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Integrating Internet of Services and Internet of Things from a Multiagent Perspective

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Abstract. To realize the Internet-based sociotechnical systems, it is necessary to build an infrastructure to support the interaction between various cloud services on the Internet and the physical world where we live in. Therefore, it is important to consider integrating the Internet of Services (IoS) that freely enables the sharing and composition of cloud services on the Internet, and the Internet of Things (IoT) that are connected with things driven by various sensors and actuators. The integration of IoS/IoT often involves multiple parties, and deals with complex issues of interaction, dynamics, scalability and decision making, it can be studied from a multiagent perspective. In this paper, we first propose a framework for integrating IoS and IoT, focusing on the integrated components for service composition. Then we describe the proposed integration framework from a multiagent perspective with two aspects. One aspect is to regard the integrated architecture of IoS and IoT as a multiagent-based architecture. The other aspect is to apply multiagent methodologies for designing sociotechnical systems based on the integrated IoS/IoT architecture. Moreover, we use an example of designing multilingual environments to discuss the above two aspects with possible future research directions.

Keywords: Internet of Things · Internet of Services · sociotechnical systems · multiagent systems.

1 Introduction

In the Internet of Services (IoS), service-oriented architecture (SOA) has been considered as a key concept. SOA enables service providers to deploy data, software and business processes as Web services or cloud services on the Internet and service users to invoke and compose available cloud services for various purposes [32]. IoS infrastructures contribute to the real-world applications in various domains. For example, we have been developing an IoS infrastructure for language services on the Internet, called the Language Grid [15]. In recent years, the emergence of Internet of Things (IoT) enables things to be connected on the Internet. Things on the IoT environments are monitored and controlled by sensors and actuators [40]. The collected information on the IoT can be used for making decisions and triggering cloud services on the IoS as well. On the other hand, cloud services on IoS can also trigger sensors and actuators in the IoT environments.

To enable easy development and deployment of systems based on IoS/IoT, it is necessary to build an infrastructure to support the interaction between various cloud services on the Internet and things in the physical world. However, there are several issues with the integration of IoS and IoT which arise due to some major challenges of the emergence of IoT: the extreme heterogeneity, ultra-large scale, and the dynamics [16]. First, the extreme heterogeneity of IoS/IoT makes it difficult for service composition based on the traditional SOA. We need to deal with the interoperability of the services on the IoS infrastructure and things on the IoT environment. Second, ultra-large scale of services and things may have negative impacts on the performance of the integrated IoS/IoT environment. Third, the dynamics of the IoS/IoT environments makes it necessary to realize new mechanisms for service composition that can deal with dynamic changes of availability of services/things and users' situations as well. Moreover, the application systems developed based on IoS and IoT always involve multiple stakeholders, and therefore can be regarded as Internet-based sociotechnical systems.

Since integrating of IoS and IoT often involves multiple parties, and deals with complex social process of service composition with important issues of interaction, dynamics, scalability and decision making, it can be relate to the multiagent systems [47] [46] [48], which is composed of a set of agents that perform complicated tasks by negotiation and cooperation. In the context of integrating IoS and IoT, the multiagent approach can provide an effective methodology for understanding behaviors of various stakeholders and modeling sociotechnical systems [34]. The multiagent perspective has been used to investigate many existing systems such as sensor networks [3] and social networks [17], which will also be useful to explore how multiagent methodologies and technologies could help design and analyze the Internet-based systems in the context of IoS/IoT.

In this paper, we first propose an integrated framework of IoS/IoT where we use the Language Grid as an IoS infrastructure for explanation of the concepts. In the framework, we mainly focus on the integrated components for service composition based on cloud services on IoS and things on IoT. Then we describe the proposed framework from a multiagent perspective from the aspects of development of the integrated architecture and design of applications by using the architecture. We first discuss the possibility of developing the integrated architecture of IoS and IoT as a multiagent-based architecture and applying multiagent methodologies for designing sociotechnical systems based on the integrated architecture. In this sense, we are not aiming to propose an agent framework for IoS/IoT integration in this paper; we would rather try to understand issues and key concepts of the integration from the viewpoint of multiagent systems.

The rest of this paper is organized as follows: In Sect. 2, we provide the background of IoS and IoT, and then introduce the issues for integrating IoS and IoT in Sect. 3. Section 4 describes a multiagent perspective for the integration of IoS and IoT. Section 5 illustrate an application of multilingual environment design. Finally, the conclusion is presented in the last section.

