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SmartShadow: Models and Methods for Pervasive Computing

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Preface

Pervasive computing is becoming an emerging paradigm of next-generation computing. It seeks to transform computer-centric computing to human-centered computing. Its goal is to build a personal living environment where digital services can be provided seamlessly at the right time at the right place in the right way. Pervasive computing is an innovation of information and computing technology, which leads to revolution in the relationship between the physical environment of human life and the cyberspace. It will greatly change our future way of life.

This book compiles some recent work from the Pervasive Computing Group of the CCNT (advanCed Computing aNd sysTem) laboratory at Zhejiang University, China. Pervasive computing, as a new computing model, spans a number of research areas with unprecedented complexity and diversity. This book describes a new model for pervasive computing, called *SmartShadow*, and its methods. A good model is not only essential to abstractly model "user-oriented" environments which is the core philosophy of pervasive computing, but which is also important in design, analysis, implementation, deployment, assessment of pervasive computing systems to support such systems with a wide range of theoretical guidance for the scalability, maintainability, adaptability, ease of use, and standardization at the model-level. The organization of the book is as follows. Chapter 1 gives an overview of the SmartShadow. It consists of a user model which represents information about of a user's personality (called *PersonalityShadow*) and a space model which represents a virtual smart space of services following a user (called *ServiceShadow*). Chapter 2 describes how a user task in the SmartShadow can migrate continuously and seamlessly between different physical spaces when users move from one to another. Context-awareness is strongly related to how smart a system is, which is presented in Chap. 3. We propose a three-layer context model in the SmartShadow to handle large-scale contextual data. In Chap. 4, we describe a new file management scheme to link files with contextual data in SmartShadow, so that we can have a human-oriented view of file dynamics. Chapter 5 builds a software infrastructure with semantics and high adaptation to support the SmartShadow. Chapter 6 presents a smart car prototype to demonstrate an application of the SmartShadow.

This book would not have been possible without many contributors whose names did not make it to the cover. We would like to give our special thanks to Mr. Li Zhang, Mr. Yuqiong Xu, Dr. Qing Wu, Dr. Jie Sun, Dr. Yanfei Liu, Dr. Shijian Li, Mrs. Tong Li, and Mr. Qunjie Qiu, who have been affiliated to the CCNT (advanCed Computing aNd sysTem) laboratory of Zhejiang University. For a long time already, it has been our pleasure to do research with them in pervasive computing. They have devoted their energy and enthusiasm to this area and relevant research projects.

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Chapter 1
SmartShadow Model

Abstract Pervasive computing has become an emerging paradigm of next-generation computing. This chapter attempts to model pervasive computing as a user-centric model *SmartShadow*, which contains a model of users and a model of computing environments. In the user model, we model user-related temporal information in three parts, raw data, activity/behavior, and intention. The user model is used to describe and infer users' needs and tasks. The environment model considers all the computing entities in a pervasive computing enviroment as pervasive services. With both models, the pervasive computing environment of a user can be modeled as a dynamic virtual user space, which follows him/her with services anytime anywhere, just like his/her shadow in the physical world.

1.1 Introduction

Pervasive computing [1] seeks to transform computer-centric computing to human-centered computing. Its goal is to build a personal computing environment that makes use of computing and communication resources in surroundings. Digital services can provide human-centered services seamlessly at the right time at the right place in the right way. Pervasive computing is an innovation of information society development, which leads to revolutionary change in the relationship between the physical environment of human life and the information environment provided by computers. Pervasive computing will greatly change our future way of life.

Pervasive computing, as a new computing model, spans a number of research areas with unprecedented complexity and diversity. Though, currently, various technologies have been researched, little has been addressed on the pervasive computing model. A good model is not only essential to abstractly model "user-oriented" environments which is the core philosophy of pervasive computing, but which is also important in design, analysis, implementation, deployment, and assessment

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of pervasive computing systems to support such systems with a wide range of theoretical guidance for the scalability, maintainability, adaptability, ease of use, and standardization at the model level [2].

