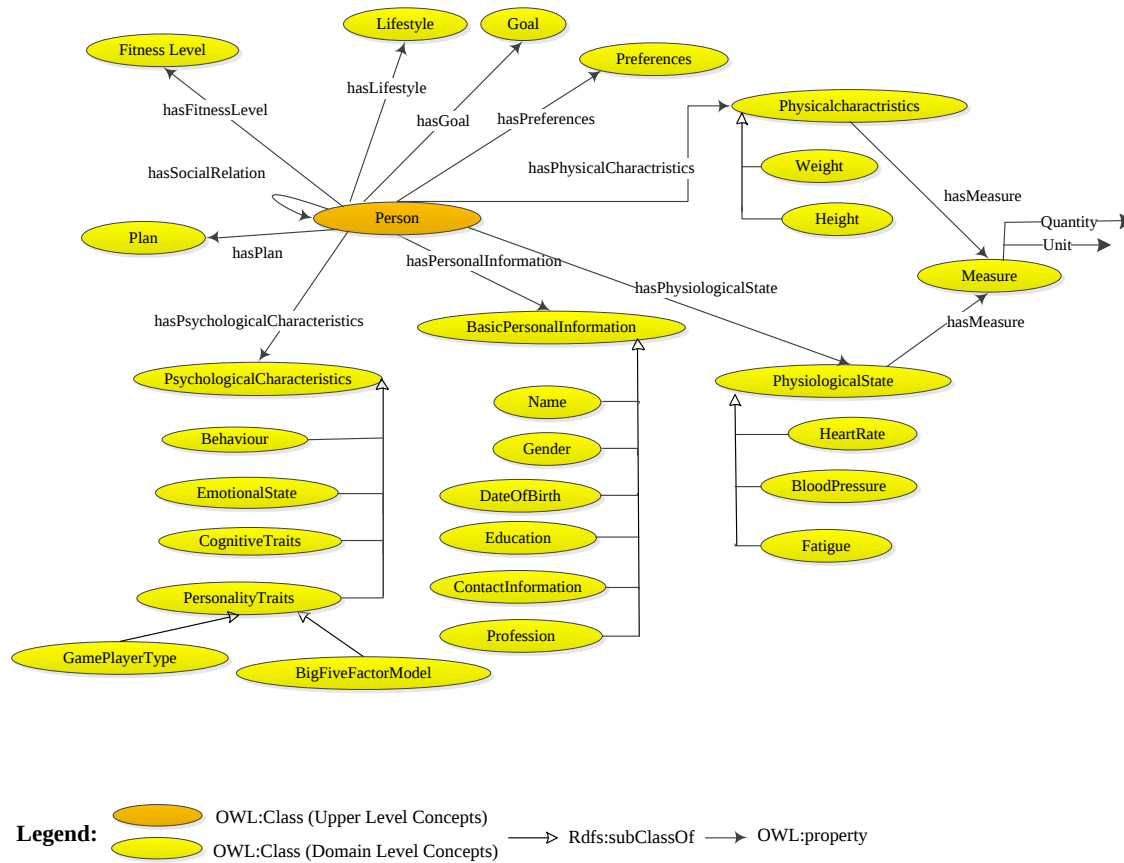


Figure 3.4 Partial Definition of ECOPA - Person Concept Ontology

Due to the significance of physical and sedentary activities in our model, we specifically extend the Activity concept to two more specific concepts: PhysicalActivity and SedentaryActivity, for representing more specific details about them. Persuasive applications improving physical activity capture, analyse, and/or provide information about users' physical activities and sedentary behaviours [38, 39, 40]. As the ontology will be used in building ontology-based applications improving physical activity, physical and sedentary activities in particular are extended and modelled.

The context of an activity performed by a person can be distinguished by several factors consisting of temporal, spatial, and environmental attributes. Characterizing activity with these

factors can help persuasive systems to provide context-aware services. The functionality of such systems depends on having information about where, when, and in what conditions an activity is being performed. Location is one of the crucial contextual factors that distinguish an activity. Activity is performed in a location. As we mentioned earlier in section 3.1.2, Location can be described in different ways. Rooms, corridors, kitchens, and other sections of a building can be used for expressing location in indoor environments. Global positioning system (GPS) is largely used for expressing location in outdoor environments. A location can also be described by an absolute or a relative address. Several fitness and physical activity motivating applications have been developed by monitoring performed physical activity based on the location [34, 120]. They calculate performed physical activity based on the changes in the location of a person using GPS coordinates.

In addition, an activity has a temporal attribute which can be useful for the physical activity persuasive application. The ontology models temporal attributes for activity. The attributes consist of duration of activity, starting time and ending time. Time can be expressed in various ways. It can be described by the day, week, month, year, or by very precise measures including seconds, minutes, and hours. Several physical activity motivating applications deal with temporal information of an activity. For example, fitness applications employ the duration of time that the user performed the physical activity to show whether they are doing enough and progressing towards their goals or not [121]. Similarly, applications that motivate their users by exercising in a group of friends take their users' preferred time for exercising and suggest doing it at a time that is feasible for all of them[121]. In these applications, in order to exercise in a group, the users require setting up a time for exercising.

Further, environmental conditions in performing an activity may be important for the context-

aware persuasive applications enhancing physical activity. To illustrate, an exercise planner may need to check the weather conditions before scheduling an outdoor exercise session, or exercise analysers may require the conditions surrounding the performed activity such as humidity and temperature to analyse the exercise performance. The environmental attributes consist of temperature, weather, humidity, pressure, noise, lighting, etc. Moreover, additional useful information that describes physical activity with more detail such as the intensity of physical activity for types of physical activity such as running, biking, and sitting are represented in our model. Figure 3.5 gives an overview of the concepts and relationships for the activity.

3.1.4 Device Ontology

The ontology models device in a pervasive computing environment. A diverse range of devices, including smart phones, smart TVs, and wearable devices, are in pervasive environments. A device is the provider of the persuasive service. In a pervasive computing environment, an application on a device may communicate with applications on other participating devices to deliver a service. Such devices have different capabilities and functionalities. Therefore, device specification gives an overview about its limitations and capabilities. To illustrate, consider an online persuasive game which provides a platform for connecting multiple users on different types of devices. In order to deliver appropriate persuasive services on time, this game should have information about each user's device to check whether it meets the requirements or not. Information consists of the required software installed on that device, operating systems, and hardware descriptions such as processor type, RAM, video card, and disk free space. Otherwise, it cannot work properly. If a user device does not have enough RAM or processing capabilities for the video game, the user cannot play appropriately.

Software concept provides a description of the software installed on the device. The specification includes name, vendor, version, and function of the installed software. According to software types and functionalities, it can be divided into sub categories including operating system, middleware, and application software. Software is responsible for providing services to other software or end-users. A service delivered to a user may be composed of services offered by software installed on the same device or other devices. Therefore, the issue of compatibility between different software becomes crucial. Modelling information about software can allow applications interested in service composition to understand compatibility issues. To illustrate, a middleware may not be able to call a service from another middleware because they are developed by different vendors. Additionally, two middleware applications with the same vendor may not be able to communicate with each other because of incompatibility issues (e.g. different versions). An overview of concepts and relationships related to device is shown in Figure 3.6.

3.1.5 Persuasive Service Ontology

At an abstract level, service is a functionality that can be consumed by users, applications, agents, and other services. Therefore, a user or a piece of software can use a service in order to achieve their goals. To give an example, considering an application forwards calls to a user's voice mail when he/she is not able to answer the phone such as when they are in a meeting. This system offers a call-forwarding service to the *end user*. In order to supply such a call-forwarding service, the application must know the location of the user, and subsequently, it uses a location service which is offered to the *software*. To enable service users, including agents and applications, to automatically discover, invoke, and compose services, we specify services in our ontology with explicit semantics.

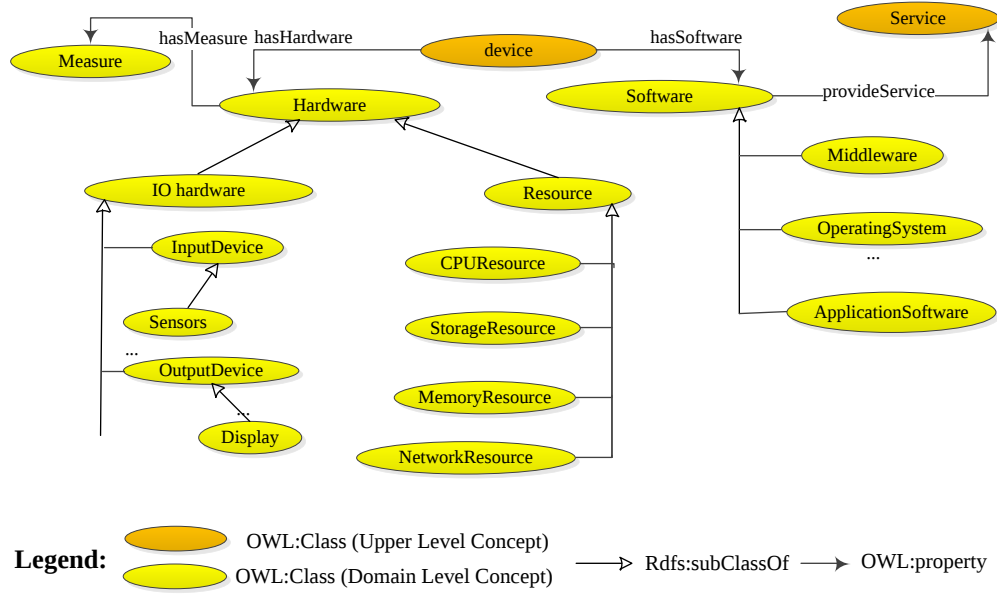


Figure 3.6 Partial Definition of ECOPA - Device Concept Ontology

Service specification should have enough details about the service. We attempt to represent a well-defined specification for describing services with a certain functionality. Figure 3.7 shows an overview of a service specification. To model the domain related to a service, we adopt a service ontology called OWL-s [122]. Although this ontology is defined for describing semantic web service in the semantic web, it has a standard and general interface for specifying a service. Based on OWL-s, the three concepts of ServiceProfile, ServiceModel, and ServiceGrounding can express a service in general. ServiceProfile provides information about the functionality of the service as what it does. This information can be used for service discovery. By using ServiceModel, a description of how a service can be used is provided. This description gives an overview of service outcomes when the service is executed and the conditions that lead to these outcomes. In other words, it specifies under what conditions and which results will be generated, so the service user will be able to evaluate whether the service is useful for it or not. ServiceGrounding describes implementation details which consist of a transport protocol,

message format and other implementation information.

