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Semantic Exploration of Distributed AR Services

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Abstract. In this paper, we present a new approach to building large-scale ubiquitous augmented reality (AR) applications. Instead of fixed AR content, presented on specific places or objects, we propose the concept of a semantic network of distributed AR services contributed by different providers. These services have different roles and offer different content and functionality, but the synergy offered by such a diverse network of services opens new fields of application for AR systems. The services in our approach are modeled using well-established standards from the domain of business process modeling, but they are additionally annotated using semantic descriptions of the role and properties of particular services and their relationships, allowing meaningful selection of dynamic exploration paths by users with different interests, constraints and privileges. An indispensable element of such heterogeneous AR systems is proper consideration of security and privacy issues, which are also covered in this work.

Keywords: Augmented reality · Business process modeling · Security policies · Semantics

1 Introduction

The aim of this research work is to develop a model enabling dynamic ad-hoc secure exploration of distributed augmented reality (AR) services using high-level semantic descriptions. Current location-aware AR platforms such as *Layar* [10] and *Wikitude* [23] have a number of underlying problems with respect to these functionalities. First of all they lack support for business services. AR platforms are not connected to internal business processes of businesses offering the services. The services are vendor-specific and they are not interoperable. Creation and management of AR services is a complex process, which requires high expertise in computer programming and graphics design. New services are often designed from scratch, which is costly and time consuming. At the same time privacy remains a serious problem – the systems do not currently really support user privacy. One central service provider may have access to all user data, when – in reality – users may want to limit this by provider and/or location. Finally, access control for AR in physical locations is an issue, in particular, limited access control rights within digital augmented reality spaces as well as lack

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of a model of rights management for physical spaces, i.e., anyone can augment any space without restrictions.

The model proposed in this paper addresses these problems by exploring how to:

1. Build a business service-oriented architecture that allows for the easy sharing of components and data between end-users and service providers, thus lowering development costs and improving interconnectivity between services.
2. Aggregate and link related business services offered by different providers to create composite services with a clearly added value for both the providers and the end-users.
3. Provide robust support for data privacy by allowing users to specify more accurately with whom, what and where they will share their data.
4. Support proper digital rights of service components, services, data and the physical environment.

In summary, the proposed model alters how location-aware AR services are delivered by combining a service oriented architecture with exploratory work on how to control digital and physical rights. This leads to lowered development costs, greater service integration and an improved ability to monetize the hybrid digital and physical space. This is complemented by a privacy approach that – in contrast to existing services – offers robust protection for both businesses and consumers. This is illustrated by use case examples.

2 State of the Art

A business process is defined as a sequence of activities that represent the steps required to achieve a business objective, such as providing a service, a product or other value for a customer. Business processes can be modeled, executed, and monitored using Workflow Management Systems (WfMS) [6], which are typically integrated in systems for Business Process Management (BPM) [9,22]. Currently, there are a variety of BPM products available on the market, both open source and commercially licensed. Examples are: *Intalio—BPMS* [8], *ActiveVOS BPM* [7], *JBoss jBPM* [17], *Activiti BPM Platform* [1], *Bizagi BPM* [3], and *Oracle BPM Suite* [16]. In the existing BPM systems, the workflow of business processes is defined with modeling tools using a graphical notation. Currently, the dominant graphical notation for modeling business processes is BPMN 2.0, which also standardizes an executable XML-based form of business process models [13].

As opposed to standard business services, AR business services are location-dependent – users may interact with the services at different locations and the location of users may influence the execution of the underlying business processes. Currently available standards for business process modeling do not take into account the spatial context, and need to be extended with new AR-specific elements, which would enable controlling the business process execution depending on the location of users and services. Business process modeling standards need also to be extended with new elements required for adequate presentation of user tasks and possible user interaction in AR environments.

