A Conceptual Framework For End-User Development in Ambient Intelligence

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Abstract. This paper proposes a conceptual framework for the design and continuous evolution of ambient intelligence environments. The framework is based on the metaphor of interconnection between humans and devices belonging to the intelligent environment. All actors are called on to perceive and act on the environment itself, giving rise to novel and unanticipated behaviors. To this aim, the proposed framework is structured along three layers - physical, inference and user - sharing an information space of events, conditions and actions. In particular, a EUD approach is advocated for the user layer to support ambient configuration and management and foster a smooth and progressive co-evolution of users and technologies.

Keywords: end-user development, interconnection, inference rules, socio-technical system

1 Introduction

The Ambient Intelligence (AmI) field is aimed at realizing scenarios where people will move and live in "intelligent" electronic environments, that is, in active places that have claims of being sensitive and responsive to their needs [1]. The choice of the adjective "ambient" is not fortuitous: it refers clearly to the fact that these electronic environments are not just "out there", as simply given to the human experience. Rather, they are something that surrounds and encircles users (i.e., inhabitants) and is formed both by their perceptions (in that the system modulates and filters away information according to the context in order to meet users' needs) and by their activities (in that users' actions are an important part of the context the intelligent environment is sensitive to). Therefore, an AmI includes and cannot exist without the intelligence of the users, i.e. without the "human" sensors and actuators making the system "sentient" [2].

This view brings into conceiving an AmI environment as a *socio-technical system*, which encompasses not only a variety of hardware and software components, such as sensors, robots, actuators, apps and Web applications, but also people that are bound together by social ties and personal relations of acquaintance and that are linked each

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other through their personal devices and the hardware/software components distributed in the environment. This results in a socio-technical network of humans and non-humans, where both kinds of actors are able to perceive and act in the environment. An important feature of such a network is the ability to cope with the continuous changes in the environment and the network itself, by reconfiguring human-human, machine-machine and human-machine relationships [2]. The ways in which each user configures the ambient surrounding her/him have deep consequences every time this environment is shared by multiple users, as also their preferences, needs and expectations come to be shared and get intertwined in the same environment, possibly leading to conflicts or incoherent behaviors. Consequently, we advocate the adoption of an End-User Development (EUD) approach [3] in the design and continuous evolution of this class of systems. EUD techniques would support end users in shaping the environment where they live by means of tools and interaction metaphors that are suitable to people without specific competencies in software technologies and programming languages.

EUD in ambient intelligence has not received, till now, the necessary attention. The survey reported in [4] underlines that many studies carried out in AmI focus on one hand on hardware devices (sensors and actuators) and, on the other hand, on artificial intelligence techniques that may help to add sophisticated capabilities to the processing of information provided by hardware devices. Among end-user programming tools, there are some interesting proposals that are mainly focused on single-user interaction: one single user is called on to define the behavior of his/her smart things [5]. Interactions among things and between humans and things within and intelligent environment are not usually considered, thus remaining far from satisfying the challenges and design principles identified in [6], [7]. Literature reveals that the Event-Condition-Action (ECA) rule-based paradigm is the most promising approach for the development of the behavior of an intelligent environment [8], [9]. The intuitiveness of the ECA paradigm has been demonstrated both in the ubiquitous computing field [10] and in other application domains (e.g. [8]). Recent web services, which allow users creating their own "recipes" for controlling their environment through their personal devices, are based on the same paradigm: see for example IFTTT[1] and Atooma[2]. Furthermore, the filtered lists metaphor adopted in these systems seems to be a good compromise between expressiveness and simplicity, thus favoring end-user engagement and participation.

In this paper we delineate a conceptual framework for the development, maintenance and evolution of a diffusely intelligent and cooperative socio-technical environment. The idea underlying this framework is that of *interconnection* [11], so as to go beyond the concept of "single device programming" in favor of the collective and participatory development of an intelligent system for the sake of a community of users who could directly or indirectly intervene in such a development. In particular, we focus on the EUD features of the framework. Open issues and possible research directions are also finally discussed.

