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Towards nature-inspired pervasive service ecosystems: Concepts and simulation experiences ☆

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ABSTRACT

Pervasive and mobile computing devices increasingly populate our environments. In this context, innovative frameworks have to be identified for the deployment and execution of pervasive service systems made up of a massive number of components, and able to exhibit properties of *self-organization* and *self-adaptability*, and of *long-lasting evolvability*. This paper discusses how such frameworks could get inspiration from natural systems, by modeling and deploying services as autonomous agents, spatially situated in an ecosystem of other services, data sources, and pervasive devices, all of which acting, interacting, and evolving according to a limited set of "laws of nature". A conceptual architecture is introduced to frame the key concepts of nature-inspired approaches and to survey the key natural metaphors that can be adopted to realize the concept of pervasive service ecosystems. Following, the key characteristics of our original ecological approach are detailed, also with the help of representative case studies, and an extensive set of simulation experiments are reported to show the potential effectiveness of the approach.

1. Introduction

Pervasive and mobile computing devices increasingly populate our environments (Estrin et al., 2002; Want, 2006). These, together with the increasing amount of Web tools that make it possible to produce and access spatially situated information about the physical world (Castelli et al., 2007), will define a global-scale and very dense, decentralized infrastructure for general-purpose usage. At the user level, the infrastructure can be used to access innovative services for better perceiving/interacting with the physical world and for acting on it. It is also expected that users themselves will be able to personalize the infrastructure by deploying customized services over it. In addition, the infrastructure will be used as a way to enrich traditional classes of services with the capability of dynamically and autonomously adapting their behavior to the context in which they are exploited.

The effective development and execution of services in the above infrastructure calls for a deep re-thinking of current service models and of service frameworks, in order to: (i) Naturally match the spatial nature of the environment and of the services within, and rely on mostly localized spatial interaction to provide support for massive scalability (Zambonelli and Mamei, 2005; Beal and Bachrach, 2006; Locatelli et al., 2010). (ii) Inherently exhibit properties of self-organization, self-adaptation and self-management that are required in highly decentralized and highly dynamic scenarios (Dobson et al., 2006; Roy et al., 2008; Brazier et al., 2009). (iii) Flexibly tolerate evolutions of structure and usage over time (Zambonelli and Viroli, 2008). This is necessary to account for increasingly diverse and demanding needs of users as well as for technological evolution, without forcing significant re-engineering to incorporate innovations and changes.

To reach this goal, we should no longer conceive services and their interactions as in usual service-oriented architectures (Huhns and Singh, 2005), where services are simply functional entities orchestrated according to mostly static patterns and with the help of specific middleware services. No one can rely on ad-hoc one-of architectural solutions to achieve specific self-* features in existing systems, resulting in an increase of complexity (Kephart and Chess, 2003). Rather, the most promising direction is that of taking inspiration from natural systems (Mamei et al., 2006; Babaoglu et al., 2006), where spatial concepts, self-organization, self-management, and long-lasting evolvability are inherently there because of the basic "rules of the game".

We are aware that nature-inspired solutions have already been extensively exploited in the area of distributed computing for the implementation of specific middleware solutions or of specific

☆ *Previous publications*: This paper extends the paper published in the Proceedings of the Second Workshop on Bio-Inspired and Self-* Algorithms for Distributed Systems (BADS 2010). The extensions include: a critical survey of related approaches in Section 3; more details on the proposed original approach; an extended set of simulation experiments to more completely assess the proposed approach. Overall, the new paper includes more than 50% new material over the workshop version.

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