Applying Semantic Web in Mobile and Ubiquitous Computing: Will Policy-Awareness Help?

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Abstract. The Semantic Web can be seen as a means of improving the interoperability between systems, applications, and information sources. Emerging personal computing paradigms such as mobile and ubiquitous computing will benefit from better interoperability, as this is an enabler for a higher degree of automation of many tasks that would otherwise require the end-users' attention. In this paper we present one possible view of mobile and ubiquitous computing enhanced with the application of Semantic Web technologies, and explore the various benefits of policy-awareness to this application domain.

1 Introduction

The emergence of *smartphones* – mobile phones capable of functions typically associated with personal digital assistants (PDAs) or even personal computers – has made *mobile information access* an everyday reality, and *mobile computing* the new (emerging) paradigm of personal computing and communications. With wide-area, local-area and *proximity* networking technologies now available on these mobile devices, we are rapidly transitioning towards Mark Weiser's vision of *ubiquitous computing* [1], where a single (personal) device is no longer the focal point of user's attention and where computation is effectively distributed to the environment surrounding the user.

Mobile and ubiquitous computing, while offering new opportunities, also pose several technological challenges not necessarily present in (or critical to) the current paradigm of personal computing based on the *desktop metaphor*. In the short term, progress is being made to better enable many typical personal computing tasks on these devices (for example, good progress has been made to enable normal "Web experience" on smartphones [2]), but ultimately the form-factor of handheld devices will force us to radically rethink user interfaces and user interaction, rather than merely suggesting a "miniaturization" of the prevalent graphical desktop interface. Even though we could eventually overcome the physical limitations inherent in mobile information retrieval, the real limitations have more to do with the usage situations of mobile devices: Information access often (if not predominantly) takes place in situations where the user is "attention-constrained"; in other words, the user is primarily paying attention to *something else* (say, driving a car) and cannot expend full attention to the process of finding and retrieving information (or to any other "personal computing" task for that matter).

In addition, *mobility* in itself introduces a more challenging environment with regard to connectivity, security, privacy, service discovery, etc., while at the same time making completely new applications possible that simply would not make sense in a more stationary form of computing. A device such as a mobile phone, by virtue of being a constant companion to the user, can also be trusted with considerable amount of useful personal and private information; this, in turn, will force us to ensure that issues of information access (security, privacy) are properly dealt with.

We believe that mobile and ubiquitous computing devices would become more useful if they could undertake tasks *on behalf of* the user, rather than – as is currently the case – forcing the user to do essentially everything herself. The transition from mobile devices as *tools* to mobile *assistants* will require the application of not only technologies for implementing *autonomous operation*, but also sophisticated ontological techniques for representing information about the mobile devices, their functionality, users, environments, etc. [3, 4]

In general, this paper discusses the possible application of Semantic Web [5] technologies to mobile and ubiquitous computing. This application is motivated by the need for better *automation of user's tasks* (as a means of making the user's life easier); we will adopt the view that automation is best enabled by improving the *interoperability* between systems, applications, and information. In particular, we hope to demonstrate the need for *policy-awareness* as the ultimate enabler of the next generation personal information systems, and will offer the observation the not only are Semantic Web technologies are particularly well suited to rich, flexible representation of various policies, but that without the policy-awareness the application of Semantic Web technologies to mobile and ubiquitous computing may be hampered.

2 Ubiquitous Computing as an "Interoperability Nightmare"

Although much of ubiquitous computing research has focused on various aspects of user interaction [6], we can argue that a key characteristic of the paradigm – and one that makes ubiquitous computing distinctly different from the current personal computing paradigm(s) – is the *proliferation of devices that need to be connected*. Today's user connects his PC to a handful of other devices (printers, network gateways, etc.) and these connections are fairly static. Distinctly different from today's situation, ubiquitous computing scenarios are anticipated to involve dozens, if not hundreds of devices (sensors, external input and output devices, remotely controlled appliances, etc.). We therefore observe that ubiquitous computing, in its full-blown manifestations, represents the ultimate "interoperability nightmare". Furthermore, with the advent of mobility and associated proximity networking, the set of connected devices will constantly change as the usage context changes and as devices come into and leave the range of the user's ubiquitous computing device(s). Because of the dynamic nature of the new paradigm, technologies that improve interoperability will be crucial.

