Co-simulation and Multi-models for Pervasive Computing as a Complex System

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Abstract. Pervasive Computing is about interconnected and situated computing resources providing us(ers) with contextual services. These systems, embedded in the fabric of our daily lives, are complex: numerous interconnected and heterogeneous entities are exhibiting a global behavior impossible to forecast by merely observing individual properties. Firstly, users physical interactions and behaviors have to be considered. They are influenced and influence the environment. Secondly, the potential multiplicity and heterogeneity of devices, services, communication protocols, and the constant mobility and reorganization also need to be addressed. This article summarizes our research on this field towards both closing the loop between humans and systems and taming the complexity, using multi-modeling (to combine the best of each domain specific model) and co-simulation (to design, develop and evaluate) as part of a global conceptual and practical toolbox. We share our vision for a strong research (and development) leading to the realization of Pervasive Computing.

Keywords: Pervasive Computing, Ubiquitous Computing, Ambient Intelligence, Human-in-the-loop, Distributed Simulation, Co-simulation, Multi-model, Emulation, Benchmarks, Multi-Agent System.

1 Introduction

Pervasive Computing [16], Ubiquitous Computing, or Ambient Intelligence is about interconnected and situated (or contextual) computing resources. They are embedded in the fabric of our daily lives and provide adapted applications and services to users in a changing context and environment.

It is at the convergence zone of four mature domains of traditional computing: personal computing, embedded systems, human-computer interaction (and artificial intelligence in some sort of way) and computer networking. In addition to this cross-domain nature, Pervasive Computing has other characteristics and constraints that are often difficult to combine and satisfy at the same time:

- Ubiquity (low-cost, embedded, distributed and non-intrusive)
- Interconnectedness (internetworking by wired and wireless technologies)
- And dynamism (a result of its mobile and adaptive applications that are able to automatically discover and use remote services).

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The notion of information appliances (small, specially designed computing devices, such as Internet Service Providers boxes, game consoles, connected TVs, and other Digital Video Recorder) is important to the success of pervasive computing. And the exponential rise of smart-phones, as the result of the convergence of Personal Digital Appliances (PDA) and mobile phones, and other tablets, is but one indication of this new computing paradigm coming of age.

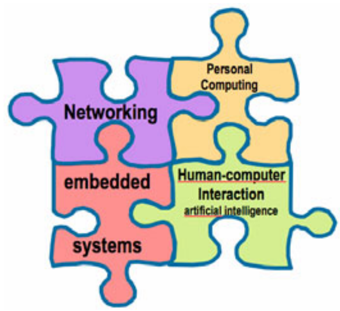

Fig. 1. Pervasive Computing: convergence of *Networking, Personal Computing, Embedded Systems* and *HCI*

Also the vocabulary depends on the community and its concerns, the overall statement is that our (as in "we, humans") environment is going to be filled with technology that will orchestrate their services to offer an improved / augmented / useful world and Internet of things. The 2 concepts, "ambient" and "intelligence", as shown in figure 2, are both relative to the human.

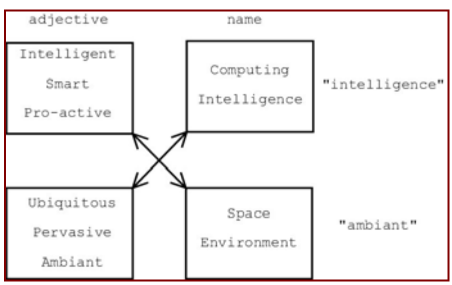

Fig. 2. Pervasive Computing, Ubiquitous Computing, Ambient Intelligence, Smart Space, Pro-active environment: a combination of some sort of intelligence provided by technology in (our) human environment

Although it may be easier to minimize or simplify his interactions and therefore his impact on the system, the "human" needs to be considered both at design and evaluation levels. He can't just be abstracted away. Another key element is related to the social side of many human activities. Not only should his physical, cognitive and biological properties be considered, but also his social interaction, cultural and scientific knowledge and abilities etc.

The remaining of this paper is organized as follows. In Section 2, we present our past proposition on how to put the human in-the-loop at every step and level, and how to model these complex systems. Section 3 details our proposition regarding the human part, starting from cognitive agents going to the Multi-Agent paradigm. Section 4 will give a short presentation of our solution applied to 2 use-cases. Section 5 opens up to new ideas and ongoing and future work, and try to synthesize our vision.

