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A biochemical approach to adaptive service ecosystems

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ABSTRACT

Emerging network scenarios call for innovative open service frameworks to ensure capability of self-adaptability and long-lasting evolvability. In this paper, we assess the need for such innovative service frameworks, and discuss how their engineering should get inspiration from natural ecosystems, i.e., by modelling services as autonomous individuals in an ecosystem of other services and data sources. We introduce a reference conceptual architecture with the goal of clarifying the concepts expressed and framing the several possible nature-inspired metaphors that could be adopted to realise the idea. On this basis, we go into details about one of such possible approaches, in which the rules governing the ecosystem are inspired by biochemical mechanisms. A case study is also introduced to exemplify the potentials of the presented biochemical approach and to experiment with some representative biochemistry-inspired patterns of adaptive service organisation and evolution.

1. Introduction

The shape of the ICT landscape and of the digital services within (whether telecommunication services or Web services) is dramatically changing. Pervasive and mobile computing devices increasingly populate our everyday environments [14] and store notable amounts of data related to our personal, social and professional activities [27]. These, together with the increasing amount of Web tools that makes it possible to produce and access contextual information about the physical world [12], will eventually define a comprehensive, integrated, and very dense decentralised shared infrastructure for general-purpose service provisioning.

At the user level, the infrastructure can be used to access innovative services for better perceiving the physical world and for acting on it. It is also expected that users themselves will be able to personalise the infrastructure by deploying customised services (in other words, the overall pervasive infrastructure will be as open as the Web currently is). In addition, the infrastructure will be used as a way to enrich more traditional classes of digital services with the capability of dynamically and autonomously adapting their behaviour to the context in which they are invoked and exploited.

In this complex emerging scenario, which is also contributing to blurring any distinction between Telecom and Web services, traditional service architectures (e.g., SOA and alike [21]) fall short in meeting a number of novel challenging requirements related to the need for the infrastructure to exhibit high degrees of adaptivity and evolvability. For this reason, a single open software platform based on innovative service models has to be provided to host and adaptively orchestrate in an integrated and self-managing/self-organising way the execution of general-purpose pervasive Telecom/Web services, and the organisation of large masses of contextual data. Such infrastructure should account for the increasingly diverse and demand-

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ing needs of users, which will also seamlessly act as consumers and producers of data and services [37], and should flexibly tolerate evolutions over time without requiring significant re-engineering to incorporate innovations and changing needs.

Against this background, this paper motivates the need for radically innovative and long-lasting adaptive service frameworks, and argues that a promising approach towards their realisation is to take inspiration from nature, by uniformly considering devices, data, and services as individuals (or agents [10]) of an ecosystem, interacting according to a limited set of "eco-laws". A conceptual general-purpose reference architecture for nature-inspired service ecosystems is proposed in Section 2, where different nature-inspired metaphors that could be adopted to realise the idea are also framed and analysed.

Our original proposal based on a biochemistry-inspired approach is presented in Section 3. The approach is based on the idea of seeing the environment of the ecology as a sort of tissue-like topology of biological compartments. Each individual is a chemical substance that is localised in one or more compartments, and whose concentration models the activity level of individuals. An individual can interact with others according to chemical-like reactions, and can diffuse to neighbouring locations by crossing its original boundaries.

A representative case study to exemplify the characteristics of the proposed biochemical approach is presented in Section 4. Experiments by simulation are also reported to show the behaviour enacted by some representative eco-laws for the case study, along with a discussion of how such eco-laws can be generalised towards a general-purpose library.

2. Adaptive service ecosystems: issues and approaches

Modern service-oriented architectures [21] conceive services as localised containers of data and functionalities, whose activities are to be orchestrated and synchronised according to specific patterns, with the support of (typically heavy-weight) middleware services such as discovery services, routing services, data and context services. This makes it hard to easily support the degree of adaptivity and evolution in service functionalities that is required by emerging network scenarios.

To overcome these limitations, a great deal of research activity has been recently devoted to produce innovative solutions to match the emerging characteristics of future networked scenarios [13,25]. Unfortunately, most of the solutions so far are proposed in terms of "add-ons", i.e., one-of solutions to be integrated in existing service frameworks. The result is often an increased complexity of current frameworks and the emergence of contrasting trade-off between different solutions. For instance, in the autonomic computing vision [25], individual service components are coupled with autonomic managers devoted to monitor what's happening, plan actions, and re-configure/restore the system as needed. However, this approach fails in deeply integrating adaptivity and context-awareness into the overall architecture, and limits itself at defining a separated and heavy-weight management plan. On the other hand, self-organising peer-to-peer overlay networks have been proposed as a mean to exchange information in distributed and dynamic scenarios and orchestrate the activities of service components [2,39]. However, these proposals serve specific classes of application problems, cannot tolerate adaptations with regard to changes in their usage and changes at the device/communication level, and prevent information about the current execution context of services from freely flowing in the network.

In our opinion, there is need for tackling all the above issues by reformulating the problem at its foundation. That is, by trying to understand if it is possible to conceive a radically new way of modelling and structuring integrated network services and their execution environments, such that the apparently diverse issues of enabling flexible means of adapting to context and situations, openness to users' contributions, flexible and robust evolution, can all be uniformly addressed once and for all.

2.1. Towards nature-inspired service ecosystems

A sound inspiration to tackle the issues of modern service systems can come from natural systems [42], where adaptability, openness, and long-lasting evolvability are there because of the basic "rules of the game" that drive the interactions and dynamics of the individual components and of the overall system. Nature-inspired solutions have already been exploited in distributed computing [3], and many initiatives recognise that the complexity of modern ICT systems is comparable to that of natural systems and requires innovative solutions [42]. Yet, beside the proposals for specific nature-inspired solutions, the idea that natural metaphors can become the foundation on which to fully re-think the architecture of these systems is far from being metabolised.

No matter whether one thinks at natural systems using specific viewpoints, e.g., in terms of physical systems, chemical systems, biological systems, or social systems. In all of the perspectives one can always recognise the following characteristics: above a common environmental substrate (defining the basic "laws of nature" and the ground on which individuals can live), individuals of different kinds (or species) interact, compete, and combine with each other (in respect of the basic laws of nature), so as to serve their own individual needs as well as the sustainability and the evolvability of the overall system. This is the sort of endeavour that we think one should assume towards the realisation of long-lasting (ideally eternal) adaptive service ecosystems: conceiving services and data components as individuals in an open ecosystem in which they interact according to a limited set of "eco-laws" to serve their own individual purposes in respect of such laws, and where adaptivity and evolvability are inherent, endogenous properties of the ecosystem rather than peculiar characteristics of its individuals [23].

Some recent research works in related areas have been sources of inspiration for the general framework we present in this paper. In the area of autonomic communications [13], many proposals for nature-inspired models exist, suggesting a foun-