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Leveraging cyber-physical objects through the concept of avatar

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1. Context

Connected objects, assistance robots and co-workers (co-Bots) will be a major market in a near future. The Web of Things (WoT) will lead to the development of advanced applications connecting heterogeneous objects. This is an opportunity for hardware and software vendors to occupy a strategic position on new marketplaces such as those envisioned by the Compose project[1]. Such applications shall attract customers with smart interaction possibilities and seamless deployment on various ranges of devices.

The **ASAWoO** (Adaptive Supervision of Avatar/Object Links for the Web of Objects) project aims at building an architecture to provide users with understandable functionalities exposed as WoT applications. This architecture is designed to fully integrate physical appliances into the Web and to enable collaboration between heterogeneous objects, from the basic sensor to the complex robot.

2. Vision

Our vision for achieving this goal is to associate each physical object with a computer object called an **avatar**. Avatars are designed to:

- Expose objects as resources on the Web: avatars can be invoked using semantic-enabled service-oriented protocols
- Compose collaborative functionalities: they interact with the avatars of other objects to negotiate and fulfill requests requiring complex functionalities, thus enabling inter-object collaboration.
- Manage context adaptation: they can adapt objects behavior according to their surrounding environmental changes.
- Cope with pervasive setups: they allow network communication disruptions and support optimized communications with remote objects
- Deploy code on the objects: they either deploy application code modules onto the objects or execute them in a cloud infrastructure if objects do not have enough resources to do so.

The objective of this project is to design and develop such avatars, as well as the WoT infrastructure they evolve in, together with the languages and protocols that will facilitate the integration of connected objects into the Web.

3. Scientific challenges

The ASAWoO project addresses several scientific locks in the following domains:

[1] http://www.compose-project.eu/

3.1. Semantic Web

Several works have been / are currently conducted in the field of the Semantic Web of Things (SWoT). The best known are the Semantic Sensor Networks ontology, as well as other vocabularies that describe the different parts of connected objects (actuators, network interfaces, processing capabilities). Nevertheless, in order to use semantic tools to achieve various avatar processing tasks (e.g. functionality discovery and exposition in REST, protocol adaptation or code deployment…), several other vocabularies must be combined for the different descriptions implied by our avatar architecture.

To be able to use these descriptions even when they are disconnected, object must embed avatars with minimal reasoning capabilities, compatible with their limited resources. Such reasoners must be designed almost on purpose wrt. the processing needs and the complexity of the ontology construct must be studied and reduced accordingly.

3.2. Web services

In order to benefit from explicit data semantics in the service protocol stack, Semantic Web Services (SWS) rely on semantic Web technologies to annotate service descriptions. Semantic service-oriented architectures have not been designed to describe the capabilities of physical objects. Moreover, HTTP with its request-response paradigm is not always suitable for controlling the behavior of complex objects over the Web. Recent M2M protocols such as COAP or MQTT have been designed but still lack semantics. A major scientific challenge consists in embedding semantics in low-energy applicative protocols, to enable semantic processing inside constrained objects.

Another challenge resides in handling the complexity of the physical world in the semantic service composition task. Indeed, service composition in ubiquitous environments differs from typical composition due to the fast evolution of environmental conditions, which require dynamic techniques for adapting service composition on-the-fly according to context evolution, to provide end users with an optimal solution. In such cases, we talk about adaptive service composition [1].

3.3. Multi-Agent Systems

Models developed in MAS are inspired from human, social and cognitive sciences. They are mainly organizational models (self-organization process, hierarchy management…), interaction/negotiation models (contract net protocol, recruiting interaction protocol…), physical environment models and user models (implementation of user's behaviors fulfilling specific needs). These facets of the whole system are integrated in the agent architectures. The first challenge consists in rethinking state-of-the-art agent architectures and multi-agents models according to (semantic) Web standards.

Secondly, an avatar evolves in an environment that it can perceive and in which it acts. It is endowed with autonomous behaviors and has its own objectives. An avatar society consists in a set of avatars situated in a common environment, which interact and attempt to reach a set of goals. Through these interactions, global, intelligent and unpredictable behaviors can emerge. Our goal will be to expose such emerging behaviors as new WoT applications and study their accuracy in regard of the users' needs.

3.4. Disruption-Tolerant Networking

Due to the mobility of the robots or of the end users, and of the limitation of the communication range of the wireless interfaces, some connectivity disruptions can appear, and connectivity islands can be formed. In such conditions, it is impossible, to maintain end-to-end paths between different islands thanks to Internet legacy protocols.

In order to address these issues, we plan to define and to implement in the ASAWoO project a specific routing protocol relying on disruption tolerant networking [2] (or opportunistic networking [3]) techniques. These techniques implements the ”store, carry and forward” principle, whose basic idea is to take advantage of radio contacts between devices to exchange messages, while exploiting the mobility of these devices to carry messages between different parts of the network. Two devices can thus communicate even if there never exists any end-to-end path between them.

3.5. Contextual adaptation

Modeling contextual data at the semantic level [4] allows aggregating heterogeneous data into a “contextual situation” and therefore deriving complex adaptation processes [5]. We aim at embedding, inside each object avatar, a context management component that: 1) aggregates data from the appliance sensors (camera, GPS…) and from external services into such contextual situations; 2) will both be able to query such data and accept events that generate them due to environmental changes; 3) will be queried by other avatar component to make adaptation decisions at different levels: exposition of the object functionalities, collaboration with avatars of other objects, communication protocol between the avatar and the object, location (on the object processor or in the cloud) to deploy each WoT application module.

4. Technical aspects

The design, implementation and deployment of the avatar architecture led us to face several technical problems and make the following choices.

In our WoT infrastructure, objects are connected to a common gateway, located in a supposedly secured local network (e.g. smart home, enterprise supply chain). Such a gateway provides multiple connectivity interfaces (Ethernet, USB, Wifi, Zigbee…) and relies on the AllJoyn™ [2] interoperability framework. It is related to a dedicated cloud infrastructure that provides additional processing capabilities and a collaboration space to the object avatars.

The avatar architecture is a distributed service-oriented architecture (SOA), partly located in the cloud infrastructure and partly on the object. It is implemented in Java as a set of OSGi services that can be dynamically deployed on one of these two sides. So can be the modules of the WoT application currently executed by the avatar-object couple. To do so on objects that cannot run Java VMs, the framework and services have to be cross-compiled to fulfill our infrastructure requirements.

5. Acknowledgements

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Learn more about this project at http://liris.cnrs.fr/asawoo/.

6. Conclusion

The ASAWoO project concretizes existing work from the Web service and semantic Web research fields, leads to context-aware solutions for dynamic code deployment on constrained devices and disruption-tolerant routing protocols and allows defining new agent interaction models for physical objects. Its key concept is the notion of avatar.

[2] https://www.alljoyn.org/

While writing this paper, the project has already started. The avatar architecture has been defined and is currently being implemented. Semantic aspects of the functionality discovery process are presented in [6] and collaborative advances in [7]. Networking solutions and deployment of the WoT application modules are also under development.

We envision several benefits from the ASAWoO project. Our WoT infrastructure will provide a scalable, out-of-the-box framework enabling high-level interaction with sets of heterogeneous objects *via* the deployment of Web of Things applications. Object-avatars couples define cyber-physical objects that augment the built-in functionalities of physical objects.

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