Development of Smart Room Services on Top of Smart-M3

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Abstract—**SmartRoom is a system supporting collaboration activities localized in a room: a set of digital services is available for organizers and participants. The Smart-M3 platform is used to set up a networked knowledge sharing environment on top of which the SmartRoom service set is deployed. In this paper we introduce the methodology and design of the SmartRoom system. We consider realization of digital environment in a room, service set structure and corresponding Smart-M3 based computing infrastructure, ontological models and their use for service construction and delivery.**

Keywords—Smart Spaces, Smart-M3, Collaborative environment, Ontology, Services.

I. INTRODUCTION

The development of smart digital environments for various problem domains is a topical research area [1]. The smart spaces concept and its open source implementation—Smart-M3 platform—provide a generic methodology and technology prototype for constructing such environments [2], [3], [4].

In this paper we continue our work [5], [6], [7], [8], [9] on the development of SmartRoom system. The system assists collaborative work activity such as conferences, lectures, or meetings. The SmartRoom system evolves the ideas evaluated in the research prototype of Smart Conference system [10], [7]. Participants are accommodated in a room, where the digital environment supports their ongoing activity by provision of a set of informational services. It simplifies the multi-party activity organization and human participation as well as automate routine functions of information acquirement, sharing, and transformation. The automated and intelligent assistance allows the participants to concentrate on the problems the activity is devoted to, not on technical details of information acquisition, sharing and transformation.

We introduce a development methodology for such a class of smart spaces service-oriented systems. The methodology is based on separation into the following conceptual blocks: 1) digital environment, 2) service set, 3) computing infrastructure, 4) ontological modeling, 5) service construction and delivery. For each block we consider properties and design solutions intended for implementation in the SmartRoom system.

The rest of the paper is organized as follows. Section II reviews related work. Section III introduces our vision of digital environment where the SmartRoom system is executed. Section IV discusses the service set that the SmartRoom provides for end-users. Section V presents details of SmartRoom computing infrastructure responsible for service construction. Section VI introduces our ontological models for representing services and user-related information in the smart space. Section VII describes the key properties of service construction and delivery. Section VIII concludes the paper.

II. RELATED WORK

The state of the art in the technology of smart digital environments is presented in [11]. Methodological aspects of using Smart Spaces and Smart-M3 in development of service-oriented multi-agent systems is considered in [1], [2], [3], [4]. A survey of smart space prototypes for assisting collaborative meeting activity and comparative analysis can be found in [12].

Kim and Fox [13] consider a ubiquitous collaboration framework for floor control in multimedia conferencing and collaboration work, where cell phones are primary end-user devices. A virtual shared workspace (conference room) is constructed for local and remote participants. Specialized coordination and sharing mechanisms are designed, see the technology of Community Grids Lab (CGL, http://communitygrids. iu.edu). In contrast, SmartRoom uses the general-purpose platform—Smart-M3, which supports interoperable ontology-driven knowledge representation and reasoning as well as aims at flexible integration of additional services.