2 Background of IoS and IoT

2.1 Internet of Services (IoS)

The Internet of Services (IoS) can be explained in different ways depending on the different definitions of a service. In the research area of service-oriented computing (SOC), services are usually defined as "self-describing, platform-agnostic computational elements that support rapid, low-cost composition of distributed applications [33]." Service-oriented architecture (SOA) has been regarded as a key concept to realize the IoS [36], where software, data or business processes are deployed as Web services by service providers and used by service clients or service users. In SOA, there are basic services or atomic services that provide single functions of software or operations of data, and composite services as well that are composed by multiple atomic services to realize complicated functions or operations. Web services are evaluated by Quality of services (QoS), which consists of several non-functional attributes including cost, response time, reputation and so on [49]. Therefore, QoS-aware service selection and service composition are important research issues for realizing the IoS.

IoS has been discussed a lot from a multiagent perspective in previous studies [11] [42]. Service-oriented systems have been said to realize many ideas from the research area of multiagent systems. The multiagent-based SOC research challenges were proposed including pervasive service environments, society-inspired systems, and computational service mechanisms [12]. Moreover, interaction protocols in multiagent systems were applied in SOA in previous research and realized as a commitment-based SOA [41].

Since IoS involves various services and stakeholders, it can be regarded as a sociotechnical system where interaction between people and technology frequently occurs. We have adopted the sociotechnical approach [7] [39] to develop an IoS infrastructure, called the Language Grid [15]. The Language Grid is developed as a multilingual service platform for supporting intercultural collaboration activities, which enables easy registration and sharing of language resources such as online dictionaries, bilingual corpora, and machine translations [13] [25]. With the Language Grid, we have conducted studies on QoS-aware service composition and recommendation [24] [9], combination of human services and Web services [21], and policy-aware service execution [45].

2.2 Internet of Things (IoT)

The Internet of Things (IoT) introduces things to the Internet, which enables easy integration of the physical world into the cyberspaces [1]. IoT is regarded as a key infrastructure in various domains including smart home, smart city, smart factory, healthcare, transportation, agriculture and so on. Typical enabling technologies in IoT include sensors and actuators, which are used to monitor and control things. By this means, information produced by things on the IoT environments can be used by various stakeholders for decision-making. Therefore, the key technologies that enable current IoT-based applications include collecting and process information from things, and making decisions from the processed information.

Since IoT is an emerging idea, its architecture, enabling technologies, protocols and standardization have been discuss from different perspectives. Identification, sensing, communication, computation, service and semantics are summarized as key IoT elements, while Big data analytics, cloud computing, high performance computing and fog computing are regarded as supporting technologies for IoT in previous study [1]. IoT was also studied from an SOC perspective, where IoT architecture was described to cosist of sensing layer, networking layer, service layer and interface layer [8]. However, IoT faces many issues related with Quality of Services (QoS) including availability, reliability, mobility, performance, scalability, interoperability, security, management, and trust.

IoT has also been studied from a multiagent perspective, where an IoT-enabled application is regarded as a social process involving multiple autonomous parties and therefore it can be realized as decentralized multiagent systems [40]. Moreover, decentralization, asynchrony and decoupled enactment, governance of security, accountability and privacy were summarized as several important elements that IoT needs. Further, possible research directions in decentralized MAS were proposed including programming models, interaction-oriented software engineering and enlightened governance.

3 Issues for Integrating IoS and IoT

To build Internet-based sociotechnical systems like the multilingual environments, we have focused on the technologies of composing cloud services provided on the IoS. With the development of IoT infrastructure and availability of various sensors and actuators, it becomes possible to provide high-quality services to users by satisfying their requirements in various situations. For example, sensors can be used to detect users' situational information like users' interests and degree of satisfaction to a multilingual interactive agent. Based on these situational information, customized atomic services and composite services on the IoS can be provided to users under different situations. Therefore, it is important to consider integrating IoS and IoT for sociotechnical systems. However, there are several issues that we need to consider when integrating IoS and IoT. In the research area of SOC, previous research has studied how the SOA paradigm may be revisited to address challenges posed by the IoT: the extreme heterogeneity, ultra-large scale, and the dynamics [16]. These challenges of IoT have great impacts on integration IoS and IoT.

