SYSTÈMES UBIQUITAIRES & RÉSEAUX AMBIANTS

UBIQUITOUS SYSTEMS & AMBIENT NETWORKS

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La version française de ce support de cours sera mise en ligne ultérieurement.

SOMMAIRE

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Objectifs

- CE COURS VISE À PRÉSENTER UN PANORAMA DES RECHERCHES FONDAMENTALES ET APPLIQUÉES DANS UN DOMAINE AUX ENJEUX TECHNOLOGIQUES CONSIDÉRABLES : LES SYSTEMES UBIQUITAIRES ET RÉSEAUX AMBIANTS (UBIQUITOUS NETWORKS).
- CES RÉSEAUX SERVIRONT DE SUPPORT À DES APPLICATIONS COMMUNICANTES OFFRANT DE SERVICES NUMÉRIQUES VARIÉS (MULTIMÉDIA, GRID COMPUTING, WEB, ASSISTANCE AUX PERSONNES DÉPENDANTES, ETC).
- FAIRE FONCTIONNER CORRECTEMENT CES RÉSEAUX HÉTÉROGÈNES COMPLEXES (HÉTÉROGÉNÉITÉ DES INFRASTRUCTURES, PROTOCOLES, APPLICATIONS, ETC.) EST UN DÉFI SCIENTIFIQUE MAJEUR POUR LES PROCHAINES ANNÉES.
- UTILISER CORRECTEMENT ET EFFICACEMENT CES RÉSEAUX EST ÉGALEMENT UN DÉFI QUI NÉCESSITE LE DÉVELOPPEMENT DE RECHERCHES DANS LES OUTILS DE COOPÉRATION, LA CONCEPTION D’INTERGICIELS, LA REPRÉSENTATION DE LA CONNAISSANCE EN PARTICULIER LE WEB SÉMANTIQUE, L’INTELLIGENCE DES SERVICES, ETC.

DESCRIPTION

- This course introduces an overview of the field of ***Ubiquitous Computing***.
- Aimed at students who want to explore it as **researchers** or track its evolution.
- Intended for advanced undergraduates students interested in ubiquitous computing research,
- It covers the major fundamentals and research in the key areas that shape the field.
- The field of ubiquitous computing is **simultaneously young and broad**.

DESCRIPTION

- Research papers in the field commonly reference **Mark Weiser**, who famously ***coined the term ubiquitous computing in his Scientific American article in 1991***.
- This is considered the start of the research area, and it has grown to encompass a broad array of technologies since then.
- Although the field is broad, there are **well-established conferences and researchers** devoted to it.
- Ubiquitous computing research can be categorized into three distinct areas where the research is focused:

(1) Systems **(2) Experience** **(3) Sensors**

DESCRIPTION

The three categories and their supporting chapters are:

1. ***Systems***—These chapters focus on *how to build the software support for deploying ubiquitous computing applications.*
   - "**Ubiquitous Computing Systems**" discusses the important issues to consider when building the infrastructure to support ubiquitous computing applications.
   - "**Privacy in Ubiquitous Computing**" explains how to maintain privacy in systems that inherently need to connect with personal devices and information.

DESCRIPTION

2. ***Experience***—These chapters highlight the critical points where ubiquitous computing technologies **touch people**.

   - "**Ubiquitous Computing Field Studies**" shows how to evaluate ubiquitous computing applications in the field.
   - "**Ethnography in Ubiquitous Computing**" details how to observe people and consider how they might use ubiquitous computing technology.
   - "**From GUI to UUI: Interfaces for Ubiquitous Computing**" focuses on moving from the graphical to the ubiquitous computing user interface.

DESCRIPTION

3. ***Sensors***—These chapters show *how systems sense location and analyze and determine context*.

   – "**Location in Ubiquitous Computing**" illustrates how to measure a person's location, one of the most important inputs for ubiquitous computing applications.
   – "**Context-Aware Computing**" explains the use of context to allow ubiquitous computing applications to deliver the right services at the right time.
   – "**Processing Sequential Sensor Data**" details how to effectively process sensor data for location and context.

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I- INTRODUCTION A L'INFORMATIQUE UBIQUITAIRE - UBIQUITOUS COMPUTING

This chapter discusses the history of the field in terms of its major research projects as highlighted by the following contents.

Contents

INTRODUCTION

Ubiquitous Computing, or **Ubicomp**, is the term given to the *third era of modern computing*.

1. The first era was defined by the mainframe computer, a single large time-shared computer owned by an organization and used by many people at the same time.
2. Second, came the era of the PC, a personal computer primarily owned and used by one person, and dedicated to them.
3. The third era, ubiquitous computing, representative of the present time, is **characterized by the explosion of small networked portable computer products in the form of *smart phones*, personal digital assistants (PDAs), and embedded computers built into many of the devices we own—resulting in a world in which each person owns and uses many computers**.

I- INTRODUCTION A L'INFORMATIQUE UBIQUITAIRE - UBIQUITOUS COMPUTING

The **early informative research** in this area began in the *late 1980s* and was pioneered by :

- Xerox Palo Alto Research Center (PARC),
- IBM Research,
- Tokyo University,
- University of California (UC) Berkeley,
- Olivetti Research,
- HP Labs,
- Georgia Institute of Technology (Georgia Tech), and
- Massachusetts Institute of Technology (MIT) Media Laboratory.

