MediaCups: Experience with Design and Use of Computer-Augmented Everyday Artefacts

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Abstract

Our view of ubiquitous computing is artefact-centred: in this view, computers are considered as secondary artefacts that enable items of everyday use as networked digital artefacts. This view is expressed in an *artefact computing model* and investigated in the Mediacup project, an evolving artefact computing environment. The Mediacup project provides insights into the augmentation of artefacts with sensing, processing, and communication capabilities, and into the provision of an open infrastructure for information exchange among artefacts. One of the artefacts studied is the Mediacup itself, an ordinary coffee cup invisibly augmented with computing and context-awareness. The Mediacup and other computer-augmented everyday artefacts are connected through a network infrastructure supporting loosely-coupled spatially-defined communication.

Keywords

Ubiquitous computing, digital artefacts, context-awareness, networking, embedded systems, Mediacup

1. INTRODUCTION

Computers are becoming ubiquitous in our everyday lives but not as the 'computers that we know'. The computer that we know is a primary artefact, explicitly perceived and used as computer. Instead, the computers that will proliferate further into our everyday lives will mostly be secondary artefacts embedded in primary artefacts that have their own established appearance, purpose and use in everyday experience. As secondary artefacts, computers will ideally be invisible and interacted with implicitly. So, in a certain sense computers will disappear, while *digital artefacts* will emerge, encompassing all sorts of devices and things that are not computers themselves but augmented with the ability to process and exchange digital information. Computer-augmentation of artefacts will not be geared toward making them more computer-alike but at preserving their individual purposes and uses while enabling added value through digital information processing.

In contrast to general-purpose computers, it can be expected that digital artefacts will be deliberately limited in computational ability, memory and processing power to levels adequate for a given specific purpose. However, two distinct abilities will be much more stressed in digital artefacts than in traditional computers: ad hoc sharing of information, and awareness of the surrounding real world environment. The ability to share information sets digital artefacts apart from self-contained embedded systems, and is fundamental for possible exploitation of synergies among artefacts of different specialisation. With digital artefacts being tied to established purpose and use, it is only in their networking and interaction that additional functionality may emerge. This idea is also expressed in Don Norman's appliance model arguing that communication is the precondition to reintroduce the versatility of a device originally traded in to make it purpose-specific and easier to use [Norman, 1998].

Most distinguishing from traditional computers will be the ability of a digital artefact to relate to their physical environment. Computers have traditionally been disconnected from the situations in which they are used, and only recently location- and context-awareness have received increased interest. In ubiquitous computing however, location and context are considered as key concepts, expressed by Weiser in his early vision paper by proposing that all computers will know where they are, and that instead of user interfaces in the traditional sense there will be "places to get things done" [Weiser, 1991]. Meanwhile, there has been a host of work on relating computing to locations, in particular driven by mobile computing, and recent advances in embedded sensor technologies drive a more general interest in context-awareness, in smart devices, and in their application in situated computing. This induces also a paradigm shift in human-computer-interaction leading from explicit interaction to implicit interaction [Schmidt, 2000].

The paper at hand presents an exploration into ubiquitous computing from the viewpoint that digital artefacts will be at the heart of the development. It constitutes an experience report from the Mediacup project, an ongoing development of an artefact computing environment with computer-augmented artefacts prototyped and deployed for empirical investigation. One of the artefacts studied in this effort is the Mediacup, an ordinary coffee cup invisibly augmented with sensors, processing and communication. The iterative development and use of the Mediacup gives some initial insights into issues in embedding computing technology into mundane everyday objects, and in particular into issues surrounding embedded context-awareness. Around the cup, other digital artefacts have emerged in our test bed environment, all connected through a network and location-based communication protocol. This growing environment of digital artefacts provides for experience in networking embedded technologies, and beyond it conveys insights into artefact inter-working toward emerging functionality.

This introduction will be followed by a brief review of related work. Section 3 is dedicated to the introduction of the artefact computing model which frames our work. Section 4 is focussed on the issue of augmenting artefacts and reports on the design, implementation, and use of the Mediacup. It is followed by section 5 concerned with artefact networking, describing the communication infrastructure developed in the project. Section 6 briefly discusses the evolution of the digital artefact environment. The paper will conclude with a summary of key points and an outlook on further development.