Location-aware augmented reality has been an area of rapid development over recent years with platforms such as *StudierStube* [19] and *MORGAN* [14] being among the earliest to provide the core services, such as the registration of 3D graphics and audio relative to the users' position. However, these early AR platforms required that developers created independent applications that had to be downloaded and installed separately. More recent and commercially successful platforms, such as *Layar* [10] and *Wikitude* [23], offer more flexibility, but they have important limitations and are commercial products. In contrast, *Mixare* [11], although offering less functionality as compared to the commercial products, is an open-source alternative, which can be easily customized. Dynamic contextual AR systems based on semantic matching of user's context and the available services have been proposed in [18, 20].

The currently available AR platforms are limited to presentation of location-based information services, which enable users to obtain basic information about the places located nearby, but do not allow them to execute business processes in AR environments. Moreover, creation and modification of services usually require involvement of highly qualified IT professionals, who are experts in the design and programming of complex interactive multimedia content. As a result, in most cases, end-users must use ready-made content, which is usually too simple and too static for real business scenarios. Therefore, new methods for flexible creation of AR services and complex business scenarios are needed.

Additionally, none of these platforms place any restrictions on what kind of content can be used for augmenting real-world locations or who can add content to a given location. This presents potentially a number of social and economic challenges for physical space owners over the coming years, as competitors could add content to their locations, while the possibility to lease physical space to augmented reality developers/providers could open new revenue streams. Furthermore, previous works in this field noted the potentially invasive impact augmented reality games can have in public spaces. For example, from a purely social level it may be desirable to restrict what people can do, e.g., not allowing game playing at a cemetery.

There are many techniques that aim at protecting multimedia data (particularly 3D models in AR systems). DRM (Digital Rights Management) is a technique to control access and usage of digital content, including multimedia data as described by Zeng et al. in [27]. Modern DRM techniques are designed to maintain control over the content during a large part of the content life cycle. However, constant progress in AR technology in conjunction with the development of ubiquitous infrastructures challenge the existing protection techniques in AR systems. In particular, content offered within AR services interacting dynamically with each other in a ubiquitous environment and created by distributed service providers cannot be sufficiently protected by current DRM systems. The most distinguished standardization effort in the domain of protecting the usage of multimedia content is MPEG-21 REL [21] – a rule-based access control language. Unfortunately, Digital Item representation, which is the base for this model, is not expressive enough to support interactive AR scenes with spatially-sensitive composite content provided by different service providers. Generic standards developed to allow modeling of rule-based access control, such as XACML [12], despite their usefulness in many multimedia protection scenarios, do not support spatial constraints. XACML has spatially-aware extension called GeoXACML [15], however, mainly due to its two-dimensional limitation and lack of AR interaction protection, GeoXACML is not sufficient for AR frameworks. The same applies to GEO-RBAC [4].

Data and service security in distributed VR/AR environments is a wide and growing topic. Fine-grained access control mechanisms designed for 3D collaborative environments that are based on analysis of the call graphs, such as proposed in [24] could set a base for further research. However, they cannot be applied directly, since they do not take into account the specificities of: augmented reality, mobile spatial interaction, and dynamic service composition. Similarly, security models for large-scale distribution of structured 3D content proposed in [25], that represent an attempt to mitigate the malicious host problem, cannot be applied directly.

There is also a need for AR-specific research on data security focused on users' privacy protection. Due to novelty of the problem, many articles only point at forthcoming research directions and do not present any solutions. An example is [5], in which OS-level access control to AR objects such as human face or skeleton is discussed. Other researchers focus on providing AR-specific location privacy [2], but they propose anonymization-based approach only. Finally, privacy-preserving frameworks for ubiquitous systems based on a trusted third party operating in a "security infrastructure as a service" model [26] could be an inspiration for AR-specific security infrastructure. Generally, in order to preserve users' privacy in AR systems, access to users' data can be limited by different techniques – separately or as their combinations:

- policy-based techniques, e.g., formalized XACML security policies,
- privacy-preserving database querying, e.g., based on data anonymization techniques,
- techniques dedicated to AR solutions, e.g., obfuscation of animation streams.