I- INTRODUCTION A L'INFORMATIQUE UBIQUITAIRE - UBIQUITOUS COMPUTING

- Many **commercial entities** also began forays into ubiquitous computing during the *1990s*, exploring the **business potential for ubiquitous services, and novel mobile devices** such as pen-based computers. At this time, we also saw the introduction of the
- ***Apple Newton***,
- and the term ***PDA*** was coined.
- Other product examples included the ***EO pad, using GO Pen software***, and later
- the ***Palm Pilot*** (with Graffiti) and the
- ***Sharp Zaurus***;
- ***Fujitsu*** also developed a series of tablet and palm-based devices particularly targeted at vertical markets.
- Later still, MP3 players from ***Archos*** and ***Apple*** also played into this market.

- Today, demonstrating the most convincing evidence of the value of ubiquitous computing,
  - the **cell phone**, or more precisely the "**smart phone**," takes center stage crossing a threshold of
    - processor performance, memory/disk capacity, and connectivity both cellular and local, making it the most widely adopted and ubiquitous computer there has ever been.

- In the remaining sections, we follow the path of research that has defined ubiquitous computing since its beginning, and discuss the various approaches and some of the philosophies that have grown up around the work.

1.1 FOUNDING CONTRIBUTIONS TO UBIQUITOUS COMPUTING

1.1.1 Xerox PARC

- The original term ***Ubiquitous Computing*** was coined by ***Mark Weiser*** ***in 1988 at Xerox PARC***, while serving as the director of the Computer Science Laboratory (CSL), one of five laboratories at the renowned research center.
- *He envisioned a future in which computing technologies became embedded in everyday artifacts, were used to support daily activities, and were equally applicable to our work, managing our homes, and for play.*

FIGURE 1. Xerox PARC—Computer Science Laboratory 1991: Mark Weiser using a Liveboard with a ParcPad visible in the foreground. (Photo courtesy of PARC, Inc., http://www.parc.com)

1.1 FOUNDING CONTRIBUTIONS TO UBIQUITOUS COMPUTING

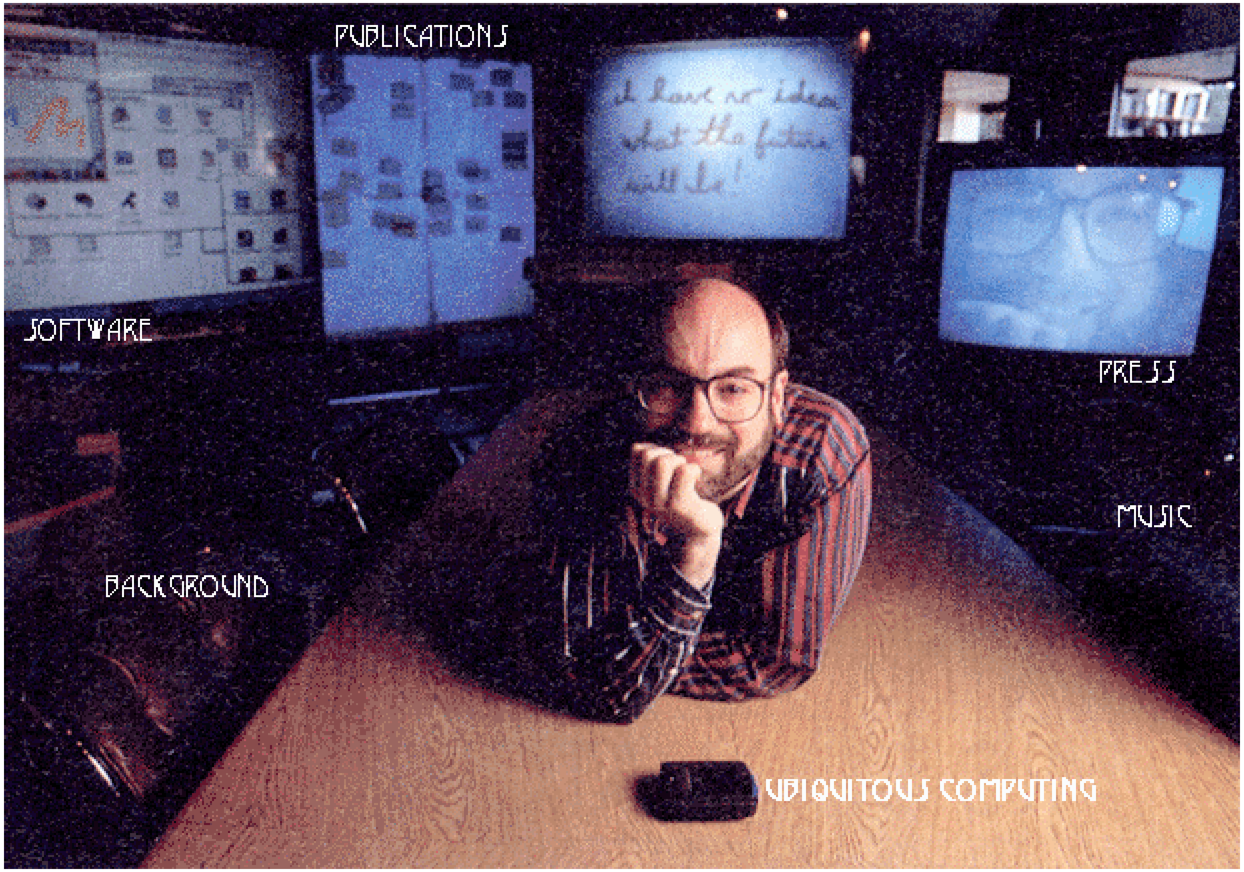
1.1.1 Xerox PARC

- A more complete description of this vision is described on a Web site maintained by PARC summarizing Weiser's work and ideas and can be found at www.ubicomp.com/weiser.
- A concise summary of ubiquitous computing, or ubicomp, as it was originally referred to by researchers at PARC, can also be found in his 1991 *Scientific American* article (Weiser, 1991), which contains his famous quote:

- ***"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it".*** —Mark Weiser

Mark Weiser, "The Computer for the Twenty-First Century," *Scientific American*, pp. 94-10, September 1991

http://sandbox.parc.com/weiser/



1.1 Founding Contributions to Ubiquitous Computing

1.1.1 Xerox PARC

- The essence of Weiser's vision is that mobile and embedded processors can communicate with each other and the surrounding infrastructure, seamlessly coordinating their operation to provide support for a wide variety of everyday work practices.

