Ubiquitous Computing

Chapter 9

Overview

- Information and communication devices are becoming so common and so small that they can truly be said to be becoming “ubiquitous” – they are everywhere.
- They may be embedded in walls, ceilings, furniture and ornaments.
- They are worn as jewelry or woven into clothing or they are carried.
- Other technologies such as electric motors are now truly ubiquitous, embedded in all manner of devices.
- The same is happening to computers – except that they also communicate with each other.
- Ubiquitous computing covers several areas of computing including wearable computing, mobile computing (sometimes collectively called nomadic computing) and computationally enabled environments, also called “responsive environments”, and cyber-physical systems.


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Introduction

Ubiquitous computing (also called ubicomp or pervasive computing) is concerned with “breaking the box”; it anticipates the days when computing and communication technologies disappear into the fabric of the world.

This might be literally the fabrics we wear, the fabric of buildings and of objects that are carried or worn.

There may be a mobile phone in your tooth and you might communicate with your distant partner by rubbing your earring.

At the other end of the scale we might have wall-sized flat display technologies or augmented physical environments with graphical objects, or physical objects used to interact with sensor-enabled walls and other surfaces.

HCI and interaction design in ubicomp environments is concerned with many computing devices interacting with many others.

Some History

The original work on ubiquitous computing was undertaken at Xerox PARC (Palo Alto Research Centre) in the early 1990s. It is summed up by one of the main visionaries of the time, Mark Weiser.

"Ubiquitous computers will also come in different sizes, each suited to a particular task. My colleagues and I have built what we call tabs, pads and boards: inch-scale machines that approximate active Post-It notes, foot-scale ones that behave something like a sheet of paper (or a book or a magazine), and yard-scale displays that are the equivalent of a blackboard or bulletin board". (Weiser 1991)

The intention was that these devices would be as ubiquitous as the written word, with labels on packaging being replaced by "tabs", with paper being replaced by "pads" and walls by boards. Many of these devices will be wearable and many will be portable.

HCI and ubicomp

- With appliances embedded in walls, implanted in people and so on, human–computer interaction becomes very different and the design of interactive systems extends to the design of whole environments.
- We will input through gestures – perhaps stroking an object, perhaps by waving at a board.
- Full body interaction will become possible.
- Output will be through haptics, sound and other non-visual media.
- The applications of this technology are many and visions include new forms of learning in the classroom of the future, augmenting the countryside with objects and placing devices in airports, university campuses and other community projects.

Full Body Interaction

- Full body interaction concerns the wide range of techniques that can be used to track body movement in a space and how those movements can be interpreted.
- Many games and home entertainment systems make some use of body movement.
- For example there are dance games that track the players dance movements and games for the Wii utilize movement.
- In these cases the player holds an infra-red sensor that provides input and movement of the body may also be tracked through a camera.
- Other systems make use of multiple sensors attached to the body allowing more accurate tracking of movement and have been used in applications such as physiotherapy at home where the patient matches correct exercises with an on-screen character.
- More sophisticated system require a whole room to be equipped with sensors and tracking devices so that complex movements such as dance can be monitored and used as input.

Ambience Intelligence (AmI)

Philips (2005) describe the main characteristics of AmI systems as:

- Context awareness: the ability to recognize current situation and surroundings.
- Personalized: devices customized to individuals.
- Immersive: improving user experiences by manipulating the environment.
- Adaptive: responsive environments controlled through natural interaction.
- In the AmI vision, hardware is very unobtrusive.
- There is a seamless mobile/fixed web-based communications infrastructure, a natural feeling human interface and dependability and security.

Seamful Interaction

- In contrast to the idea of seamless ubicomp, Matthew Chalmers and others have suggested the opposite may be a better design principle.
- Ubicomp environments inevitably contain a degree of uncertainty.
- For example locations can often not be determined with absolute certainty or accuracy.
- Rather than the system pretending that everything is as it seems, we should design so that the seams of the various technologies are deliberately exposed.
- People should be aware when they are moving from one area of the environment to another.
- They should be aware of the inaccuracies that are inherent in the system.
- This allows people to appropriate technologies to their needs (i.e. take advantage of how the technology works) and to improvise.

