On emergent phenomena in everyday activities taking place in AmI spaces

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Abstract

This work aims at a) identifying the forthcoming changes in our everyday life due to the ever-increasing level of complexity that inculcates our interactions with the devices surrounding us, b) introducing a bio-inspired world model (framework) that deals with different perspectives of the interrelations developed in symbiotic ecologies where people and artefacts coexist, and c) proposing a high level architectural scheme of an AmI space reflecting the basic ingredients of the future indoors/outdoors applications based on Swarm Intelligence and Complexity Science.

Keywords: Complex Systems, Emergent behaviour, Ambient Intelligence, Swarm Intelligence, Ubiquitous Computing applications

Introduction

The vision of Ambient Intelligence (AmI) implies a seamless environment of computing, advanced networking technology and specific interface ([1], [2]). In one of its possible implementations, technology becomes embedded in everyday objects such as furniture, clothes, vehicles, roads and smart materials, and people are provided with the tools and the processes that are necessary in order to achieve relaxing interactions with this environment. The AmI environment can be considered to host several Ubiquitous Computing (UbiComp) applications, which make use of the infrastructure provided by the environment and the services provided by the AmI objects therein. An important characteristic of AmI environments is the merging of physical and digital space (i.e. tangible objects and physical environments are acquiring a digital representation); hence, the AmI objects differ from traditional objects in that they can communicate with other AmI objects and can interact with the environment. Of special interest is the information that AmI objects process, which can be descriptions of the context of use, data to be used for a task, guidelines on how to perform a task, messages to be sent or that have been received from other objects. The result of information processing is a set of services, that is, a set of abilities that appear in the digital space. This work builds upon the envisaged structure of AmI environment as one populated by thousands of communicating tangible objects and virtual entities. At a minimum, AmI environment will contain network infrastructure and it will be available making anytime, anyplace (within boundaries of acceptability) interaction among and with these objects feasible.

Research issues and requirements

The heterogeneity of AmI objects makes necessary the development of middleware systems on top of which UbiComp applications can function transparently with respect to the infrastructure [3]. The dynamic nature of UbiComp applications and the mobility of AmI objects, force the middleware to use services and capabilities with changing availability [4]. To ease the development of such applications it is necessary to decouple application composition from context acquisition and representation, and at the same time provide universal models and mechanisms to manage context [5].

Key research challenges have to focus in services availability including both services aimed at end users as well as machine to machine services, and to deal with dynamic composability and adaptability, context awareness, autonomy and semantic interoperability. Essentially, new research issues arise concerning i) the system complexity emerging by the thousands local interactions between people and artefacts, ii) the need for flexible and dynamic system architecture capable to evolve and adapt to new situations and configurations, iii) the context dependence of the exchanged information, and iv) the human involvement and especially new, more natural, human-machine interaction schemes. These features make necessary to the development of a framework that will help us deal with the complexity of using UbiComp applications within AmI environment. The framework must be capable to reflect the available services as well as the potential use of the participating objects. Although the available services may somehow be exhibited, the potential use of the objects emerges mainly from the interactions of the humans with the devices and these interactions are not only time-dependent but also space- or context-dependent.

The next sections set the scene of a near future everyday living/working environment and describe an engineering approach inspired by biological structures capable to deal with phenomena arising in such an environment.

Proposed conceptual framework

A living/working AmI space comprising of many heterogeneous objects with different capabilities and provided services could be considered that is populated by a *heterogeneous swarm*. The swarm will comprise different typologies of societies, and so it will be heterogeneous also from the provided services point of view. Such differences will contribute to the overall capabilities of the system. As a general principle, the services should be as simple as possible. Ideally, the composition should emerge based on previous interactions and on the context (time and place) they took place.

Traditional Artificial Intelligence (AI) focused on addressing intelligence as an individual phenomenon considering (intelligent) agents with cognitive states which maintain a (partial) model of the world they inhabit in and a (partial) model of the others. A radically different approach is based on the belief that intelligent behaviour is inextricably tied to its cultural context and cannot be understood in isolation. Indeed, many natural systems can be described in terms of many individually "simple" components, interacting in "simple" ways and influencing their neighbours, and yet, are able to exhibit "complex" overall system level behaviour; those systems that exhibit this "emergent" globally complex behaviour from simple components are referred to as "complex systems" [6]. In contrast to traditional AI, Swarm Intelligence (SI) is defined as the emergent collective intelligence of groups of simple (unsophisticated) agents and, as an engineering approach, offers an alternative way of designing intelligent systems, in which autonomy, emergence, and distributed functioning replace control, pre-programming, and centralization ([7], [8]).

Typically, when focusing on situated social systems in dynamic and non-deterministic environments, it is very hard (if not aimless) to embody into each organism complete models of the environment and of the others. Alternatively, no explicitly represented world models could be considered ([9], [10]). All the necessary information is out there changing dynamically; thus the world is the model itself. All we need is the means to capture, qualify and exploit the information that surrounds us. In order to deal with the collective behaviour of large ecologies in situated domains, a recent approach is the analysis and synthesis of small pieces of primitive behaviours that result from individual interactions.