In our ontology, we distinguish the persuasive service from the general service term. In our definition, a persuasive service is a specialized context-aware service that is offered to the end users to persuade them to engage in physical activity based on the context. Moreover, a persuasive service is also defined as a kind of multimedia service using one or multiple types of medium such as text, audio, and/or video to deliver persuasion content. For example, a virtual trainer application, that we mentioned earlier, plays a video on how to correctly perform an exercise movement if the network and device hardware allow it. Otherwise, it will show the exercise movement with images and text. Therefore, the persuasive service is carefully selected in regards to the device context and uses the media types of video or text and image.

Furthermore, persuasive services differ from each other with respect to the persuasive strategies used, such as praise, reward, and cooperation. A persuasive strategy is a technique used to persuade a person to do or stop certain behaviour. The applications developed based on our proposed context model can analyse and deliver a persuasive service based on the context. For example, consider a serious game engine that allows its users to play a game while exercising. The goal of this game is to make the process of exercising entertaining and to motivate users to exercise more. The strategy of the game is like other computer games; however, the user essentially has to exercise to continue the game. The game engine delivers a gaming environment service based on the user context. Some people get motivated by social interactions; however, cooperation and competition may negatively influence others. The game engine selects the environment with respect to the user's personality. The engine has two modes of single user, or multiple users, and uses the three persuasion strategies of rewards, competition, and cooperation [71]. The environments can be: single user with rewards, in which the user collects

points and is rewarded, multi-user with competition, or multi-user with cooperation. Thus, the persuasive service is chosen by taking into account various contextual factors. Figure 3.7 shows the Persuasive service concepts and relationships.

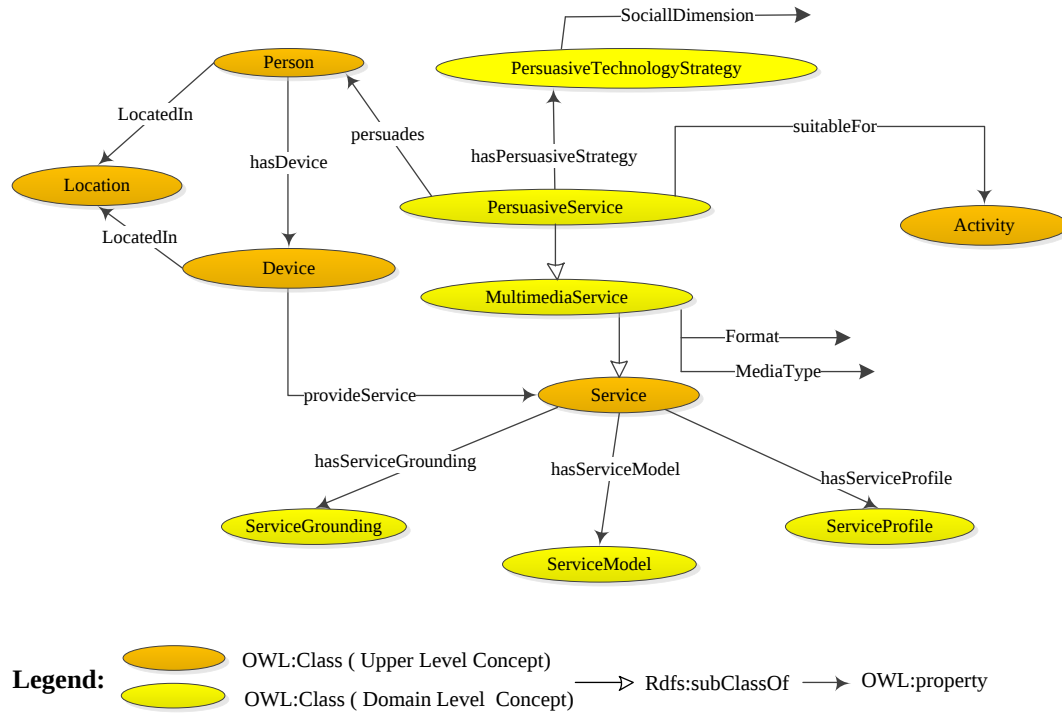


Figure 3.7 Partial Definition of ECOPA - Persuasive service Concept Ontology

3.2 ECOPA Applications

Our primary aim of ECOPA is to supply a shared context model for supporting context-aware persuasive applications for improving physical activity. In this section, we give some use-case scenarios to show the usability and feasibility of the proposed ontology in developing persuasive context-aware systems for promoting physical activity. To put it simply, the purpose of presenting use-cases is to show that ECOPA facilitates representing, manipulating, and accessing

the context data. Hence, it makes the process of developing persuasive applications that promote physical activity easier and faster. Such applications would have a coherent data model and therefore would be better able to monitor, analyse the context, and provide appropriate persuasion. Thus, the availability of infrastructures for developing context-aware systems facilitates the process of building these applications. The context-aware infrastructure needs a context model for representing and managing context data [123]. In the use-cases, SOCAM is used as the infrastructure for building persuasive context-aware applications and services and ECOPA ontology is used as the context model. The use-cases demonstrate context-aware applications promoting physical activity developed for a smart home. Before presenting the scenarios, we give brief descriptions about the SOCAM architecture.

3.2.1 SOCAM architecture

The SOCAM architecture provides an infrastructure for developing context-aware services in pervasive computing environments [124]. SOCAM uses CONON as a shared context model which enables context reasoning to create context-aware services. SOCAM architecture comprises three main components: context provider, context interpreter, and context-aware services. The context provider component is responsible for acquiring contexts from heterogeneous sources and converting them into OWL representations. The context interpreter processes context and infers high-level context from low-level context using context reasoning. Context-aware services are agents, applications, and services that use contextual information provided by the context provider to react accordingly. Context-aware services can acquire contexts by performing a query to the context provider or by listening for events sent by the context provider. These services can be called whenever a set of rules becomes true through

changes within the current context. The application developers can simply develop methods that are invoked when the predefined rules in a condition are triggered. Figure 3.8 represents the SOCAM architecture.

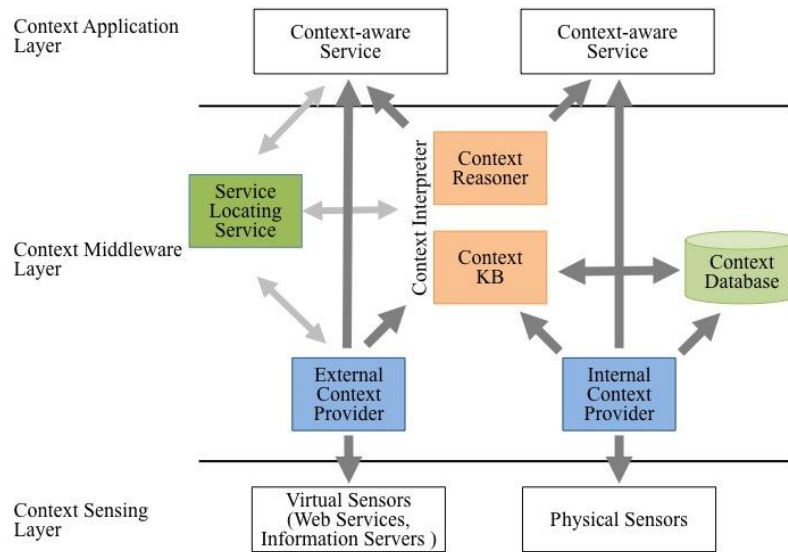


Figure 3.8 Overview of the SOCAM Architecture

3.2.2 Scenarios

The ECOPA ontology can be used with the SOCAM architecture as a formal context model to create persuasive context-aware services motivating users to improve physical activities and/or engage in fewer sedentary activities. Technological tools can persuade people to change their behaviour. Self-monitoring, personal awareness, social awareness, and providing enjoyable interactions are amongst the strategies for persuading people [47, 71]. The following use-cases demonstrate some typical applications of ECOPA ontologies in SOCAM to create persuasive context-aware services.

3.2.2.1 Scenario 1

Sam resides alone at his home. When he sits on the sofa, the status of the weight sensor attached to the sofa turns on. The context provider acquires the status of the sensor and fuses it to the *Device Ontology* predefined in ECOPA ontology. The context interpreter asserts that Sam is sitting on a sofa using the ECOPA Ontology. By triggering a rule in the condition that the status of the sofa sensor turns on, it is concluded that Sam is sitting on the sofa. Therefore, it is inferred that Sam is performing a sedentary activity. One typical persuasive context-aware service is monitoring a user's sedentary activities and providing awareness with appropriate content about the length of time the user spent engaged in sedentary activities. At the end of the day, an awareness service using Activity Ontology in ECOPA composes a description of the sedentary activities performed by Sam. Sam receives a notification on his cell phone telling him the duration, type, and negative consequences of sedentary activities he has been involved in during the day at home.