Fluid Interfaces

- At the MIT media lab the Ambient Intelligence Group has recently changed its name to "fluid interfaces" to reflect the relationships between ubiquitous and mobile computing.
- One of their projects is the Engine-Info Application, where miniature devices (including microprocessor, LEDs, Infra-Red transmitters and receivers) were placed on engine components, and could be interrogated to give information about their function (Merrill & Maes, 2007).
- People could select components by gaze, and the devices' LEDs flashed to gain attention, but the most interesting aspect was voice audio, which allowed people to have a 'conversation' with the engine to learn about its operation.

Cyber-Physical Systems

- These are another form of these ambient environments where the physical world is augmented with computational devices that are often enabled through Wireless Sensor Networks (WSN).
- A WSN is an interconnected network of computing devices.
- A node on a WSN contains (at least) a computer processor, one or more sensors and some communication ability.
- Some WSNs are fixed, but others include mobile elements that can quickly join and leave networks and networks that can configure themselves to suit different contexts (ad hoc networks).
- The smart-dust project was pioneering in the field of wireless sensor networks and is currently one of the most advanced projects has resulted in the production of WSN nodes called MOTES.
- The Speckled Computing project has developed Specks (nodes in a speckled WSN) that will have a full transceiver and “Specknets” are intended to be decentralized and ad hoc.

Other Examples

- Nanotechnologies are computing devices that are the size of molecules and could enter the body, repairing damaged functions such as eyesight.
- Nanotechnologies are already with us, helping to create new self-cleaning fabrics, for example..
- “SensorTags” and “Smart Pebbles” use a form of technology that follows the principles of static RFID tags; they gain power from an external source via electromagnetic induction).
- When a “reader” passes in close proximity (either hand-held, mounted on a vehicle etc), the device gains enough power to transmit its unique ID and sensor reading.
- Siftables from MIT are small bricks that form networks and can be applied to a wide range of applications.

Responsive Environments

- Responsive environments is a term used for systems that combine art, architecture and interaction in novel ways at the boundary of new interactive technologies.
- Lucy Bullivant surveys the field under chapter headings such as interactive building skins, intelligent walls and floors and smart domestic spaces.
- At the MIT Media lab the responsive environments group is more concerned with exploring future environments from a functional rather than artistic perspective.
- The ubiquitous sensor portals project consists allows live real time linking between the Media Lab and a virtual laboratory space in the virtual world, Second Life.
- Another project uses RFID tags to monitor the movement of cargo.
- This approach to automatic monitoring is widely used.
- For example cattle can be monitored as they move through field gates.

WSNs Summary

- Devices can adapt to the specific context of use (context aware computing).
- Devices can spontaneously join networks or form themselves into networks.
- Although WSN (wireless sensor network) technology is relatively young it would be wrong to assume that there are only small scale deployments. For example ARGO is a global network with an intended 3000 sensors that will monitor salinity, temperature, fresh water storage etc. of the upper layers of the oceans, and transmit results via satellite.
- Ubiquitous computing can be on a world-wide scale as well as in local environments.

Information Spaces

- Ubicomp environments all share the fact that information and interaction is distributed throughout the information space.
- In physically distributed ubicomp environments information and interaction is distributed through physical space as well.
- Moreover, many ubicomp environments will include objects that are not computing devices at all.
- The physical architecture of an environment will affect the interaction as will the existence of signs, furniture and other people.
- In order to understand this wider context it is useful to introduce concept of an information space.

Information Spaces (cont..)