Inspired by the biological social systems (ecologies), the analysis of artificial swarm systems could range in different levels depending on the desired granularity, e.g., as single behaviour building blocks [11], as neural networks that can learn and evolve [12], as sensor networks owning limited power, computational capacities and memory [13], etc. Independently of the analysis level, the computational capabilities (and the intelligence) of the ecology are distributed over the central “nervous” system, the peripheral system, the materials of the ecology’s body and the physical phenomena created by the interaction of the ecology with its environment. Putting such entities into a UbiComp environment could lead to extelligent ecologies, where knowledge and tools are diffused in the environment [14], underlying thus the corporal literacy of the ecology, meaning the awareness of the extelligence and the working knowledge of all senses. This will pave the way for the generation of theory and technology of synthetic phenomenology (of the resulting ecology) meaning the understanding of the own self and its relation with the surrounding world. Drawn from the above, the proposed high level architectural scheme that consistently reflects bio-inspired self-aware emergent symbiotic AmI space ecologies consists of the following fundamental ingredients (Figure 1): i) *basic building blocks* including sensors, hardware resources, software modules, artefacts, etc., ii) *ecologies*, that are groups of building blocks, their interrelationships and the associated environment, iii) *ambient knowledge*, that provides a means to emergent consensus as a substitute for social and cultural memory, and iv) *people* divided into the classes of developers (building block developers, hardware designers, artefact manufacturers, application developers, etc.) and end-users.

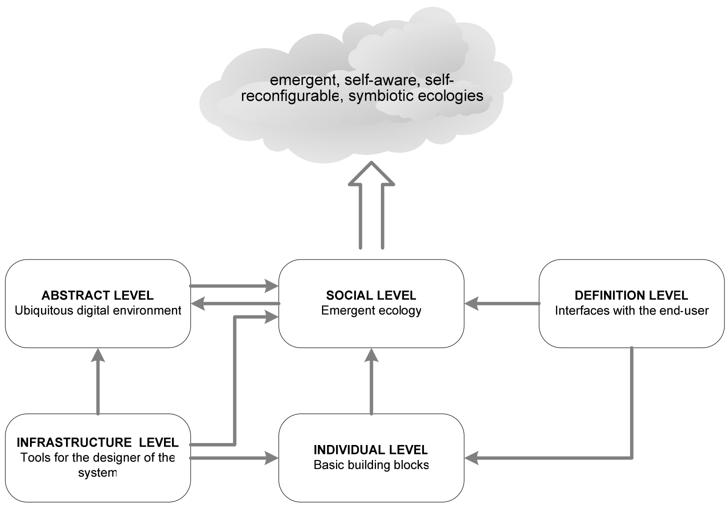

Figure 1. *High level architecture of the system. Individual and Social levels correspond to the basic building blocks and ecologies, respectively. Abstract level encloses the social memory of the ecologies; such knowledge must be transferred to the ecologies implicitly e.g. as stimuli of the environment, since individuals and consequently the emergent ecologies do not contain any knowledge representation scheme neither reasoning mechanism. Infrastructure level provides system designers with the appropriate tools to develop a system. Definition level is the user interface with the final user.*

Engineering emergent phenomena

An especially complex task is to model and build autonomous interactive entities that could form extelligent ecologies exhibiting corporal literacy and leading to a synthetic phenomenology approach. The task is additionally complicated by considering that the resulting ecologies will operate into a ubiquitous environment and will be driven by autonomy, local perceptions and interactions, emergence, and distributed functioning. An important aspect on this focus is that although the entities will not have explicitly represented models of the world or of the others the emergent ecologies will unfold coherent collective behaviour based only on the entities’ own agenda of actions and their intrinsic inclination to preserve their own goals.

Realizing the potential benefits of the UbiComp applications populated by simple autonomous entities will require improvements in currently available technology platforms and a translational research paradigm from basic-research findings. Hence the driving force behind the whole idea focuses on the adaptation of concepts from complex biological systems and novel fabrication technology platforms to build truly innovative swarm artificial systems for emerging real-life applications. Technological challenges posed by this approach and the investigative methodology to overcome them are described below.

1. *Basic building blocks development*

Several levels of abstraction are possible for the formulation of the basic building block. Immediately, the engineer strives with the questions on i) which should be the basic building block, ii) what structural and functional properties it should encompass, iii) how it could interact with the others, and iv) how it could be realised. From a technology development point of view, an essential plan is needed which initially centres about the basic building block and considers as such every self-sustained digital (h/w or s/w) artefact with certain functionality that can operate without the contribution of others.