2 Pervasive Computing: Modeling a Human-Centric and Complex System

Pervasive Computing is in essence augmenting the human environment with smart technology to provide advanced services. It can be considered human-centric, since the most important evaluation metric will be the human acceptance and the impact on his activities and behavior. But it is at the same time a human in-the-loop system, where several interacting entities may exhibit non-predictable and non-controllable behaviors, and where the functional interaction should be well specified.

2.1 A Complex System

In future fully and commercially viable embodiments of Pervasive Computing, a large number of heterogeneous and autonomous objects, users, and systems will interact in a continuously changing environment. Mostly rooted in Social Science, Natural Science and Mathematics, a complex system is a set of interconnected elements that has global properties that can’t be inferred from the properties of the individual elements, whether it comes form the large number of entities, their dynamicity, their heterogeneity, their autonomy etc.

2.2 Layered Pervasive Computing Model

The LPC [3] (Layered Pervasive Computing) model is inspired by the ISO-OSI [1] and TCP/IP networking models and their abstraction layers. It was developed in the NIST Aroma project [2]. It gives a first conceptual framework that aims at classifying issues raised during design, evaluation or analysis of a Pervasive Computing system.

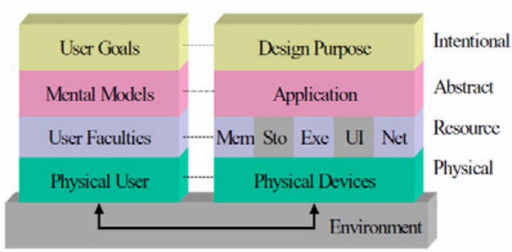

Fig. 3. The LPC (Layered Pervasive Computing) model, both the *user*(s) and the *environment* are considered in addition to the technological system

The first two layers are about the physical and physiological properties of the actors and their environment. The environment must be factored into the model: issues beneath the physical layer of the computer and users can be crucial. The growing interest for Sensor (and Actuator) networks and all the environmental information needed for pertinent context assessment justifies this layer (temperature in a smart home for a simple example). And the environment is also the medium through which all the other layers will interact. The physical layer deals with compatibilities. For example a device should match the physical capabilities of its users, or adapt to his disability. Simple mistakes such as inadequacy of a touch screen with big fingers could be avoided by carefully looking into the issues raised in these layers.

The resource layer essentially tries to match the computational resources (memory, processing power, storage etc.) with the potential user skills and abilities (his education or skills, is language or is temperament). Too often, the developer makes wrong assumptions about the future users of his system which can be time and money consuming, since the product or system will need reengineering at a sooner stage. Users have tasks or goals that should not be frustrated by a poor design. We can put in this layer services such as auto-configuration and self-management and concerns such as ergonomic. The abstract layer is equivalent to the application layer in the OSI model, where application is matched with the users mental models, which in turn are greatly dependent on their faculties. There are limits to the complexity the various users can cope with in Pervasive Computing environment. They won't waste time learning how to use a program designed by a computer scientist with his own vision of the product and its usage, but reuse the mental models they have acquired from former experience with similar designs. There is a need for consistency here. Finally, the intentional layer represents the purpose of an application that should be in harmony with the users goals. The user's mental representation of the underlying layer is directly linked with his goals. The requirements phase of any project should be where all starts and ends.

In the Aroma project at NIST, we've used this model to study a smart space populated with discoverable projectors and smart objects, which reveals quickly issues that should have been addressed to realize our prototypes as commercial products.

The model is still conceptual, and in order to be valid, the inter layers and same level layers interaction should be more formally described. Problems such as dimensional consistency (time, space, etc.) and formalizing interactions have to be resolved.

3 From Using Cognitive-Agents to Multi-agent Systems to Assess and Develop Pervasive Computing Systems

Depending on the application and the situation or context, human physical or cognitive abilities, as well as his behavior (considering the situation or context, acting upon his environment) should be considered. While this is the case for user interfaces (UI) or interfaces in general, it is quite not the case in other domains when considering computing elements such as communication technologies (network, services).

In the Aroma project, we have also developed EXiST, the Experimental Simulation Tool. It has being created to explore Pervasive Computing requirements and use cases. We were exploring the use of Intelligent Agents firstly for representing the users in our simulation [4]. Intelligent or cognitive agents can learn or even teach how to use resources by interacting with human users, providing a higher level of intelligence to the environment, but they also can be used as human models in simulations or in expert systems. We used a cognitive agent modeling toolkit with EXiST to create unit agents to help define usability metrics in Pervasive Computing.