For complexity characteristics of pervasive computing patterns, early researchers proposed a number of hierarchical models. Dima et al. proposed a hierarchical conceptual model for pervasive computing. With reference to the Open Systems Interconnection Model (OSI model) for computer networks, they model pervasive computing with a bottom-up model divided into five parts: the environmental layer, physical layer, resource layer, abstraction layer, and intention layer [3]. Muhlhauser et al. proposed a three-tier model [4] for pervasive computing, based on granularity and integration degree. Pervasive computing concepts are divided into three levels: the base components level, integration level. and universal-world level, in which the integration level is a software system that supports scalability and adaptability. Henricksen et al. divide pervasive computing into four elements: devices, users, software components, and user interfaces, in which software components and devices can dynamically form a complete application with user interface to interact with users [5]. Xu et al. analyzed related scientific problems and view pervasive environments as a duality of physical space and cyber space [6]. Dual relations between cyber space and physical space are established using human–computer interaction (HCI). Such models are based more on the perspective of system hierarchies which only describe coarse-grained computing entities and lack support for describing the interactive and dynamic nature of pervasive computing environments.

Recently, researchers have carried out several studies on more issues relating to a pervasive computing system, such as functional verification, interoperability, equipment, architecture at the model and theoretical level. Ranganathan et al. proposed a pervasive computing model based on environment (ambient) calculus and logic, in which any description of the environment can be formally verified for its function and role. This model is adopted in a prototype application on the Gaia system [7]. Blackstock et al. designed a general model called UCM for assessment and analysis on interoperation in pervasive computing environments, and this model is based on their analysis of existing systems and development experience and provides some high-level abstraction for pervasive computing systems to characterize interoperability of devices and software components. Scott de Deugd et al. put forward Service-Oriented Device Architecture (SODA) [8], by which devices can be used as a service to service-oriented software architecture, which enhances system scalability and flexibility. Costa et al. are dedicated to design a common software infrastructure for pervasive computing space [9]. They have produced ten keys and seven challenges across every aspect of the life of a pervasive computing system.

The works above reflect some new research trends regarding the models and architectures of pervasive computing research, so as to abstract the computing resources over a wide range into a group of basic entities, to focus on interactions between cyber space and physical space, and to adopt service-oriented views of system constructions. However, rarely is research taking place on pervasive computing to model computing entities and the environment as a whole.

This chapter introduces a ubiquitous computing model called *SmartShadow*. Some part of the work has been published as [10, 39]. The model is based on the modeling of users and smart environments. In this model, the context of the environment and the intentions of users can be dynamically mapped into a collaboration of pervasive services as a user-centered virtual personal space. This model can achieve an environment-and-user-aware adaptive pervasive service. Established in our model, dynamic user-service mapping makes pervasive services act as a shadow following the user moving across spaces, and automatically adapts to the "light source" (environment context and services).

1.2 SmartShadow: An Overview

Differing from previous pervasive computing models, SmartShadow contains a user model that represents information about a user's personality and a space model that represents a virtual smart space of services following a user and serving him in different environments. Information for user personality (called *PersonalityShadow*) can be sensed, recorded, and learned, which implies the user's personal lifestyle, behavior, and thinking; a virtual smart space (called *ServiceShadow*) is a composition of environment computing resources to work for users' intentions. PersonalityShadow and ServiceShadow together described the interaction between users and environments.

In order to build a sophisticated model to appropriately explain how user cognitions, activities, and desires are generated under certain environments and how environments satisfy such desires, we have deeply studied internal relationships between the user and the environment. We expect our model will significantly improve pervasive computing systems in understanding and adapting to users and environments. Our goal falls into twofolds: one is to learn everyday life of users from gathering sufficient data to describe their life, the other is to learn how to satisfy user desires with computing resources in pervasive computing environments.

1.2.1 PersonalityShadow: Model of People's Life

PersonalityShadow is actually about relations between context and people's life. Using context as an input to characterize the environment and to reason about user desires is one of the major characteristics of ubiquitous computing. This research is known as context-aware computing. Context-aware computing is a computing paradigm in which applications can sense, react, and adapt to their environment. In a context-aware system, the most important information is the state of the environment, the devices, and the users, which we call context. Context is any information that can be used to characterize the situation of an entity.

Current context-aware computing systems with their models are not sufficient to model all factors in people's life, because there are plenty of factors that are hard to sense and predict, such as the psychological state of a person or activities involving many people. Such features as activities and physical-psychology status reflect the higher-level lifestyle of people, which makes the sensed context meaningful and actually connects user requirements and computing applications. Such higher-level information is more useful and important than sensed context but there exist gaps between lower-level information and higher-level information that make models of pervasive computing incomplete.