3.2.2.2 Scenario 2

When Sam exercises on the treadmill, he uses a smart music player application on his cell phone. Instead of playing a predefined playlist, the music player intelligently selects and plays a song that will encourage him to be on track with his exercise goal [125]. His goal is to exercise with a desired intensity. The intensity is calculated through heart rate as number of beats per minute. Sam's heart rate is measured using the physiological sensors connected to his body. The context provider collects heart rate from the sensors and calculates the intensity. It feeds the information into the Person ontology. The music player selects the next song based on Sam's workout

intensity just before the current song ends. The player uses the ECOPA Ontology to acquire the exercise intensity and the user heart rate. If the intensity was less than the desired intensity, a song with a higher tempo should be chosen to entice Sam to speed up the exercise, while a lower tempo song should be selected when the intensity is higher than the desired value. To conclude, based on whether Sam is required to speed up, slow down, or keep the pace, the application executes a set of rules defined on the top of the ECOPA ontology.

3.3 Context Reasoning

One of the significant advantages of formal modelling is its support for logic reasoning. Ontology modelling enables inferring high-level context from low-level context. In pervasive environments, through input sensors, context-aware systems collect different types of low-level contextual data such as GPS coordinates, temperature, or other environmental data and then fuse them into the ontology model. By accessing various implicit types of context in an aggregated model, they infer and create high-level explicit context including the current location and user activity. Context reasoning can be performed over our proposed ontology to deduce high-level and implicit context, which can be used to build context-aware persuasive services and applications from sensor-driven data. To demonstrate the role of reasoning in these applications, we use the scenarios presented in the previous section 3.2.2. We will describe context reasoning based on the ECOPA ontology in those scenarios. The rules are written using the Semantic Web Rule Language (SWRL) [126] which is a language that extends OWL for expressing first order logic.

Table 1.1 Rule for Detecting Sedentary Activity

High level context	Reasoning Rule
WATCHING TV <i>(Sedentary Activity)</i> <i>“Person <u>P</u> is Watching TV”</i>	$\text{Persosn}(\text{?p}) \wedge \text{hasStatus}(\text{sofaSensor}, \text{ON}) \wedge \text{hasStatus}(\text{TVSet}, \text{ON}) \rightarrow$ $\text{perform}(\text{p}, \text{WATCHING_TV})$

According to the first scenario presented in the section 3.2.2.1, considering the awareness and health-monitoring service that tracks a user’s sedentary activities while watching TV. If a user watches TV more than a specific time of three hours, a message will pop up on the screen of the smart TV or be sent to his/her smart phone to warn the user about his/her behaviour. To create this service, it is first necessary to identify the user’s activity. Activity recognition, in this case “Watching TV”, is deduced from low-level data gathered from pervasive devices. By creating a reasoning rule written in first order logic, high-level context such as “what is the user doing?” can be inferred from corresponding low-level context. Table 3.1 shows the reasoning rule for identifying the “Watching TV” high level context. The actions such as sending a message to the user’s cell phone or a pop up message on the TV screen will be triggered when a defined rule becomes true. In this case, the rule is if the user is watching TV for more than three hours then the notification must be sent. Table 3.2 demonstrates the defined rules for triggering notifications.

With respect to the second scenario described in the section 3.2, the musical service selects the next song based on the user context. The high-level and implicit contexts such as speeding up, slowing down, or keeping the same pace, are inferred from low-level and explicit contexts; in this case, the user’s workout intensity and heart rate. According to the driven context, the music player can choose the tempo of the next song. In Table 3.2, you can see the defined rule for playing a faster tempo song.

Table 1.2 Rules for Describing Context Aware Persuasive services

Service	Description	Reasoning Rule
<i>Pop up a notification on the TV screen</i>	<i>sedentary activity for more than three hours</i>	Person(?p) $\wedge$ perform(?p, ?activity) $\wedge$ SedentaryActivity(?activity) $\wedge$ hasTemporalDescription(?activity, ?duration) $\wedge$ TemporalDuration(?duration) $\wedge$ Hour(?duration, ?h) $\wedge$ swrlb:greaterThan(?h, 3)
Playing Faster Tempo Music	Speed up <i>USER_INTENSITY is Less than DESIRE_INTENSITY</i>	Person(?p) $\wedge$ perform(?p, ?physicalActivity) $\wedge$ hasPhysicalActivityDescription(?physicalActivity, ?description) $\wedge$ hasIntenisty(?description, ?intensity) $\wedge$ hasIntensityMeasurement(?intenisty, ?measure1) $\wedge$ Unit(?measure1, ?unit1) $\wedge$ Value(?measure1 , ?targetHR)$\wedge$ hasPhysiologicalState(?p, ?state) $\wedge$ HeartRate(?state) $\wedge$ hasPhysiologicalMeasurement(?state, ?measure2) $\wedge$ Unit(?measure2, ?unit2)$\wedge$ Value(?measure2, ?currentHR) $\wedge$ sqwrl:equal(?unit1, ?unit2) $\wedge$ swrlb:lessThan(?currentHR, ?targetHR)

4 CAPP: an Architecture for Building Persuasive Applications Promoting Physical Activity

By developing a formal context model supporting the development of Persuasive Applications Promoting Physical Activity (PAPPA), it is very useful to have a architecture to support the acquisition of various contextual information from different sources, modelling of the context using the proposed ontology, reasoning on the low level context to create a high-level one, and delivery of context-aware persuasive services. Developing context-aware applications is a time-consuming and difficult process due to the lack of suitable infrastructure that supports building such applications [20]. Consequently, the same problem exists for developing PAPPAs which are a kind of context-aware applications. Since the proposed ECOPA ontology allows semantic context representation, context reasoning and knowledge sharing, it can be used as a formal context model to represent and manipulate context information in an architecture that helps the development of PAPPAs. In this chapter, we propose a reference architecture, called CAPP,

using an ECOPA ontology to facilitate building PAPPAs. Moreover, we design a PAPPa called ExePeEnhancer based on the proposed architecture aimed at improving users' performance during an exercise and assists them to achieve their predefined exercise goals.

4.1 The CAPPa Reference Architecture

Based on the proposed context ontology, the CAPPa architecture is designed (Figure 4.1) with the goal of providing an efficient support for building persuasive applications that promote physical activity. It is a layered architecture that showcases the various key components in a typical PAPPa. To provide persuasive services based on contexts, the architecture enables the definition of services and their contexts semantically, and allows logic reasoning to discover the right persuasive service which must be provided in a particular situation. According to CAPPa architecture, the contextual information acquired from sensors is converted into a shared and formal representation. The architecture consists of four main components and three layers that include the Context Gathering Layer (CGL), the Context Processing Layer (CPL), and the Context-Aware Persuasive Application layer (CAPAL). In the following sections, these components are described in detail. Figure 4.1 shows the CAPPa reference architecture.

4.2.1 Context Gathering Layer

The Context Gathering Layer (CGL) is responsible for abstracting contexts from heterogeneous sources and transforming them into OWL representations that can be used by other components. It collects raw context data from virtual and physical sensors. Contexts have various types and formats and include time, person's activity, physiological, psychological, ubiquitous device specification, location, etc.

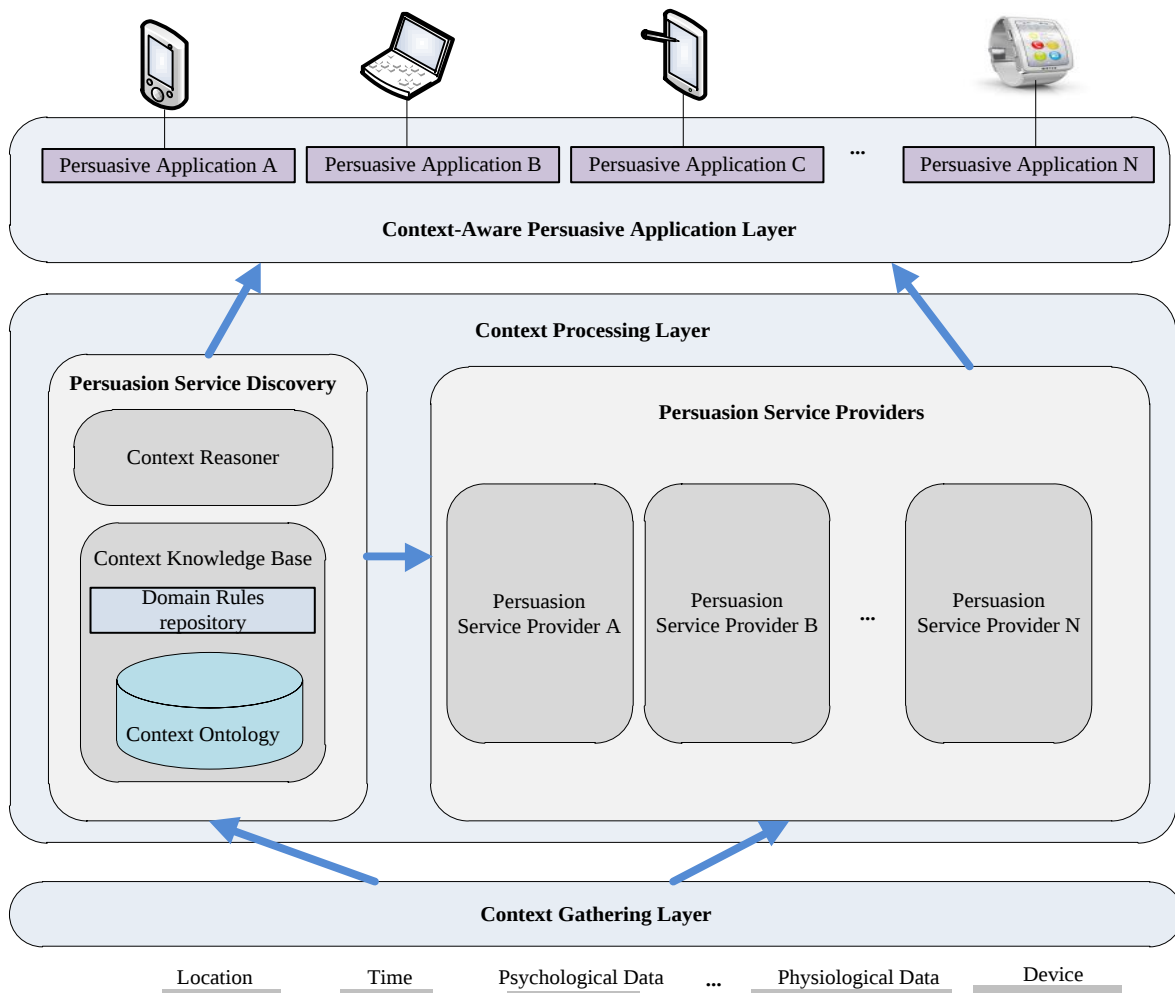


Figure 4.1 Overview of the CAPPA Reference Architecture

Some of them can be acquired directly from ubiquitous sensors such as ECG devices for heart rate monitoring, whereas others can be acquired from software and applications, such as acquiring a person's free time from his/her scheduler application on their smart phone. Context can be static, such as with a person's personality, or dynamic, such as with a user's physiological information. The CGL collects low-level sensed contextual data and converts them into OWL descriptions, which facilitates high-level context manipulation.