First, the extreme heterogeneity of IoS/IoT makes it difficult for composition of services and things. For example, the granularities of steaming data collected by sensors on the IoT and function-based cloud services on the IoS are totally different, and therefore it is difficult to combine them as what can be easily done in SOA. In traditional SOA, service users can easily access and invoke Web services through standardized protocols or lightweight message transfer frameworks. However, the diversity of things and interaction styles between service users and providers in the IoT environment makes it difficult to apply SOA as is. Therefore, it is necessary to consider middleware-level components for service access in IoT [35] [30]. That is, we need to deal with the issues by addressing how to handle the interoperability of the services on the IoS infrastructure and things on the IoT environment.

Second, ultra-large scale of services and things is a huge challenge to the performance of the integrated IoS/IoT environment. Therefore, we need to deal with the issue for ensuring realtime execution of services. In previous study, we have proposed a framework of parallel service execution in the IoS infrastructure considering policies of service providers [45] in IoS. Moreover, the ideas of fog computing [4] and edge computing [38] were proposed to deal with this issue in the IoT environments by handling data processing and event processing in different layers of servers. However, more factors need to be considered for improving the performance in the integrated IoS/IoT environments, including mechanisms for parallel execution of rules and handling of the massive complex event processing.

Third, the dynamics of the IoS/IoT environments has two aspects: dynamic changes of available services/things, and the dynamic changes of users' situations. Therefore, the important issue here is that the integration framework need to enable service composition and recommendation according to dynamic changes of environments. Although we have already conducted studies on dynamic service selection [24] and service recommendation [9] with the Language Grid on the IoS, it is necessary to extend these studies into the integrated IoS/IoT environments.

Moreover, it is also important to consider complicated issues by the application systems based on IoS/IoT, which can be regarded as Internet-based sociotechnical systems with multiple stakeholders involved.

4 Multiagent Perspective on Integrated IoS/IoT

4.1 Integration of IoS and IoT

To explain the integration of IoS/IoT in a easier way, we use the Language Grid as an example of IoS infrastructure. We have developed and operated the Language Grid as an IoS infrastructure to support intercultural collaboration for more than ten years. The Language Grid is built on service grid server software, and consists of five parts: Service Manager, Service Supervisor, Grid Composer, Service Database, and Composite Service Container [26]. Based on the federated service grid architecture [27], we also realized the federated operation of the Language Grid in several Asian countries including Japan, Thailand, Indonesia and China. As of July 2018, 226 language services are shared among the federated Language Grid. Moreover, an extended framework for service design was proposed with the Language Grid by bridging the gap between stakeholders involved in the language service infrastructures and those who develop and operate multi-language systems [23].

The key concept of IoS infrastructure like the Language Grid is to standardize the service interface for each category of resources (data, software, business process, etc.), and enable flexible service management and service composition. In the IoT environments, standardization and composition of things are also regarded as important fundamentals [2]. For example, OpenIoT is one typical initiatives to realize standardization of IoT [43], while Web of things is another proposal for composing embedded devices on IoT [10]. Moreover, a SOA-based IoT architecture was proposed in previous work to realize flexible service composition with trust management in the IoT environments [6].

In this paper, we mainly focus on the service composition and interaction between IoS/IoT to deal with the integration. In the following sections, we describe the integration from a multiagent perspective with two aspects. One aspect is to regard the integrated architecture as a multiagent-based architecture to address the complicated interactions across IoS/IoT. The other aspect is to apply multiagent methodologies for service design with the integrated IoS/IoT architecture.

4.2 Multiagent-Based Architecture

We consider some typical patterns of service composition and interaction in the integrated IoS/IoT environments as shown below.

1. Information of things on IoT are collected and aggregated by sensors, and it triggers invocation of atomic services or composition of services on the IoS platform. For example, appropriate language supporting services are invoked based on the information collected and analyzed from the eyetracker that identifies a non-native speaker's difficulties encountered in a multilingual conversation [5].
2. Actuators trigger invocation of atomic services or composition of services on the IoS platform. For example, the lightening of different colors of IoT LED or push of different buttons triggers invocation of machine translation services with different input parameters of language combinations, which will be useful for multilingual support in international conferences [28].
3. Execution of atomic services or composition of services on the IoS platform drives actuators or sensors on IoT. For example, whenever a composite translation service is executed by a certain user, a group of sensors like GPS and counter are driven to record the behavioral or situational data of the users together with the service invocation information, which can help improve the accuracy of situated service recommendation in the integrated IoS/IoT environments [9].