We propose the PersonalityShadow that covers almost all aspects of a person's life. The PersonalityShadow is divided into three stages: low-level personal information, mid-level personal information, and high-level personal information according to semantic levels and relative convenience. The low-level personal status can be directly sensed using sensors, the mid-level needs pattern recognition or inference, and the high-level hides the internal user's mind. We believe context states at the lower level can influence context at the higher level, and the higher level is more decisive regarding a user's intentions and requirements. In our work, we enumerate a great number of characteristics of user's life and classify them into the three levels accordingly. We also provide intelligence to manage such information and to infer higher-level status. The PersonalityShadow literally follows its owner moving around across different environments to make computing environments know his lifestyle.

1.2.2 ServiceShadow: User-Centered Virtual Space

Pervasive computing environments are full of software, devices, sensors, actuators, and web services that can be used as computing resources. By reasoning context information and user personality, an environment can obtain a user's intention. Then the environment can integrate suitable services to collaborate with the intention to form a user-centric virtual space called ServiceShadow or SmartShadow Space.

We propose a model of the environment, in which the environmental context is characterized. Any computing resources of software and hardware are viewed as services. A ServiceShadow is a group of composite services to serve user intentions as shown in Fig. 1.1. When a user moves, the ServiceShadow follows him to another place, migrates service status to new local services, and keeps uninterrupted execution; and if the environment context affects service quality, the ServiceShadow adapts itself accordingly to behavior and resources to achieve seamless user experience. We also proposed approaches to handle service integration for user intention and adaptation in different conditions to keep the ServiceShadow seamlessly serving with satisfactory quality.

A comparison of ServiceShadow with other smart spaces is shown in Table 1.1. ServiceShadow is a user-centric space, which follows the mobile user and adapts to environment dynamics.

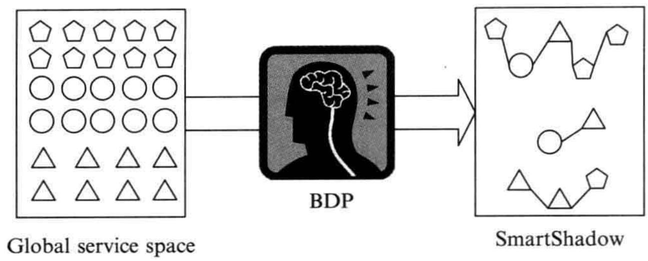

Fig. 1.1 Mapping to a virtual service

Table 1.1 Comparison between ServiceShadow and smart space

	Mobility	Dynamics	Abstractness	User-centric organization
Smart Spaces	Static	Weak	Physical	No
ServiceShadow	Mobile (like a shadow)	Strong	Virtual	Yes

1.3 Semantics in SmartShadow

For a uniform description of various users and spaces, a semantic model for SmartShadow is essential to specify characteristics of human personality, computing resources, environment, and relative management mechanisms to monitor environment context, to infer user status and desires or to integrate/coordinate behavior and resources of computing services.

1.3.1 Basic Concepts

The concept "Semantics" is a study about meanings and relationships between different meanings. This concept is originally about word and form changing in the development of languages. But today it contains many new ideas from the past to the technology. "In linguistics, it is the study of interpretation of signs or symbols as used by agents or communities within particular circumstances and contexts. Within this view, sounds, facial expressions, body language, proxemics has semantic (meaningful) content, and each has several branches of study. In written language, such things as paragraph structure and punctuation have semantic content; in other forms of language, there is other semantic content" [12].

To make computing systems understand the meaning of the world, the Semantic Web is proposed. The Semantic Web [13] is an evolving extension of the World Wide Web in which web resources are annotated, identified, and interlinked in a meaningful way, thus permitting software agents to find, share, and integrate information more easily and readily. The official website of W3C's Semantic Web gives a more definitive description:

> The Semantic Web is about two things. It is about common formats for integration and combination of data drawn from diverse sources, where the original Web mainly concentrated on the interchange of documents. It is also about language for recording how the data relates to real world objects. That allows a person, or a machine, to start off in one database, and then move through an unending set of databases which are connected not by wires but by being about the same thing.

