Physical-Virtual Integration, Ubicomp Applications & Implications

Friedemann Mattern

ETH Zürich

Outline

- The Vision
- Linking Atoms and Bits
- Bridging the Gap
- Our Contributions
- Applications
- Implications

Outline

- The Vision
- Linking Atoms and Bits
- Bridging the Gap
- Our Contributions
- Applications
- Implications

The Vision

„In the 21st century the technology revolution will move into the everyday, the small and the invisible…"

Mark Weiser (1952 – 1999), XEROX PARC

The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.

The Vision

„In the 21st century the technology revolution will move into the everyday, the small and the invisible…"

Mark Weiser (1952 – 1999), XEROX PARC

- Small, lightweight, cheap, mobile processors and sensors
  - in almost all everyday objects („embedded computing")
  - on your body („wearable computing")
  - embedded in the environment („ambient intelligence")

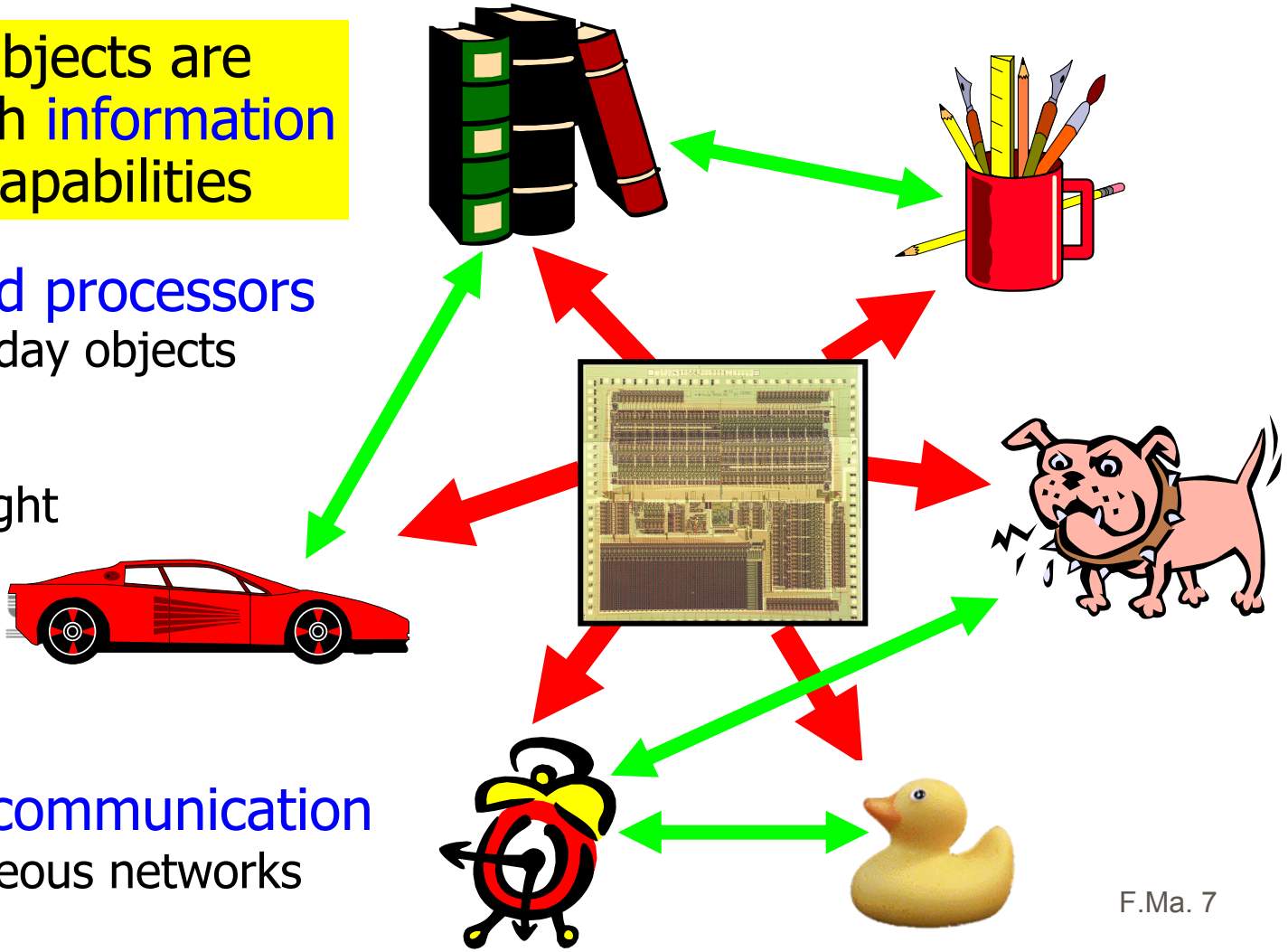
The Vision

- in almost all everyday objects („embedded computing“)

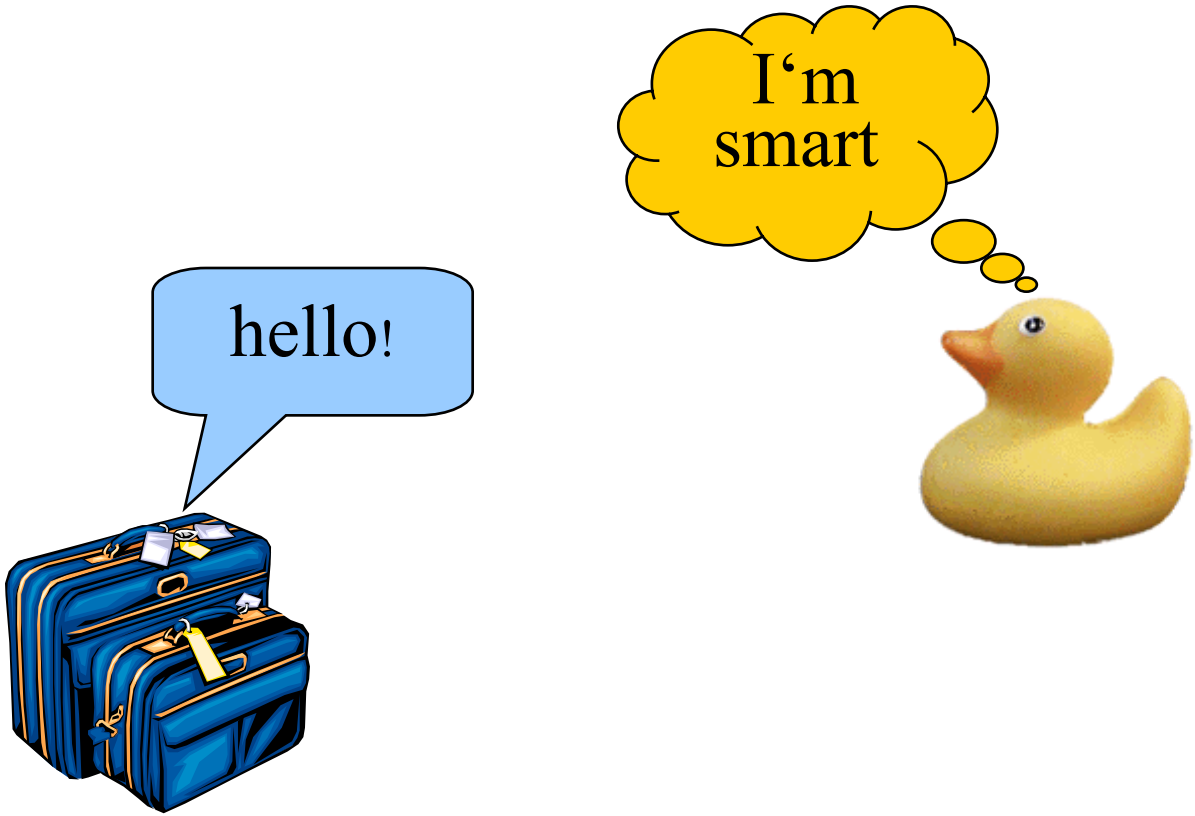
Embedded Computing Enables „Cooperating Smart Things“