Given the need to dynamically connect to a large ever-changing set of devices and services, devices in a ubiquitous computing environment should be capable of sophisticated discovery and *device coalition formation*: the goal should be to accomplish discovery and configuration of new devices without "a human in the loop." In other words, the objective is the discovery and utilization of services offered by other automated systems without human guidance or intervention, thus enabling the automatic formation of device coalitions through this mechanism. Ultimately, one of the most important components of the realization of the Semantic Web (and also that of mobile and ubiquitous computing) is "serendipitous interoperability", the ability of software systems to discover and utilize services they have not seen before, and that were not considered when the systems were designed [7]. To realize this, qualitatively stronger means of representing service semantics are required, enabling fully automated discovery and invocation, and complete removal of unnecessary interaction with human users.

Semantic Web techniques have proven useful in providing richer descriptions for Web resources, and consequently they can also applied to describing *functionality*: Semantic Web *Services*[1] appear to be an appropriate paradigm to be applied in representing the functionality of ubiquitous computing devices. Virtual and physical functions can be abstracted as services, providing a uniform view of all different kinds of functionality [3, 9]. Realization of this is contingent on the continuing emergence of suitable ontologies for modeling ubiquitous computing environments [10].

Avoiding *a priori* commitments about how devices are to interact with one another will improve interoperability and will thus make dynamic, unchoreographed ubiquitous computing scenarios more realistic. With reference to the aforementioned *serendipitous interoperability*, the true fulfillment of the vision for ubiquitous computing has a promise of serendipity in it that cannot be realized without discovery mechanisms that are *qualitatively stronger* than the current practice.

Semantic Web technologies represent a potential for this qualitatively stronger interoperability as compared to the traditional standards-based approach (where one essentially has to anticipate all future scenarios). With the Semantic Web approach it is possible for agents to "learn" new vocabularies and – via reasoning – make meaningful use of them. Furthermore, in addition to current notions of device and application interoperability, the Semantic Web represents interoperability at *the level of the information itself.*

3 Role of Context-Awareness in Ubiquitous Computing

As a primary means of addressing many of the issues in mobile and ubiquitous computing, *context-awareness* [11] offers a way to adapt a device's behavior to each usage situation, location, environment, user goal, etc. More generally, determining the user's *context* serves as a convenient means of limiting the search space along multiple dimensions of the system's operation:

Information retrieval: *Which information is interesting, relevant and applicable?* Given that her attention is focused elsewhere, the mobile user may merely "have questions" and will need very specific (and thus potentially terse) answers; using context information to limit the scope will make it easier to provide high-quality answers. Generally, having access to information in "raw" form (i.e., without any forethought as to how the information is to be presented or formatted), combined with the representation and reasoning capabilities enabled by Semantic Web technologies, will be helpful, because then *what* information gets presented (and *how* it gets formatted) can be a context-based decision.

User Interfaces: *Which user interface choices and configurations are appropriate?* Mobile devices suffer from various limitations such as small display size, awkward keyboard, etc. Taking *context* very broadly – covering just about everything that is known about the user, her task, the current environment, and the *device* she is using to access information – allows us to customize

[1] *Semantic Web Services* are generally defined as the augmentation of Web Service descriptions through semantic annotations, to facilitate a higher degree of automation of service discovery, composition, invocation and monitoring in an open, unregulated and often chaotic environment [8].

user interfaces; it may, in fact, be possible to go well beyond contemporary *content repurposing* approaches (such as [12]). We have been able to demonstrate that context information, combined with rich semantic models of the user, her environment and tasks, can be helpful in providing good default values and more generally tailoring the user interfaces to be ergonomically efficient for a particular user, task or purpose [13].