The Semantic Web draws on the standardization effort of a formal representation framework for describing the semantics of web resources. The semantic theory underlying this formal representation framework provides a formal account of "meaning" in which the logical relationship of web resources, which can be a webpage, a database record, a program, a web service, and so forth, can be explicitly described and specified without loss of the original meaning. Functionally speaking, it would enable us to aggregate and recombine the right data we want seamlessly and instantly; for example, automatic scheduling of a meeting across the calendars of different people, arranging travels based on the profiles of both providers and requestors, facilitating integrative knowledge discovery from an unbound set of data repositories, etc.

As the crucial thing for realizing the vision is a well-defined resource description model and web languages for sharing meanings, the standard organizations, like the Internet Engineering Task Force and the World Wide Web Consortium (W3C), have devoted and directed major efforts at specifying, developing, and deploying the semantic web languages.

In 1999, the W3C released the first semantic web standard, the Resource Description Framework (RDF) specification, as a W3C recommendation. RDF provides a simple but powerful triple-based representation language for describing web resources and the relationship among them. The simplicity consists in the triple statement model, which actually cannot be any simpler for describing something in the world. This simplicity guarantees the extensibility and adaptability for future development.

The RDF Schema [14], as a basic vocabulary language, became a recommendation in February 2004. RDFS takes the basic RDF specification and extends it to support the expression of structured vocabularies such as classes and properties. It provides the basic constructs to develop ontology but lacks the necessary expressiveness for many advanced applications.

For those who require greater expressiveness in their object and relation descriptions, OWL (the Web Ontology Language) [15] is the choice. OWL has more advanced facilities and representing constructs such as those for describing property restrictions, concept cardinality, making it a fully-fledged knowledge representation language capable of describing knowledge from simple metadata such as tags to complex conceptual models such as a biological ontology.

As the semantic languages have gained ground and mature, commercial RDF/OWL reasoners and stores have also been ready at customers' disposal, the need arises for reliable and standardized access to the RDF data they hold. The SPARQL language [16], which became a W3C recommendation in 2007, was designed to meet this requirement. SPARQL can be viewed as the standardized ontology query language for retrieving and querying the RDF repository.

Furthermore, other significant progress includes the GRDDL (Gleaning Resource Descriptions from Dialects of Languages) [17], which provides a means to extract RDF from XML and XHTML documents using transformations expressed in XSLT (Extensible Stylesheet Language), and the Rule Interchange Format, an attempt to support and interoperate across a variety of rule-based formats, by which more advanced rule-based reasoning capability can be enabled.

Most recently, more advanced efforts have been made on top of these standards and technologies. For example, the suggested Named Graph [18] allows users to attach contextual information such as digital signature, trust policies, time stamps, provenance information, etc., onto a group of RDF assertions. The extension of RDF to Named Graphs provides a formally defined framework to be a foundation for the Semantic Web trust layer.

Along with the busy production line of the standardization effort are the phenomenal endeavors in industry-level tool development and commercialization, such as Jena.

1.3.2 Models and Systems in Pervasive Computing

Semantic models have been widely used to describe context information in pervasive computing. Context is any information that can be used to characterize the status of an entity [19]. An entity may be a person, a place, or an object that is considered relevant to the interaction between a user and an application, including the user and application themselves. Commonly used contexts consist of location, identity, time, temperature, and activity. We consider that the involved objects in environments are all contexts. Context awareness is the ability to sense and use different contexts. Any application that takes advantage of context is a context-aware application. Context-aware computing is the ability of computing devices to detect, interpret, and respond to changes in environment and system. The semantic information of contexts is essential for dealing with the complex tasks in ubiquitous computing environments. However, representing sharing and reasoning of the contexts is very difficult. In smart spaces, context is hard to represent and use due to its complexity. It requires an approach with strong expression and easy sharing capabilities and many research works have investigated these issues.

CoBrA (Context Broker Architecture) proposes a semantic broker approach that explores the use of semantic web languages in building an architecture for supporting context-aware systems [19]. CoBrA is an agent-based system that supports smart spaces (e.g., offices, smart homes, and cars) with context brokers. Context brokers are intelligent agents that share a common model of context semantics. CoBrA uses the Web Ontology Language OWL, a W3C Semantic Web standard, to define ontologies of context (people, agents, devices, events, time, space, etc.) with strong expressive power to support context reasoning and high-level knowledge sharing.