Real world objects are enriched with information processing capabilities

1. Embedded processors
   - in everyday objects
   - small
   - cheap
   - lightweight
2. Sensors
3. Wireless communication
   - spontaneous networks



Cooperating Smart Things



The Vision

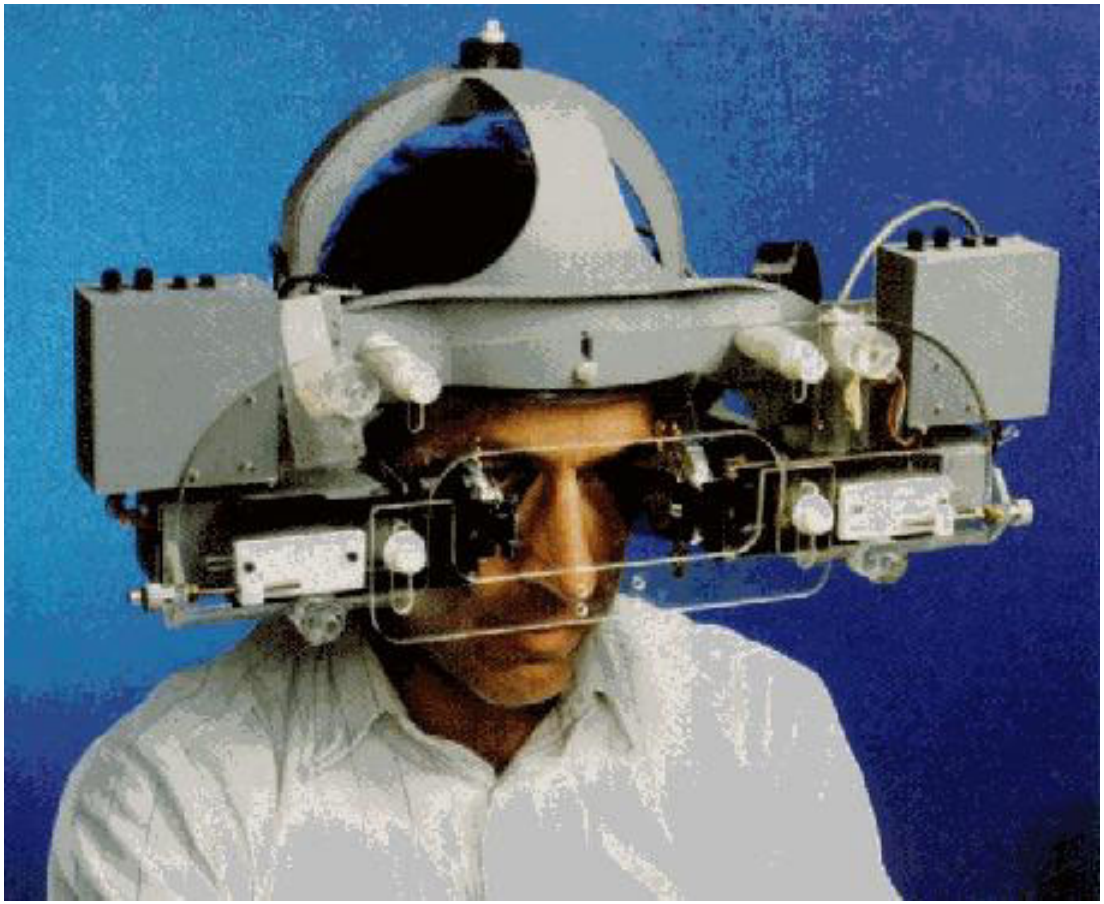
„In the 21st century the technology revolution will move into the everyday, the small and the invisible…"

Mark Weiser (1952 – 1999), XEROX PARC

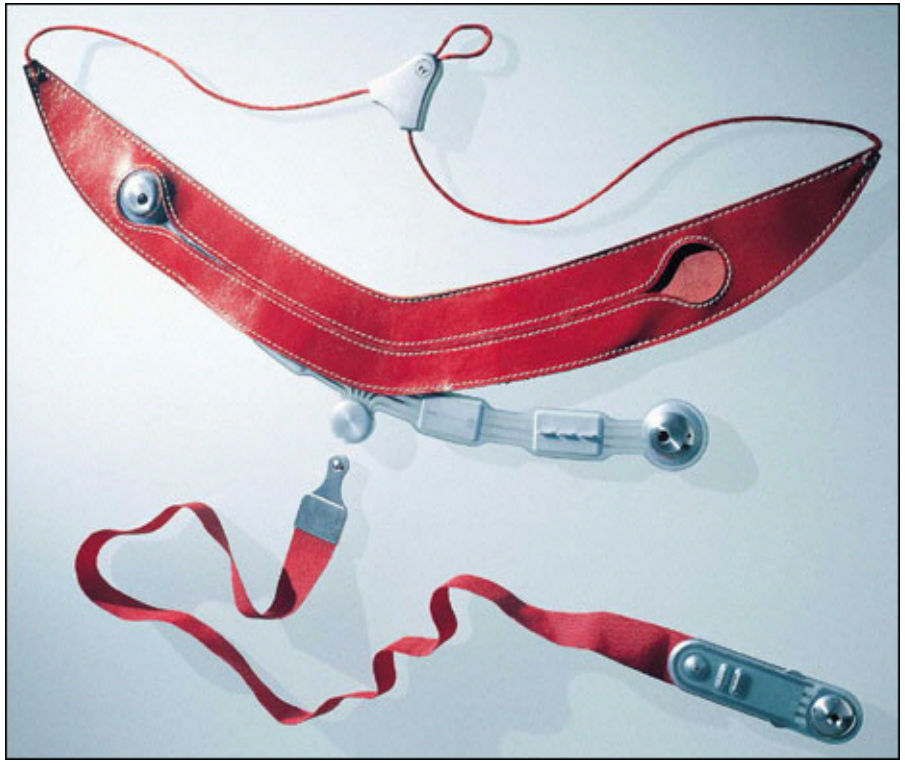
- Small, lightweight, cheap, mobile processors and sensors
  - in almost all everyday objects („embedded computing")
  - on your body („wearable computing")
  - embedded in the environment („ambient intelligence")

- on your body („wearable computing“)

The Pioneers...