Service Discovery: *Which services to consider as relevant and/or applicable?* Service discovery in completely open-ended situations may suffer from the difficulty of having to pick services with little guidance and/or no limitations wrt. the search space; context here serves as a means of providing tighter boundaries for queries. Furthermore, characteristic to mobile and ubiquitous computing environments is that services are often tied to a particular location (or other notion of context); being able to choose or substitute appropriate functionality will enable flexible and robust operation [14].

Security & Privacy: *How to appropriately restrict access to information and services?* Access is sometimes dependent on the user's context. For example, a context may include *associative* aspects of the user's situation (e.g., a particular context may depend on who the other people are in the user's immediate vicinity), which, in turn, may have ramifications to privacy-related services and functionality.

Automation & Autonomy: *How to decide which operations to automate, and how?* Autonomous operation (which can be considered the extreme form of automation) is typically implemented using automated planning technologies (e.g., in agent-based systems); context can, again, serve as a means of limiting the search space when performing planning.

The process of determining context benefits from access to as many sources of information as possible, related to the user, her task, the environment, etc. [15]; we will subsequently argue that without a proper solution for security and privacy, efforts to implement context-awareness may be hampered.

4 Benefits of Policy-Awareness

In a general sense, a *policy* is a prescriptive means of limiting a system's behavior in some future situations. Typically policies are expressed using various *deontic modalities* [16] such as rights and obligations. With regard to information *access*, the use of an open, *policy-aware* infrastructure has been proposed for the World Wide Web [17]; we argue that this is a potentially applicable approach in mobile and ubiquitous computing as well. Semantic Web techniques, again, are well suited to describing, reasoning about, and exchanging *policies* [18, 19].

Policy-awareness may benefit mobile and ubiquitous computing in several ways:

Access: By providing access to maximal amount of information, policy-awareness enables higher-quality context derivation than would otherwise be possible. With the proper application of security and privacy policies it may be possible to base context derivation on data whose other uses would be prohibited.

Autonomy: The view of a policy as a prescriptive set of instructions about how a system should behave in some particular situation supports the use of policies as part of the realization to increase personal computing systems' overall capability of autonomous behavior. Mobile and ubiquitous computing require intelligent response to changing conditions in a system's operating environment (e.g., changes in communication bandwidth); the use of policies may enable correct yet opportunistic exploitation of these changes without constant user intervention.

Contracts: Since devices in mobile and ubiquitous computing environments are always dependent on external services and functionality, mechanisms for *contracting* between systems will be necessary. As a general notion, contracting between agents has been and remains a standard technique in distributed problem solving [20]; more recently, the idea has been extended to allow contract representation using standard Semantic Web formalisms and to make it possible to reason about contracts [21, 22].

5 Conclusions

Semantic Web technologies offer several benefits to new computing paradigms such as mobile and ubiquitous computing. Not only do Semantic Web technologies lend themselves well to representation, reasoning and exchange of many different kinds of information (about functionality, contexts, policies, contracts, user models, etc.), but generally these technologies are a qualitatively stronger approach to *interoperability* than contemporary standards-based approaches. With sophisticated ontological representations we can realize effortless access to heterogeneous information sources and services, independent of the access device or the user's context; furthermore, we can finally untap the serendipitous potential that exists in unchoreographed encounters of automated and autonomous systems in cyberspace.

We do believe, however, that a pervasive framework for expressing and *enforcing* policies described using rich knowledge representation formalisms, is necessary for the full realization of this vision. For mobile and ubiquitous computing, the application of policy-awareness enables several key characteristics such as better access to information, higher degree of autonomy, and the ability to use and enforce contracts when employing external services and functionality.