- A consequence of this approach is that each device needs to limit the range of its communication to enable valuable wireless bandwidth reuse.

- As a result, he introduced the notion of **bits-per-second per-cubic-meter** to the ubicomp vision (Weiser, 1993a), and inspired many researchers to explore techniques for spatial reuse of the radio spectrum.

1.1 Founding Contributions to Ubiquitous Computing

1.1.1 Xerox PARC

In the early 1990s, there were no short-range wireless standards that could provide this capability, but today we have

- **Bluetooth**,
- **Near Field Communication** (NFC),
- **IrDA**,
- **Zigbee**, and
- **WiFi** (soon **WiFi PAN**),

which have enabled wide deployment of devices that take advantage of local ad hoc communication, and can be used to build the **ubicomp** vision.

1.1 Founding Contributions to Ubiquitous Computing

1.1.1 Xerox PARC

- Going beyond technology per se, ***Weiser saw ubicomp as an opportunity to improve on the style of computing that has been imposed on users since the early days of the mainframe also carrying over to PCs*** —namely, sitting in a chair, staring at a screen, typing on a keyboard, and making selections with a mouse.
- Through this style of interaction, traditional computers consume much of our attention and divorce us from what is happening all around us, resulting in a somewhat **solitary all-consuming experience**.
- Weiser believed that in a ubicomp world, ***computation could be integrated with common objects that you might already be using for everyday work practices, rather than forcing computation to be a separate activity***. If the integration is done well, you may not even notice that any computers were involved in your work.
- Weiser sometimes also referred to this as ***invisible computing*** and wrote a number of articles about his philosophy (Weiser, 1993b).
- Another term Weiser used to describe ubiquitous computing was "The coming age of ***calm technology***" (Weiser and Seely-Brown, 1997).

1.1 Founding Contributions to Ubiquitous Computing

1.1.1 Xerox PARC

- Although there is no simple formula to convert a PC application into a calm embedded computing experience, ubiquitous computing takes the opposite philosophy to the PC, which tries to virtualize our world (e.g., the familiar PC desktop and icons representing documents, printers, and trash can).
- Instead, ubicomp pushes the computerized versions of these technologies back into the physical world (Weiser, 1994).
- For example, rather than reading documents on a PC screen in a graphic made to look like a printed page, the objective would be to create a dedicated document reader with an embedded processor that you can hold and use just like a book.
- This is an old idea from PARC originally conceived by **Alan Kay** with his **Dynabook** project, but was later updated by Weiser's vision, making it highly connected and coordinating wirelessly with the surrounding systems.

1.1 Founding Contributions to Ubiquitous Computing

1.1.1 Xerox PARC

- From a **user's perspective**, the experience of using such a device is simplified relative to a PC because it has a dedicated function (a design point sometimes referred to as an ***information appliance***);
- it does not need the complex arrangement of nested menus and control functions required by a generalized computing platform.
- Although this concept has been tested several times in the marketplace, for example, Rocketbook and Softbook, which were not commercially successful, the idea is still being revisited in the marketplace today with Sony's e-reader and Amazon's Kindle.
- Similar to the evolution of the PDA, each generation learns from the failures of the previous generation, and at the same time technology improves, allowing an e-book to more

1.1 Founding Contributions to Ubiquitous Computing

1.1.2 Tabs, Pads, and Liveboards

- Under Weiser's leadership, CSL set out to design and build a ubiquitous computing environment within the confines of the research center.
- PARC has long had a philosophy of "Build what you use, and use what you build" and the ubicomp research theme continued that tradition.
- However, given the **resource constraints of research**, it was necessary to limit the scope of the ubicomp exploration to a manageable set of projects.

- Toward this goal, a guiding philosophy was inspired by the **traditional units of length**.
  - The units ***inch***, ***foot***, and ***yard*** were born out of everyday needs and had a different origin than the more scientifically rationalized ***metric system with the millimeter, centimeter, and meter.***

1.1.2 Tabs, Pads, and Liveboards

Consider how the traditional units came about: they most likely represent significantly different uses from a human perspective.

1. **Yard-scale** *measurements are typically* ***used to measure objects around us that are large and immovable***.
2. **Foot-sized** objects can be held in your hands and carried, but are large enough that they are not likely to be carried with us at all times.
3. **Inch-scale** objects can fit in a pocket and be forgotten about while carrying out other unrelated daily activities.

1.1 Founding Contributions to Ubiquitous Computing

1.1.2 Tabs, Pads, and Liveboards

In other words, these three measurements represent three very different scales of **human interaction**, and define scale transitions for how we interact with the world around us.

If ubiquitous computing systems were built to mimic everyday capabilities that occur at these three scales, any observation of such a system would probably have generic characteristics that would hold true for a much larger set of devices, each falling into one of these categories.

PARC thus embarked on the design of three devices:

1. **ParcTab**, or **Tab**, an inch-scale computer that represented a pocket book or wallet (Want et al., 1995);
2. **ParcPad**, or **Pad**, a foot-scale device, serving the role of a pen-based notebook or e-book reader; and
3. **Liveboard**, a yard-scale device that provides the functionality of a whiteboard.