The Access Grid (http://www.accessgrid.org) provides resources and technology to support group-to-group interactions. It can be used as an advanced type of videoconferencing facility that allows participants from multiple locations to interact in real-time. In addition it provides mechanisms to share data, collaborate using a variety of shared applications (such as sharing presentation material), utilize large-format displays, and can employ multiple video sources to allow room-to-room conferencing capabilities. Similar ideas were elaborated in the Global-MMCS Project (Global Multimedia Collaboration System, http://www.globalmmcs.org), which builds a service-oriented collaboration system to integrate various services including videoconference, instant messaging, and streaming. Our SmartRoom system focus on intensive in-room collaboration using pervasive surrounding devices for
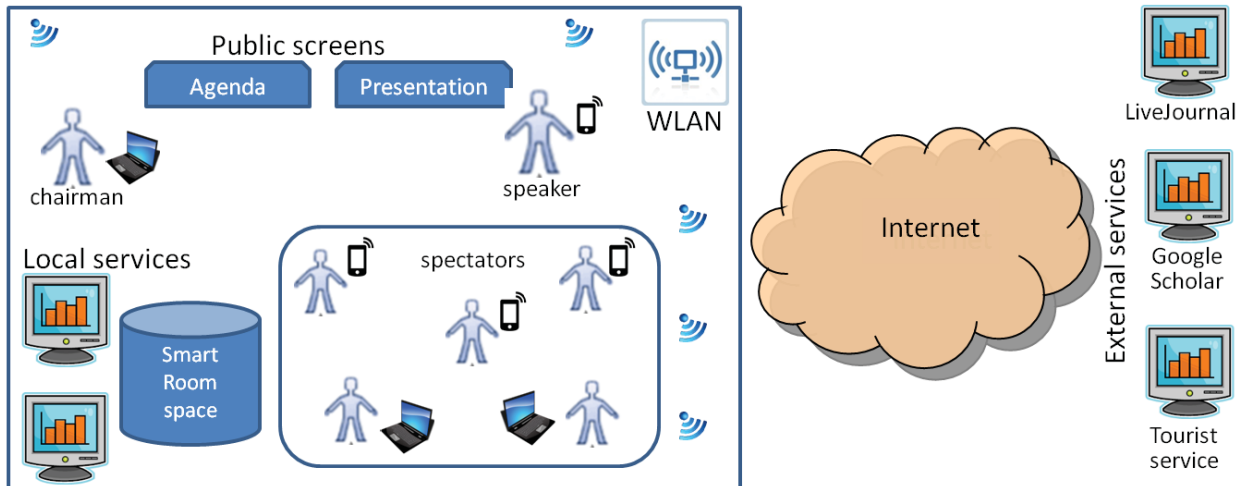
Fig. 1.   Digital environment of the SmartRoom system

hosting the system and personal mobile devices for access and control points of participants.

The Smart Conference system [10], [7] is the closest work to ours. That system is a research proof-of-the-concept prototype, which elaborated the original idea of assisting the collaborative conferencing activity. It successfully evaluated the feasibility of implementation on top of the Smart-M3 platform. The SmartRoom system takes into account the lessons learned in Smart Conference and further evolves its idea by introducing advanced architecture and service set. In addition to conferencing, SmartRoom is oriented to a wider class of collaborative activity, e.g., meeting and lectures.

III.   SERVICE ENVIRONMENT

The SmartRoom system belongs to a class of multi-agent intelligent systems where the agents cooperate within a shared smart space—*SmartRoom space*. On the application level, a smart space is a logical entity to acquire and apply knowledge about its environment and to adapt to its inhabitants for improving their experience in that environment [1], [2]. On the agent level, a smart space is a named search extent of shared information [3], [4], which the agents cooperatively utilize running on various computational devices. Schematic view of the environment and SmartRoom space is shown in Fig. 1.

Computing equipment is localized in a room, i.e., surrounding devices are installed in the spatial physical area and WLAN provides the network connectivity. Examples of devices are interfaces for media information (e.g., projector–computer pairs, TV panels, interactive boards), sensing devices (e.g., physical sensors and actuators, network activity detectors, microphones, cameras), user access and control devices (e.g., laptops, netbooks, smartphones), WLAN infrastructure (e.g., Wi-Fi access points).

From the point of view of the Internet of Things, Smart-Room requires any device to be a smart object [14], [15]. A physical/digital object augmented with network capabilities

becomes applicable to interact within a smart space [2], [4], understanding and reacting to the environment.

The SmartRoom WLAN is attached to the Internet, allowing external systems to be smart space participants. This property supports the following important extensions. (1) Resource-consuming processing can be delegated, e.g., to nearby servers of the corporate computing system or to cloud systems. (2) A rich set of existing Internet services can be used, extending the functionality of the SmartRoom system.

Participants (service end-users) are chairman, active speaker (in turn relay manner), and spectators (including inactive speakers). The core SmartRoom services are Agenda and Presentation. They maintain the activity program in the room and digital presentational content of the speaker, respectively. Other services can be constructed, either by augmenting the core ones or independently. The SmartRoom service set can be separated into several groups; its exemplary structure is shown in Fig. 2.

Two big public screens are user interfaces for the services: Agenda-Screen shows the activity program (timetable-like format) and Presentation-Screen shows presentational material of a speaker (slides-like format). If a service is intended for all participants then its information is visualized on a public screen, possibly composed with related information from some other services. The environment is extendable: additional public screens can be introduced if some services need more area for visualization. This option, however, requires careful analysis since the higher interface multimodality can reduce the usability.