3 Proposed Approach

3.1 Architecture for Explorable AR Services

The goal of this work is to develop an open, dynamic and secure framework for building interactive and collaborative mobile business environments based on AR business services. The conceptual model of the proposed framework is presented in Fig. 1.

Within the framework, *Basic AR Business Services* are contributed by different *service providers* (businesses, administration or citizens) and are combined by *service aggregators* (ad-hoc or based on higher-level models) into *Aggregated*

AR Business Services, in which users interact with different services, and services also interact with each other to form more complex scenarios. The services (basic and aggregated) are formally specified through models of the underlying business processes. *Service models* and *aggregation models* are created by *AR service managers* and *aggregation managers*, accordingly, using BPM tools extended with AR-specific elements. Service managers define allowed usage of their services in *AR Service Policies*, taking into account inter-services interactions and spatial constraints.

The AR business service models are deployed to the *Server AR Platform*, which consists of the following components: *AR Service Catalogue*, *AR Service Execution Platform*, and *Security & Privacy Enforcement Platform*.

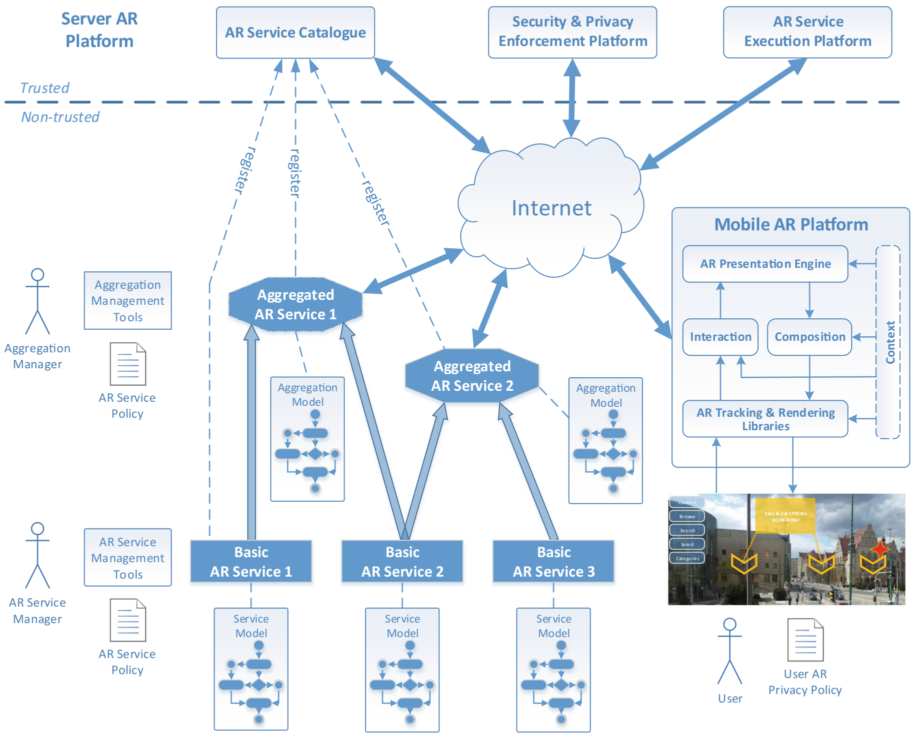

Fig. 1. Conceptual model of the proposed framework.

The *AR Service Catalogue* is used for registering AR business services in multi-dimensional context regions (with dimensions related to location, time, semantics, access rights, preferences, etc.). Therefore, the services can be discovered by users (implicitly or explicitly) depending on their current context. With AR business services, users can access up-to-date information related to their context and can execute actions. Since AR business services are formally modeled as business processes, which can access IT platforms of the service providers, the current status of the providers can be taken into account during aggregation and exploration of the services.