Since there are complicated interaction of various types in the integrated IoS/IoT, it can relate to a multiagent-based architecture as shown in Fig. 1. The interaction across IoS/IoT can be realized by complex event processing agent and rule agent that manage various rules including sensor data aggregation rule, actuator driving rule, and service invocation rule. Complex event processing agent and Rule agent are key parts in the IoS/IoT integration components. Agents in the integration components interact with sensor data aggregation agent, actuator driving agent, and service invocation agent in the IoS and IoT sides to realize service composition. The IoS/IoT integration components are supposed to address the issues we described in the previous section.

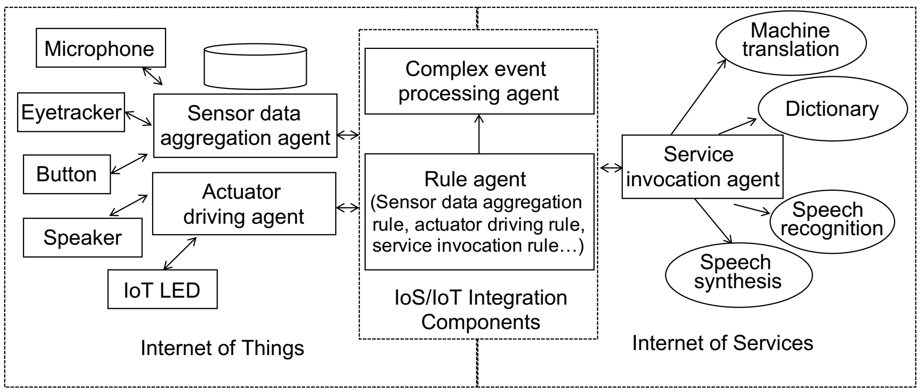

Fig. 1. Agent-Based Integration of IoS and IoT

4.3 Multiagent Methodologies for Service Design

We discussed the possibility of using multiagent-based approach to deal with the integrated componets for IoS/IoT. However, it is also important to consider complicated issues by the application systems with integrated IoS/IoT. The reason lies in that service design process with integrated IoS/IoT can be regarded as a process of Internet-based sociotechnical system design where multiple stakeholders are also involved in. Therefore, multiagent methodologies can also be applied for the service design process.

We have studied the service design process with the IoS infrastructure in previous work [22]. To design sociotechnical systems for the real world, iterative service design approach is always applied, which consists of the four phases: the observation phase is to understand users' requirements and evaluation criteria for QoS; the modeling phase is to define the service process that can best satisfy users' requirements by composing available cloud services based on QoS evaluation; the implementation phase is to realize service composition by embedding composited services into application systems; the analysis phase is to evaluate the designed service by analyzing the log data and interview results based on the defined evaluation criteria of QoS [20]. This iterative service design process can also be applied to the service design with integrated IoS/IoT.

Based on various experiences of service design, we proposed the field-oriented design methodologies by using a multiagent approach [14], which deal with the service design in the field where complex issues are often faced. The service design process always starts from understanding the problems in the field and proposing services for solving those problems at the early stage. Due to the interdependency between problems and their changes over time, it is more important to develop a continuous problem solving process than to solve currently faced problems. In this context, multiagent methodologies were proposed for experiments of service design with multiple stakeholders, including role playing games [44], participatory simulations [19] and gaming simulations [29].

5 Applications: Multilingual Environments with Integrated IoS/IoT

We use an application of multilingual environments to show the integration of IoS and IoT. Figure 2 illustrates a scenario of multilingual conversion between an interactive agent and a user. In the scenario, a German visitor is shopping at a historic Japanese marketplace where there is a muntilingual interactive agent provides necessary support. When the visitor is asking something in German, the interactive agent first selects use a composite translation service to translate it into Japanese. The composite translation service is recommended by a service invocation agent on IoS based on the difficulty and language of the input sentences of the visitor, which usually consists of a speech recognition service, a machine translation service, and a dictionary service of domain knowledge. Meanwhile, the sensor data aggregation agent on IoT is interacting with the rule agent and complex event processing agent by sending the event information about what the visitor is looking at. The rule agent and complex event processing agent then triggers a composite dialogue generation service through interaction with the service invocation agent. In the example shown in Figure 2, the service invocation agent recommends a culturally situated dialogue generation service that maps a concept in one culture into another culture for explanation [18].