In addition to the public screens, SmartRoom services can be accessed personally using client agent [6] It is installed on end-user device (e.g., smartphone, laptop, PC). Although all services are potentially applicable for any participant, a specific service subset should be offered for each user based on her/his preferences and current context. It aims at personalization and enables proactive delivery of services.

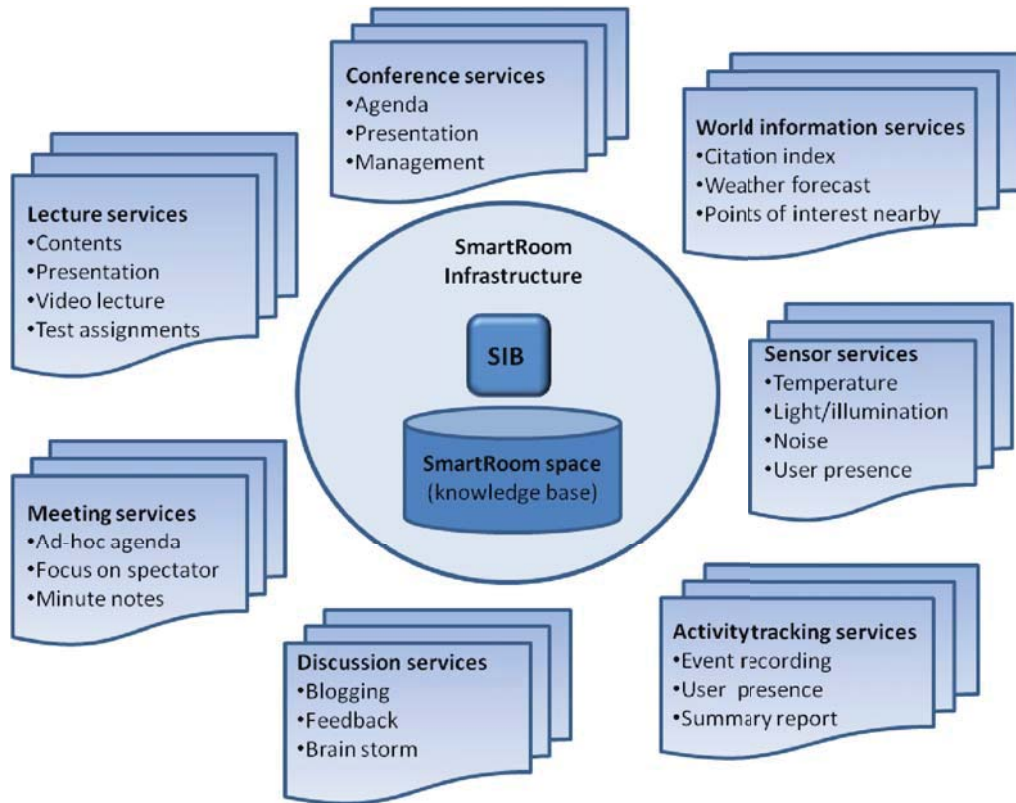Public screens and end-user clients form the primary set

Fig. 2. Structure of the SmartRoom service set. Each service group can be extended. More groups can be introduced

of SmartRoom UI elements, i.e., user interfaces for visual representation of information from services. UI elements are also used for input: users can explicitly or implicitly provide information for sharing in the space. This option implements control actions when ingoing information effects the process (e.g., slide control, changes in the agenda, camera focusing).

The role of SmartRoom space is essential. It acts as a hub to relate all data sources and participants. Furthermore, as a knowledge base it provides means to access collected information and reason knowledge over it. Knowledge appears as a result of cooperation and then derived facts are shared in the space. The basic maintenance is performed by Smart-M3 Semantic Information Broker (SIB) [16]. Nevertheless, extensive application-specific support is required, which is implemented on the level of SmartRoom infrastructure.

IV. SERVICE SET

Any SmartRoom service is informational; it provides digital resources for end-users via SmartRoom UI. A typical scenario is real-time visualization of ongoing processes in the room. Straightforward transfer of information from the smart space to SmartRoom UI elements is a simple passive form. It feeds the participants with information for making their own decisions on the activity.

