Interacting with ubiquitous computer applications: issues and methodology

Achilles Kameas

Computer Technology Institute
Research Unit 3
61, R. Feraiou Street
Patras, Greece
Achilles.Kameas@cti.gr

Irene Mavrommati

Computer Technology Institute
Research Unit 3
61, R. Feraiou Street
Patras, Greece
Irene.Mavrommati@cti.gr

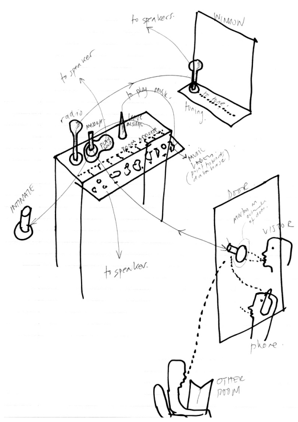
ABSTRACT

This paper describes a set of issues that we were confronted with when trying to specify people's interaction with a ubiquitous computing application. In such an application, the computer "disappears" and computing services are made available to users throughout their physical environment. Issues are presented in two levels: usage and technical. The approach we adopted in the context of a related research project in order to deal with these issues is also presented.

KEYWORDS: ubiquitous computing, artefacts, interface, affordances, interaction for tangible objects, process.

INTRODUCTION

The present days seem to mark the end of an era in computing history: that of the computer! During the past few years, several applications are emerging, in which the computer is no longer a multi-purpose distinct device, but has become very small and sometimes embedded into non-computing objects (possibly objects of everyday use). It seems that in this new paradigm, the computer will become a distributed system of many disappeared computers. [7].



This approach has been termed "ubiquitous computing", or "ambient computing", or "disappearing computer". No matter how it is called, the main idea behind it is that the computer "disappears" and computing services are made available to users throughout their physical environment [10], [16].

Background

The potential of the ubiquitous or disappearing computer paradigm has been recognised and several important research activities have been undertaken [1],[2],[3],[4] while some products not resembling computers have already hit the market [5]. Recently, EU launched the "Disappearing Computer" (DC) Initiative with the goal "to explore how everyday life can be supported and enhanced through the use of collections of interacting artefacts. Together, these artefacts will form new people-friendly environments in which the computer-as-we-know-it has no role. The aim is to arrive at new concepts and techniques out of which future applications can be developed" [6].

Specifically, the initiative focuses on three inter-linked objectives:

- Developing new tools and methods for the embedding of computation in everyday objects so as to create artefacts.
- Research on how new functionality and new use can emerge from collections of interacting artefacts.
- Ensuring that people's experience of these environments is both coherent and engaging in space and time.

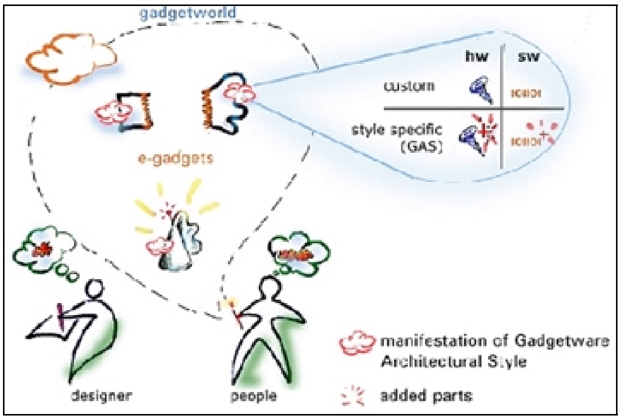
In the context of the DC initiative, 16 projects were selected for funding. Each of them deals with a different research issue on the subject. Among them, Extrovert Gadgets (acronym: e-Gadgets) aims at defining a Gadgetware Architectural Style (GAS) to describe the emerging behaviour of artefacts [8].

Terminology

Broadly, *GAS* consists of a set of architecture descriptions (syntactic domain) and a set of guidelines for their interpretation (semantic domain). We are interested in extending component-based architectures to the realm of tangible objects. GAS is not simply a software architectural style (as are component-oriented architectures) but it combines a software architectural style with guidelines on how to physically design and manipulate artefacts (we could call it "a style for tangible objects").

A *Gadget* is a tangible (physical) object enhanced with intelligence, processing and communication abilities. For the needs of the project, all gadgets are GAS-aware artefacts used as tangible components to form clusters with collective function (gadgetworlds). Any gadget is of dual nature: it has a physical existence (demonstrated by its form and shape) and an informational existence (consisting of a hardware part and a set of software modules).