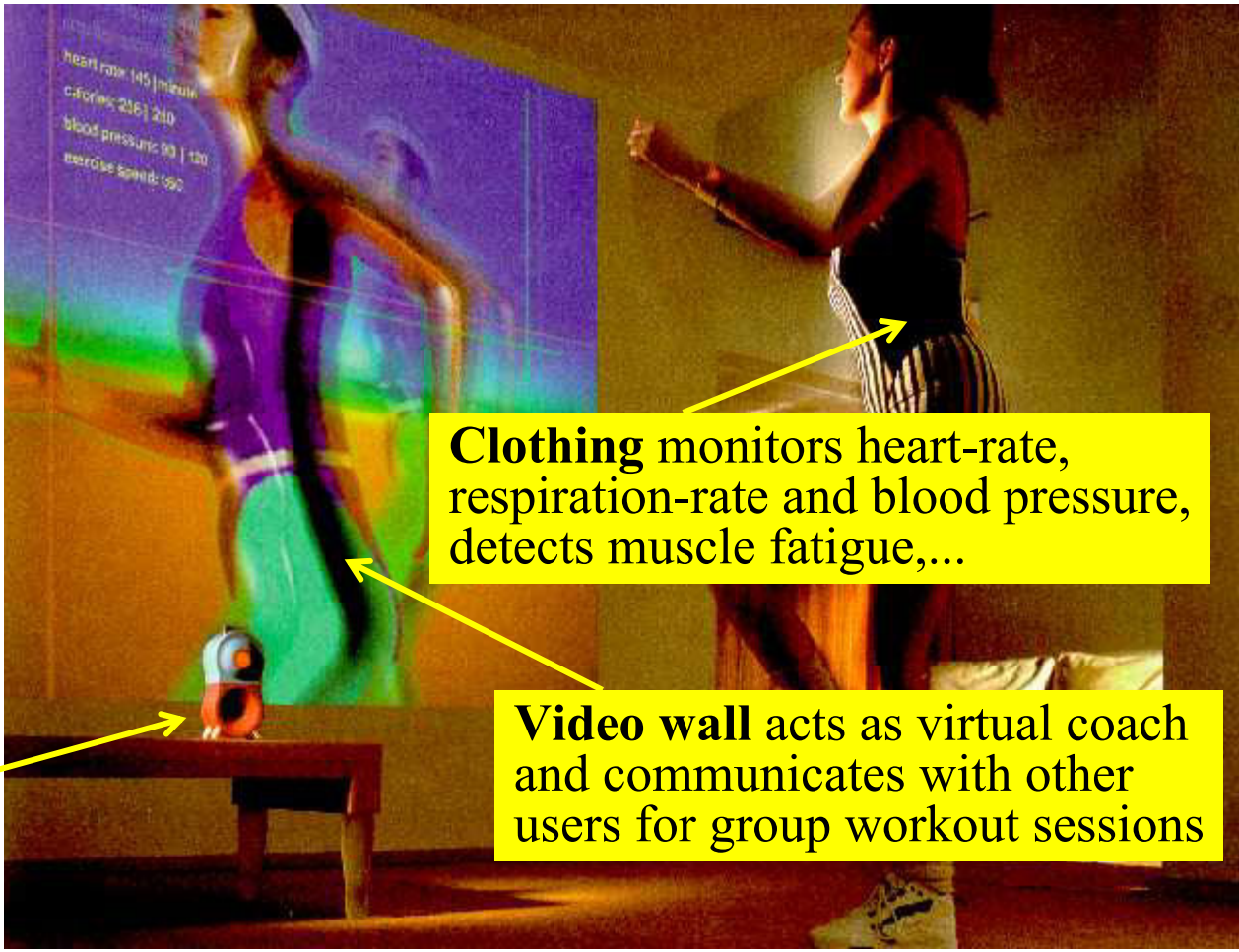
Life Recorder Concept (Motorola)



- embedded in the environment („ambient intelligence“)

Ambient Intelligence

- Seamless environment of computing
- Gesture and speech control
- Adaptive, personalized, anticipatory



Clothing monitors heart-rate, respiration-rate and blood pressure, detects muscle fatigue,...

Video wall acts as virtual coach and communicates with other users for group workout sessions

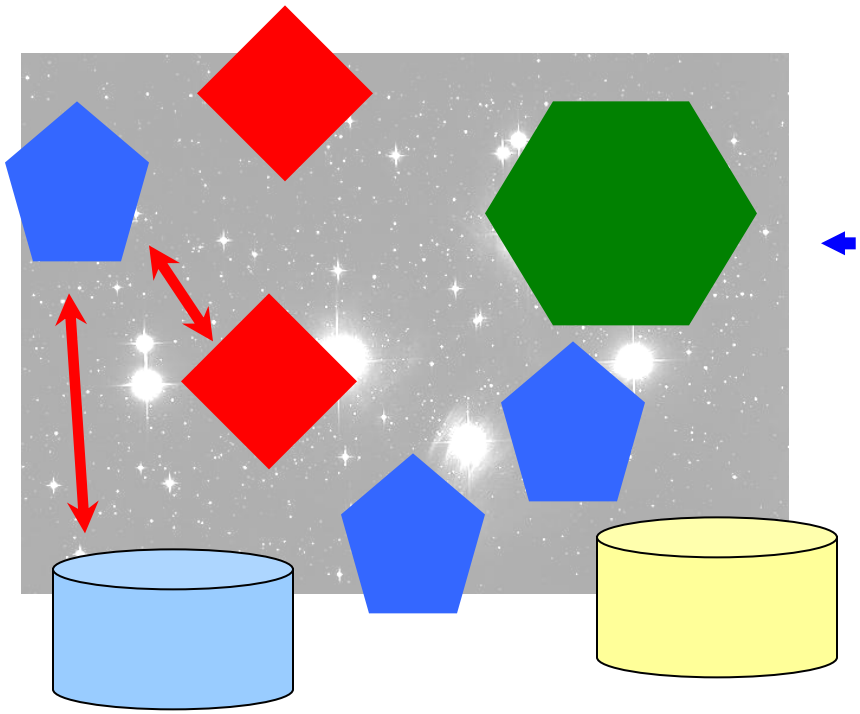
Camera inserts user into the video to highlight excercise pattern and guide workout routines