1.1.2 Tabs, Pads, and Liveboards

1. **Tabs** communicated wirelessly with a *ceiling-mounted basestation* using 10 kbps diffuse infrared signaling.
   - Each room was typically fitted with one basestation providing an infrared wired *microcellular* communication network.
   - Each basestation also communicated through a wired serial connection to a nearby workstation attached in turn to the building's Ethernet, thus providing a connection to distributed services available on the network.

- **ParcTabs** were effectively dumb terminals generating pen/key events in response to user actions, and these were sent to remote applications running on servers attached to the network, resulting in application state changes that sent back screen updates to the Tab displays.

FIGURE 3 (a) Xerox ParcTab a palm (inch-scale) computer communicating using diffuse infrared (IR) signalling;

1.1.2 Tabs, Pads, and Liveboards

2. **ParcPads** employed a similar design approach using a low-bandwidth X-protocol across a radio link, communicating with a basestation through a proprietary short-range near-field radio (Katarjiev et al., 1993).

- The radio basestation was also mounted in the ceiling of each office or laboratory, and had a 3–4 m range, similar to the infrared system but with 25. more bandwidth at 250 kbps.
- The reason infrared was used on the Tabs versus the Pads was that it could be operated at much lower power, and was more suited to the small battery used by the inch-scale ParcTab device.

(b) an infrared transceiver basestation nstalled in the ceiling of each room comprising the ubicomp environment. Note the ring of IR emitters at the edge of the circular board, and four IR detectors at the center pointing in four cardinal compass directions. (Photos courtesy of PARC, Inc., http://www.parc.com)