A *gadgetworld (gw)* is a collection (configuration) of gadgets, which communicate and / or collaborate in order to display a collective function. Although every collection of communicating gadgets does in fact constitute a gw, we are interested mostly in a so-called "meaningful" gw. A meaningful gw is formed by people so as to explicitly serve a purpose (i.e. offer services to the user, help the user perform certain tasks etc).



In principle, people should be able to explicitly form a gw by selecting gadgets and putting them together in order to serve a specific function. People can then act upon the gadgetworld by setting goals, forming plans and perceiving results. In order to design an architectural style to support these, the project needs to:

- provide a vocabulary that can be used to describe a gw; the vocabulary should appear "natural" to the gw users and at the same time recognisable by the gw
- provide a framework for the interpretation of the gw (that is, for assigning meaning to the vocabulary)
- provide rules that will define the appropriateness of the gw or constrain it

Thus the project has to engage into inter-disciplinary research, the starting point of which has to be the specification of interaction between a gadgetworld and its user(s). The issues that have come up during this effort are described in the next section. The third section presents the methodology we adopted in order to tackle these issues. The results up to this point are discussed in the conclusive section.

ISSUES

In this paper, we adopt a two level approach to the disappearing computer paradigm. At the *physical level*, the computer ceases to exist as a distinct device and:

- It is broken down to its parts, which are then "hidden" in various separate locations. These computer parts communicate and co-operate in order to offer computing services, or
- Tiny computer boards, offering basic computing and communication services, are attached to devices of everyday, non-computing use, thus enhancing (or even altering) their intended uses.

At the *cognitive level*, the disappearance of the computer forces peoples to form new mental models about the (non-computer-related) tasks, which used to involve a computer. On the other hand, if the appearance and function of everyday objects change (or new objects appear into our everyday life), then people will have to adapt or form new models of tasks involving these objects.

Interaction in a ubiquitous computing environment takes place in two levels:

- Device-to-device: since such devices are capable of computing and communicating, device-to-device interactions take place unseen to the user.
- User-to-environment: people will be continuously interacting with many computing-enabled devices. These devices are distributed and interact at a second level. The user interacts:
  - With any single device, in order to use its services
  - With a collection of co-operating devices, attempting to use their collective (emerging) functionality

In the rest of this section, interaction issues with ubiquitous applications are considered with regard to the usage and -in less extend- the technical level.

Usage issues

Each object that participates in our everyday world has been designed with certain tasks in mind. For example, a cup is used to hold a certain volume of liquid that we can possibly drink. The ways that we can use an ordinary object (sometimes implied by the "object's affordances" [13]) are a direct consequence of the anticipated uses that object designers "embed" into the object's physical properties. This association is in fact bi-directional: not only the objects have been designed to be suitable for certain tasks, but also their physical properties constrain the tasks people use them for.

Nevertheless, ordinary people may put objects to other than anticipated uses: a cup, for example, may be used as a flowerpot or as a paperweight. In general, ordinary objects can be used in many different ways, provided that the limits of their physical properties are not violated.

Contemporary computers are distinct objects, thus having their own physical properties and uses. When the computer disappears in the environment, then it is no longer an object that the user can explicitly manipulate to carry on his/her tasks. Moreover, as everyday objects are "enhanced" with computing and communication capability, the user has to learn the new ways that they can be used (indicated by designing new affordances) and the tasks they can participate in.

Thus, the ubiquitous computing paradigm introduces several challenges for human-computer interaction. Firstly, users will have to update their task models, as they will no longer interact with a computer but with a computationally enabled object. Secondly, people will have to change their habits and form new models about the everyday objects they use; these new models will be a subject of HCI research. [14] , [17]

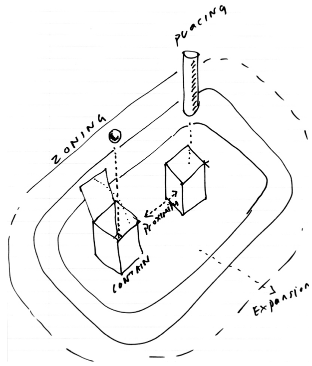
The human-computer interface will transcend the limits of the computer and enter the physical world, as computer applications will be distributed in objects around us. In such a world, the direct manipulation paradigm will have to include metaphors describing interaction with tangible objects, (which is in fact carried out by using the objects and therefore direct manipulation might become "direct action"). The design of the object's form and physical properties will also affect the interaction. In fact the design of objects, -which constitutes their interface-, may have to be reconsidered so that their new capabilities can be promoted to the user (indicated by appropriate affordances).