The dialogue between the interactive agent and the visitor in above example seems simple, but it is generated based on complicated interactions between various agents on the integrated IoS/IoT environments and service composition based on situation-aware recommendation mechanisms. To realize such high-quality multilingual environments with IoS/IoT, we deal with two major issues. First, we need to realize the situated service composition that fully utilize cloud services on IoS and sensors/actuators on IoT to satisfy users' various situations. Second, multilingual interactive agent need to be realized for supporting users.

Situated Service Composition. Service composition is one of the most important topics in the area of SOC, which is also true in the integrated IoS/IoT

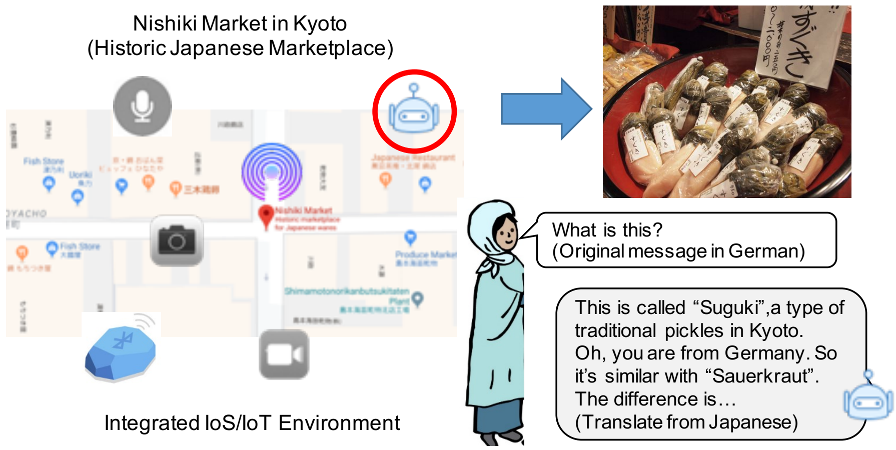

Fig. 2. An application of multilingual environment with IoT and IoS

environments. Traditionally, service composition is a technology that composes multiple atomic services accumulated in the IoS infrastructure to satisfy users' requirements of Quality of Services (QoS). Service composition has been realized by automatically generating service workflow based on AI planning and other technologies. The key lies in how to select appropriate services to execute the service workflow since there are always numerous candidates of atomic services for the same function. One of the major challenges to realize this application is to deal with the composition of various services on the integrated service platform and the interaction between agents across IoS and IoT. Since existing service recommendation approaches fail to fully consider the influence of situation information, such as time, location, and user relations thoroughly. Our solution is a situated QoS prediction for service recommendation that combines observed factor learning and latent factor learning. The detailed proposed mechanism is described in [9].

Multilingual Interactive Agents. Another issue in the provided application is to realize multilingual interactive agents. The interactive agents are playing essential roles in many fields. For example, there are increasing demands in the fields of tourism and healthcare to use interactive agents because the shortage of human resources due to aging population. In such circumstances, interactive agents are required to handle dialogues with end users in various situations. Moreover, it becomes important for interactive agents to provide multilingual support to end users. However, it is always difficult to ensure the quality of dialogues generated by the agent especially at an early stage. Previous research has widely used Wizard of Oz (WoZ) for prototyping and evaluating dialogue-based computer systems that have not yet been realized. In our service design process, we also apply WoZ to prototype and improve the interactive agent gradually. In our proposed framework, the recommender system provides a candidate list of dialogues to the Wizard based on service composition. The Wizard then selects or creates appropriate dialogues and provides them to the interactive agent. This design process of interactive agent can be regarded as an agent-based participatory design process. The detailed framework of interactive agent is described in [31] [37] [18].

6 Conclusion

This paper deals with the issues of integrating Internet of Services (IoS) and Internet of Things (IoT) for realizing the Internet-based sociotechnical systems. We describe the integrated IoS/IoT framework from a multiagent perspective. First, we adopted a multiagent-based approach for the integrated IoS/IoT architecture. Then, we discussed the possibilities of applying multiagent methodologies for designing sociotechnical systems based on the integrated architecture. Further, we used an example of designing multilingual environments to illustrate the multiagent perspective.

Although we provide a multiagent perspective to study the integration of IoS/IoT. The discussed multiagent architectures and methodologies need to be extended to deal with the massive scale in the context of integrated IoS/IoT, which may result in related future possible research directions in massively multiagent systems.

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