In general form, a service supports automation and control of the ongoing activity. The SmartRoom space keeps represen-

tation of activity processes. Any change in the representation is a control action. Therefore, a service analyzes the online space content, reasons over this information, and updates (possibly without human intervention) the representation. For instance, detection of absent speaker leads to canceling her/his presentation, recalculating the agenda, and delegating the control on Presentation to the next speaker.

The SmartRoom system can operate in several modes, depending on the type of activity holding in the room. We distinguish the following types: *Conference*, *Meeting*, and *Lecture*. Any activity type requires a specialized set of services, and the corresponding service groups are intentionally separated in Fig. 2 (the left-top part).

The core services—Agenda and Presentation—appear in any of these groups, though in a specialized form. Example of Agenda-screen for conference is shown in Fig. 3.

The organizers have full manual control of the services. For instance, the chairman can manipulate with the activity program of Agenda, in addition to automated actions such as canceling the presentation if the speaker is absent. Presentation-service is controlled by current speaker and also can be affected by the chairman. Personalized view of Agenda-service and Presentation-service is achieved by participants from their clients on end-user devices.

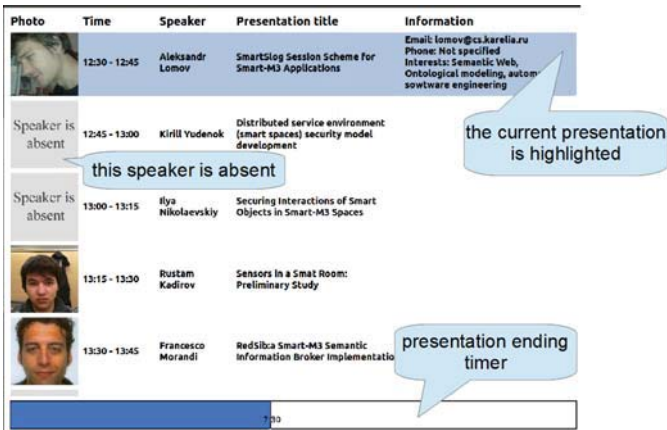Each core service can be augmented with advanced ser-

Fig. 3.   Conference program is visualized on the public Agenda screen in a timetable format

vices, see Fig. 2 (the right-bottom part).

World information services are accessed from the web. They provide information and processing facilities that can be used in the smart room. For instance, information trackers find appropriate knowledge collected in the global Web, e.g., presenter's citation index from Google Scholar or remarkable pictures of tourist objects around [17].

Discussion services allow online discussions between the participants. It uses public blog services available in the Internet. For instance, participants can discuss each other's presentations during the conference or publish their opinions during the meeting [7].

Activity tracking services are deployed locally in the smart room. They accumulate knowledge appeared in the room and derive new knowledge. For instance, personalized reports are sent to each participant after the conference [8].

Sensors services use sensor devices deployed in the room. They monitor parameters of internal physical environment and publish the measurements into the smart room space. The data can be visualized on the Agenda-screen, composed with the primary information [9].

Based on the above groups the variety of services can be constructed. The variants are only limited by the imagination. Table I presents examples of scenarios that we currently work on.

V.   SMART-M3 BASED INFRASTRUCTURE

Realization of the SmartRoom service set requires an interoperable information sharing platform that turns the data from various sources of the environment into a shared commodity [4]. We employ the Smart-M3 platform [16]. Agents communicate sharing their knowledge (data, semantics and any digitally encoded information) in the SmartRoom space. Information interoperability is achieved due to ontological representation models (RDF, OWL) and the smart space access protocol (SSAP, a part of Smart-M3). SSAP is XML-based

TABLE I.   EXAMPLE SCENARIOS FOR USE IN SMARTROOM SERVICE SET

Scenario	Description	Devices
Personal microphone	Speaker uses her/his phone also as a microphone. The audio flow is forwarded to room's audio system.	Smartphone, embedded audio system
Interactive presentation	Speaker can interrupt her/his slide show and make additional drawings. The drawings then attached to the presentation.	Touch sensor whiteboard
Remote speaker	The speaker is physically outside the room and makes the presentation remotely.	End-user computer
Social program	Participants collaboratively develop their social program by matching their interests, plans, and available points of interests nearby the location.	Local computer

TABLE II.   DEPLOYMENT OPTIONS FOR INFRASTRUCTURAL KPs

Option	Properties
Cluster near SIB	Core services. Online 24/7 service mode. Ease of installation and control
Device-specific	An embedded or consumer electronics device becomes a SmartRoom space inhabitant (smart object), which participates in a specific service chain.
Server-like	Extensive or complex processing. Mediation of external data sources and services.

and implements communication (on top of TCP) between an agent and the space: join/leave, insert/update/remove, subscribe/unsubscribe.