Task representation & synthesis

Another result of the disappearance of the computer into everyday objects is that the conceptual models people have of these objects will have to evolve. In fact, they will have to:

- Remove the computer as a physical object from several task models
- Replace the computer in other task models with a new object
- Update the usage models and redesign the physical affordances of several common objects to include the new possible use/functions

Objects will be able to process data (possibly gather them as well) and to communicate with each other. In a world with enhanced everyday objects, people will be able to carry out more complex tasks nvolving such objects. Task synthesis will involve putting all the necessary objects within communication range, connecting them and describing the task. To achieve this, people will interact at the same time with individual objects and with their configuration. Therefore people may initially use objects in more complex ways [13]



Let us take an example: someone wants to have his/her coffee cup send a signal to the coffee maker when the volume of coffee in his/her cup decreases, so that when he/she tries to refill, the coffee maker is not empty. After making sure that the two devices can communicate with each other (either directly or indirectly via an ambient communications infrastructure), the user will have to "connect" them, in order to achieve this particular function.

None of these tasks is in the conceptual model that ordinary people have about coffee cups and coffee makers, nor are any of them straightforward. Ordinary cups do not communicate via an ambient network; gadget-like cups will, so the user will have to update his/her model about cups. Therefore several issues arise:

- *How can the user tell whether his/her cup is a gadget-like cup or an ordinary cup?* If the form of the cup changes, then this must be done in a way that will not violate nor render as obsolete the existing conceptual model that the user has of the cup, or he/she might not "trust" the new object
- *How can the user understand the state of the cup?* Ordinary cups declare their state by their shape and contents: they are intact or broken, they are empty, full or half-full, they are cold or hot, they are clean or dirty, etc. The enhanced cup will have to accommodate in its form ways to communicate to the people the state of its new features (i.e. whether it is connected or not, whether the coffee is warm or cold, whether the newly brewed coffee is ready or not etc)
- *For how long will the user have to think explicitly about the cup?* Ordinary cups are not apparent in people's task models: they care about drinking coffee, not about the cup itself [12]. Gadget-like cups introduce two factors that cause the breakdown of the

existing model: users will have to make sure that they can still carry on with ordinary tasks, and they will also have to become familiar with the new abilities of the cup. It seems that a period of familiarisation with the new gadgets will be required. The length of this period will depend on factors such as the gadget's form and affordances, the tasks it can participate in, its penetration in everyday life, etc.

- *How can people use the cup?* In addition to existing skills (i.e. pouring hot coffee in the cup without spilling it) people will have to develop skills for explicitly linking the cup with the coffee maker (i.e. there may be two coffee makers available, one that makes filter coffee and one that makes espresso, so the user will have to link his/her cup with his preferred one) and understanding the feedback they receive from the cup regarding its state.

- *How can people state and achieve their goals?* In order to use everyday objects, people act naturally upon them. When interacting with gadgets, people will have to be able to state their goals. This should be possible to happen implicitly (i.e. by manipulation), or explicitly (i.e. by programming). In addition, people will have to interact with collections of gadgets and probably cause the appearance of emerging behaviour (i.e. not anticipated by the gadget designers).

- *Why should people use a gadget-like cup and put themselves in all this mess?* None among us can be convinced that an ambient network infrastructure must be in place so that we can drink a cup of coffee! So people may have two alternatives: exploit or ignore the gadget-like cup features. If they fail to use the enhanced cup features in a number of first attempts (or if they fail to see any benefit from using them), they will revert to their safe, ordinary model of cups. People have to be motivated to use the new gadgets. Motivating factors may include:
  - New, enhanced services and tasks made possible
  - Better response rate in ordinary services
  - Savings in effort and time in carrying complex tasks
  - Low intrusion of the new gadgets in existing task models
  - Steep learning curve of the use of the new functionality
  - Trendy design and appealing shape
  - Appropriate (tangible) user interface using affordances effectively.

- *What are the factors that may cause a breakdown?* Can the cup be cleaned in the washing machine? Is it safe to pour hot coffee in it, or will the digital circuitry of the cup be damaged? How can the user be sure that he/she has performed the correct connections and actions? Will there be coffee ready in the coffee maker? Is the network operational?