image source: Phillips

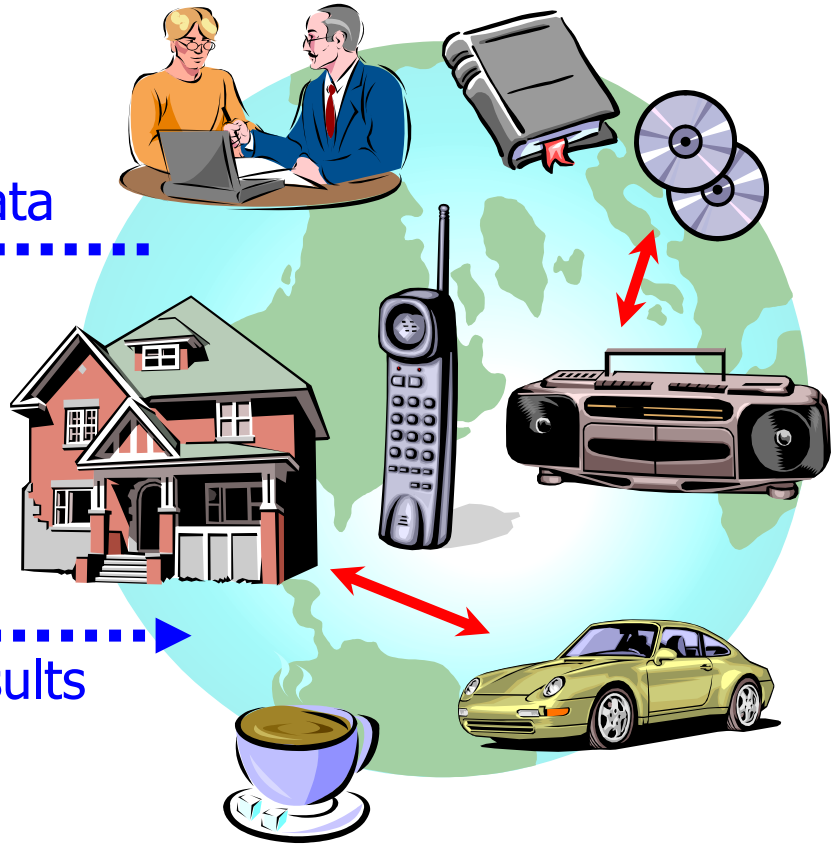
Outline

- The Vision
- Linking Atoms and Bits
- Bridging the Gap
- Our Contributions
- Applications
- Implications