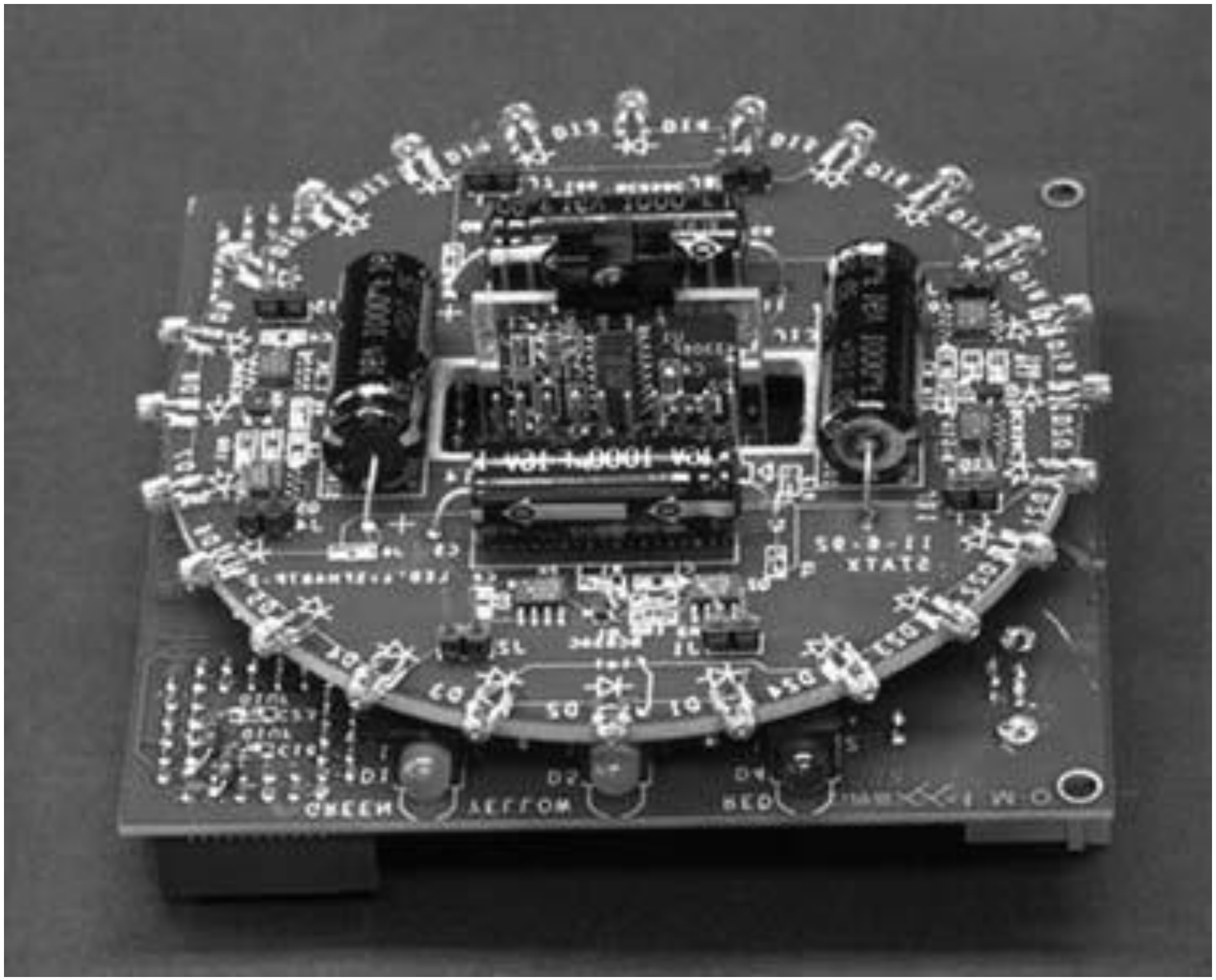
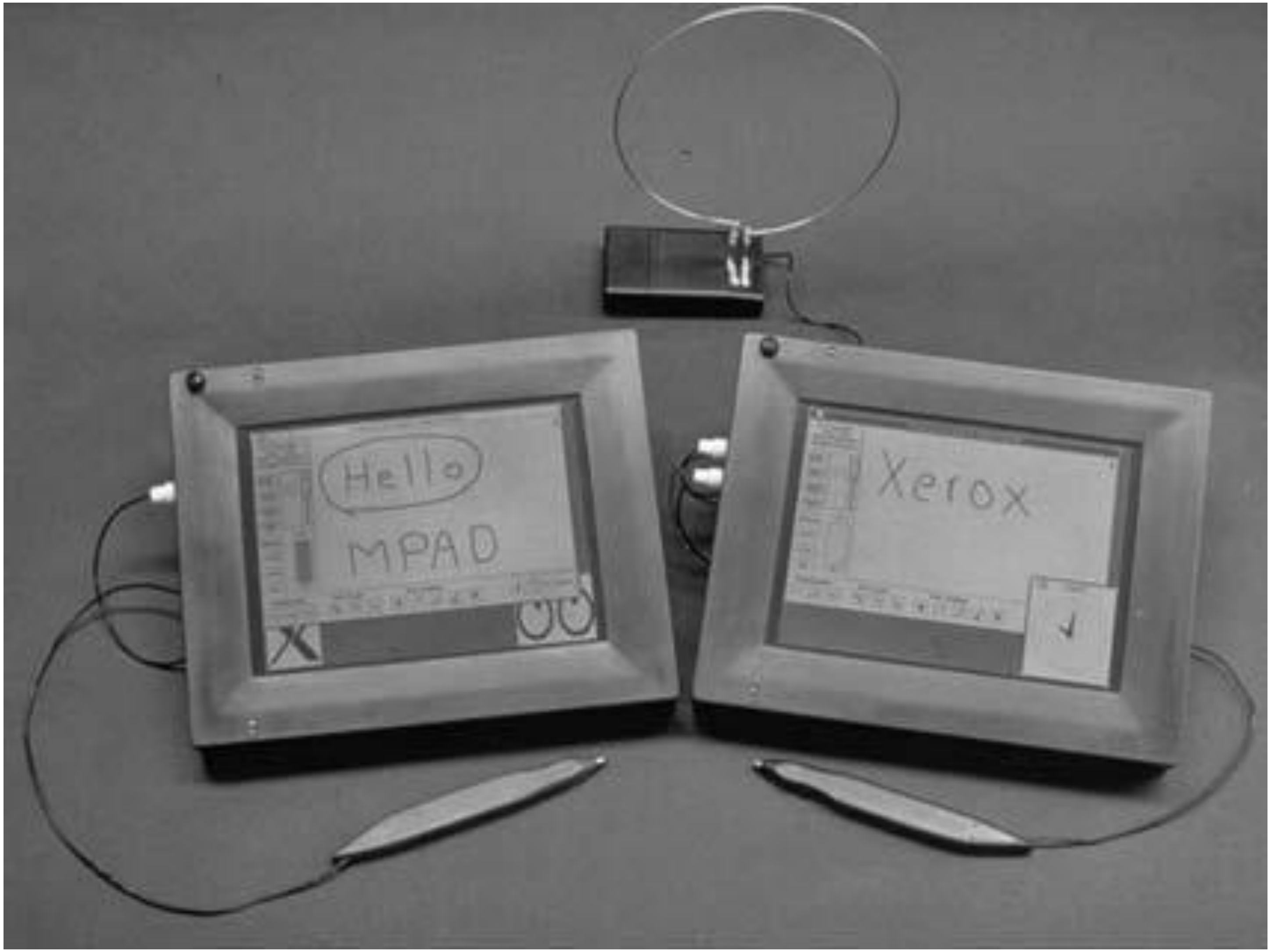
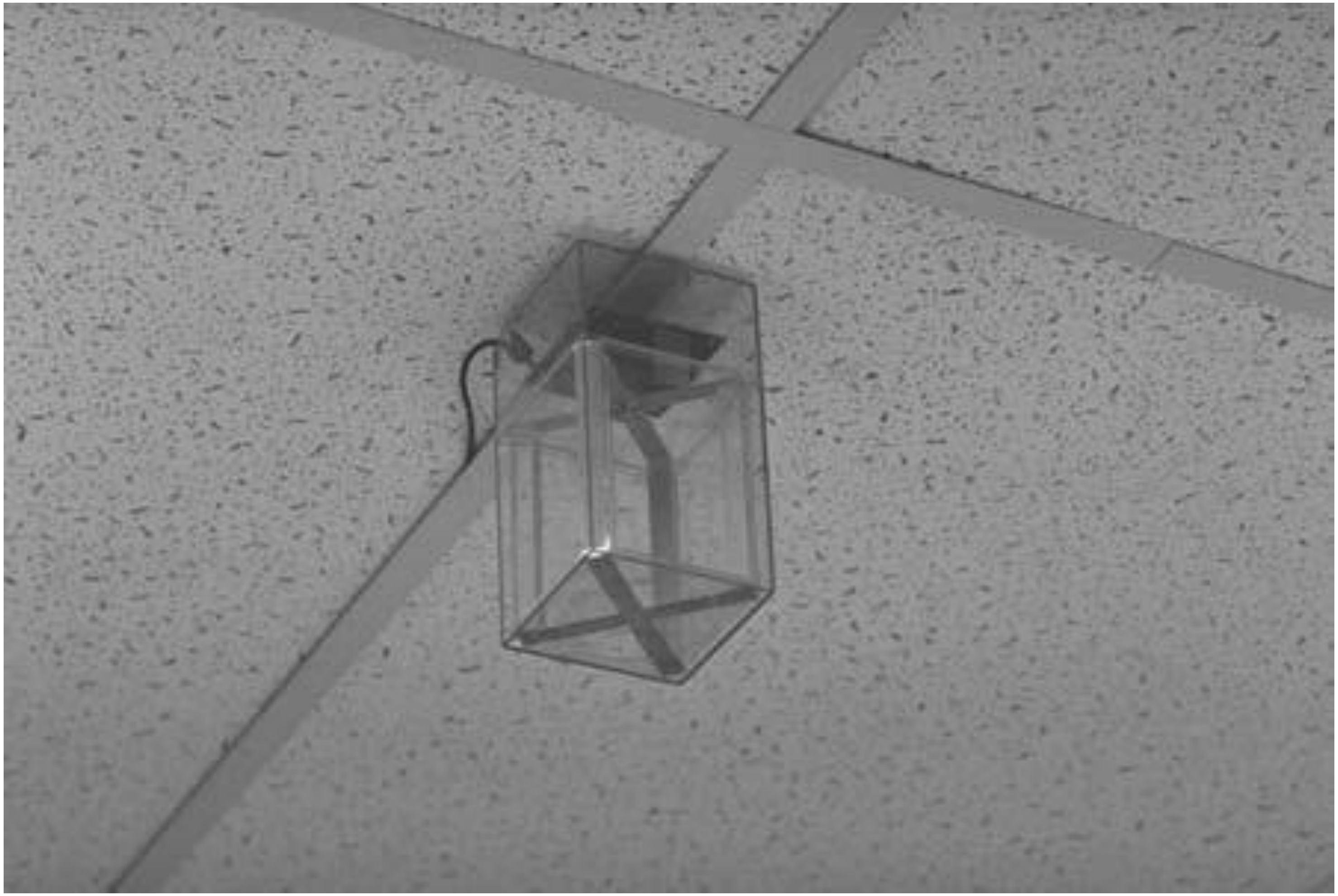