- Three types of object are found in information spaces; agents, devices and information artifacts.
- Devices include all the components of a space that are not concerned with information processing (such as furniture) and those that can only receive, transform and transmit data.
- Devices do not deal in information. Things like buttons, switches and wires are devices. Communication mechanisms are devices as are the other hardware components that constitute the network.
- Information artifacts (IAs) are systems that allow information to be stored, transformed and retrieved. An important characteristic of IAs is that the information has to be stored in some sequence and this has implications for how people locate a specific piece of information.
- We also identify a third type of object that may be present in an information space, agents. Agents are systems that actively seek to achieve some goal.

Information Spaces (more..)

- Information spaces allow people to plan, manage and control their activities. Information spaces provide opportunities for action.
- Sometimes information spaces are designed specifically to support a well-defined activity, but often activities make use of general-purpose information spaces and information spaces have to serve multiple purposes. e.g. the signage system in an airport consists of some devices (e.g. display devices, cabling, gates, communication mechanisms, chairs, etc.) some information artifacts (e.g. TV monitors showing the times of departures and arrivals, announcements made over a system of loudspeakers, signs showing gate numbers, etc.) and some agents (e.g. people staffing an information desk, people checking boarding cards).
- A university campus makes use of physical signs to provide information along with electronic forms of information on the web site and delivered through wi-fi communications.
- In a modern vineyard sensors are spread around the vineyard, there is a central database of sensor readings. The manager of the vineyard may use a mobile device to interact with the database or with the sensors in situ.
- Note that in the information spaces people undertake several different activities and no activity is supported by a single information artifact.

Navigation

- A key feature of information spaces is that people have to move from one IA to another; they have to access devices and perhaps other agents.
- They have to navigate through the information space.
- In the case of an airport, or other distributed information space, people need to navigate between the different objects: the agents, information artifacts and devices that constitute that space and physically move through the geographical space.
- This raises many issues for people interacting with ubiquitous computing, particularly as the computational devices become increasingly invisible. It is difficult to know what systems and services exist.

Sketching Information Space

- Sketches of information space can be used to show how the information is distributed through the components of a space.
- Activities are rarely correlated one-to-one with an information artifact.
- People will need to access various sources of information in order to complete some activity.
- Importantly, some of that information may be in the heads of other people and so sketches of information space should show whether this is the case.
- People can be treated as “information artifacts” if we are looking at them from the perspective of the information they can provide.

Distributed Information Space

- Increasingly designers are concerned with developing information spaces that surround people.
- In the distributed information spaces that arise from ubiquitous computing, people will move in and out of spaces that have various capabilities.
- We are already familiar with this through the use of mobile phones and the sometimes desperate attempts to get a signal.
- As the number of devices and the number of communication methods expands, so there will be new usability and design issues concerned with how spaces can reveal what capabilities they have.
- The sketching method is useful and we have used it in the redesign of a radio station's information space, lighting control in a theatre and navigation facilities on a yacht.

Information Architecture of Information Spaces

- In designing information spaces, interaction designers need to think about the whole experience of the interaction, about the trajectories of the experiences and the information architecture of the whole space.
- In ubicomp environments information architecture is truly in three dimensions .
- Recall that information architecture is concerned with the structure and organization of objects in an interactive system.
- The first thing designers must do, then, is to decide how to conceptualize the domain; they need to define an ontology.
- The ontology – the chosen conceptualization of a domain – is critical and will affect all the other characteristics of the information space.

Ontology - Tradeoff

- Deciding on an ontology for some domain of activity is deciding on the conceptual entities, or objects, and relationships that will be used to represent the activity.
- Choosing an appropriate level of abstraction for this is vital as this influences the number of entity types that there are, the number of instances of each type and the complexity of each object.
- A *coarse-grained ontology will have only a few types of object, each of which will be 'weakly typed' – i.e. will have a fairly vague description – and hence the objects will be quite complex and there will be a lot of instances of these types.*
- Choosing a *fine-grained ontology results in a structure which has many strongly typed simple objects with a relatively few instances of each. In a fine-grained ontology the object types differ from each other only in some small way; in a coarse-grained ontology they differ in large ways.*