Smart-M3 semantic information broker (SIB) hosts the SmartRoom space. The primary case is the SIB running on a server machine.[1] It is outside the room while from the same corporate network (intranet). Nevertheless, the SIB can be deployed on a machine in the room, hence reducing the network delays on the cost of local server installation. We employ the RedSIB branch [18] of Smart-M3 SIB.[2]

SmartRoom agents operate as Smart-M3 knowledge processors (KP) using the SIB. They have own local knowledge, access shared knowledge, apply reasoning over that knowledge, and make consequent decisions in accordance to the application logic (with possible publication of derivative knowledge in the SR space). Basic reasoning is performed on the space side (i.e., by SIB) using Semantic Web technologies (e.g., SPARQL queries in SSAP operations).

In Smart Spaces, agents and their cooperative activity are basic elements of service provision chains [2], [3], [4]. A service is constructed by iterative activity of KPs. In addition to the basic SIB support, SmartRoom provides a problem-oriented infrastructure for service construction and delivery. To implement a service, one or more *infrastructural KPs* are used. This modular approach achieves the following properties.

1) Other KPs become service consumers since processing is delegated to the infrastructure.
2) A new service may utilize already available KPs, making the integration more flexible.

We consider several deployment options for infrastructural KPs, which are summarized in Table II.

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[1]Now its public name is smartroom.cs.petrsu.ru.

[2]Available at http://sourceforge.net/projects/smart-m3/, latest release is 0.9, Sep. 2013.

The first option is running a KP on the same machine with the SIB. Being launched on a powerful machine, such a KP can support online services in 24/7 mode, perform resource-consuming processing if needed, and access the SmartRoom space with minimal network delay. Examples are the KPs for Conference-service and Content-service. The former handles the conference program runtime. The latter is a local Smart-Room repository for massive digital content suitable for storing neither in the smart space (due to the massiveness), nor in the global Internet or surrounding device (due to the performance). The Content-service manages the content and shares the links in the SmartRoom space for effective use by services.

Notably that the SIB and its surrounding infrastructural KPs are running on Ubuntu Linux. Their launching is implemented with Upstart init daemon.[3] It automates the process of SIB and KP (re)starting, taking into account the specific order of bootstrapping the SmartRoom system components. This clustering of most important services with the SIB provides an easier way for control the system.

The second deployment option is running a KP on a dedicated computer, which is connected to one or more specific SmartRoom devices (screen, whiteboard, sensor, camera, microphone, etc.). The option is for services that depend essentially on the device's role. Examples are Agenda-service and Presentation-service. The respective KPs run on the computers paired with the multimedia projectors of public SmartRoom screens. This type of KPs can also serve as gateways for low-capacity devices that cannot host own KPs [9], [19], e.g., small sensor devices.

The next deployment option is running a KP on a server-like system, different from the server machine with the SIB. That KP supports services with resource-intensive computation. Examples are EventRecording-service [8] and UserPresence-service. They analyze the smart space content for deducing certain knowledge, e.g., a chain of important events or history of user joining/leaving the room.

Another important class for server-like deployment option is KP-mediators. They connect external data sources and services to the smart space [20], [7]. The required data transformation and synchronization is typically a resource-consuming task.

The server-like option supports a variety of computers: from local servers in the room or corporate servers in the intranet to cloud systems in the Internet.

The SmartRoom infrastructure includes KPs for administration and control the system. They leave a possibility of human intervention even if the ongoing activity processes are automated. For instance, a SmartRoom administrator is able to start or stop a service without explicit knowledge of the computers that host infrastructural KPs for this service.