FIGURE 4 (a) The ParcPad, a notebook-sized (foot scale) tablet computer;



(b) the near-field communication basestation mounted on the ceiling of an office at PARC. (Photos courtesy of PARC, Inc., http://www.parc.com)



1.1.2 Tabs, Pads, and Liveboards

3. **Liveboards** were designed around standard computer workstations, but with much larger pen-based displays, and pen-based input.

- At PARC, several of these were deployed at fixed locations around the building and linked by a wired network.
- The display was implemented using a backprojected LCD panel and a 45° mirror to realize the image on a 67-inch frosted display panel.
- For writing and selection, **Liveboard** employed an infrared pen that was tracked across its screen using a four-quadrant infrared sensor mounted in the optical path behind the screen.
- The output of the optical sensor was fed through a calibration table resulting in a representative screen coordinate.
- The primary pen-based interaction software for Liveboard was called **Tivoli**, also developed at PARC, and allowed many unique **pen-centric operations** for the drawing and manipulation of graphical freeform objects (Elrod et al., 1992).

1.1 Founding Contributions to Ubiquitous Computing

1.1.2 Tabs, Pads, and Liveboards

- Although the objective for designing **Tabs, Pads, and Liveboards** was to replace equivalent objects in the workplace by offering similar physical affordances, an equally important goal was to enhance their capabilities relative to the original technology, and thus **make a compelling value proposition for the user.**
- For example, a **conventional whiteboard** allows a teacher to write notes about a lesson which can be captured while interacting with the class.
- However, **Liveboard** provides this as a baseline capability, but adds the option of indexing the pen-based markup with contextual events to make future search and retrieval easier. The annotations and graphics drawn on the board could also be played back using an interactive timeline to support a discussion that revisited earlier topics.

FIGURE 5 A commercial version of the Liveboard, sold by Liveworks in the mid-1990s, which evolved out of the original wooden laboratory prototype developed at PARC (Photo courtesy of PARC, Inc., http://www.parc.com

1.1 Founding Contributions to Ubiquitous Computing

1.1.2 Tabs, Pads, and Liveboards

- At the foot scale, a book is just a single book with no interactive capability, but ParcPad could be potential thousands of books delivered across the network (or recall them from its local disk). It could also support electronic markup through its pen interface, and thus allow for hyperlinked text, word definition look-up, and cross-referencing with other material (all common today through Web interfaces, but not in the early 1990s).
- Last, the ParcTab (replacing the pocket planner), served as a simple Personal Information Manager, but using its infrared network connection ParcTab also supported one of the first wireless pocket email readers. It could also edit documents stored in the network; serves as a remote controller for a room's heating and air-conditioning system; and play games.
- Because the ParcTab was easily carried, it could also serve as a location beacon, and the system could keep track of the Tabs as they moved around.
- This led to the notion of context aware applications (Schilit et al., 1994), which has become a central research theme in many other ubiquitous computing programs today.

1.1.3 Context Awareness

- **Context-awareness** allows applications to comprehend the environment in which they are being used, and adapt their operation to provide the best possible **user experience.**
- A **user** or **device context** is difficult to model because it has **many dimensions**, such as
  - **location**,
  - the **identity of devices close by**,
  - **who else is present**,
  - **the time**, and
  - **environmental factors** such as ***sound***, ***motion***, ***temperature***, ***orientation***, and other physical variables, many of which can be measured through on-platform *sensors*.

1.1.3 Context Awareness

Context awareness can also span multiple levels of system architecture.