4.2.2 Context Processing Layer

The Context Processing Layer (CPL) stores, manages, and manipulates various contextual data and creates useful persuasive services. This layer consists of two components: Persuasive service Discovery (PSD) and Persuasive service Providers (PSPs).

4.2.2.1 Persuasive Service Discovery

The Persuasive service Discovery (PSD) is responsible for selecting or triggering the most suitable persuasive service according to the relevant context, and locating the service provider that offers the persuasive service. Various persuasive services are available in pervasive environments. To persuade a person effectively, each persuasive service should be provided based on the particularities of a given situation. Therefore, this unit analyses the relevant contexts using the context knowledge stored in the Context Knowledge Base and chooses the most appropriate persuasive service through logic reasoning. For instance in a smart home, the PSD analyzes a user's level of activity. If it determines that the user has been sitting and watching TV for more than three hours through knowledge inference, it concludes that a persuasive service giving awareness about the user's sedentary status can be provided to the user.

This PSD component consists of two sub-components:

Context Knowledge Base: It stores the ECOPA ontology and domain rules. When a context gathering unit converts contextual data into an OWL description, it stores them in the context ontology. The context ontology consists of contextual knowledge in the form of descriptive logic rules and axioms. For example, 'user A has preference B' is asserted in the context ontology.

Moreover, domain inference rules in the form of first order logic can be stored in the Context Knowledge Base. These rules have an IF-THEN-ELSE format. For instance, if “user A” is “sitting” and the “TV” is “on” then “user A” is “watching TV” is a rule. Facts such as “User A” is “sitting” and “device status” is “on” are asserted in the ontology knowledge base and domain rules such as Rule1 below are stored in the domain rule repository.

hasActivity(userA, SITTING) ^ DeviceStatus(TV, on) -> hasActivity(userA, WATCHING-TV) Rule1

Context Reasoner: To select or trigger the appropriate persuasive service relating to relevant contexts, the Context Reasoner performs logic reasoning on the context knowledge stored in the context knowledge base. Simply put, the Context Reasoner is a rule engine that executes asserted rules in the knowledge base and semantically chooses the most relevant persuasive service to run.

4.2.2.2 Persuasive service Providers

The Persuasive Service Providers (PSPs) component is responsible for creating the persuasive services. Each PSP can run one or a set of persuasive services. Information about PSP units and the set of services they can offer is specified in the PSD component. The PSD component is used to identify the persuasive service most appropriate for a specific context, and the PSP is used to provide that service. Using the awareness service example previously presented in section 4.2.2.1, when PSD recognizes that the service must be provided, the relevant provider is called to run the service. The provider in this case can be an agent that creates messages with informative content about the user’s sedentary behaviours. It sends the generated messages to the user’s smart phone application that shows the user’s daily sedentary activity.

4.2.4 Context-Aware Persuasive Application Layer

The Context-Aware Persuasive Application Layer (CAPAL) constitutes a set of persuasive applications and agents that execute on the pervasive computing devices. They deliver persuading services to the end user and adapt their behaviour to the current context. They provide a persuading environment that enhances physical activity. For example, they can be a software module controlling a haptic actuator that produces feedback regarding the exercise intensity or progress, or a media player that plays songs to motivate users to exercise more. To deliver a persuasive service to the user, persuasive applications may use services offered by a persuasive service provider.

Persuasive applications use two methods to deliver context-aware services. The first method is that application developers write a set of rules in the PSD unit to specify the conditions for triggering that service. Whenever the conditions for that context become true, a context-aware persuasive service must be triggered. The PSD either notifies a persuasive application in the CAPAL to invoke the persuasive service or notifies a PSP that ultimately invokes a context-aware persuasive service in the CAPAL. As an example, if a user sits for a long time on a chair, the haptic actuator must give haptic feedback. A set of rules that specifies the context of running that service such as “sitting for a long time” is defined in the PSD. When the context is met, PSD invokes the haptic service provider, and the provider sends the command to the software that controls the haptic actuator in the CAPAL.

The second method is to have the persuasive applications or agents query the PSD to specify what services are suitable based on the current context and locate the PSP which offers the service. These applications can provide a set of persuasive services to the end user, and that's

why they query the PSD to provide the most appropriate one for the context. To give an example, consider a persuasive game that offers three game scenarios. Using the PSD, the application tailors the game based on the gamer's personality.

4.3 ExePeEnhancer: A Case-Study of CAPPa Architecture

Using the CAPPa reference architecture, we have designed a persuasive application called ExePeEnhancer. The application assists users to reach their exercise goals by enabling them to track their exercise performance during physical activity and gives feedback about their performance to increase their awareness. It allows users to define their goals, constantly monitors a user's biological information, and provides persuasive services to encourage them to achieve their goals. The application is designed to improve cardiorespiratory fitness using physical activities such as running and cycling. The user can define her/his goals based on a preferred intensity. More information about cardiorespiratory fitness, related activities, and exercise intensity are provided in section 4.2.1.

To enhance the effectiveness and influence of the application, ExePeEnhancer offers various persuasive services and tailors the selection of the services based on the context. According to Berkovsky et al. [127], tailoring strategies can largely increase the impact of persuasive applications. Persuasive services include: playing appropriate music to motivate the user to reach her goal, giving vocal feedback, haptic feedback, visual feedback, and games. These services are offered on various pervasive computing devices that include smart phones, tablets, and smart watches, according to the capability of the device to provide them. To improve the effectiveness and adaptation of the application, it tailors the service based on the context such as user preference, user personality, activity type and place, and device capability. Figure 4.2 shows how

we have applied the CAPPA architecture in the development of the ExePeEnhancer application. The application and its main components are described in the following sections.

4.2.1 Cardiorespiratory Fitness

Cardiorespiratory fitness (CRF) is a health-related component which reflects body fitness level. CRF is defined as a measure of body ability for providing oxygen during prolonged physical activity, which involves the circulatory, respiratory, and muscular system [128]. Simply put, the CRF measures the body's ability to carry oxygen to muscles during sustained physical activity, as well as the ability to absorb oxygen for producing energy.

Performing prolonged exercise that involves the aerobic energy system improves cardiorespiratory fitness [128]. Prolonged exercises increase heart rate and results in aerobic fitness. To exercise effectively and obtain appropriate results for cardiorespiratory fitness, the American College of Sports Medicine (ACSM) [129] has developed standard guidelines for aerobic exercise frequency, intensity, time, and type (FITT) of aerobic workouts. Frequency refers to the number of days that a person should set for exercising. Intensity defines how hard the exercise should be performed. Time represents the duration of the exercise workout, and type stresses the kinds of muscular activities for improving cardiorespiratory fitness [129].

ACSM recommends exercising regularly between three to five days per week. The number of days depends on the exercise intensity and goal. Regular physical activity should be performed three days per week with vigorous intensity, or five days per week with moderate intensity. The intensity of an exercise can be measured in various ways. The Perceived Exertion scale and Talk test are two subjective methods for quantifying activity intensity. The former method, also called the Borg Scale [130], is a scale indexed from 0 to 10, where 0 represents the effort for an

activity such as sitting and 10 represents the maximum possible effort.