Organizing the files in your office

- Some people have a fine-grained structure with many types (such as Faculty Research Papers, Faculty Accommodation, Faculty Strategy, etc.) whilst others have a coarser structure with only a few types (such as Faculty Papers).
- These different structures facilitate or hinder different activities.
- The person with the fine-grained ontology will not know where to put a paper on Faculty Research Accommodation, but will have less searching to do to find Minutes of April Research Committee.
- For example: In my office I have a large pile of papers. This makes filing a new paper very easy – I just put it on the top but it makes retrieval of specific papers much more time-consuming. My colleague carefully files each paper she receives, so storage takes longer but retrieval is quicker.

Designing Information Spaces

- The key thing is to achieve a good relationship between
- the conceptual structure (the ontology).
- the physical characteristics of the interfaces and display objects.
- the activities that people are doing.
- Inevitably there will be trade-offs arising from the constraints of technologies and how the many different activities that people are undertaking can be supported by the information space design.
- Understanding key aspects of the information space (as it is *designed, note – not as it is) will help designers avoid major problems. These characteristics are discussed below.*

Features of Information Spaces

- Volatility - concerned with how often the types and instances of the objects change.
- Given a small, stable space, it is easy to invent maps, or guided tours to present the contents in a clear way. But if the space is very large and keeps changing then very little can be known about how different parts of the space are and will be related to one another.
- Size - The size of an information space is governed by the number of objects which in turn is related to the ontology.
- A fine-grained ontology results in many object types with fewer instances of each type, and a coarse-grained ontology results in fewer types but more instances. A larger space will result from a finer-grained ontology, but the individual objects will be simpler.

Volatility Example

For example, consider the information space that supports train journeys.

- The ontology most of us use consists of stations, journeys and times.
- An instance of this might be “The 9.10 from Edinburgh to Dundee”.
- This ontology is quite stable and the space fairly small so the train timetable information artefact can be produced on paper
- The actual instances of the journeys such as the 9.10 from Edinburgh to Dundee on 3 March 2010 are subject to change and so an electro-mechanical display is designed that can supply more immediate information.
- The volatility of the objects (which in itself is determined by the ontology) demands different characteristics from the display medium.

Looking at Size

- Hence the architecture should support locating specific objects through the use of indexes, clustering, categorization, tables of content and so on.
- With the smaller space of a coarse-gained ontology the emphasis is on finding where in the object a particular piece of information resides.
- A fine-grained ontology will require moving *between objects; a coarser grain requires moving within the object.*
- The physical organization of the information artefact and the functions provided to manipulate types and instances will determine how effective the design is.
- Navigating within a large display requires people to use scrolling, page turning and so on to find the information they want.
- On small displays they can immediately see all the information, but only of one part of the whole space.

Conceptual and Physical Objects

- Any information space will be populated by a variety of objects and devices.
- For example, a hospital environment has various information (conceptual objects) such as the patients personal details, medication, operating schedules and so on.
- In addition to these conceptual objects, there are physical/perceptual devices that are used to interact with this space – monitors, hand-held devices used by doctors, RFID tags attached to patients and so on.
- The relationship between physical/perceptual devices and conceptual objects is critical to the design of the space.
- A good mapping between conceptual and physical objects generally results in better interaction.
- This relationship between the conceptual and physical objects and the conceptual and physical operations that are available in the interface objects fundamentally affects the usability of systems.

Topology

- The topology of an information space concerns both conceptual and physical objects.
- The conceptual structure will dictate where conceptual objects are, that is how things are categorized.
- The physical topology relates to the movement between and through physical objects and how the interfaces have been designed.
- In a museum, for example, the conceptual structure will dictate whether things are grouped by type of object (china, jewelry, pottery, clothing, etc.) or by period.
- This is all down to the conceptual information design of the museum – the conceptual topology.
- How they are physically laid out relates to the physical topology.