AR business services are accessed by the *Mobile AR Platform*, which enables discovering services of interest to a user, or requested by some other services, through the use of the *AR Presentation Engine*. AR business services – provided as a result of business processes run by service aggregators and service providers – are presented and interacted with using an AR interface in the form of multimedia widgets, which are connected through service-oriented interfaces to remote business logic of business processes running on the *AR Service Execution Platform*. *User AR Privacy Policies* allow users to define privacy settings (identity privacy, location privacy, path privacy) and access control settings related to in-device sensitive data. The *Mobile AR Platform* is responsible for *composition* of graphical presentation of AR services and handling user *interaction* according to the execution context (e.g., time, location, preferences, the status of service providers). The *AR Service Policies* and the *User AR Privacy Policies* are verified and enforced by the *Security & Privacy Enforcement Platform*, which plays the role of a trusted third party between service aggregators and service providers, and between end-users and service providers/aggregators. The platform is offered in the *Infrastructure as a Service* model enabling several instances of the platform provided by different entities.

3.2 Exploration of AR Services

For representation of aggregated AR services, we propose the use of concepts from the field of business process modeling. This enables specification of service logic using a standard notation as well as automation and monitoring of service execution with well-known software tools. To enable this kind of application, the BPMN 2.0 standard must be extended with:

- new AR-specific elements to take into account the spatial context of the service execution (location of users and services);
- new elements enabling presentation of user tasks and user interaction in AR environments;
- semantic domain-specific descriptions of flow objects (events, activities, gateways), connecting objects (sequence flow, message flow, association), lanes, and artifacts (data object, group). Semantic compounds reflect different relationships between content and services and their collections, e.g., belonging to the same class/category, similarity of meaning, location in space, availability in time, etc.

An aggregated AR service in the proposed approach is represented as semantically enhanced business process model, as presented in Fig. 2. Sub-services as well as connecting objects of the model are annotated with semantic descriptions. Different domain-specific ontologies can be used for creating the descriptions. For example, museum ontology, shopping ontology, nature monuments ontology,