References

1. Weiser, M.: The computer for the twenty-first century. Scientific American **265** (1991) 94–104
2. Nokia: Nokia develops a new browser for Series 60 by using open source software. Nokia press release, 2005-06-13 (2005)
3. Lassila, O., Adler, M.: Semantic Gadgets: Ubiquitous Computing Meets the Semantic Web. In Fensel, D., Hendler, J., Wahlster, W., Lieberman, H., eds.: Spinning the Semantic Web. MIT Press (2003) 363–376
4. McGrath, R.E., Ranganathan, A., Campbell, R.H., Mickunas, M.D.: Use of Ontologies in Pervasive Computing Environments. Technical report, University of Illinois at Urbana-Champaign (2003)
5. Berners-Lee, T., Hendler, J., Lassila, O.: The Semantic Web. Scientific American **284** (2001) 34–43
6. Abowd, G.D., Mynatt, E.D.: Charting past, present, and future research in ubiquitous computing. ACM Transactions on Computer-Human Interaction **7** (2000) 29–58
7. Lassila, O.: Serendipitous Interoperability. In Eero Hyvönen, ed.: The Semantic Web Kick-off in Finland – Vision, Technologies, Research, and Applications. HIIT Publications 2002-001. University of Helsinki (2002)

8. Payne, T., Lassila, O.: Semantic Web Services (guest editors' introduction). IEEE Intelligent Systems **19** (2004) 14–15
9. Masuoka, R., Parsia, B., Labrou, Y.: Task Computing – the Semantic Web meets Pervasive Computing. In Fensel, D., Sycara, K., Mylopoulos, J., eds.: The SemanticWeb - ISWC 2003. Volume 2870 of Lecture Notes in Computer Science., Springer-Verlag (2003)
10. Chen, H., Perich, F., Finin, T., Joshi, A.: SOUPA: Standard Ontology for Ubiquitous and Pervasive Applications. In: International Conference on Mobile and Ubiquitous Systems: Networking and Services (MobiQuitous), Boston, MA (2004)
11. Dey, A., Abowd, G., Salber, D.: A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications. Human-Computer Interaction **16** (2001) 97–166
12. Nokia: Nokia acquires Eizel to enhance mobile enterprise portfolio. Nokia press release, 2003-04-22 (2003)
13. Khushraj, D., Lassila, O.: Ontological Approach to Generating Personalized User Interfaces for Web Services. 4th International Semantic Web Conference, to appear (2005)
14. Lassila, O., Dixit, S.: Interleaving Discovery and Composition for Simple Workflows. In: Semantic Web Services, AAAI Spring Symposium Series, AAAI (2004)
15. Lassila, O., Khushraj, D.: Contextualizing Applications via Semantic Middleware. In: The Second Annual International Conference on Mobile and Ubiquitous Systems: Networking and Services (MobiQuitous), IEEE Computer Society (2005)
16. Mally, E.: Grundgesetze des Sollens: Elemente der Logik des Willens. Graz: Leuschner und Lubensky, Universitäts-Buchhandlung (1926)
17. Weitzner, D.J., Hendler, J., Berners-Lee, T., Connolly, D.: Creating a Policy-Aware Web: Dicretionary, Rule-based Access for the World Wide Web. In Ferrari, E., Thuraisingham, B., eds.: Web and Information Security. Idea Group, Inc., Hershey, PA (2005)
18. Kagal, L., Parker, J., Chen, H., Joshi, A., Finin, T.: Security and Privacy Aspects. In: Security, Privacy and Trust in Mobile Computing Environments. CRC Press (2003)
19. Kagal, L.: A Policy-Based Approach to Governing Autonomous Behavior in Distributed Environments. PhD thesis, University of Maryland Baltimore County, Baltimore MD (2004)
20. Davis, R., Smith, R.: Negotiation as a metaphor for distributed problem solving. Artificial Intelligence **20** (1983) 63–109
21. Grosof, B.N., Poon, T.C.: SweetDeal: representing agent contracts with exceptions using XML rules, ontologies, and process descriptions. In: WWW '03: Proceedings of the 12th international conference on World Wide Web, New York, NY, USA, ACM Press (2003) 340–349
22. Uszok, A., Bradshaw, J.M., Jeffers, R., Johnson, M., Tate, A., Dalton, J., Aitken, S.: Policy and Contract Management for Semantic Web Services. In: Semantic Web Services, AAAI Spring Symposium Series, AAAI (2004)

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