2. *Engineering emergent behaviour*

In dynamic environments, an individual must be reactive, that is, it must be responsive to events that occur in its environment, where these events affect either the individual's goals or the assumptions, which underpin the procedures that the individual is executing in order to achieve its goals [15]. In order to apply the well-established primitive behaviours approach in swarm societies that can learn and evolve component-oriented principles and practices could be employed. Synthetic behaviour control mechanisms could be developed based on bio-inspired approaches like spiking neural networks. These behaviour control mechanisms responsible for the arbitration and/or the composition of the primitive behaviours could also be subject of learning and evolution. The individuals may exhibit varying behaviour – capable of perceiving/exploring their environment, selectively focusing attention, initiating and completing several tasks. The learning and evolution could be studied and investigated at both the individual and social levels. In this case, the focal point must be the components of behaviour control mechanisms. The outcome could contribute to a novel dynamic and adaptive architecture of swarm systems that exploits the global effects through local rules/behaviour.

3. *Engineering collective behaviour*

Developing a robust swarm system, capable of exhibiting emergent intelligent collective behaviour is a non-trivial task. The nature of the social/collective behaviour sought and the environment that allows efficient development of ecologies requires research. In building a swarm system communication plays a pivotal role and this explains the profuse number of publications in this area. A flexible and light-weight approach is the indirect (stigmergic) communication. The essence of stigmergy is that the individual modifies a local property of the environment, which subject to environmental physics, should persist long enough to affect the individual's behaviour later in time. It is the temporal aspect of this phenomenon, which is crucial for emergent collective behaviour (collaborative exploration, building and maintenance of complex insect nest architectures etc) in societies of ants, agents and robotics. Thus, the individuals could be provided with the proper periphery (actuators/sensors) enabling them to emit/perceive electromagnetic signals emulating thus the biological "quorum sense" signals. Such a quorum sense communication may be based on an application-specific vocabulary that will be encoded in the signal. The specifics of the temporal modulation aspect of this "quorum sense signal" will come from theoretical biology and existing simulation studies.

Summary

As everyday objects are being enhanced with sensing, processing and communication abilities, the near future of our everyday living/working is indicated by a high degree of complexity. The emergent complexity concerns the machine-machine and human-machine interactions as well as the provided services aimed at end users and at other machines. Into this rapidly changing AmI environments new requirements and research issues arise, and the need for a conceptual and analysis framework is apparent. This work attempts to introduce a bio-inspired word model that draws features from natural systems and applies them into symbiotic ecologies inhabited by both humans and artefacts. Furthermore, it introduces a high-level architecture of AmI spaces that encloses the fundamental elements of bio-inspired self-aware emergent symbiotic ecologies.

References

[1] Disappearing Computer initiative: http://www.disappearing-computer.net/

[2] ISTAG website: http://www.cordis.lu/ist/istag.htm

[3] Kameas A, Bellis S, Mavrommati I, Delanay K, Colley M, Pounds-Cornish A: An architecture that treats everyday objects as communicating tangible components, in *Proceedings of the First IEEE International Conference on Pervasive Computing and Communications,* (*PERCOM2003*), Texas-Fort Worth, 2003.

[4] Kameas A, Mavrommati I, Markopoulos P: Computing in tangible: using artifacts as components of Ambient Intelligent Environments. In *"Ambient Intelligence: The evolution of Technology, Communication and Cognition",* (G. Riva, F. Vatalaro, F. Davide and M. Alcaniz, eds), IOS press, pp 121-142, 2004.

[5] Christopoulou E, Goumopoulos C, Zaharakis I, Kameas A: An Ontology-based Conceptual Model for Composing Context-Aware Applications, *Workshop on Advanced Context Modelling, Reasoning and Management, Sixth International Conference on Ubiquitous Computing* (*UbiComp04*), Nottingham, England, 7-10 September 2004.

[6] Bullock S, Cliff D: *Complexity and emergent behaviour in ICT systems*, HP Labs report HPL-2004-187, 2004.

[7] Bonabeau E, Dorigo M, Theraulaz G: *Swarm Intelligence: From Natural to Artificial Systems*. Oxford University Press, 1999.

[8] Kennedy J, Eberhart R: *Swarm Intelligence*. Morgan Kaufmann Publishers, 2001.

[9] Brooks R A: Intelligence without Reason. In *Proceedings of 12th Int. Joint Conf. on Artificial Intelligence*, Sydney, Australia, August 1991, pp. 569—595, (1991).

[10] Brooks R A: Intelligence without representation. *Artificial Intelligence*, 47:139–159, 1991.

[11] Lund H H, Marti P: Physical and Conceptual Constructions in Advanced Learning Environments. *Interaction Studies Journal,* 5(2): 271-301, 2004.

[12] Lund H H: Neural Building Blocks. In *1st International IEEE EMB Conference on Neural Engineering*, Capri, Italy, March 20-22 2003. IEEE Press.

[13] Akyildiz I F, Su W, Sankarasubramaniam Y, Cayirci E: A survey on sensor networks. *IEEE Communications Magazine*, 40(8):102–114, 2002.

[14] Stewart I, Cohen J: *Figments of Reality: the origins of the curious mind.* Cambridge University Press, 1997.

[15] Wooldridge M: Intelligent Agents, in G. Weiss (ed.) *Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence*, MIT Press, pp. 27-77, 1999.