2. RELATED WORK

The main themes addressed in the project we report are the computer-augmentation of artefacts, specifically the embedding of context-awareness in artefacts, and the provision of an infrastructure for communication and artefact inter-working. In this section we will discuss work related to ours with respect to these themes.

Many popular ubiquitous computing scenarios and research and development efforts are based on computer-augmentation of consumer appliances, most notably home audio/video equipment, household appliances and personal communication devices [Schmidt et al., 1999]. There is comparatively little work on augmentation of more mundane everyday artefacts, in particular artefacts that are not based on electronics to start with, into the world of computing. The common approach to interface such non-technical artefacts is to tag them so they can be referenced in computer applications without embedding computing capabilities. A well-suited tagging technology are RFID tags as they can be attached post hoc and in unobtrusive ways to everyday artefacts. The utility of RFID tags has been explored by Want et al [Want et al., 1999], while others have shown that even simpler technologies such as barcodes can facilitate ubiquitous computing applications [Ljungstrand et al., 2000]. Tagging though keeps computing away from artefacts and stays short of enabling artefacts as more autonomous components in ubiquitous computing environments.

Beyond tagging there is some work that like ours is based on embedding computing capabilities in everyday artefacts. Most notably, research groups affiliated with the Things That Think consortium at MIT Media Lab have produced a wide range of computer-augmented artefacts [Things that Think]. Also notable are computer-augmented toys with embedded sensors, processors and actuators, for example ActiMates Interactive Barney, a two-way interactive, talking and moving, wireless plush dinosaur [Actimates]. Computer-augmentation in these examples is generally geared toward the improvement of artefact-specific functionality and use experience, or, as in the case of Ishii's work in the TTT context, toward employment of artefacts as tangible and supposedly natural user interface to the computing world [Ishii & Ullmer, 1997]. In contrast, our work investigates computer-augmentation of artefacts to enable them to capture their context, and to share context among artefacts, with applications not restricted to the original domain of the artefact [Gellersen et al., 1999].

With respect to communication, major requirements imposed by ubiquitous computing are integration of different networking media and technologies, and openness toward a growing variety of devices. Most research and development in this area assumes the Internet as ubiquitous transport vehicle, or else the adoption of domain-specific standards such as Home Audio Video [HAVi]. To cater for openness, most approaches adopt a service-based model with services as abstraction for applications, functions and devices. These approaches, for example Jini [Jini], generally provide support for service discovery, enabling devices to use services of devices or provides not known a priori. In addition, protocols are introduced that facilitate service negotiation, for example JetSend [Hp, 1999], effectively enabling clients to talk to devices for which they do not have specific driver software. The work we report in this paper is likewise concerned with communication in ad hoc communities of devices, however it is specifically aimed at integration of non-technical artefacts and as such less assuming with respect to embedded technology, anticipating that a computer environment suited for attachment to mundane artefacts may not be powerful enough to provide full Internet capabilities or Java support. Another difference is that in our model artefacts export context rather than services, with context serving for loosely-coupled communication within spatially defined environments.

At a more abstract level, the artefact computing model also relates to Norman's appliance model [Norman, 1998]; like Norman's information appliances, artefacts are special-purpose entities with the ability to exchange information to enable versatile uses. In contrast however, the artefact computing model stresses inclusion of everyday artefacts that are not primarily associated with being information devices.

3. THE ARTEFACTS COMPUTING MODEL

The artefact computing model is based on computer-augmentation of everyday artefacts to yield digital artefacts:

> An **everyday artefact** is a non-computational physical entity with established purpose, appearance and use in everyday experience.
>
> A **digital artefact** is an everyday artefact augmented with computing and communication, enabling it to establish and exchange information about itself with other digital artefacts and/or computer applications.

These definitions stress the integration of non-computational artefacts as opposed to introduction of a new kinds of information artefacts. The rationale is to move computing and information processing to the background of familiar activities such as the manipulation of familiar artefacts. Hence the idea is to augment artefacts in a way that does not compromise their original function and use, while enabling new functionality to emerge from digital artefact networking. The model for artefact networking is to have artefacts broadcast context information within a spatially defined environment.

> **Artefact context** is the information a digital artefact maintains about itself and its immediate physical environment. Digital artefacts can embody sensors and perceptual computing to establish their context.
>
> **Spatial context communication.** Digital artefacts communicate their context into a geometrically defined congruent communication space. Digital artefacts and/or computing devices can retrieve artefact context from any communication space they physically enter without further knowledge of the artefacts from which the contexts originate.