[1] www.ifttt.com
[2] www.atooma.com

2 The Conceptual Framework

We propose a framework based on the central concept of *interconnection* among all actors involved in the intelligent environment, i.e., devices and humans, and of fluid exchange of states, conditions and behaviors. This should be guaranteed so that the intelligent environment could really align dynamically and adaptively to the user needs of information and support for action. The main point of this metaphor is that an AmI environment is not simply an aggregation of computational devices endowed with either perceptual or effectual capabilities, or both of these, bound together by functional relations; but rather what emerges as something new from this aggregation. In other words, it is an environment where some *states* and *conditions* are visible and available (e.g., the temperature of the room, what time it is, if the door is open, etc.) and some *actions* are feasible (e.g., raise the room temperature, mute the mobile, call the security, etc.). And, last but not the least, where "intelligent inference" is kept in the loop between conditions and actions, so that some value for the ambient inhabitants is created through a collective intelligence [12]. The point is that value is created by interconnection, that is by having any cognitive or computational actor getting access to the whole information space made available (and also created on purpose) so that proper action can be performed both by the system supporting the intelligent environment and the inhabitants at due time. Like in a solution where chemical reactions happen according to the actual elements poured in, and not necessarily according to a master plan that precedes the event of mixture, so should an AmI environment not be designed a priori, but rather be able to adapt over time. To some extent we advocate that an approach similar to that conceived for collaborative applications with the phrase "design for unanticipated use" [13] is adopted also for AmI systems.

The above considerations bring to conceive an AmI environment as emerging from the good fit of three layers into a single coherent conceptual architecture (see Figure 1): 1) the *physical layer*, where devices operate, with their perceptual and effectual capabilities, and inter-operate, through a shared information space that collects their states and acts as both a blackboard and a communication medium; 2) the *inference layer*, where logical reasoning is automatically performed to link perceptions to actions; 3) the *user layer*, where people are called on to express their preferences through actions, also in response to state changes and/or ambient conditions, as well as to modify and manipulate the "logic" (i.e., rules, policies, complex behaviors) their ambient should follow to either assist or satisfy them (EUD activities).

The last 10 years or so of AmI research has brought to devices that are sufficiently reliable and capable to interoperate with other devices and the overall hosting infrastructure [4]. Also the inference layer has reached a maturity level where consolidated inference engines combine efficiency with flexibility (e.g., [14]). Therefore, time has also come to invest more efforts in the user-related layer. This means to address new challenges like the *perception of relative advantage* and *long-term sustainability*. The former regards a known principle from the diffusion of innovation model theory [15]: it is important that users perceive the new thing as giving them a clear advantage with respect to the traditional counterparts (whatever these are) in order to have an impact on their daily life. For example, in the AmI context, this means that setting up a home

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lightening policy should be somehow as easy as switching a light on manually (or easier!). In order words, end users should consider participation in rule creation as a meaningful activity and not as an additional duty that they must satisfy. On the other side, the sustainability challenge is closely related and regards the fact that users should find convenient to interact with their intelligent "ambients" even after that the thrill for the technology novelty and curiosity have faded out and/or after that some expert has gone away and left the lay user alone with her/his own computational support. This is an aspect that is seldom considered in the AmI literature and it means to carefully design the user layer and its EUD features, so that an AmI environment can smoothly co-evolve with the users' needs and technologies available (see Figure 1), without forcing users to perform difficult and undesired tasks.

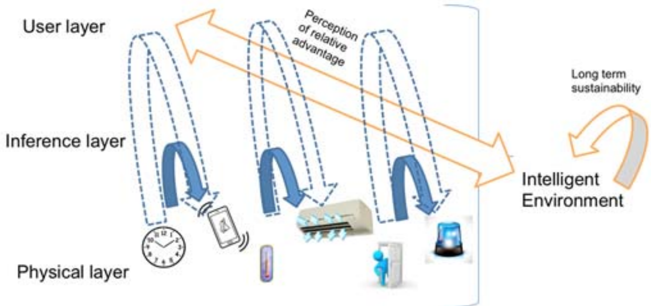

Fig. 1. The conceptual framework.

3 Future work

The implementation of the proposed conceptual framework will include an exploration of different solutions for the user layer, to identify the best interaction mechanisms that may sustain participation and collaboration to rule creation. In particular, we have already started such exploration by considering a variety of user-oriented tools in the AmI and Internet of Things domains. The idea is to take inspiration for the design of an interaction metaphor that is compatible with the interconnection metaphor of our conceptual framework and able to address some challenges that the framework brings about: rule definition and modification by different users, management of conflicting rules, openness to environment and/or community extensions over time, simplicity and expressiveness of single rules, overall readability of the configuration of the AmI environment. In particular, the filtered lists metaphor of IFTTT and Atooma appear as the most suitable for collaborative and distributed development of ECA rules, to be managed by the underlying distributed inference engine foreseen in our framework. Therefore, we will start with a comparison between these two systems. Another complementary line of research would pursue the perceived relative advantage of people already using an AmI system since a while, to fill the gap in the literature between technical feasibility and human-centred sustainability over time.

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