Distance and Direction

- Conceptual and physical distance results from the conceptual and physical topologies chosen by the designer.
- The notion of distance relates to both the ontology and the topology of the space, with the ontology coming from the conceptual objects and the topology coming from how these are mapped onto a physical structure.
- Issues of distance in turn relate to how people navigate the information space.
- Direction can be important in information spaces, which way should you go to find a specific item in a museum?
- It depends on the ontology and topology, both physical and conceptual.

Other features of information spaces

- Media - Some spaces have a richer representation that may draw upon visual, auditory and tactile properties, while others are poorer. Issues of colour, the use of sound and the variety of other media and modalities for the interaction are important components of the information space.
- Design - If the space has a coherent design it is easier to convey that structure to people. Museums are usually carefully designed to help people navigate and to show relationships between objects. Other spaces have grown without any control or moderation.
- Agents - In some spaces, we are on our own and there are no other people about. In other spaces we can easily communicate with other people or agents and in still other spaces there may not be any people now, but there are traces of what they have done.

Distributed Resources

- Wright, Fields and Harrison (2000) present a model of distributed information spaces called the Resources Model in which they focus on information structures and interaction strategies.
- They propose that there are six types of resource that are utilized when undertaking an activity:
- *Goals describe the required state of the world.*
- *Plans are sequences of actions that could be carried out.*
- *Possibilities describe the set of possible next actions.*
- *History is the actual interaction history that has occurred – either the immediate history or a generic history.*
- *Action–effect relations describe the relationships between the effect that taking an action will have and the interaction.*
- *States are the collection of relevant values of the objects in the system at any one time.*

Resources Model

- These resources are not kept in any one place, but rather are distributed throughout an environment. Wright *et al. (2000) identify four interaction strategies that may be used:*
- *Plan following involves the user coordinating a pre-computed plan, bearing in mind the history so far.*
- *Plan construction involves examining possibilities and deciding on a course of action (resulting in plan following).*
- *Goal matching involves identifying the action–effect relations needed to take the current state to a goal state.*
- *History-based methods rely on knowledge of what has previously been selected or rejected in order to formulate an interaction strategy.*

Home Environments

- The home is increasingly becoming an archetypal ubiquitous computing environment.
- There are all sorts of novel devices to assist with activities such as looking after babies, keeping in touch with families, shopping, cooking and leisure pursuits such as reading, listening to music and watching TV.
- The home is ideal for short-distance wireless network connectivity and for taking advantage of broadband connection to the rest of the Internet.
- Since the „information age‟ came upon us, homes have been invaded by information and communication technologies of various sorts and the impact of these has been examined from various perspectives.
- Indeed it may be better to think in terms of a „living space‟ rather than a physical house, since technologies enable us to bring work and community into the home and to take the home out with us.
- Our understanding of technologies and people needs to be expanded from the work-based tradition that has informed most methods of analysis and design to include the people-centred issues such as personalization, experience, engagement, purpose, reliability, fun, respect and identity (to name but a few) that are key to these emerging technologies.

Resources Model

- Households are fundamentally social spaces and there are a number of key social theories that can be used.
- *Consumption is concerned with the reasons why people use certain products or participate in activities. There are practical, functional reasons, experiential reasons which are more to do with having fun and enjoying an experience, and reasons of identity – both self-identity and the sense of belonging to a group.*
- *Appropriation is concerned with why people adopt certain things and why others are rejected. The household is often a mix of different ages, tastes and interests that all have to live side by side.*
- *Domestication focuses on the cultural integration of products into the home and the ways in which objects are incorporated and fit into the existing arrangement.*
- Venkatesh proposes a framework based around three spaces.

✓ The physical space of the household is very important and differs widely between cultures and between groups within a culture.

✓ The technological space is defined as the total configuration of technologies in the home.

✓ The social space concerns both the spatial and temporal relationships between members of a household.

Smart Homes (Eggen, et al.)