Linking Atoms to Bits



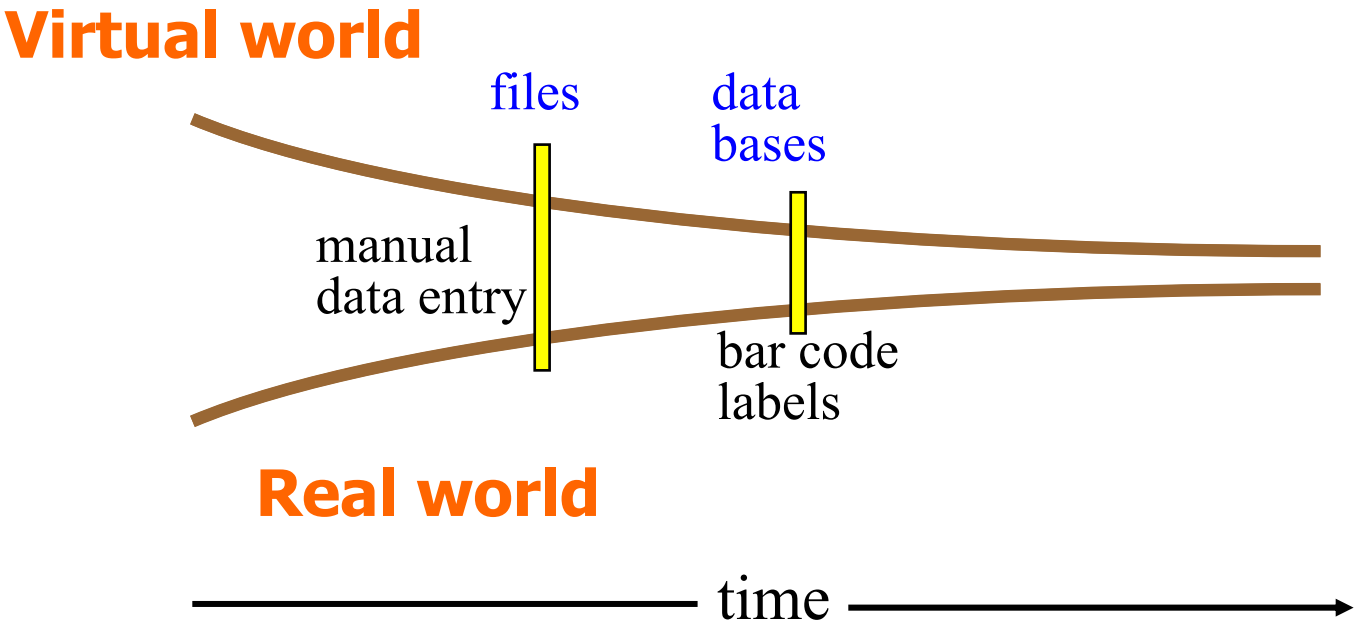
Data



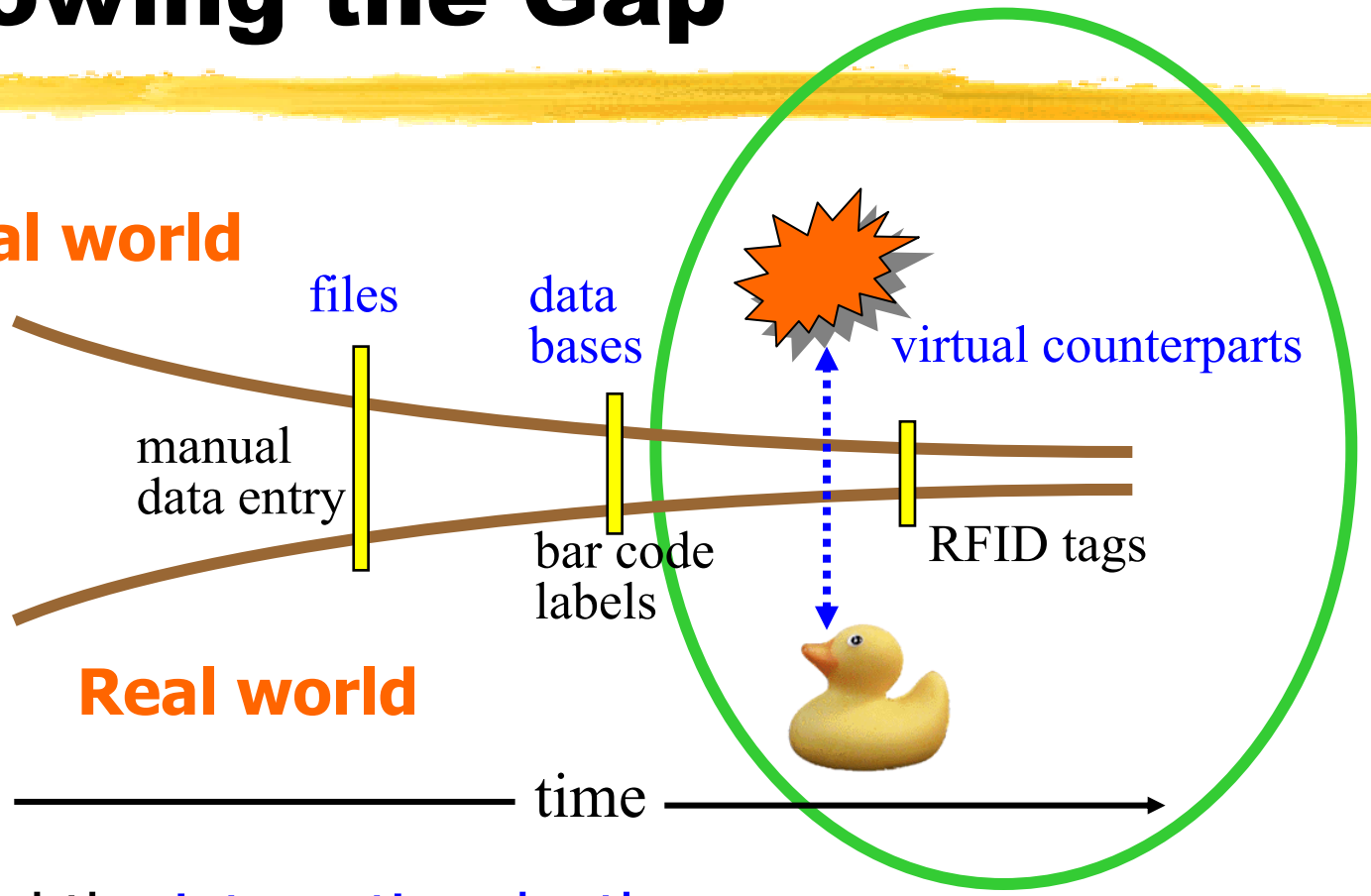
Results

- Data processing
- Information processing
- Simulation
- Virtual Reality

Narrowing the Gap



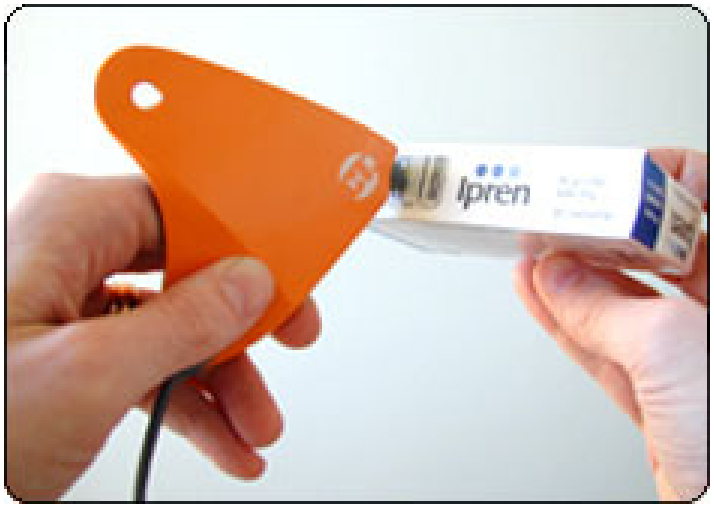
Narrowing the Gap



- Extend the integration depth
  - tie up smart things automatically with information systems
  - avoid media breaks and input errors
  - timely information

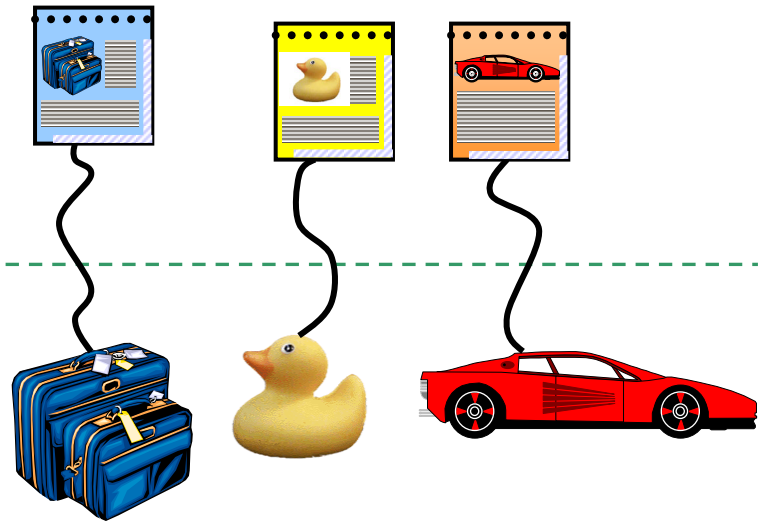
Linking Atoms to Bits

- Connect the real world to the digital world
  - e.g., by using bar code readers or RFID readers

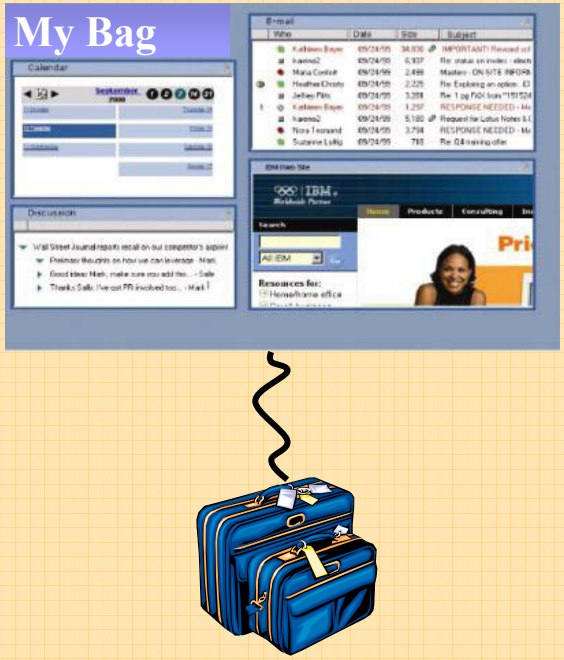


- e.g., transform number to an URL, return associated Web page
- identifies object instance, not object type (e.g., UPC)