VI. ONTOLOGY

Smart-M3 requires all data in the smart space to be described in RDF triples, which can be further structured
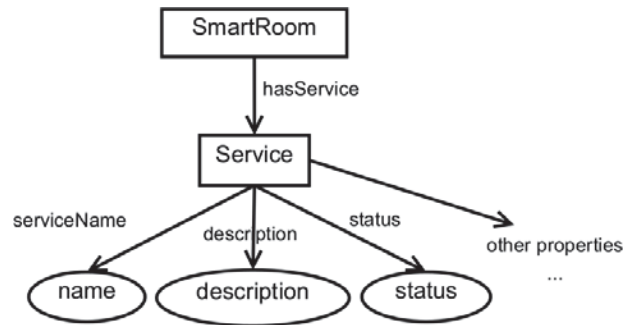
Fig. 4. Ontological model for a generic SmartRoom service

by some ontology. In the SmartRoom system the ontology defines how the data related to different services and users is represented. The SmartRoom ontology consists of two parts: service ontology and user profile ontology.

The service ontology describes a generic SmartRoom service, as Fig. 4 schematically shows. The class SmartRoom is the main class containing all services of the system. Each service is represented with the class Service and has such properties as name, description, and status (whether the service is available at the moment or not). A service allows extending with its own properties. The SmartRoom service ontology can be considered as a collection of several subontologies, each aims at a specific service. That is, a KP may operate only within certain subontologies, without the need of understanding the whole system [15].

Consider the ontological model for Conference-service. Recall that it handles the conference runtime by forming the conference agenda, starting/ending the conference, controlling speaker's time limits, and switching presentations in accordance with the conference agenda. The companion service is Agenda-service that implements UI of the service on the public screen.

The services use the same ontology shown in Fig. 5. The main class is AgendaService. It contains all activities to be held with the SmartRoom system (class Activity). Activity has title and consists of several sections (class Section). A section also has a title and start time. The agenda of a particular section is represented as a sequence of timeslots (class TimeSlot). Each timeslot holds a separate report (e.g., presentation, speech, media show) and has such properties as speaker's name, report title, and expected duration. A section also keeps two timeslots: the start timeslot (the first speaker starts from) and the current speaker timeslot. Timeslots are linked using the property nextTimeSlot, forming a sequence of reports. Besides each timeslot links to speaker's profile (property personLink), allowing this semantic information about "the timeslot user" to be easily applied for reasoning. Agenda-service displays the sequence of timeslots in a timetable form (see Fig. 3) and computes start/end times for every report using section start time and duration of timeslots.

The ontological model for Presentation-service is depicted in Fig. 5. The service shows presentations in a slide show
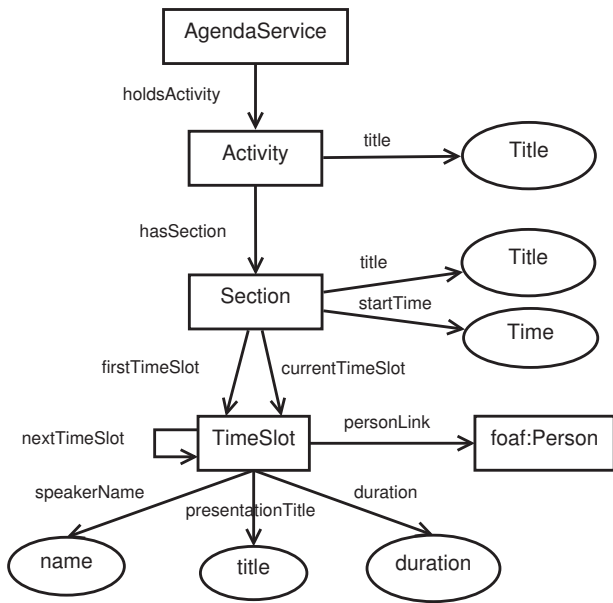
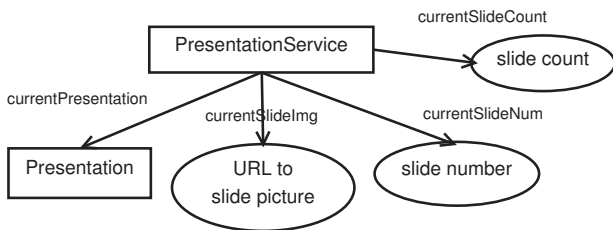Fig. 5. Ontological model for Agenda-related services

Fig. 6. Ontological model for Presentation-service

form. Starting a talk, Conference-service requests Presentation-service to show the presentation on the public screen. Then the control is forwarded to the client on end-user device of the speaker and she/he manipulates with the slides. The class PresentationService models services with the following properties: current presentation, URL of the current slide image (for end-user devices), current slide number, and the total number of slides of the current presentation.