- **Operating locally at the device level,** it can take advantage of on-board sensors.
  - For example, inverting a ParcTab detected by an on-board tilt sensor would invert its screen to maintain the orientation of the display.
- **At a higher-system level**, applications could use context to modify their behavior.
  - For example, the ParcTab used an application called a *Proximity Browser*, which provided a user with the option of viewing files that had been accessed at its current location on a previous occasion. The objective was to take advantage of the cache principle: files that had been used at a location in the past were likely to be useful again.

1.1 Founding Contributions to Ubiquitous Computing

1.1.3 Context Awareness

- This summary represents the focus of ubicomp at PARC between 1988 and 1996 when these projects were completed.
- However it has taken ~15 years for
  - the underlying technologies to mature,
  - communication standards to be ratified,
  - and for many of the models to gain traction in the marketplace.
- This is the nature of ubiquitous computing.
- It is very sensitive to the affordances of the devices that technologists are trying to replace and, as technologies advance, whether it **be processor performance per watt, storage capacity, network bandwidth, display resolution, device size, and weight.** Each year more possibilities for the mainstream application of ubiquitous computing open up.

1.1 Founding Contributions to Ubiquitous Computing

1.1.4 IBM Research: Pervasive Computing versus Ubiquitous Computing

- In the mid-1990s, IBM began a research direction it called ***pervasive computing*** (IBM Mobile and Pervasive Computing), which had many similarities to the goals of ubiquitous computing.
- In fact, many texts today describe pervasive and ubiquitous as the same thing. Although the notion of being freed from the desktop computer and building on the opportunities opened up by connected mobile and embedded computers is a theme common to both, in 1991 the connection with **invisible and calm technologies** was a uniquely Xerox PARC perspective.
- However more than 10 years later, any unique position described by either party has been slowly integrated into the shared vision and by the mid-2000s any publications that set out to describe this topic presented fundamentally the same position.

1.1 FOUNDING CONTRIBUTIONS TO UBIQUITOUS COMPUTING

1.1.4 IBM Research: Pervasive Computing versus Ubiquitous Computing

- IBM, to its credit, was one of the first companies to **investigate the business opportunity around pervasive systems, and created a business unit dedicated to the task.**

- One of the first commercial deployments of a pervasive computing system was born from a collaboration between **IBM Zurich and Swissair in 1999** (IBM Swissair), enabling passengers to check-in using Web-enabled (WAP) cell phones.
  - Once the passengers had accessed the service, the phone also served as a boarding pass, showing gate seat and flight departure information, and identifying the traveler as having valid fight credentials.
  - Although this was one of the most publicized projects, IBM also applied these technologies to other service opportunities in **banking and financial services,** gaining early experience in this area.

FIGURE 6. IBM provided Web-based services for Swissair using WAP on a cell phone to create an electronic boarding pass. (Courtesy of IBM Corp.)

1.1 Founding Contributions to Ubiquitous Computing

1.1.4 IBM Research: Pervasive Computing versus Ubiquitous Computing

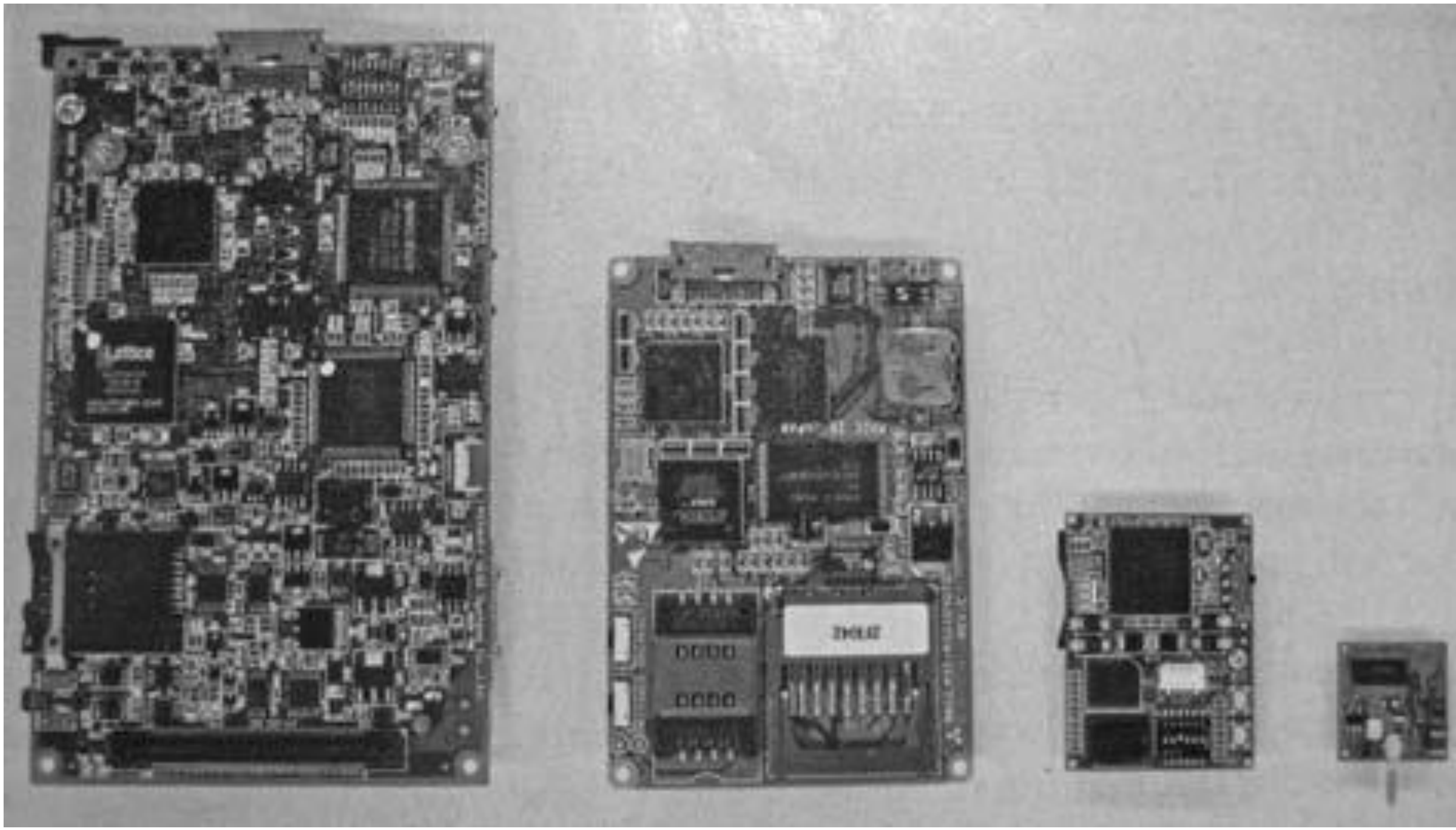
- Ubiquitous computing system-level solutions tend to
  - be **cross-discipline**, and
  - involve the integration of many disparate technologies to meet the original design goals.
- One of the key enablers for pervasive solutions has been the development of **wireless/mobile platforms** running standard operating systems that are already widely deployed in the form of smart phones.
- Today, this has enabled the use of generalized software environments, such as **Web Sphere and the J9 Virtual Machine**, to name two of their well-known software projects.
- The strengths of IBM's system integration have played well together to take advantage of a growing commercial service opportunity around pervasive systems.