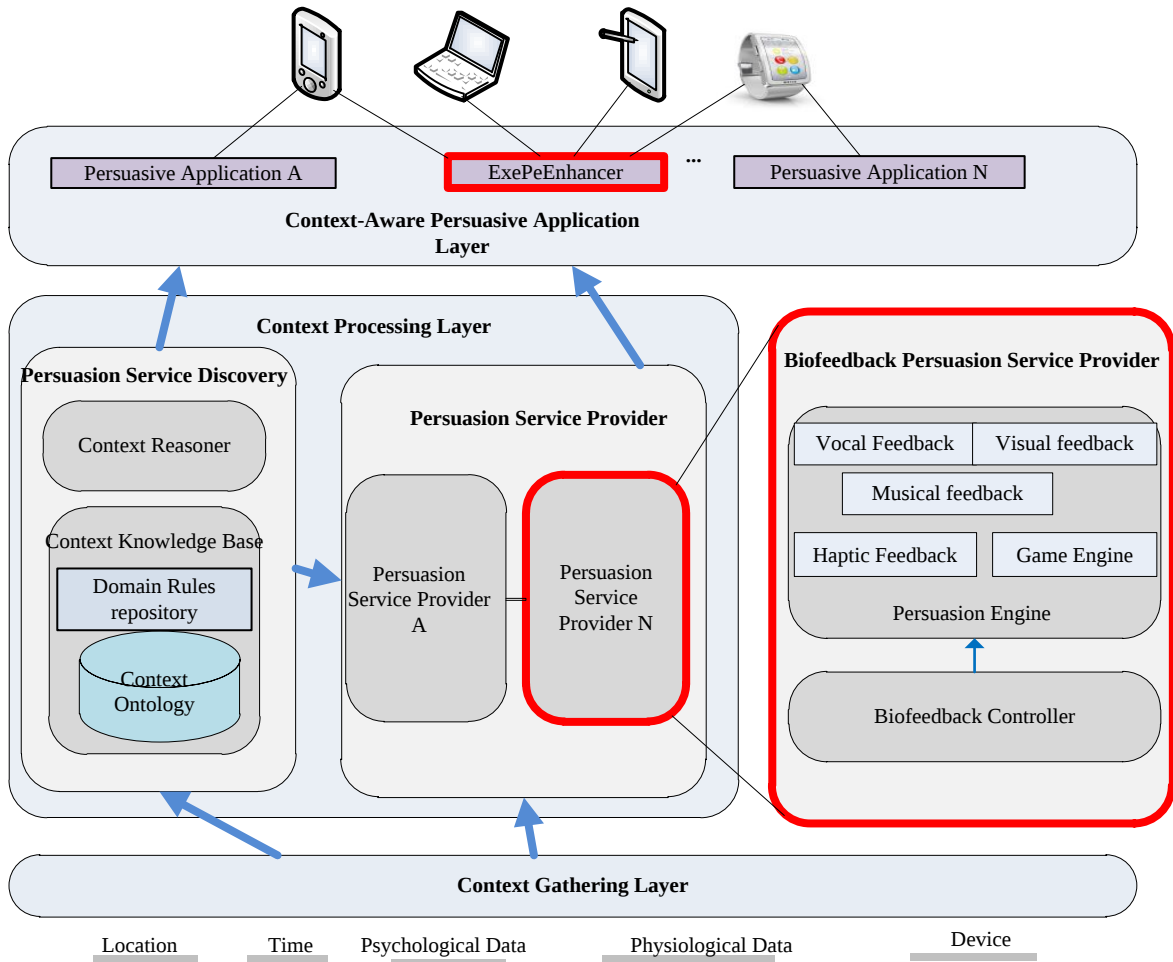


Figure 4.2 Overview of CAPPA Reference Architecture

The latter method states that a person exercising at a moderate level can talk but not sing, while the person exercising at a vigorous level is not able to say a few words without any pause for a breath.

Furthermore, intensity can be determined by employing a more technical method using heart rate. As there is a relationship between heart rate and oxygen intake (VO₂), exercise intensity can be calculated as percentage of maximum heart rate [131]. Equation 4.2 shows target heart

rate based on maximum heart rate. However, the equation does not accurately show exercise intensity, as people have different resting heart rate ranges, which is not reflected in the formula [129]. A more precise formula for calculating intensity is the Karvonen formula, which considers heart rate at rest and refers it by heart rate reserved. The Karvonen formula is shown by equation 2.

$$HR_{max} = 220 - Age \quad \text{Equation 4.1}$$

$$Target\ Heart\ Rate = \%Intensity \times HR_{max} \quad \text{Equation 4.2}$$

$$Target\ Heart\ Rate = \%Intensity \times (HR_{max} - HR_{rest}) + HR_{rest} \quad \text{Equation 4.3}$$

4.2.2 ExePeEnhancer Persuasive Services

The ExePeEnhancer application offers several persuasive services that employ various persuasive strategies to improve exercise performance. Some of the services constantly provide feedback about exercise performance using different mediums which aid the user in tracking his/her performance. Visual, audio, and haptic feedback services use personal awareness as a persuasion strategy. Visual feedback is a persuasive service that displays relevant information and recommendations for the next action that the user should take in order to get closer to the target goal. Audio feedback is a virtual trainer that provides vocal feedback about the user's current state of activity and what he should do to reach the target. Haptic feedback is another persuasive service that provides vibration feedback which tells the user whether to increase or decrease his/her effort. Moreover, musical feedback uses the effects of music on physiology and physical activity. Musical feedback is a persuasive service that selects the next song with particular features to motivate the user for rising, reducing, or keeping the speed of exercise. In

addition, games are another persuasive service offered by the application to encourage the user by adding fun and entertainment to the activity.

4.2.2.1 Persuasive Service Discovery for ExePeEnhancer

In the PSD component, persuasive services and the contexts that lead to triggering them are formally expressed. Contexts gathered by the CGL through soft sensors are fed into the context ontology as new pieces of knowledge. Each service and the contextual conditions that cause the application to deliver that service are expressed by domain rules. Domain rules are written in SWRL. When the application requests that the PSD select a persuasive service for delivery, the reasoner is called to perform an inference using the knowledge and rules defined for selecting the persuasive service. The Jess rule engine is used to manipulate ontologies and for rule-based reasoning. The rules are written based on the restrictions and conditions of providing a persuasion. Some of the requirements and restrictions used to define the rules used for selecting a specific persuasive service are as follows:

Firstly, as user preferences play a key role in the success of persuasive systems [111] and since several persuasive services can be provided, user preferences are considered in the selection process to increase the effectiveness of the application. Secondly, a Smart watch has restrictions on providing persuasive services that include playing music, games, and vocal feedback. Moreover, when a user is cycling or running outside, giving visual feedback or a game on her cell-phone are not appropriate as they may distract her and cannot effectively motivate her. Since the user should bring her cell-phone to see the screen, it may be very disturbing. Therefore, the user may slow down each time she looks at the screen, which negatively affects her performance or she may not care about the persuasive service after a while. A big problem of wearable

exercise monitoring systems is that they should provide useful information without interrupting or disturbing their workout [47]. In this context, visual feedback and games should not be offered during the outdoor activity. However, it is possible to give visual feedback on the smart watch since it is feasible to use the watch while doing these types of exercises. Furthermore, tablets are not appropriate for outdoor activities, as using one's hands while running or cycling outside may be very disturbing. In addition, haptic feedback may not be provided on a tablet, since the user cannot wear it. Lastly, games have three modes: multi-user with cooperation, multi-user with competition, and single user, which must be tailored based on the gamer's personality. According to these restrictions and facts, rules for selecting a persuasive service are defined.

4.2.2.2 Persuasive Service Provider for ExePeEnhancer

After choosing the persuasive service by the PSD and finding the provider of that service, the application requests the relevant PSP to supply the service. In our application, the biofeedback persuasive service provider is the PSP. The biofeedback persuasive service provided has the two components of persuasion engine and biofeedback controller. The persuasion engine contains 5 types of separate programs that provide supplementary services to the application. These programs include a vocal feedback provider, a visual feedback provider, a haptic feedback provider, a musical feedback provider, and a game engine. There is another unit that receives the user's biological data and creates meaningful commands and information which is used by the persuasion engine. In the following section, more details about the PSP are presented.

Biofeedback Controller: The biofeedback controller receives a user's current heart rate and creates useful information for the persuasion engine. In order for the user to achieve his/her goal, based on the current performance, he/she should take one of the actions of increasing,

decreasing, or continuing at the same pace. The biofeedback controller is responsible for tracking the user's heart rate and identifying the next action as speeding up, slowing down, or keeping the same speed of exercise, which can help the user to maintain the exercise intensity. By constantly monitoring the user's heart rate, the controller checks whether it is in the target heart rate range or not. The controller calculates the average heart rate it receives for a period of time. If it is in the range, then it produces the command to keep the pace, which means the user should continue the exercise with the same effort. If it is less than the lower bound of the target zone, then it creates a command to speed up, which means the user should increase his effort. Contrary, if it is higher than the upper bound of the target zone, then it generates a command to slow down to decrease his effort and to return the user to the correct range. Figure 4.3 shows the algorithm for analysing the heart rate. It sends the relevant command along with the user heart rate information to the persuasion engine.

Persuasion engine: In the persuasion engine, there are 5 types of programs that create useful content and essential information for the application to run the persuasive service. After receiving the command and heart rate information from the biofeedback controller, the persuasion engine passes them to the relevant provider program. The visual feedback provider creates the content that the application has to display about the user's current heart rate, current intensity, target heart rate, target intensity, and the next action for getting closer to the target intensity.

The vocal feedback provider creates the sentences and phrases for the virtual trainer. The virtual trainer guides users by giving audio instructions. The haptic feedback controller creates the pattern of vibration with respect to the command it gets from the biofeedback controller. By sensing vibration, the user knows that he/she should speed up or slow down. In order for the user

to be able to differentiate between slowing down and speeding up, two patterns of vibration are generated by the provider. The musical feedback provider selects the next song according to the user's exercise performance during the previous song.

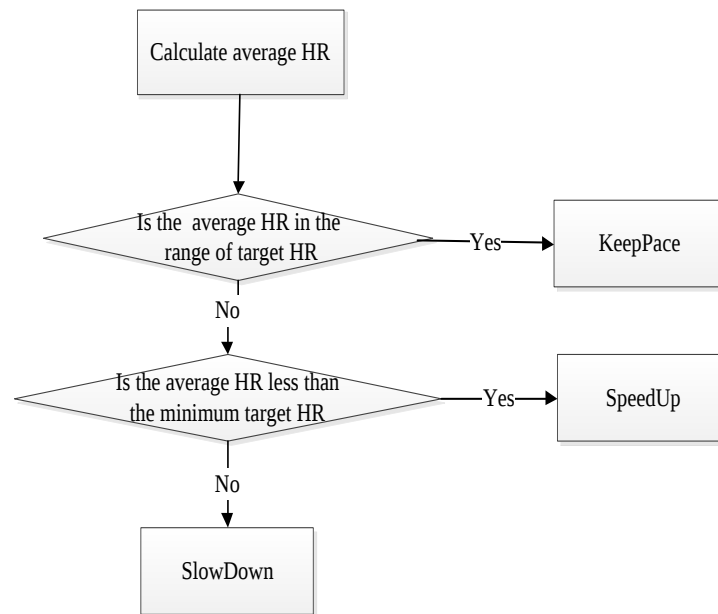


Figure 4.3 Algorithm of Heart Rate Analysis

If the user's heart rate was less than the lower bound of a target heart rate range, it chooses a song with a faster tempo to motivate the user to exercise more. If the user's heart rate was higher than the upper bound of the target heart rate range, it chooses a song with a slower tempo. If the user's heart rate was in the target heart rate range, it chooses a song with the same tempo. The game engine calculates the score of the player(s) and their positions in the racing rounds with respect to the users' performances.