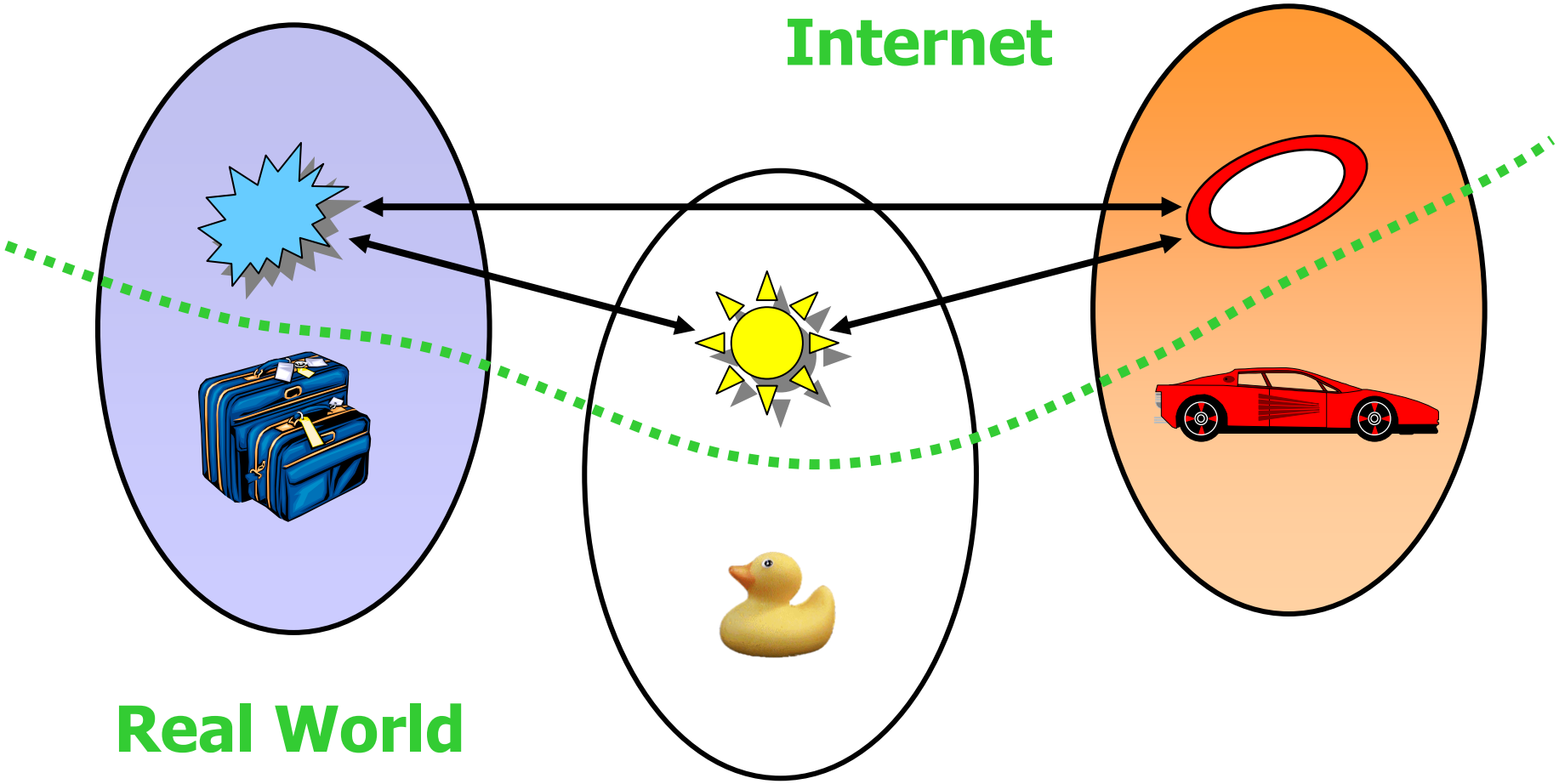
What If Every Object Had Its Own Internet Home Page?



- Or even better - its own portal?

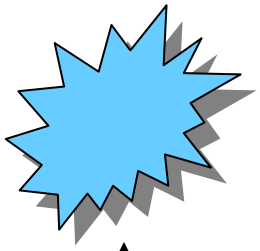


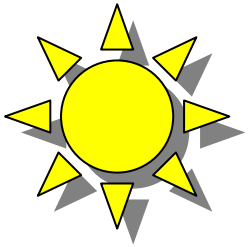
What If Every Object Had a Smart Proxy in the Internet?