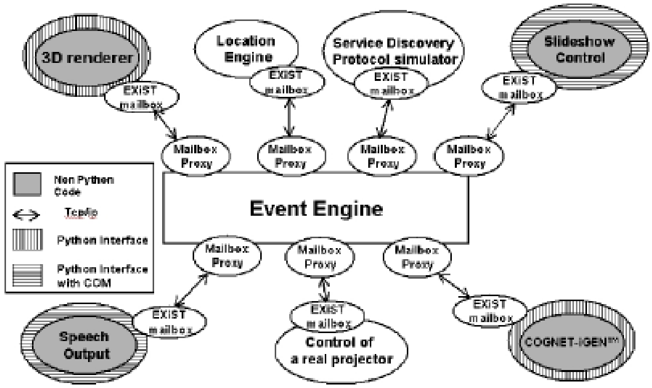

Fig. 4. EXiST co-simulating an Aroma projection room, with simulated users and environment and real projector and applications

Cognitive agents are full blown agents that can be used to model reactive to strategic human actions, but in some scenarios where we deal with hundreds, thousands or more users, for resources reasons (both computing and scientist), simpler agents could be used.

For example, in the domain of dynamic networks (adhoc, P2P networks), which is one of our case study (see next section), the number of nodes may be quite high and two users' properties need to be integrated and their impact evaluated: movement or mobility and application usage. In that type of situation, where individual behavior needs to be modeled, but where global behavior can't be forecasted, the multi-agent paradigm is well fitted. It can model sets of situated autonomous proactive entities interacting together, and with and within an environment. It is widely used in human and social sciences, ecology or in robotics. The system is described with (at least) 3 components: agents, environment, and interactions. Agents only have a partial (local) view of the environment and decide which action to take according to their perceptions and reasoning.

MAS (Multi-Agent Simulation) are adapted when we want to model users' behavior, goals and actions. Instead of using a global equation to model users' trajectories, we can, via the agent based model, re-create the way users move. It means that we can directly model behaviors such as "if there are obstacles, avoid them" or "follow a target during five minutes and then stop". Using this tool in our global strategy, we can also model complex behaviors such as willingness to use an application and share a resource depending on the available bandwidth or the generosity of a user. We can also deal with reactions to unlikely events.

4 Multi-modeling and Co-simulation Use Cases: Smart Environment and Mobility Models

We've defended the case for co-simulation in [5], stating that like in every field of science, simulation is a key tool for researchers, developers and designers when used in a co-simulation setting. By co-simulation we mean mixing real or prototype devices or application or users within complex simulated environment, and devices and users, in a refining development cycle.

As seen in figure 3, we've coupled several simulators and real devices using EXiST, focusing on the co-simulation aspect. With this setting we were able to test prototype applications and devices such as a smart wireless projector and a wireless sharing service. Combine with the LPC model, we have been able to pinpoint scientific and technological challenging issues. But we haven't considered the modeling and coherence issues in that first set of experiments.

In the frame of the SARAH (Advanced Services for Adhoc Networks) French research ANR project, we've tried to study such problems, with a strong focus on wireless technologies and services, context awareness and users' behavior.

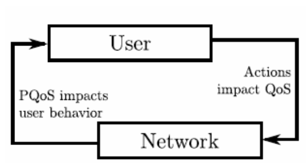

Fig. 5. Multi-modeling: user and network in a closed-loop

In wireless technologies, ad hoc or mesh routing protocols, or ubiquitous services are often designed and evaluated using network simulators. More specifically, when studying MANETs (Mobile Ad hoc NETworks), real world experimentations with a representing set of devices is excessively time and money consuming, or even is scientifically of little relevance since reproducing a scenario / an experiment is not possible, network simulators are almost mandatory. In simulation, nodes move according to a mobility model [9] but for real dynamicity, we need to close the loop between the user's actions (mobility being one of them) and network performance (the perceived quality of service seen in figure 4). We're using the work on pedestrian [7] and distributed flock and herd behaviors [6] as basis for our mobility models.

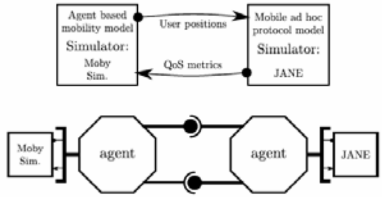

Fig. 6. The AA4MM framework used in multi-modeling and multi-simulation of mobility models in adhoc networks. Coupling *Jane* and Masdynes.