4.2.2.3 Context Gathering for the ExePeEnhancer

The Context Gathering unit collects contextual data from virtual and physical sensors. Contexts for this application include device specification, physiological data, location, activity type, user preferences and user gamer type according to BrainHex [132].

5 Evaluation and Results

To validate the proposed ExePeEnhancer, we conducted a user study with 14 participants. The purpose of this study was to evaluate the efficacy of the ExePeEnhancer in helping the users to achieve their pre-defined exercise goals. The distinguishing characteristic of the ExePeEnhancer is using different persuasive services and delivering the adapted persuasive service (or adapting them) by taking the context into account. We believe that this characteristic improves the efficacy of the ExePeEnhancer. As a result, through this study, we want to evaluate the effect of this characteristic on the system efficacy in assisting users to achieve their exercise goals. We designed the study in a similar way to the user study performed in the research work done by de Oliveira et al [47], since in their study they evaluate the efficacy of their proposed system on user performance using physiological information and the intensity of an exercise. In this chapter, we present the general information about participants, materials, methods and procedures for performing the study, followed by a discussion of the results.

5.1 Participants

14 participants volunteered for the study: 2 of them were employees at Information Technology companies, 2 of them were university staff, 2 of them were unemployed, and 8 of them were university graduate students with several backgrounds which included engineering, education, and management. The participant's age ranged between 24 and 45, with an average age of 30.9 and modal age of 28. Of the 14 participants, 10 were male while 4 were female.

Before the experiment, the participants were asked to self-report their level of activity, using a questionnaire adopted from the Physical Activity Questionnaire (IPAQ) [5.2, 5.3]. Using the guidelines for data processing and analysis of the IPAQ [5.1], 9 of the participants were determined to be minimally active, while 5 of them were inactive. Moreover, all of the participants reported more than 4 hours of sitting during a week day. They were also asked to fill out an online pre-run questionnaire about their demographic information, exercise habits, and technology familiarity (Table 5.1). As ExePeEnhancer aims at providing different services, from music to game, we needed to collect backgrounds information about the users' familiarity with such services. We present a summary of their responses to the pre-run questionnaire in the following.

With regards to fitness apps, 10 of participants had never before used any application as a support to physical activity, whereas the remaining testers already had some experience with such kinds of applications. 3 of the participants reported that they regularly used fitness apps. It is interesting to note that all of participants had listened to music during exercise at least once. 8 of them reported that they regularly listened to music during a workout while 4 of them reported that they sometimes listened to music during a workout. However, all of the participants believed

that having a music player or a fitness app could help them to improve their exercise performance and achieve their exercise goals.

In terms of their video gaming background, most of the participants had a familiarity with video games. Only one of them had never played any video game, whereas 9 of them occasionally played video games. 8 of the participants used a heart rate monitor at least once while running. The main reason to monitor heart rate is the benefit of being aware of the training zone and the ability to keep the heart rate inside the training zone. Interestingly, 12 of them reported feeling bored while exercising alone, such as while riding a bike or running. Also, 10 of them reported that they defined goals or training zones during exercise.

5.2 Apparatus

In order to perform the study, we built a prototype of ExePeEnhancer. We used the Samsung Galaxy S5 and Samsung Galaxy Ace II as a smart phone, the Samsung Galaxy Tab as a tablet, and the Samsung Galaxy Gear Smartwatch as a smart watch. The Android SDK version 19 was used for developing the applications on these devices. A Zephyr HxM heart rate monitor was used to collect physiological data. To evaluate the system, the participants were required to exercise with and without the system, which in this study meant riding a stationary bicycle in the experiment room. The experiment room was equipped with the following items: a stationary bicycle (ERGO bike 8008TRS), a large screen TV (63in), and a comfortable loveseat sofa. Figure 5.1 shows the layout of this room. One of the contextual elements that should be considered is location. The participant had to exercise in outdoor and indoor environments. Since we wanted to keep all the variable context types, except the variable context, the same for the participants, we conducted all the experiments inside the room and simulated the outside

environment. In other words, in an outside environment, environmental conditions such as temperature and humidity which may affect the results are variable for all the participants. To simulate the outside environment, a large screen TV was located in front of the stationary bike. In the cases that the participants were exercising in an outside environment, the large screen TV displayed cycling workout videos.

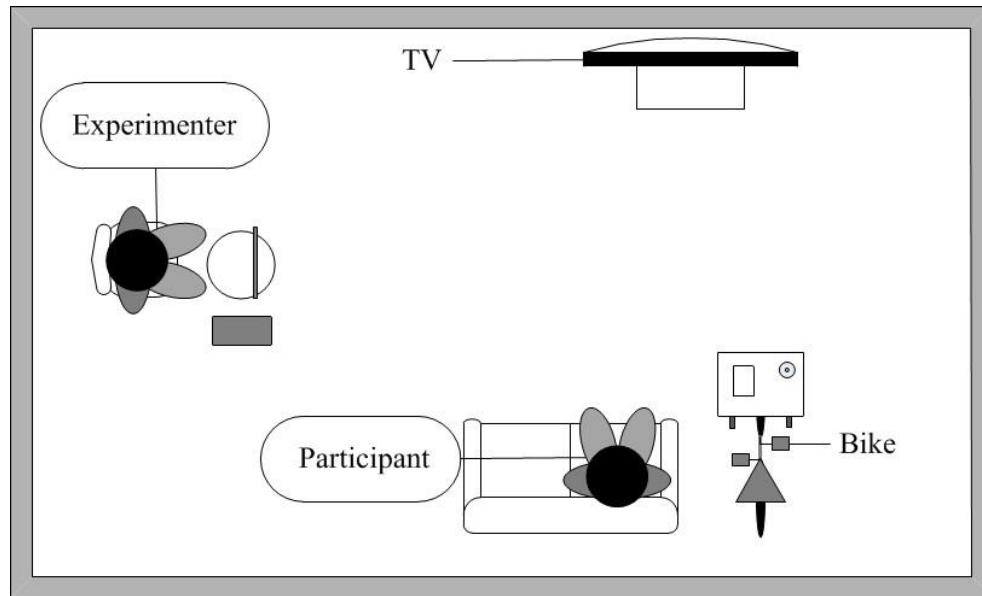


Figure 5.1 Layout of the Study Room

5.3 Study Design

We wanted to validate the efficacy of the ExePeEnhancer in assisting users to achieve their workout goals. More specifically, we planned to investigate how adapting the persuasive service based on the context, while the system used different persuasive services, influenced the system efficacy in helping the users to achieve their exercise goals. Therefore, to evaluate the ExePeEnhancer, we compared its efficacy in assisting users to achieve a predefined workout with a system's efficacy that provides a single persuasive service in a different context.

Table 5.1 The Pre-Run Questionnaire About User Demographic, exercise habits, and technology familiarity

Index	Questions and Answers Options				
Q1	First Name				
Q2	Last Name				
Q3	Age				
Q4	Occupation				
Q5	Gender				
	Female	Male	I would rather not specify		
Q6	Have you ever played any type of video game?				
	Yes, once	Yes, sometimes	Yes, regularly	No, never	Other:
Q7	Do you listen to music during physical activity?				
	Yes, I once	Yes, sometimes	Yes, regularly	No, never	Other:
Q8	Do you monitor your heart rate during physical activity?				
	Yes, I have done so at least once	Yes, sometimes I monitor my heart rate during physical activity	Yes, I regularly monitor my heart rate during physical activity	No, I do not monitor my heart rate during physical activity [skip question 9, 10]	Other:
Q9	Do you use wearable heart rate monitor device, such as wristband heart trackers or chest strap heart rate monitors, to monitor your heart rate during physical activity?				
	Yes, at least once	Yes, sometimes	Yes, regularly	No, never	Other:
Q10	If you use a heart rate monitor, please specify the reason[s]:				
	being aware of the intensity and activity level	adjust the effort in the training zone during exercise	Other:		
Q11	If you do not use a heart rate monitor, please specify the reason[s]:				
	I do not have one	I do not see any benefit of using it	Inconvenience of wearing it	Other:	
Q12	Do you use any fitness applications during physical activity?				
	Example: RunKeeper, Nike+				
	Yes, once	Yes, sometimes	Yes, regularly	No, never [Skip questions 13, 14, 15, 16]	Other:
Q13	Do you use any fitness apps on [smart phone]?				
	example: RunKeeper, Nike+				
	Yes, at least once	Yes, sometimes	Yes, regularly	No, never	
Q14	Do you use any fitness apps on [Gear fit]?				
	Yes, at least once	Yes, sometimes	Yes, regularly	No, never	Other:
Q15	Have you used a fitness app on a [smart TV and/or Tablet]?				
	Example: Fitness VOD, a personal trainer on Samsung smart TV				
	Yes, at least once	Yes, sometimes	Yes, regularly	No, never	Other:
Q16	Have you used any fitness app that uses, analyses, and/or represents your heart rate?				
	Example: RunKeeper with heart rate monitoring option				
	Yes, once	Yes, sometimes	Yes, regularly	No, never	Other:
Q17	Do you feel bored while exercising alone such as riding a bike or running on a treadmill?				
	Yes	No			
Q18	Do you define goals or a target training zone during physical activity?				