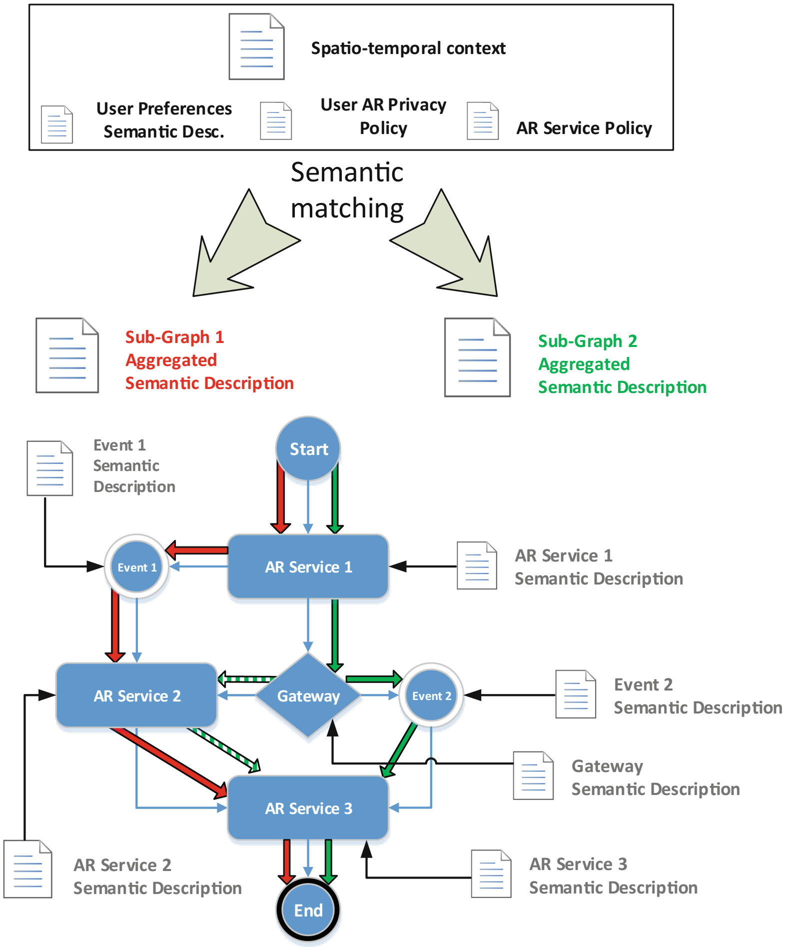

Fig. 2. An aggregated AR service.

can be used to describe services, while another set of ontologies, e.g., city exploration ontology, tourist agency ontology and history lesson ontology, can be used to describe connecting elements of the model.

When a user selects an aggregated AR service from the service catalogue, a service exploration graph is formed. The exploration graph is a subgraph of the AR service model adjusted to selected static elements of the user's context (e.g., preferences, privileges, device used). The exploration graph complies with given constraints and maximizes the value of a declared goal function based on semantic proximity.

Each exploration graph contains all possible exploration paths in the given preset context. Particular exploration paths that will be followed by a user depend on variable context elements (e.g., location and time), user interaction with the aggregated AR service (e.g., selecting an option in the user interface), and results of execution of sub-services (e.g., ticket availability). The exploration graph can be also dynamically updated during the exploration process, based on changing constraints and context.

3.3 Security Requirements for AR Exploration

A shift towards an ownership and rights model that includes content, services and physical space is proposed. The model enables semantic representation, processing and execution of the rights of physical object/space owners, allowing specification which objects, how, and in what context, can be augmented at their locations (e.g., limiting a location to informational services only, preventing paid services). Also, policy decision and enforcement mechanisms for dealing with the considered rights are proposed.

To assure end-users' privacy, the model of representation, processing and execution of users' AR privacy policies is developed. Policies enable defining location-disclosure preferences (user identity privacy, user position privacy, user movement path privacy) in the context of user anonymity, unlinkability and data unobservability. For example, users are able to define that their position can be sent to a given service provider, but with accuracy decreased to a given threshold. Moreover, an obligation can be defined, that only position at the given time can be analyzed, contrary to the complete movement path. Also, non-spatial usage history as well as access control to mobile device sensors and data sources can be taken into account in the user AR privacy policies. The model provides end-users with customizable access control mechanism for the case in which AR scenarios on the client device interact autonomously with other objects that have access to confidential data, hardware or can run security-sensitive scripts.

Unintended service usage seen from the AR service-providers perspective is also an issue. The model of representation, processing and execution of usage control policies related to AR services is developed to address these concerns. The proposed model assures that services and content are used only in the intended manner, taking into account mutual interactions and spatial constraints. For example, AR service providers are able to restrict who can use their AR services by defining spatial proximity requirements in order to prevent mass scale market-sensitive data harvesting. Another provider could restrict that only a given class of aggregators can aggregate their services, e.g., in connection with non-commercial services only. A mobile network operator could publish AR services for exclusive usage by their network clients.

AR service composition security can be seen also from the AR service aggregator perspective. The goal here is to give aggregators confidence that they can rely on AR service descriptions within the service aggregation process. A solution to this problem is a scheme for the proof of authenticity of the AR services descriptions that proves descriptions' consistency with their actual implementation and execution. It is possible due to introducing a trusted party – the *Security & Privacy Enforcement Platform* – that can fully control the *AR Service Execution Platform*, and therefore can examine the service execution process (the platforms are provided in the IaaS model enabling co-existence of independent and competing instances).

4 Application Domains of the Proposed Approach

Two application domains of the proposed approach are discussed below. The first is a network of touristic and cultural services offered in a city by different stakeholders. The second is a maintenance scenario, in which AR services offered by different providers are used by technicians during their routine work.