Virtual Counterparts of Real World Objects

Virtual world

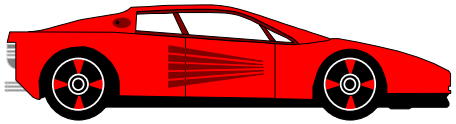




virtual counterparts

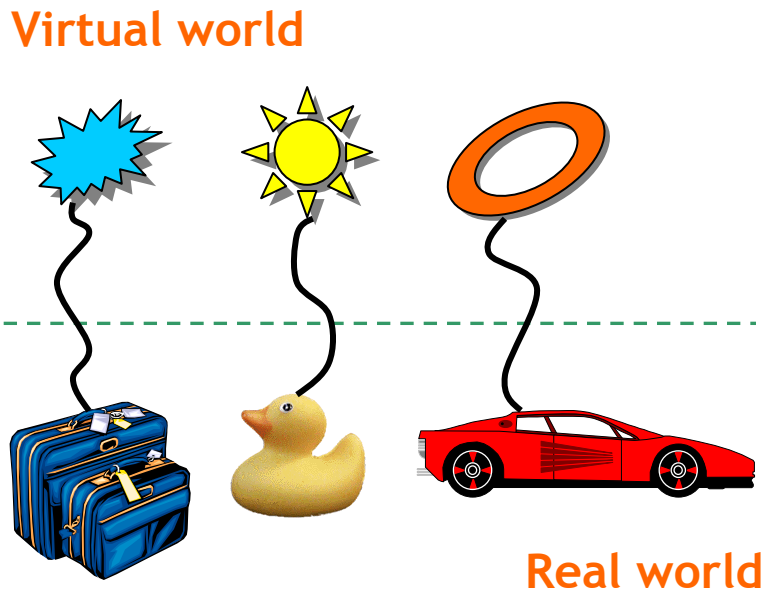
pure virt. object

Real world

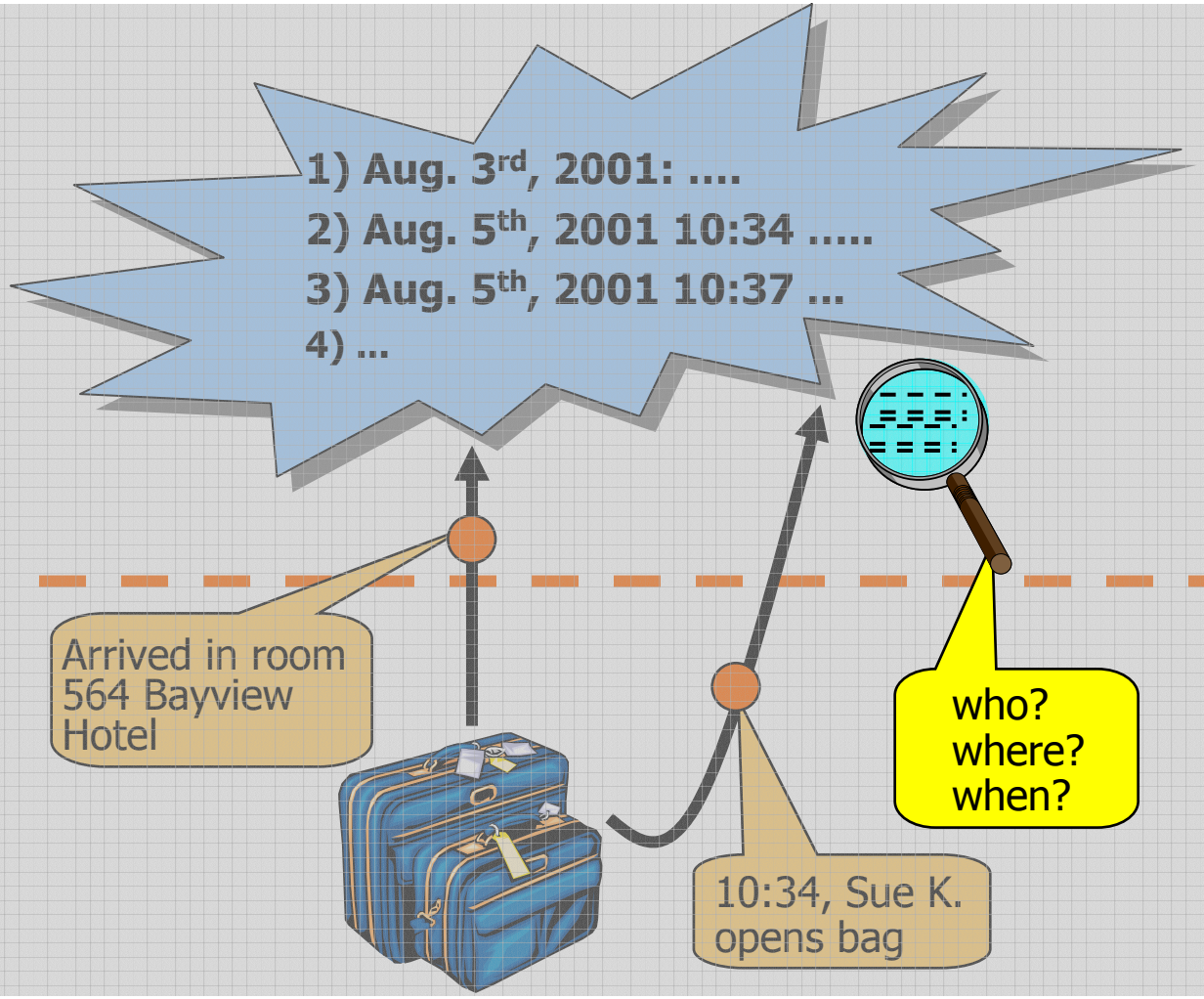


Virtual Counterparts of Real World Objects

- Virtual counterparts represent their real-world artifacts in a virtual world
  - passive („homepage“)
    [e.g., HP‘s Cooltown project]
  - active („proxy“) or
  - service interface („portal“)
- Extend artifacts by information processing facilities
  - embedded processors
  - sensors
  - tagging (bar code, RFID tags)



Virtual Counterparts as Artifact Memories



Virtual counterparts act as memories for their real artifacts

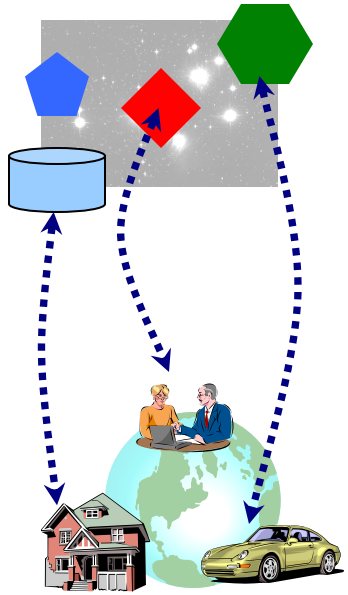
Updates triggered by events

Queries from the real world return memory content

Sensors generate events

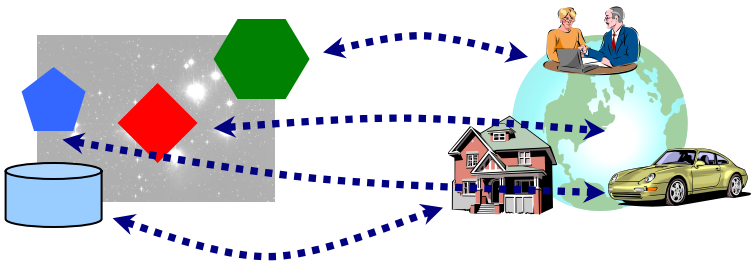
Interactive Physical Objects

- Various techniques for identifying physical objects
  - "bridge" or at least "narrow" the gap
- Identification precondition for coupling of physical objects to virtual counterparts
- Need tools or means that
  - make virtual counterparts accessible or visible
  - allow for interaction with virtual counterpart
- Physical objects become "clickable" and interactive
  - „physical hyperlink" (→ Cooltwon project, HP)



An Old Paradigm, But a New Quality

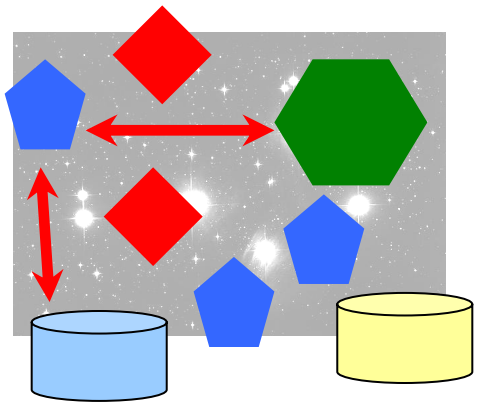
- Classical paradigm: mapping the real world through thoughts, ideas, data collections, bookkeeping, simulation, factory automatization...
- But provide a new view:
  - everything has a unique virtual counterpart
  - bridges are ubiquitous
  - interactions are immediate