ASC Model (Aspect-Scale-Context Information) is proposed by Thomas Strang [20]. ASC defines the semantics of core concepts of the computing environment with ontology, which guarantees sharing and reuse of context knowledge. In the ASC model, an aspect is used to manage several scales and a scale accumulates several context informations. Each scale defines a valid range of context information. In order to implement the ASC model, CoOL (Context Ontology Language) is proposed. This language can be divided into two parts, CoOL core and CoOL sets. CoOL core maps model to commonly used ontology languages, such as OWL, DAML+OIL, and F-LOGIC to predigest development of knowledge. CoOL sets include the framework, protocols, and standards to make CoOL core feasible in any systems such as a web service.

CONON provides common concepts of context-awareness and enables users to add a new concept into the model [21]. There are two types of concepts in CONON: upper ontology and domain-specific ontologies. Upper ontology defines common characteristics of location, users, and computing entities that form the framework of the model and index of concept information. Domain-specific ontologies define concepts in different application domains in which applications and services can be divided into different subdomains such as home applications or office applications. Concepts in a different domain share a common model but are distinct in characteristics. The CONON model defines 14 sets of core entities. Each entity represents a physical or conceptual object such as users, behavior, computing entities, and locations.

SOUPA ontology includes two parts: SOUPA core, which defines common onlotogy in a pervasive computing domain, SOUPA extensions, which define specific application domains [22]. SOUPA core includes modularized definitions about users, smart agents, time, space, events, user profiles, behavior, privacy, and security policy and forms nine distinct ontology documents. SOUPA extensions define concepts in a specific application domain, currently supporting context-aware applications and P2P data management of conference, schedules, documents, images, and locations.

Nexus Project aims to establish a global platform to manage context semantics. It provides a uniform standard for modeling context by enabling any context model to join in the platform. This standard is a global object-oriented ontology and defines context sharing between application and data providers. The keystone of the project is to research how to manage local models in a global view [23].

1.3.3 Semantic Issues in SmartShadow

Built on top of techniques such as Semantic Web, SmartShadow is dedicated to modern scientific research on user-awareness and smart space management, which faces several challenges calling for more innovative approaches. Below, we identify a set of basic issues concerned with SmartShadow.

1.3.3.1 Knowledge Representation for SmartShadow

In people's life and environment, there is a significantly huge amount of personal information, including context, physical–psychological status, behavior, activities, and desires. Also, heterogeneous computing resources, including sensors, actuators, software components, devices, web services, etc. The diversity and heterogeneous nature of SmartShadow calls for a more advanced knowledge model to describe these contents formally, explicitly, with flexibility and scalability, so as to enable more intelligent mechanisms for context management, event and intention inference, automated service discovery, matching, integration and resource coordination. The ontology language and related techniques can play an important role in alleviating the problem and facilitating information exchange. Formal rules are useful for specifying personality status, coordination policy, security settings, transaction configurations, trust dependencies, etc.

1.3.3.2 Semantic-Based Personality Inference

Inference of user personality is essential in SmartShadow to capture user requirements. The PersonalityShadow model aims to integrate many rich-semantic descriptions of people's personalities to recommend appropriate entities or arrange services for users whose requirements need to be inferred from formal semantic descriptions about his/her personality. We need semantic-based and formal inference mechanisms.

1.3.3.3 Semantic Service Composition and Resource Coordination

ServiceShadow constitutes various computing resources that are viewed as services, so service descriptions, discovery, registration, and composition are common requirements of all smart spaces. But heterogeneous systems may have different implementations, although they are used for identical missions. To orchestrate such a ServiceShadow, it is crucial to provide unified ways to represent the process semantics and bridge the discrepancies and mismatches among different service models. We need to adopt semantically enriched service descriptions and manage to pursue more advanced service interaction and collaboration.

1.3.3.4 Semantics for Trust and Security

One defining characteristic of a smart space is the need for trust and security. In such an open environment with multiple users and services involved, trust management and related security issues such as authentication, encryption, and privacy are even more intrusive and tricky. SmartShadow requires all of these issues to be handled