Technical issues

How far are we from being able to construct and use gadgetworlds? Although the concept seems quite simple and natural, there are many technical issues that need to be resolved, until gadgets become widely available. The more important of them are listed briefly below:

- *Miniaturisation and packaging of computer boards.* In order to add computation and communication ability to everyday objects, computer boards need to be attached to them. These boards have to be small and compact, so that they do not affect the physical shape of the objects. Although the techniques to build small and compact CPUs, memory chips, transceiver chips etc. are available, their production is still costly.
- *Robust wireless protocols.* In the recent years several wireless communication protocols have been defined (for example, Infrared, Bluetooth, IEEE 802.11 etc). These are to be applied as the principal communication means between gadgets. However, none of these protocols has been field tested extensively, while other issues still remain to be resolved, such as the range of allowed message transmission, the spectrum of frequencies available, interference issues etc.
- *Power and consumption.* For gadgets to be autonomous objects, it seems that they have to be battery-operated. However, with the expected abundance of gadgets, one will have to keep a large stock of batteries! Novel ways to supply power to gadgets have to be used or invented (for example, producing power from physical phenomena, such as light, pressure, heat etc, of transmitting power to gadgets etc). In addition, the consumption issue, together with possible thermal environmental pollution, have to be considered.
- *Ambient networking infrastructure.* Wireless communication might be enough for close range communication between gadgets, but Internet protocols may be required for remote communication. Several issues are involved here:
  - global availability of compatible Internet protocols
  - anytime, anywhere availability of communication infrastructure
  - robustness, reliability and quality of networking services
  - global identification algorithms and availability of context-based addressing
- *Software architectures.* The composition of gadgets into a gadgetworld is similar to the construction of a software application using software components or routines. Thus, the existing component-oriented soft-

ware architectures have to be extended to include the unique features of gadgets

- *Distributed control.* Since each gadget is an autonomous and self-contained object, when many gadgets form a gadgetworld, there is an issue of whether there is a need for a *master* gadget (and if so, which one among them is the master gadget). In the general case, all gadgets are peers and no master gadget needs to be used. However, client-server architectures are far more easier to specify and implement

- *Distributed intelligence.* Some gadgets (probably all of them) will be intelligent, in the sense that they will be able to learn and improve their function by observing the consequences of their actions. Then, these gadgets will compose a distributed intelligent application. Issues that need to be solved include the software architecture and technology that will be used to implement intelligence, algorithms that gadgets will use to learn, representation of self, abilities, intentions, knowledge, common-sense, etc.

The lack of the necessary technology required to build the ideal gadgets and gadgetworlds makes the design and evaluation of prototypes a difficult process. People's feedback is indispensable if we are to build useful gadgets. On the other hand, attempts not carefully designed may destroy the value of the idea right from the start.

PROCESS

The way we identified CHI issues in the e-Gadgets research process, is outlined in this section. The process followed in e-Gadgets has the following widely accepted steps: a) Orientation / analysis, b) Conceptualisation, c) Development through prototypes & evaluation, d) Finalisation and summative evaluation. The project has three yearly iterative cycles of development; each of these ends with an evaluation; the conclusions taken from the evaluation into the next development cycle. Through the iterative loops of prototype development - evaluation gradually more completed stages of the Architectural style are achieved.

Initiation – Orientation / Analysis on issues

As in every project, the first few months are dedicated to orientating on the field of research (analysis phase). Raising the team awareness on Ubiquitous Computing Interaction issues was done by organising workshops, allowing for discussion to take place, and by the development of many scenarios.

<u>A multidisciplinary team including Experience Design.</u>

Since several of the issues mentioned previously are linked to the mental model of the people using the artefacts – gadgets, special attention was taken to include Experience Design from as early as the research analysis phase. [15].

<u>Un-focusing on Scenarios</u>

A technique that we used in the analysis phase was not to focus on one scenario to implement, but keep open to many possible scenarios; this helped us to identify and classify a range of issues. Looking at a multitude of scenarios was a starting point of the analysis phase. A two-day brainstorming workshop produced about 50 scenarios that were split in different clusters. By not focusing in only one scenario to implement we avoided limiting ourselves to a subset of the user issues (and therefore solutions), at an early stage in the project.

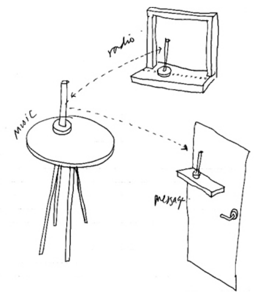
- Several different configuration-types of objects, came up via the scenarios.

- Ideas and terms from other fields were borrowed (i.e.: biology, sociology, etc) to help us understand and describe object relationships.

- Classes of most important functions, operations, and object-relationships were identified.