	Yes	No			
Q19	Do you believe that a fitness app or music player can help you to exercise more , and/or achieve your goal[s]?				
	Yes	No			
Q20	If your answer to the previous question is yes, please specify the reason(s):				
	More entertaining and more enjoyable - adding more fun	Helps to keep track of my progress	Effectively maintain physical activity level in the target training zone	Providing motivation to keep up with my target goal	Other:

VisPeEnhancer was designed and developed as the system that gives a single persuasive service in different contexts. Since giving visual awareness is one of the most common techniques used by various persuasive systems such as [33, 8, 34], VisPeEnhancer gives visual feedback as its persuasive service.

Thus, to quantitatively evaluate this study, a participant's heart rate being in the target training zone was defined as the exercise goal. Correspondingly, the efficacy measure examines the success in maintaining the participant's heart rate inside the predefined training zone. The efficacy was evaluated both subjectively and objectively. The objective method evaluated the efficacy of users using the performance score function, which is presented in section 5.4. The subjective method evaluated efficacy using a post-run questionnaire completed by users after performing the exercise sessions in the study. In the questionnaire, users self-reported their efficacy and the effect of the systems on their performance. We present the procedure of the study in section 5.4.

5.4 Procedure

In this study, participants were asked to complete a pre-questionnaire and two online forms about their demographic information, exercise habits and technology familiarity. Then, they were

asked to take part in sessions of: a Baseline Session, a VisPeEnhancer Session, and a ExePeEnhancer Session. Each session has 3 phases: warm up, workout, and cool down. Physiological data was collected and analyzed only during the workout phase. The first session for every participant was the baseline session.

In the baseline session, the participants were asked to exercise without any persuasive systems to find baseline intensity. In the other sessions, participants were asked to keep their heart rate as close as they could to that baseline intensity. Instead of asking participants their preferred intensity range, we decided to perform a baseline session, since some of our participants were inactive and they were not confident in the intensity that they could maintain. In this session, after wearing the heart rate monitor, the subject was asked to sit on the sofa near the stationary bike and take a rest for at least 10 minutes until she/he felt relaxed. After relaxing, the subject's physiological information was collected and recorded for 2 minutes. The average acquired heart rate was used as the heart rate at rest. Then, we asked the participant to exercise for 15 minutes on the stationary bike, which was broken down into 3 minutes of warm up, 10 minutes of workout, and 2 minutes of cool down. Using the average recorded heart rate along with the average heart rate at rest, the intensity of the workout was calculated. We refer to this intensity as the target training zone.

After performing the baseline session, participants had to perform either the VisPeEnhancer Session or the ExePeEnhancer session. If all the participants performed the VisPeEnhancer and ExePeEnhancer sessions as their second and third sessions respectively, it would affect the fair comparison between ExePeEnhancer and VisPeEnhancer. Therefore, to prevent biasing the results, we asked 50% of them to perform the ExePeEnhancer and VisPeEnhancer sessions as the second and third session respectively, while the rest performed the reverse pattern for the

sessions. Moreover, the location of the activity had the potential of biasing the results. One type of considered context was the location of the activity, which can be an inside or outside environment. To have a fair comparison, we asked 50% of the participants to exercise in the outdoor environment (in our study, the outdoor environment was simulated as described in section 5.2), while the rest exercised in an indoor environment.

Before the VisPeEnhancer and ExePeEnhancer sessions, each participant was given instructions and a demonstration on how to use the system that corresponded to that session. It was emphasized that their workout goal was maintaining their heart rate as close as possible to the target training zone during their workout phase. Both VisPeEnhancer and ExePeEnhancer sessions consisted of 3 minutes of warm up, 20 minutes workout, and 3 minutes of cool down. After these sessions, participants were asked to complete the post-run questionnaire corresponding to their experience with the system used in that session. Finally, at the end of the three sessions, participants completed a questionnaire relating to a comparison of the two systems.

5.4.1 Performance Score function

To measure how well the participants were exercising towards their desired workout, we used the performance score function proposed by [47]. The function corresponded to the amount of time that a participant spent inside the target zone during the workout to the whole time of the workout. Equation 1 presents the performance score function, where x in the equation represents the duration of time in seconds.

$$ZoneAccure(x) = \frac{SecondsInZone}{x} \quad \text{Equation 5.1}$$

5.5 Results

This section presents the results in evaluating the efficacy of ExePeExerciser from both the subjective and objective methods. Finally, it gives a brief discussion about the results achieved and the challenges faced during the study.

5.5.1 Objective Method Results

As mentioned earlier in section 5.4, the users' workout goal corresponded to keeping the heart rate as close as possible to the target heart rate range, also called intensity. The efficacy measure was defined as the user's success in maintaining his/her heart rate inside the training zone. In the subjective method, the efficacy of the systems was evaluated with the performance score function. This function gives the percentage of time that the subjects spent inside the predefined training zone. According to the performance score function, overall, the results revealed that the ExePeEnhancer was more effective than the VisPeEnhancer in terms of keeping the subject's heart rate in the target training zone, since 10 out of the 14 subjects spent more time inside their training zone with ExePeEnhancer than with VisPeEnhancer (Figure 5.2). In addition to this, the average percentage of time inside the training zone with ExePeEnhancer (Avg. = 63.78%) in comparison with VisPeEnhancer (Avg. = 53.07%) was 10.71% higher ($P > 0.05$, $p = 0.09$, two-tailed paired t test). Therefore, we conclude that ExePeEnhancer was more successful in helping participants maintain their heart rate in their training zone, although ExePeEnhancer was not statistically significantly more effective than VisPeEnhancer due to haptic feedback service results. Moreover, in our experiment, we noticed that haptic feedback was not effective in assisting users to keep their heart rate in the target zone. ExePeEnhancer provided haptic

feedback for 2 out of the 14 subjects in the indoor environment; for one of them, haptic feedback was given using a smart phone, and for the other one, haptic feedback was given using a smart watch. After analyzing the results of these two subjects, we think the reason of this failure may relate to the fact that the subjects were confused about the vibration patterns and took action which was contrary to the vibration feedback message received. In the cases that the device was vibrating with the pattern of slowing down, they increased their speed and vice versa. However, we cannot confidently state that this failure was mainly due to the implementation of the vibration patterns or the nature of giving haptic feedback, and further research is needed to further investigate this matter.

It is interesting to note that the average percentage of time spent inside the training zone with ExePeEnhancer without hapticfeedback (Avg. = 68.83%) was statistically significantly higher than the average of time spent inside the training zone with VisPeEnhancer (Avg. = 54.25%) ($P < 0.05$, two-tailed paired t test). Therefore, ExePeEnhancer without haptic feedback was significantly more effective than VisPeEnhancer in keeping subjects' heart rates inside their desired training zones.

Further analysis revealed that generally the subjects were more active with ExePeEnhancer. Ten of the 14 subjects using the ExePeEnhancer spent less time with a heart rate lower than the target zone in comparison with the VisPeEnhancer, In addition, the average percentage of time spent with a heart rate lower than the target zone was 22.35% with the ExePeEnhancer while the average for the VisPeEnhancer was 27.28%.

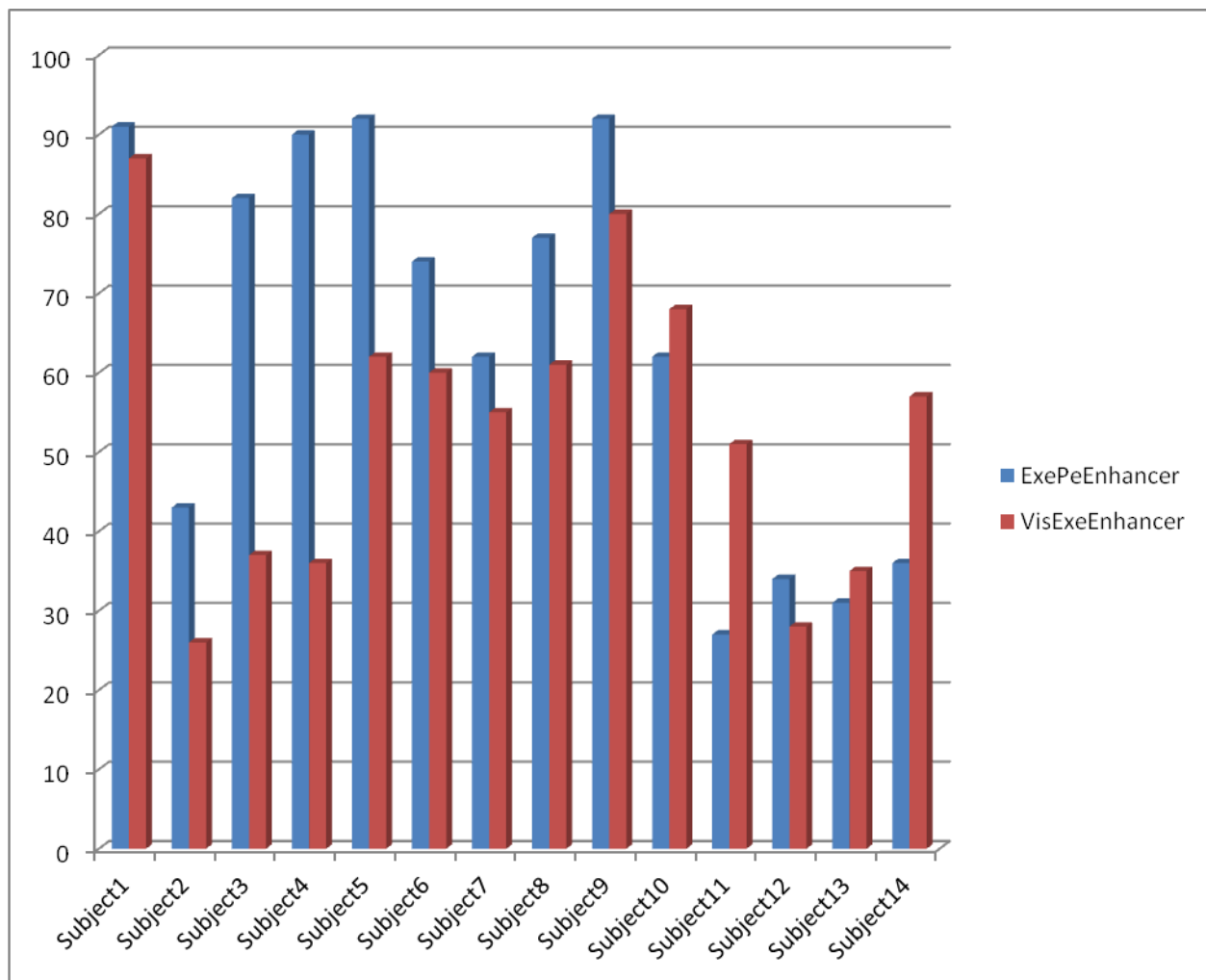


Figure 5.2 Percentage of Time Spent Inside the Target Heart Rate Zone by Each Subject with ExePeEnhancer and VisPeEnhaancer