The user profile ontology is shown in Fig. 7. It defines the class Profile, which consists of context information about user (class Context) and personal information (class foaf : Person).

User profile keeps username and password for SmartRoom participant identification and authentication. Context represents mutable characteristics of participant (activity level, mood, etc.) while person information describes permanent or long-term user properties. Person information is based on FOAF ontology[4], which provides a widespread vocabulary for describing people and relations between them. The use of well-known standardized ontologies leads to simpler integration with other systems.

We use such FOAF properties as name of person, age,

[4]http://www.foaf-project.org/

phone, interests, and some others. In the user profile, the FOAF ontology is extended with additional properties, e.g., to store presentations. Presentation information is collected in the class Presentation: presentation title, tags, and URL. Personal information can keep data of blog accounts, supporting easy user participation in blog discussions related to the activity in the SmartRoom.

A SmartRoom participant profile forms a personal subspace in the SmartRoom space. Similarly each service defines its own service subspace. Although such subspaces distinguish data in the global smart space and make it isolated, subspaces can be linked to support interactions. For instance, data on the current presentation in the Presentation-service space is borrowed from the personal space of the speaker.

The ontological models imply that the smart space is not a permanent storage of information. Instead, it is a hub that connects different information sources. The content of the SmartRoom space is dynamic and often contains links to the data. For example speakers' presentations are not duplicated in the smart space. It keeps only metadata and URLs to presentation resources located in the external file sharing services.

VII. SERVICE CONSTRUCTION AND DELIVERY

The SmartRoom infrastructure is responsible for service construction. SmartRoom UI elements are service consumers. Table III summarizes the properties the system implements to make its service environment smart.

The basic property of service construction is explicit representation of the service using our ontological model of a generic service (Fig. 4). The infrastructural KPs of this service create the service representation in the smart space and update it during the activity. Service clients (UI elements) subscribe for the representation and incoming notifications lead to information updates for end-users. For instance, when a participant joins the system her/his photo is visualized on the Agenda-screen.

SmartRoom UI elements are used for visualizing multi-service information. For instance, the primary role of Agenda-screen is visualization of recent activity program (e.g., list of time–speaker–topic). It can be augmented with additional information, e.g., speaker citation index from Google Scholar, temperature in the room, or latest comment from the online discussion. That is, services should be supported with visualization logic, which allows making decisions on appropriate composition of related information on a given UI element. The logic is implemented directly by KP of the UI element.

TABLE III. SMART SERVICE CONSTRUCTION AND DELIVERY

Property	Description
Explicit representation	Service is represented as an ontological instance in the smart space. A change in the representation activates the delivery.
Compositional visualization	UI element uses multiple services and composes the most important information on a area-restricted screen.
Personalization	End-user UI element uses personal information and context when visualizing the services.
Collaboration	Service representation is constructed in a P2P manner by several KPs, including clients.

Fig. 7. Ontological model of a SmartRoom end-user (participant)

Compositional visualization is supported by ontology-level relations between services. The relations are represented in the smart space and the analysis provides relevance estimates of different sources of information. Similarly, personalization is supported by ontology-level relations between services and users.

SmartRoom recently implements initial and straightforward solutions to support the properties of compositional, personalized, and collaborative visualization. We leave the development of advanced solutions to our further work.

VIII. CONCLUSION

This paper has considered the research development of the complex multi-agent service-oriented system based on the Smart Spaces concept and, in particularly, on its open source implementation—the Smart-M3 platform. Prototype releases of the SmartRoom system are available at http://sourceforge.net/projects/smartroom/.

Our methodology splits the development into the following parts: digital environment, service set, computing infrastructure, ontological models of smart space content, and methods for service construction and delivery. The defined properties and proposed solutions to these parts can be applied in development of similar service-oriented systems.

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