The core idea here is that everyday artefacts are augmented so to make information about themselves available for computing within a local environment, assuming that such context is of primarily local value. Our primary interest is in the use of this communication model to connect artefacts. However, the model does not assume that digital artefact with implicit computing will fully replace explicit computing devices, and it is anticipated that artefact context will not exclusively serve for artefact communication, but also to support context-aware applications in explicit computing scenarios.

We have explored the artefact computing model in the Mediacup project. The subsequent sections discuss this experience, first in section 4 with respect to the augmentation of everyday artefacts with sensors, processing, and communication; and then in section 5 with respect to implementation of an infrastructure for spatially defined communication between artefacts.

4. Augmenting Everyday Artefacts: The MediaCup

For exploration of the artefact computing model we have augmented ordinary coffee with computer technology embedded in the base, creating *Mediacups*. The Mediacups contain hardware and software for sensing, processing and communicating the state of the cup as context information. While coffee cups may seem a fancy choice for the study of computer-augmented artefacts, they are in fact a typical everyday object that is frequently used but usually remains in the background of the user's attention. Moreover coffee cups have changing states and they are used in different places and situations which altogether means that there is a lot of context information that potentially can be obtained by means of computer-augmentation.

Implementation

The current implementation of the MediaCup, shown in figure 1, is the result of a number of design iterations that have been carried out over a period of nearly two years. The objective of the hardware development was to augment an ordinary coffee cup with sensing capabilities, processing power, and communication. The design challenge was to provide these additional features without changing the basic properties (shape, size, and weight) of the cup noticeably and without compromising everyday use (ensuring robustness, and maintenance-free use).

Figure 1. The Mediacup is an ordinary coffee cup with sensors, processing and communication embedded in the base.

Sensors have been integrated to capture movement and temperature of the cup. For motion detection, three metal ball-switches have been integrated to measure orientation, and a switch in the base to detect when a cup is placed on a surface as opposed to held or carried. A Dallas DS1621 chip is integrated to measure temperature (-55 to 125 °C, 1 µA standby, 400 µA communication current). Signals from the sensors are computed at the Microchip PIC 16F84 microprocessor which also contains memory and I/O ports. The power is stored in two large capacitors (Panasonic GoldCaps, 1F each), which can be wirelessly charged using a resonant circuit with 20kHz. The entire hardware is laid out on a circular PCB only 6mm high with all components mounted so it can be placed unobtrusively in the cup base. To the user, the hardware remains invisible as it is sealed away and does not compromise everyday cup handling.

The Mediacup software controls acquisition of raw data from sensors and of cup-specific context from application of basic perceptual computing. The process of sensor reading and abstraction is designed to minimize energy consumption. Movement is a parameter that can change fast and frequently, but most of the time a cup will actually remain still over longer periods. To detect movement by sensor polling would have required readings about every 20ms; to avoid this, the motion detectors are connected to the interrupt pins of the processor, triggering readings only when changes have occurred. Detected movement is recorded as event, and a short history of such events is used in a rule-based heuristic to detect more abstract events with a cup-related meaning; these are *cup is stationary, cup is moving*, *drinking out of the cup*, and *fiddling with the cup*. In contrast to movement, temperature is a parameter that is changing slowly in the real world. Also, the adaptation speed of the sensor is very slow, and therefore it is read only every two seconds. The tracked temperature information in conjunction with some motion information is used to compute further cup-related context: *filled up*, *cooled off*, and *current temperature.*

Experience from Design and Use

The design and use of the Mediacups provides substantial experience on different issues surrounding the embedding of computer technology in non-technical everyday artefacts. Not surprisingly, the embedding of technology in artefacts that are not powered themselves raises a host of issues with respect to power management. Our experience from iterative design of the Mediacup is that power concerns become a key issue that influence a wide range of design decisions:

- Processing. The used microcontroller runs with a reduced clock speed of only 1 MHz; this reduces the power consumption to below 2mA at 5.5V in processing mode. The processor is switch to sleep mode (power consumption below 1 µA) whenever possible.
- Motion detection. In one of the early versions of the cup an accelerometer (ADXL202) was used. To reduce the power consumption and to make it feasible to wake up the electronic from sleep mode whenever the cup is moved without active polling the accelerometer was replaced by three ball switches. These switches are connected to the external interrupt inputs of the microcontroller. This makes it feasible to put the microcontroller more than 99% of the time in sleep mode without losing the information if the cup is moved.
- Recharging. Users can not be expected to change batteries or explicitly recharge a perceivably non-technical artefact such as a coffee cup. These leaves two design alternatives, first the provision of batteries that last for the life time of the cup, or secondly a mechanism for implicit recharging that does not require any explicit action on the user side. In the Mediacup, the latter approach is adopted: a cup saucer is augmented so the cup gets wirelessly charged whenever the cup is placed on the saucer. When the Mediacup is not used much, for example when it is stored in the cupboard, it can run up to a week with the 2 F capacity. With normal usage the MediaCup needs a 15 minutes recharge about every 24 hours.

5. Networking Artifacts: The MediaCup environment

Computer-augmentation of everyday artefacts is one area of study in the Mediacup project, however our main research interest is in how computer-augmented artefacts can inter-work to enable emerging functionality in artefact communities. A precondition is provision of a communication infrastructure to connect artefacts. In this section we describe the network infrastructure developed in the Mediacup project to connect Mediacups and other digital artefacts to the local area computer network. We also describe the communication protocol developed to implement spatial context communication, i.e. broadcast of context within a spatially defined environment.

Network Infrastructure

The Mediacup environment integrates different network media. Mobile digital artefacts such as the Mediacups use infrared for communication with a ceiling-mounted transceiver infrastructure. The transceivers use a Car Area Network (CAN) as backbone. The CAN in turn is integrated with the local area network as overall communication backbone in our environment. This infrastructure is depicted in figure 2.

Mediacup communication is message based. Cups broadcast their context as event message together with their unique ID every two seconds. The cups are equipped with an infrared LED (HSDL4420) that faces overhead, and use the IrDA-physical layer coding. The IrDA coding is done in software on the micro-controller to keep the number of hardware components on the Mediacup board small. The data rate is set to the maximum that is feasible with software implementation in the current design (19.2kbit/s) to minimize the time the infrared diode has to be powered. The communication range is about two meters with an half-angle of 30°.

The cup information is collected through an overhead transceiver infrastructure consisting of multiple access points that forward packets from received from the wireless communication channel to the wired backbone and vice versa. This infrastructure is installed in the usage environment of the cups, i.e. currently in 4 rooms in our office environment. The access points are based on HP's HSDL 1001 IrDA chip and have

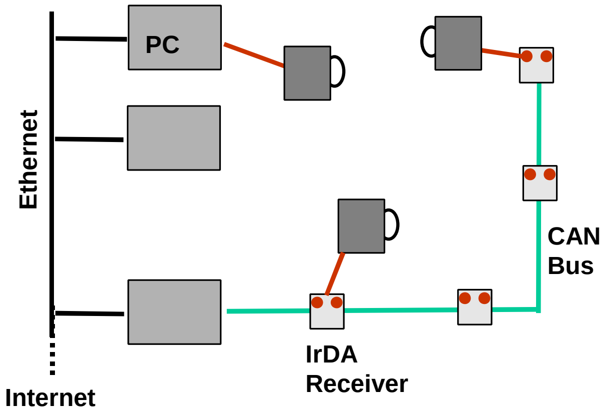

Figure 2. The network infrastructure of the Mediacup environment integrates IR, CAN, and LAN technoloogy.

a footprint of about 1,5m². They are connected through a CAN bus infrastructure using Phillips SJA 1000 controllers. The SJA 1000 is a CAN 2.0B stand-alone controller handling the complete layer 1 and 2 protocol. A router forwards messages to the local Ethernet if necessary, in which collected context is broadcast in UDP packets.

The data transmission technologies in the Mediacup environment are chosen because of their specific characteristics that make them especially suitable for operation in Ubiquitous Computing environments. One of the main characteristics of IrDA infrared communication is the sharp delimited range of acceptable infrared intensity. We use this characteristic both to locate objects inside the footprint of an infrared beam and to allow objects to determine their position.

The CAN bus system is used as backbone because of its flexibility and robustness. The CAN specification allows a bus length up to several kilometers with lower data rates and data rates up to 1 Mbit/s on shorter buses. The CAN protocol can also detect and handle a broad range of errors as loss of termination or shorted data line. In such cases the bus recovers with a reduced transmission speed. This characteristic makes the CAN bus particularly well-suited for use in unsupervised environments. Moreover, the real-time characteristic allows to use CAN for time-critical communication.