The design as in EXiST is inspired by the DoD HLA (High Level Architecture) which main goal is re- usability and interoperability of different simulators. The framework fosters the use of existing simulators (or other entities e.g. visualization systems) and combines their specialization. It is therefore a multi-model simulation and evaluation environment. Each domain retains its specialist and tools and replacing a simulator does not require major changes on the existing architecture.

The AA4MM (Agent and Artefact for Multiple Models) [11] framework is used to combine the JANE[10] (Java Ad Hoc simulator) Network Simulator and our own Multi-Agent Simulator for the users' behavior. AA4MM itself is grounded in the Multi-Agent paradigms, since the multi-models and their corresponding simulators are seen as a society of entities. The dimensional discrepancies are dealt within the framework that acts as a synchronization and conversion middleware. The actual implementation is centralized using JMS, but in principles it is distributed and has no explicit synchronization entity (global clock). In our case, nodes are modeled as agents with goals and tactics, and the network layer provides feedback.

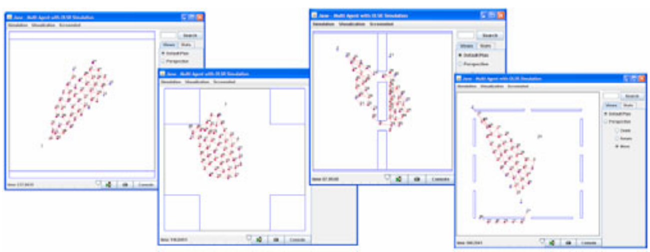

Fig. 7. Mobility models: several environments with same behavior

From simple new mobility models ... to new functionalities and benchmarks. Typical scenarios and simulation, as shown in figure 6, where the advanced mobility model is used in different environments (Corridor, Crossroads, Walls and Museum), shows how simple is it to tweak or integrate new mobility models, i.e. new behavior in our networking simulations. Furthermore, our approach allows the creation of mobility models that interact with the network. For example, depending on the signal strength, a user may decide to stay put or move. In a middle term, it may be interesting to present a set of mobility models, a set of environments and their combination that would be both virtualized (modeled and simulated) and have a real setup (a typical existing room or building or city modeled in 3D for example). They would serve as references that could be used to evaluate the performances and applicability of a solution, and validate it in certain contexts, thus providing the pervasive computing community with a benchmark evaluation toolkit.

The AA4MM conceptual framework and prototype implementations applied for mobility modeling exhibit the following results

- The Multi-Model approach is a separation of concern (and problems) approach
- The tools allow even non-specialists to scientifically implement and validate their solutions, and the low-levels designers to give "real-life" example for their technology or protocols

- While it still provides the usual mobility models, it is very simple to design, fine-tune, redesign those models or even design new ones.
- The new mobility models can take into account networks or more generally environment inputs, basically having a closed-loop system where something closer to the ”human behavior and real-life” is considered.

Therefore, our approach offers a basis for valid comparison of wireless technologies and services but it can be extended to any dynamic environment, such as P2P or more complex pervasive computing networks for example and basically for every situation where there are interactions between the users and the (networking) environment.

5 Ongoing and Future Work

First of all, technically, our platform will be extended:

- The core distributed engine will be rework to handle both horizontal (scalability) and vertical (across abstractions and domains) co-simulations
- More standard and novel mobility models (node/users behaviors), and reference environments will be developed
- Testing and visualization tools should be integrated in the near future, and should be extended to the analysis of security

And our work needs to be confronted with real environments, users and usage. This is planned in a joint-work with Supélec Metz and its Smart Room, where advanced services and complex user behaviors will be tested.

Another interesting playing field is the gaming industry [8,15]. Massively Multiplayers games and Pervasive gaming would provide real-life, large-scale, complex experiment and results.

Finally, we will explore the fundamental needs behind the fabric and the building of a sound by design (provable) Pervasive Computing system:

- On the domain of formal methods: they are starting to look into multi-modeling and co-simulation [14]
- On the modeling and mathematical theory of integration between humans and system [12,13].

5.1 The Best is Yet to Come …

After surveying the situation in Pervasive Computing, or example when surveying major scientific or technological conferences in the field, it seems that:

- The technologies has reached a certain level of maturity, the computing power embedded in our smartphones or the new interaction devices such as the Microsoft Kinect™
- But the community still focuses on technical challenges, like location and awareness or novel interactions

On a large system view, the engineering processes and tools are yet to be tangible. It is still largely more the work of a scene, of some crazy scientist and hackers.