1.1.5 University of Tokyo: T-Engine and the ITRON Operating System

On the other side of the Pacific Ocean in the late 1980s, researchers in Japan also realized the time had come for a **new computing paradigm based around embedded systems.**

- **Prof. Ken Sakamura from Tokyo University**, a famous computing architect even before his interest in ubiquitous computing, created the **TRON research program**.
- He developed a series of embedded computing platforms called **T-Engines** that were designed to be embedded in devices ranging in size from mobile electronics to home appliances and smart sensors.
- Sakamura developed **ITRON**, an embedded real-time operating system that was portable across the various scales of T-Engine, and also able to run on a number of commercial platforms (Krikke, 2005).

FIGURE 7. Several examples of T-Engines designed to support embedded computation at various scales of devices from information appliances to sensors. (From Krikke, J., *IEEE Pervasive Computing 4(2), 2005.*



1.1.5 University of Tokyo: T-Engine and the ITRON Operating System

- **ITRON** became very popular because it was an **embedded solution** that unified the development of software between various computer vendors in Japan, and what had been a very fragmented approach to building embedded systems began to coalesce around one design solution.
- The license for ITRON was also attractive to businesses because although it was **open source**, allowing development, improvement, and software additions, any changes did not need to be integrated back into the source tree, and thus given away to competitors.
- Instead, each company could keep these changes as a differentiator for their product.
- Although these advantages served the community, it also led to incompatibilities in some cases, which limited the ability to share and run application code.
- Nonetheless, ITRON has been extremely successful in this market, and has supported a high degree of innovation in mobile and embedded products, all of which teach us lessons about the development of mainstream ubiquitous computing applications.

1.1.6 Hewlett Packard: Cooltown

- The **Cooltown project** (Kindberg et al., 2002) popularized the notion of **linking real-world objects with Web content**.
- The key observation was that every object could have a Web page capable of describing it, such as its name, ownership, origin, and associated network services, etc.
- This technique has clear value in a corporate setting, providing simple ways to configure and interact with networked systems.
- For complex devices such as printers and routers, a Web server can be embedded into the device, and accessed through a network connection (wired or wireless).
- However, there is also an opportunity to provide Web presence for simple, nonelectronic, and unsophisticated objects by attaching electronic tags that encode a unique ID.
- When used in conjunction with a database that maps these unique IDs with information, the combination becomes a powerful tool; this is similar in concept to the “Bridging Physical and Virtual Worlds” project at Xerox PARC in 1998 (Want et al., 1999).
- In Cooltown, the tags were implemented with barcodes or IR beacons, and could contain either the full textual URL or a unique number that could be mapped to the URL in order to access the corresponding server.

1.1 FOUNDING CONTRIBUTIONS TO UBIQUITOUS COMPUTING

1.1.6 Hewlett Packard: Cooltown

Although well suited to a corporate environment in which the efficient coordination and tracking of equipment are important, it can also be generalized to bring advantages to almost any everyday situation by **tagging people, places, and things**.

- A system that
  - has access to the identity of all the people and objects in a particular place also
  - has access to the defining context, and can make inferences about the activities taking place.
- **Cooltown** created a distributed system to represent people, places, and things in the system, and constructed various experimental environments to understand how they could be used to support work practices.
- In addition to work and office situations, Cooltown also deployed its Web presence system in museums and other public exhibits to enhance user experience in that setting.
- The applications of Cooltown provide us with another unique example of how a ubiquitous computing environment can be designed and deployed in the real world.

FIGURE 8. A Cooltown environment at HP Labs, Palo Alto, CA, in which all objects have a Web presence. (Photo courtesy of Hewlett-Packard Corp.)

1.2 UBIQUITOUS COMPUTING IN U.S. UNIVERSITIES

To be continued