

# The Case for Simulation-based Evaluation of Ubiquitous Computing Environments

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## Abstract

Ubiquitous computing (a.k.a. pervasive computing) is ill-defined due to its novelty and the community's current emphasis on its technological aspects. This can lead to serious "existential" issues during the evaluation of ubiquitous computing technologies. Use-case driven simulations can address these issues by providing a context for the analysis of ubiquitous computing measurements and metrics.

Ubiquitous Computing is an emerging computing discipline which lies at the intersection of desktop computing, networking and embedded systems. Because of its novelty and the community's current emphasis on its technological aspects, ubiquitous computing is ill-defined. This, in turn, can lead to serious 'existential' issues during the evaluation of its underlying technologies. By this we mean that while an evaluation metric may be easily computed and measured, its relevance will come into question. In the end, competing evaluation methodologies will result in confusion and loss of confidence in the possibility for objective evaluation in ubiquitous computing.

We have been working to define the term "ubiquitous computing" to support our measurement and standardization efforts [1]. Most definitions appear to focus on the underlying implementation technologies rather than particular user needs. The lack of a user-centric approach complicates evaluation, standardization and measurement efforts because there is little context in which to evaluate emerging technologies, standards and metrics. At the same time, the novelty of ubiquitous computing means that potential users do not have enough experience to clearly articulate their requirements to ubiquitous computing researchers and developers. This may lead to a chicken-and-egg situation where many early attempts to apply ubiquitous computing to real-world problems are likely to fail before accidental successes begin to define the field.

Our experience with prototyping a "smart" projector has led us to the conclusion that prototyping is not a panacea for the evaluation of emerging technologies [2, 3]. Implementation decisions must be made early and these decisions can hamper or bias the exploration of potential use cases and their corresponding requirements. Prototyping can also be costly and time consuming.

We have begun to explore the use simulation techniques to address these issues. Simulation has been widely touted as an effective means to explore system engineering issues prior to costly investments of resources [4]. It can be used during the design process to compare several alternatives [5]. Once scenarios of particular interest are found, more resource intensive methods can be used to confirm the validity of the simulated results. The use of simulation requires the proper collection of data and measurements. Because simulation plays an early role in research and development, its use will force research and development teams to properly account for measurement early in the research and development cycle [4].

Simulation plays a significant role in traditional scientific research for similar reasons. Many experiments, for example, in particle physics, require enormous resources. Simulation allows researchers to optimize the use of these limited resources. Research communities are also typically composed of experts whose experiences may lead each to different subjective conclusions about an open issue. Simulation can provide a shared context for communication and consensus. [4] For all of these reasons, we are confident that ubiquitous computing research will also benefit from simulation. Despite these advantages, it has been suggested that

the software engineering community in particular does not fully exploit simulation techniques [4]. This is unfortunate because ubiquitous computing relies heavily on software to implement its “ubiquitous” nature.

Our confidence in the role of simulation in ubiquitous computing research is underscored by our efforts to develop the Experimental Simulation Tool (EXiST) to explore ubiquitous computing requirements and use cases with the ultimate goal of simplifying the evaluation of this new technology. Although we cannot give a detailed description here, EXiST is a Parallel Virtual Machine-based distributed system designed to support real-time, interactive simulations of ubiquitous computing systems. EXiST consists of a collection of nodes coupled via a PVM-based message-passing system. A node can represent a portion of the system being simulated or a component such as a 3D graphical renderer. This contrasts with the Department of Defense’s High Level Architecture (HLA) in which the components, called “federates” represent entire simulations [6]. An important goal of the HLA is to enable reuse of expensive military simulations [7]. As a result, the HLA is a comprehensive architecture and HLA simulation design is a relatively complicated task. EXiST, on the other hand, is designed to provide a means to rapidly develop ubiquitous computing simulations in order to evaluate relevant use cases.

We believe that the human users should play an important role in the evaluation of ubiquitous computing technologies [1]. EXiST will serve as a visualization tool to allow researchers to communicate with the user community to establish realistic use cases for ubiquitous computing applications. Once these use cases are established, we plan to be able to perform more refined simulations, including “mixed-mode” simulations involving simulated and real-world entities. We have already demonstrated this ability with an early prototype of EXiST with which we used cognitive agent software to simulate human users using a real-world device, our “smart” projector [8].

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