4.1 Touristic and Cultural AR Services

A prominent application domain of the proposed approach is access to cultural and touristic information and services. Augmented reality offers in this field clear advantages as it helps users to navigate in potentially unknown environments (e.g., a city visited by a user for the first time), and locate and identify specific points of interest. AR also helps to precisely explain meaning of specific elements (e.g., buildings or monuments), directly superimposing information on the view of the real environment.

In this domain, however, there is a variety of service providers and information sources, which must be properly amalgamated, taking into account security and privacy concerns. The first source of information may be municipal services providing maps and guidance through the city. Second are cultural heritage sites and museums, which offer information services on items both inside and outside the museums. Third are touristic agencies, which offer guiding and planning services that help users to properly organize their visit taking into account specific constraints (e.g., available time), preferences (e.g., interests in specific type of objects) and privileges (e.g., acquired access permissions).

A specific case, which demonstrates the importance of the proposed AR access control techniques, is a museum which would like to sell their own outdoor AR services, but prevent others from doing so at their site. They may, however, allow general tourist information and social networks AR services to remain active. It would allow for developing a marketplace within the AR area, similarly to existing environments in social spaces and games. The fundamental change here is that the rights are drawn not only on the ability to rent or own content and services, but also on aspects such as the underlying rights held by the property owners. This allows property owners to lease their space for use in AR, and service owners to lease their services to the physical space owners.

4.2 Maintenance AR Services

The proposed approach can be also applied in a use-case scenario in which AR services are used to support maintenance and monitoring work as well as training within existing and developing technical installations. AR technologies are used to provide maintenance, monitoring and training staff with up-to-date contextual information required or useful for their tasks. This information is displayed on multimedia mobile devices, such as smartphones, tablets or AR glasses, directly in the vicinity of the control and measurement points. In order to maximize service reliability in difficult weather or lightning conditions, visual identifying markers for particular installation elements can be used (e.g., QR codes) to support robust feature detection.

Content presented on mobile devices corresponds to interactive scenarios describing the operator's actions. These scenarios contain descriptions of tasks (manual activities, tools) as well as supporting information regarding maintenance procedures, parameters, technical conditions, safety standards, norms, repair manuals, etc. The different kinds of data are served by a number of distributed AR services offered by distinct service providers (e.g., technical, security and safety services), according to their AR business process definitions. On each level of the scenario execution, an operator receives instructions regarding tasks as well as contextual data containing, among others, current values of device's parameters. Instructions can have the form of animated graphical content, still images, text or audio/video sequences, superimposed directly on the view of selected infrastructure elements. Scenario progress is monitored at runtime by the system, so that warning messages can be generated in case of exceptional or dangerous situations. Moreover, automated verification of the task result's correctness can be performed, which is particularly useful in the training process. Functionality of the mobile AR application can support also collaborative scenarios with other users – local or remote.

Application of the proposed approach for such a use case scenario would directly influence the effectiveness, comfort, safety and security of maintenance works. Having access to the current context data directly in the workplace allows keeping proper order of the consecutive activities and allows employees to conveniently access data about particular elements of the specific installation (including dependencies between a given element and the state of other control elements), and therefore allows for faster and more accurate decision making. Consequently, applying the proposed approach would shorten the duration of tasks execution while increasing their safety. In turn, taking advantage of a context-based AR information system in the training domain would increase the effectiveness of the training process by providing trainees with access to data presented in the context of specific control points in a meaningful and intuitive manner and by decreasing the effort of the trainers by partial automation of the training process.

5 Conclusions

In this paper, we have presented an approach to building a new class of context-aware and secure AR services based on a high-level semantic model of a network of services offered by different providers. Any non-trivial application of AR to real-world problems, which is based on a sound business model, must take into account elements presented in this paper: diversity of sources, their relationships, context and preferences of users, and last but not least – security and privacy issues. Without these critical elements AR cannot be applied on a ubiquitous scale in serious applications.

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