- Some scenarios were targeting facilitation of every-day tasks, while others were addressing emergent behaviour and unanticipated use.

- Several possible roles for artificial intelligence within the configurations were suggested.



Via the variety of different scenarios we identified what the e-Gadgets architecture should be able to cater for.

<u>Facilitating Multidisciplinary Workshops:</u>

We identified the scenarios, issues and possible solutions aided by several multidisciplinary workshops (addressing technical and usage issues). An example is the workshop aimed at defining a number of Usage scenarios that would function as input to the project. Another example was the multi-disciplinary workshop on "cognitive versus physical disappearance", (i3 spring days 2001) [9].

Conceptualisation

The scenario clusters were taken as a starting point to define one scenario for developing an e-Gadgets prototype:

- Compare on paper, (testing in theory) our solutions with the issues stemming from the scenarios clusters.
- Identification of the 'state of the art' (in packaging, architecture, agents, etc).
- One demo scenario (with a couple of possible configurations) implemented as a test-bed.
- Making a structure and vocabulary of an Architectural style
- Creating a prototypical agent for the demo's needs
- Packaging sensors, processing and communication into prototypical objects.
- Building up the demonstrators by putting all these 'ingredients' together.

Future work

Development (through prototypes) and evaluation, are the forthcoming stages of our research activities. Our research will proceed by creating one detailed scenario. Then building two demonstrator-versions of the selected scenario. The first is a portable demonstrator, from which we can gather feedback from experts in the field of Ubiquitous Computing, during exibitions, workshops etc. The second demonstrator is build in a room: an intelligent dormitory in the University of Essex, inhabited by a student. With this we can observe how the GAS prototype is used over a longer period of time and get valuable feedback. The results of each evaluation of the demonstrator feed back in the process, by altering / fine-tuning the demo-scenario and the interaction specifications. Incrementally we will re-evaluate the state of the art, and our initial assumptions. Throughout the development iterations we are looking to gradually improve until the final result is reached. A final summative evaluation at the end of the research will evaluate the results in terms of user experience, but also give valuable input to the other/future projects with a similar core.

CONCLUTIONS

We hope that this project, along with the technological innovation will serve as a case study on how to integrate design for people's experience and evaluation, into research processes. We hope that it will be a point of reference (in terms of process, as well as results), in the development of computing and interaction with tangible objects.

BIBLIOGRAPHY / REFERENCES

1. Project Oxygen: http://oxygen.lcs.mit.edu/
2. Research on wearable computing: http://www.starlab.org/bits/intell_clothing/
3. Presence: http://www.presenceweb.i3net.org/
4. LiME: http://www.living-memory.org/
5. Products : http://www.csl.sony.co.jp/person/rekimoto/datatile/ http://www.anoto.com *i-pot*: A Non-Command Internet Appliance: http://www.useit.com/alertbox/20010318.html
6. The Disappearing Computer initiative: http://www.disappearing-computer.net/
7. Time magazine, Europe, article 'Not very PC'. Vol. 155, no.8. Feb 29, 2000. http://www.time.com/time/europe/magazine/2000/228/devices.html
8. e-Gadgets website : http://www.extrovert-gadgets.net
9. Workshop on Cognitive versus Physical Disappearance (WS4). i3 Spring Days, Porto, 23 March 2001. http://ovelix.cti.gr/i3
10. Weiser, Mark. Some Computer Science Issues in Ubiquitous Computing. ACM, 36(7), July 1993, pp 75-84
11. Abowd, Gregory. Software Engineering Issues for Ubiquitous Computing. ICSE99 pp75-84
12. Winograd and Flores. Understanding Computers and Cognition. Ablex, 1985
13. Norman, Donald. The Invisible Computer. MIT press, 1998
14. Nielsen, Jacob. Non Command User Interfaces. *Communications of the ACM* **36**, 4 (April 1993), 83-99. (Revised version, http://www.useit.com/papers/noncommand.html)
15. Baumann, K. and Thomas, B. User Interface Design for Electronic Appliances, Taylor & Francis, 2001. Chapters 3 and 4
16. In the *Roomware* approach, computer augmented objects are integrating room elements with information technology . http://www.roomware.de/
17. Streitz, N.A., Geißler, J., et al. i-LAND: An interactive Landscape for Creativitiy and Innovation. ACM Conference on Human Factors in Computing Systems (CHI '99) , Pittsburgh, Pennsylvania, U.S.A., May 15-20, 1999. ACM Press, New York, pp.120-127.