Additionally, for the outdoor environment, the ExePeEnhancer showed a statistically significant increase in the efficacy compared to the VisPeEnhancer, since the average percentage of time inside the training zone was 64.28% with the former system and 51.14% with the latter one ($P < 0.05$, two-tailed paired t test). Game and Audio feedback persuasive services provided by ExePeEnhancer (Avg. = 80.50%) showed a statistically significantly improvement in subjects' workout efficacy in comparison with the VisPeEnhancer (Avg. = 70.75%) ($P < 0.05$, two-tailed paired t test).

5.5.2 Subjective Method Results

For the objective evaluation of efficacy, we asked the subjects to complete two post-run questionnaires. The first questionnaire was given to the subjects after performing each session of the ExePeEnhancer and the VisPeEnhancer and asked them about their experience with the system used during that session using a 7-point scale. Table 5.2 represents the questions and the answer options. To evaluate the efficacy of the systems using these questionnaires, the subjects were asked to rate, out of 7, the system's help in keeping their heart rate in the target training zone as well as the overall effectiveness of the system. In terms of helping them to keep their heart rate in the target training zone, the participants gave the ExePeEnhancer a higher score, with an average score of 6 (*Sd.* = 0.91), compared to the VisPeEnhancer, with an average score of 4.46 (*Sd.* = 1.50) (Table 5.3). With respect to the overall effectiveness, the average score for the ExePeEnhancer was also higher, (*Avg.* = 6.30, *Sd.* = 0.75), compared to the average score for the VisPeEnhancer (*Avg.* = 4.07, *Sd.* = 1.32) (Table 5.4). Therefore, it can be concluded that participants found the ExePeEnhancer more effective than the VisPeEnhancer.

Furthermore, in the second post-run questionnaire (Table 5.5), we asked the subjects to choose the system of their preference. 12 out of 14 participants preferred the ExePeEnhancer to the VisPeEnhancer. This difference in the perception of efficacy obtained from the objective evaluation confirms the performance evaluation results. Therefore, we can conclude that the ExePeEnhancer was more effective than the VisPeEnhancer in helping the participants to achieve their workout goals.

Table 5.2 The Post-Run Questionnaire

Index	Questions and Answer Options								
Q1	First Name								
Q2	Last Name								
Q3	The system effectively helped me to keep my heart rate in the target training zone (assisted me effectively to achieve the pre-defined goal)								
		1	2	3	4	5	6	7	
	Strongly disagree	☐	☐	☐	☐	☐	☐	☐	strongly agree
Q4	The system gave me greater control over my exercise								
		1	2	3	4	5	6	7	
	Strongly disagree	☐	☐	☐	☐	☐	☐	☐	strongly agree
Q5	The system increased my productivity during the workout								
		1	2	3	4	5	6	7	
	Strongly disagree	☐	☐	☐	☐	☐	☐	☐	strongly agree
Q6	This system efficiently monitored my performance during physical activity								
		1	2	3	4	5	6	7	
	Strongly disagree	☐	☐	☐	☐	☐	☐	☐	strongly agree
Q7	Overall, I find the system effective for the workout								
		1	2	3	4	5	6	7	
	Strongly disagree	☐	☐	☐	☐	☐	☐	☐	strongly agree

Table 5.3 Rating Results for the Question "the system helped participants in keeping their heart rate inside the workout training zone"

	Median	Mean	Std. dev.
ExePeEnhancer	6	6	0.91
VisPeEnhancer	4.46	4	1.50

Table 5.4 Rating Results for the Question "I find the system effective for the workout"

	Median	Mean	Std. dev.
ExePeEnhancer	6.30	6	0.75
VisPeEnhancer	4.07	4	1.32

Table 5.5 Post-Run Questionnaire of System Comparison

Index	Questions	Answers Options
Q1	First Name	
Q2	Last Name	
Q3	Which system helped you more to keep your heart rate in the target training zone?	☐ VisExeEnhancer ☐ ExePeEnhancer ☐ Both of them ☐ none of them
Q4	Which system gave you greater control over your exercise?	
Q5	Which system increased your productivity during workout?	
Q6	Which system monitored your performance more effectively during workouts?	
Q5	Which system do you find more motivating during exercise?	
Q6	Which system do you find more enjoyable and entertaining?	
Q7	Overall, which system do you find more efficient for the exercise?	
Q8	Overall, which system do you prefer or like more for exercising?	

5.6 Discussion

This section discusses some points relating to participants' comments and results. After the study, the participants were asked to give their general comments and further opinions about both systems. It is notable to mention that one of the subjects' opinion about vocal feedback was *"I would never like the system that gives me instructions; I do not like that someone tells me what to do! I do not like to be under control of someone!"*. However, another subject preferred the vocal feedback and pointed out that *"I was looking for something like this; I want someone who tells me what is next"*. These comments further highlight the fact that the type of persuasive feedback should be tailored to the user's context and individual needs. Moreover, we noticed that the participants' general perception of the increase of productivity with the ExeEnhancer, As it was shown in the subjective evaluation in section 5.5.1, confirms the objective results, which show that the average percentage of time spent with heart rate below the target training zone with

the ExeEnhancer was less than with the VisPeEnhancer. Based on the results of the post-run questionnaire, 11/14 subjects believed that ExePeEnhancer increased their productivity during the exercise more than VisPeEnhancer. In addition, the question that asked “The system increased productivity during the workout” about ExePeEnhancer received a higher score (Avg. = 6.07, *Sd.* = 0.86) than the same question for the VisPeEnhancer (Avg. = 4.6, *Sd.* = 1.3).

6 Conclusions and Future Work

This chapter discusses the achievements of this thesis followed by a short discussion about possible future works.

6.1 Thesis Summary

In this study, we introduced the ECOPA ontology and the corresponding architecture CAPPa with the intention of facilitating the process of building context-aware persuasive applications promoting physical activities. Due to the fact that the aforementioned applications are highly demanding, designing context-aware ones can improve their adaptability and effectiveness in terms of providing appropriate persuasion based on users' needs and other relevant contexts.

An extensible and adaptable ontology, ECOPA, with the ability to enhance physical activity was proposed in this research. The discussed ontology is used for modeling the general contextual aspects of pervasive computing applications. ECOPA was designed in two levels: an upper level and a domain level context ontology. The upper level context ontology identifies the general entities that are common in different domains. By extending the upper level context ontology to

the domain ontology, it models the context for the specific domain of our target applications. Person, Activity, Persuasive Service, and Device are considered the core context entities for the domain ontology. We extended these entities by adding more classes and relationships between those classes to provide a context model with sufficient details for the domain of mentioned applications.

Moreover, a lack of adequate infrastructure in building context-aware systems makes the development process of context-aware systems complex and time-consuming. Therefore, we proposed an architecture for building Context-Aware Persuasive applications motivating Physical Activity, called CAPPa. This architecture provides adequate support for tasks dealing with contexts, including collecting contexts from different sources, interpreting, and unifying them into a formal shared model to build applications enhancing physical fitness. In this architecture, ECOPA is used as the context model for semantically representing contexts. CAPPa consists of three layers of Context Gathering Layer, Context Processing Layer, and Context-Aware Persuasive Application layer.

To evaluate the effectiveness of developed applications based on CAPPa and ECOPA, we built a prototype application called ExePeEnhancer and conducted a user study with 14 participants. This application aims at assisting users to achieve their exercise goals. ExePeEnhancer provides different persuasive services in the forms of musical feedback, a game, and haptic feedback. By taking various contexts into account, this application selects a persuasive service relevant to that particular contexts. In our experiment, the application was compared with an application that did not consider those contexts for providing persuasive

services. Based on the results, ExPeEnhancer was found to more effectively assist users to achieve their exercise goals than the non context-aware application.

6.2 Future work

There exist some possible rooms for future directions and improvement over this research that can be addressed in future works. According to ECOPA, the next step will be mapping the domain ontology to SUMO in order to improve the interoperability between different domains by using a universal SUMO ontology. With respect to the CAPPA architecture, our future work will focus on prototyping more context-aware persuasive applications. In this way, we can show the feasibility of this architecture in development of ontology-based persuasive applications promoting physical fitness. It incidentally gives the opportunity to discover other possible improvements for this architecture.

Regarding ExePeEnhancer, to improve the effectiveness of ExePeEnhancer in assisting users for achieving their goals, we plan to design and implement an algorithm that provides persuasive services not only based on the current context, but also the effectiveness of previous persuasive services been provided to the user. Then, we will study the new version of ExePeEnhancer on more subjects for the duration of at least three weeks.

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