Spatial Context Communication

A principle adopted for digital artefact communication is to reflect the spatial relationship of artefacts. RAUM is a communication model based on this principle [Hupfeld & Beigl, 2000]. In this model, a device can define regions of interest in which they communicate; such a region is called RAUM. A RAUM is described as congruent geometric space in the physical world; the geometric space is defined as envelop over all points defining the RAUM. Communication in a RAUM-based system is bounded by the physical locations of the artefacts taking part in the communication; only artefacts that are inside the space of interest are also inside the communication scope.

The RAUM concept is implemented as routing protocol. Artefacts that broadcast messages attach information to it that describes the spatial communication scope. In the Mediacup environment, a simple symbolic model is used for identification of communication spaces. This information is used in the routing process to ensure that messages are only broadcast within the defined scope. While RAUM is conceptually a layer 3 protocol, it is in fact implemented over IP in the Mediacup environment. It should also be noted that RAUM communication spaces are not limited to the physical broadcast range of any medium; different

Figure 3. Artefacts and applications that have emerged in the Mediacup environment. From left to right: Mediacup activity viewer; smart door plate; a PC-based watch; and an IPC-controlled coffee machine.

media can be bridged with RAUM routers that forward messages based on the location of the sender and the defined communication scope.

Spatially-defined communication implies that participating artefacts do not have to know each others identity or capabilities (e.g. their services). Instead communication is solely based on co-location within a well-defined spatial region, with the spatial region serving as mediator for messages. This ensures artefacts can exchange information without being explicitly designed to that end and even without knowing of each others exsitence.

6. EVOLUTION OF THE MEDIACUP ENVIRONMENT

Other networking Artefacts

The Mediacup environment is not made up of coffee cups only. Instead it stadily evolves with introduction of additional digital artefacts and context-aware applications. This reflect the open nature of the artefcat computing model: artefact computing environment are not considered to be developed top down but rather to evolve over time.

Figure 3 shows applications and artefacts that have emerged in the Mediacup environment over the course of our project so far. The Mediacup activity viewer is similar to visualisation found in people locator systems however it has to be noted that the cups are deliberately not personalized; that means the activity view does not relate individual people's activity but the overall buzz within a group as captured by visualization of coffee cup movement and temperature.

The smart door plate is an interactive display for information associated with a room, for instance for the names of the people working in the room, or for events taking place there. With the Mediacup's context locally available, a context-aware application of the smart door plates can emerge: whenever co-located hot cups are present in the room, the door plate indicates that a meeting takes place. This is a small and certainly not far reaching applications, however it is indicative of how new artefacts may have use for other artefact context in evolving environment. The smart door plate is also an example for how a communication of interest is exploited. The doorplates define the rooms to which they are designated as their context communication spaces through which they obtain context from locally present artefacts.

The other artefacts shown in figure 3 are a PC-based watch with infrared that allows users to access digital artefact context directly, e.g. to read the coffee temperature, and a coffee machine that is controlled by a Beck IPC connected to the Ethernet.

7. CONCLUSION AND FURTHER WORK

In this paper we have reported experience from the Mediacup project investigating computer-augmentation of everyday artefacts and communication infrastructure for the evolution of artefact computing environments. Our work demonstrates the feasibility the approach and indicates the potential of augmenting everyday artefacts so they can capture their own context and share it in a networked environment.

One strand of our future research will investigate generic technology for augmentation of everyday artefacts with context-awareness, generalizing the Mediacup experience. The objective is to develop a configurable awareness device that integrates core sensors and perception techniques but that can be dynamically re-configured to compute context specific to an artefact. The vision is that such devices will be small and unobtrusive enough to have them post hoc attached to any kind of artefact, as is now possible with RFID tags. This vision will be approached in the Smart-Its project [Smart-Ist], funded by the European Commission under the Disappearing Computer research initiative.

Another strand of research will be concerned with emerging functionality in artefact computing environments. In our work we observe a shift from top-down developed applications to emerging applications that are gradually enabled by introduction of digital artefacts into an open environment. The research issue is to develop an understanding of how emergence of functionality can be supported through services, architectures and design practice.

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