- Home is about experiences (e.g., coming/leaving home, waking up, doing things together, etc.). People are much less concerned with doing tasks. People want to create their own preferred home experience.
- People want technology to move into the background (become part of the environment), interfaces to become transparent, and focus to shift from functions to experiences. Interaction with the home should become easier and more natural.
- The home should respect the preferences of the inhabitants.
- The home should adapt to the physical and social situation at hand.
- The home should anticipate people's needs and desires as far as possible without conscious mediation.
- The home should be trustworthy. Applications should, for example, adequately take consideration of privacy issues. People stress that they should always be in control.

Smart Homes

- Ambience is important; the fabric of the house should contain the technologies so that they are unobtrusive.
- The house needs to be trustworthy and should anticipate needs.
- This is going to be very difficult to achieve because of the inherent problems of agent-based interaction.
- We might also expect that people will be wearing much more technology
- The interaction between what is worn, carried and embedded in the fabric of buildings will bring wholly new challenges.
- Essentially these are the challenges of ubiquitous computing.

Supportive Homes

- Smart homes are not just the preserve of the wealthy.
- They offer great promise for people to have increased independence into their old age.
- With increasing age comes decreasing ability to undertake activities that once were straightforward, such as opening curtains and doors.
- In supportive homes controllers and electric motors can be added into the physical environment to ease the way on some of these once routine activities.
- The problem that arises then is how to control them – and how to know what controls what.
- If I have three remote controls just to watch television, we can imagine the proliferation of devices that might occur in a smart home.
- If physical devices do not proliferate then the functionality available on just one device will cause just as many usability problems.

Navigating Ubiquitous Computing Environments

- Our own work in this area has been concerned with how people navigate through such mixed reality environments – particularly in WSNs that are distributed across a physical environment (Leach and Benyon, 2008).
- Various scenarios have been investigated such as a surveyor investigating a property that has various sensors embedded in the walls.
- Some monitor damp, some monitor temperature some monitor movement and so on.
- In such an environment, the surveyor first has to find out what sensors exist, and what type of things they measure.
- The surveyor then has to move through the physical environment until physically close to the sensors that are of interest.
- Then the surveyor can take readings using a wireless technology such as Bluetooth.

Interacting with a Ubicomp Environment

- We can see the process of interacting with, and navigating through a ubicomp environment in terms of overview, wayfind and interpretation.
- An individual would start by gaining an overview of the distributed data in the network,
- They would then move physically to the location where the data was generated (wayfinding)
- They then view the data in the context of the environment to assist them in their task.
- There may be several resolutions at which data can be viewed; moving through a series of refining searches – physically and digitally shifting perspectives on the network until the required information is discovered.
- Thus people spiral down into more detail of getting an overview, wayfinding, and data gathering.

Tool for Ubicomp Navigation

- Overview can be well-supported through an auditory interface as it is 360 degrees and omindirectional.
- There are many examples of systems that aid wayfinding such as a waypoint system: proceed forewords, turn left, turn right, and make a u-turn.
- These directions were conveyed both graphically on the screen and with vocalised audio (as used in satellite navigation systems).
- Once the people reach the required place an augmented reality system ARTag can be used to display the data.
- Gaze selection was used to allow the display of actual values, to enable interpretation and a menu button was used to make the final selection.
- Dynamic filtering was also included that used a tilting mechanism to select the value range of interest.

Summary

- Computing and communication devices are becoming increasingly ubiquitous. They are carried, worn and embedded in all manner of devices.
- A difficulty that this brings is how to know what different devices can do and which other devices they can communicate with.
- The real challenge of ubiquitous computing is in designing for these distributed information spaces.
- There are a variety of ubiquitous computing environments that may all be considered as information spaces consisting o devices, information artifacts and agents.
- Designers need to think about how they can develop information spaces that indicate different uses and possibilities for action.
- Designers can use a variety of methods for sketching information spaces and where the distributed information should reside.
- Navigation in ubiquitous computing environments requires new tools to provide an overview, assist in wayfinding and display information about the objects using techniques such as AR.