6 Final Thoughts

This article explores more than 10 years of Pervasive Computing research driven by networking and services management concerns. We've proposed a conceptual model (LPC) and seen that formal methods and mathematical theories may help us engineer better applications. We believe that using well-defined models and tools from specialist in every domain is the good path to follow in the near future, and we are building a conceptual framework (AA4MM) based on multi-agent systems for multi-modeling as well as tools (EXiST–AA4MM) for the evaluation and development using co-simulation.

Our goal is to provide a framework where technologies could be evaluated and ideally certified ”for a standard type of environment”. This would give the ability for a technology designer to say: ”my service, my device, my protocol will or wont' work in those environments with those type of users”. About a specific solution, its designer could still satisfy his scientific colleagues with:” it works well with high density, low mobility scenarios and conforms to the formal specification”, but he could also add: ”it works well in downtown scenarios at rush hour, but not in a shopping mall on Saturday afternoon” and we believe that is what will make all the difference.

During this period, the technologies have progressed tremendously and a future a la Harry Potter can be envision, where our gesture and thoughts will be seen and interpreted by our augmented environment (full or useful services, robots and clouds). But when looking into the conceptual matter, cross-layer issues and the engineering side of the domain, we can only see that we are still a long way from the realization of commercially sound-by-design, large-scale, fully-integrated, cross-layer, failed-proof secure Pervasive Computing environments.

References

1. Day, J.D., Zimmerman, H.: The OSI Reference Model. Proceedings of the IEEE 71, 1334–1340 (2003)
2. Mills, K.L.: AirJava: Networking for Smart Spaces. In: Usenix Embedded Systems Workshop (March 1999)
3. Ciarletta, L., Dima, A.: A Conceptual Model for Pervasive Computing. In: International Workshop on Parallel Processing (2000)
4. Ciarletta, L., Dima, A., Iordanov, V.: Using Intelligent Agents to assess Pervasive Computing Technologies. In: IAWTIC 2001 (2001)
5. Ciarletta, L.: Emulating the Future with/of Pervasive Computing Research and Development in What make for good application-led research. Workshop Pervasive (2005)
6. Reynolds, C.W.: Flocks, herds, and schools: A distributed behavioral model. Computer Graphics 21, 25–34 (1987)
7. Teknomo, K., Takeyama, Y., Inamura, H.: Review on microscopic pedestrian simulation model. In: Proceedings Japan Society of Civil Engineering Conference (2000)
8. `http://www.massivesoftware.com/`
9. Bai, F., Helmy, A.: A Survey of Mobility Models. In: Wireless Adhoc Networks. University of Southern California, U.S.A (2004)

10. Gorgen, D., Frey, H., Hiedels, C.: Jane - the java ad hoc network development environment. In: ANSS 2007: Proceedings of the 40th Annual Simulation Symposium, pp. 163–176. IEEE Computer Society, Washington, DC (2007)
11. Leclerc, T., Siebert, J., Chevrier, V., Ciarletta, L., Festor, O.: Multi-Modeling and Co-Simulation-based Mobile Ubiquitous Protocols and Services Development and Assessment. In: 7th International ICST Conference on Mobile and Ubiquitous Systems (2010)
12. Fass, D.: Rationale for a model of human systems integration: The need of a theoretical framework. Journal of Integrative Neuroscience 5(3), 333–354 (2006)
13. Chauvet, G.A.: Hierarchical functional organization of formal biological systems: a dynamical approach. I. An increase of complexity by self-association increases the domain of stability of a biological system. Phil. Trans. Roy Soc. London B 339, 425–444 (1993)
14. Fitzgerald, J., Larsen, P.G., Pierce, K., Verhoef, M., Wolff, S.: Collaborative Modelling and Co-simulation in the Development of Dependable Embedded Systems. In: Méry, D., Merz, S. (eds.) IFM 2010. LNCS, vol. 6396, pp. 12–26. Springer, Heidelberg (2010)
15. McGonigal, J.E.: This Might Be a Game: Ubiquitous Play and Performance at the Turn of the Twenty-First Century, doctoral dissertation. University of California, Berkeley (2006)
16. Weiser, M.: The Computer for the 21st Century, Scientific American Special Issue on Communications, Computers, and Networks (September 1991)