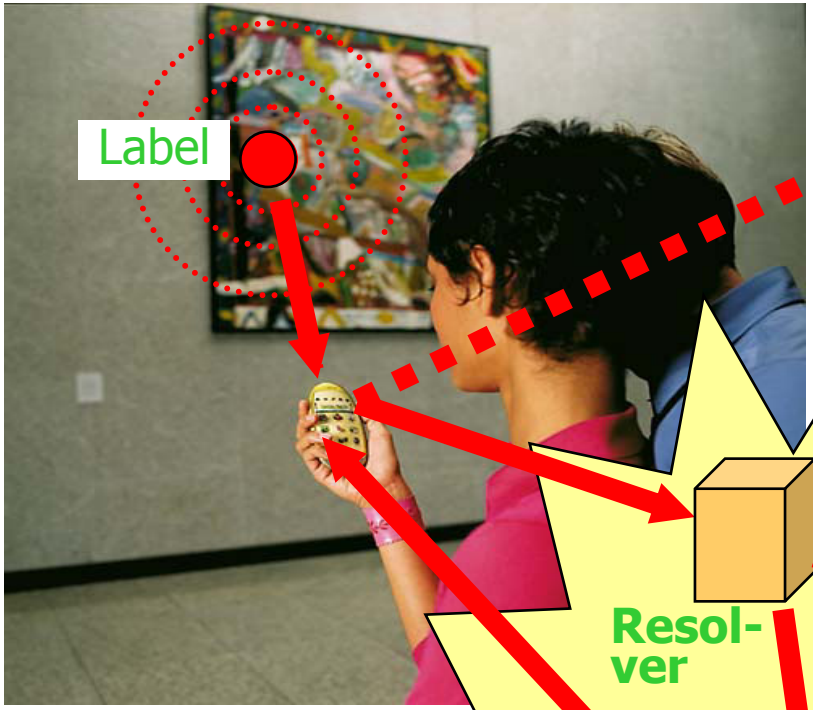
- Actions in one world are reflected in the other
  - real transactions manipulate virtual objects („sensors")
  - virtual actions trigger real-world actors („actuators")

Structure of the „Shadow World“?

- Architecture? Elements? Principles?
  - do object relations reflect an ontology?
  - how are the relations represented?
  - when are new objects created?
- What level of detail is appropriate?
  - depends on purpose and application
- Computer science knows about engineering concepts for virtual structures!
  - design principles, object orientation
  - data structures, information systems
  - knowledge representation, semantics
  - …



The Power of Name Resolving



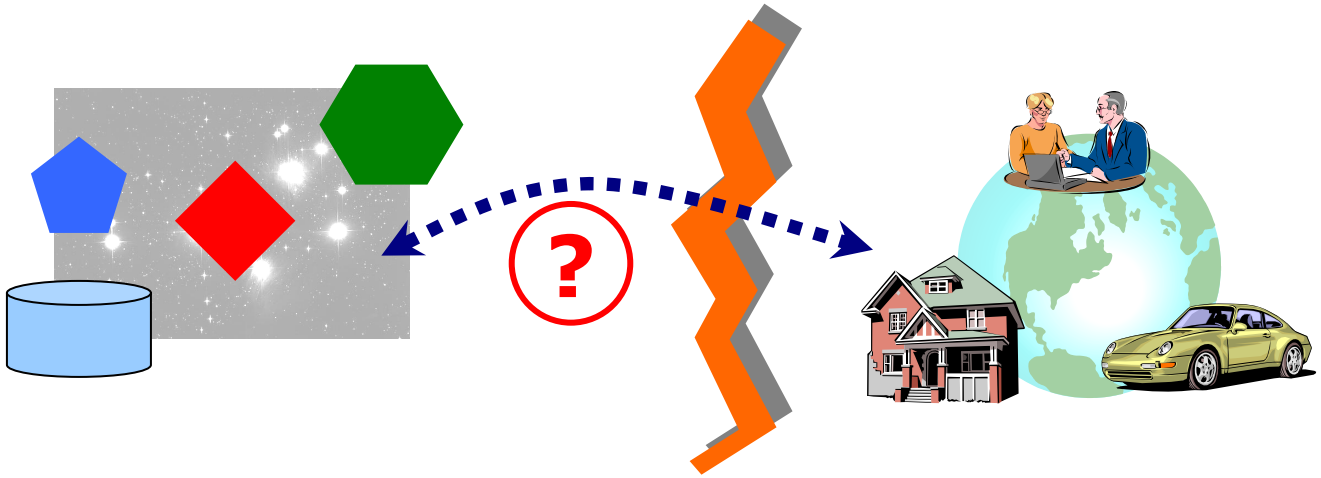
Cf. Cooltown project (HP)

- Who operates resolvers?
- **Who controls information and interpretation?**
- Economic / legal / political issue?

Outline

- The Vision
- Linking Atoms and Bits
- Bridging the Gap
- Our Contributions
- Applications
- Implications

Bridging the Gap Between the Real World and the Virtual World



„Historic“ Example 1: „Bar-Mail“

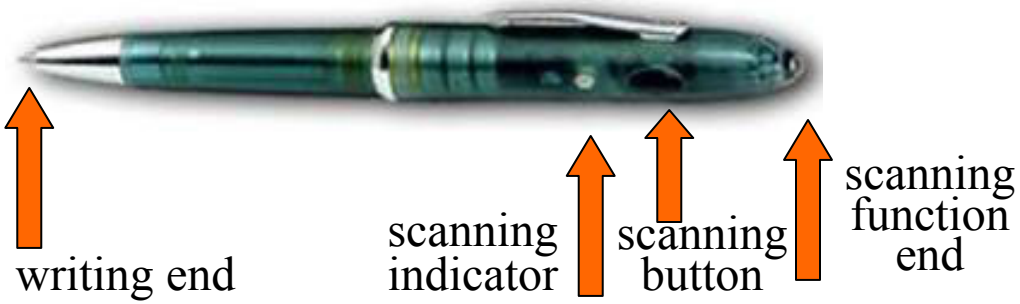
- Barcode reader with memory
  - capacity to store 100 codes
- Stand-alone or connected to mobile phones
- Send codes via SMS to bar-mail server
  - www.bar-mail.org
  - server sends back e-mail
- Company founded 1997 with help from Ericsson
  - June 2000: Motorola investment
  - what happened to it?
- Filed for protection for "from atoms to bits and back again"

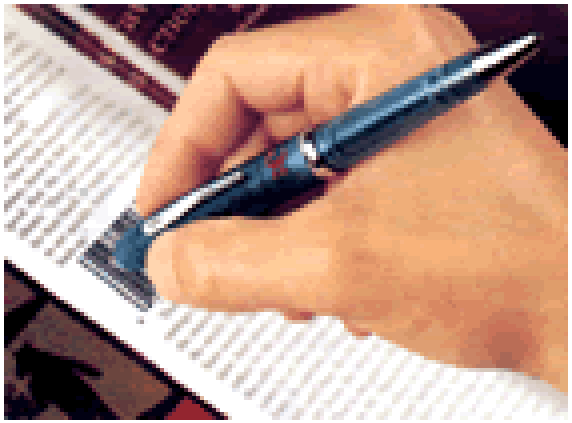
„Reading“ Tagged Artifacts – Barcodes as Physical Hyperlinks

Current technology:

- Phone attachments
  - scan document or artifact
  - retrieve content (e.g., via WAP)
  - possible use: show information content, store calendar entries, place calls, play tunes, ...
- Memory scanners (e.g., Symbol CS2000)
  - connect to PC
  - retrieve content from the Internet
- Compact flash-card barcode scanners
  - wireless content retrieval (WLAN, Bluetooth)
  - possible use with PDA etc.: show Web document,...

Example 2: „Cross Convergence“



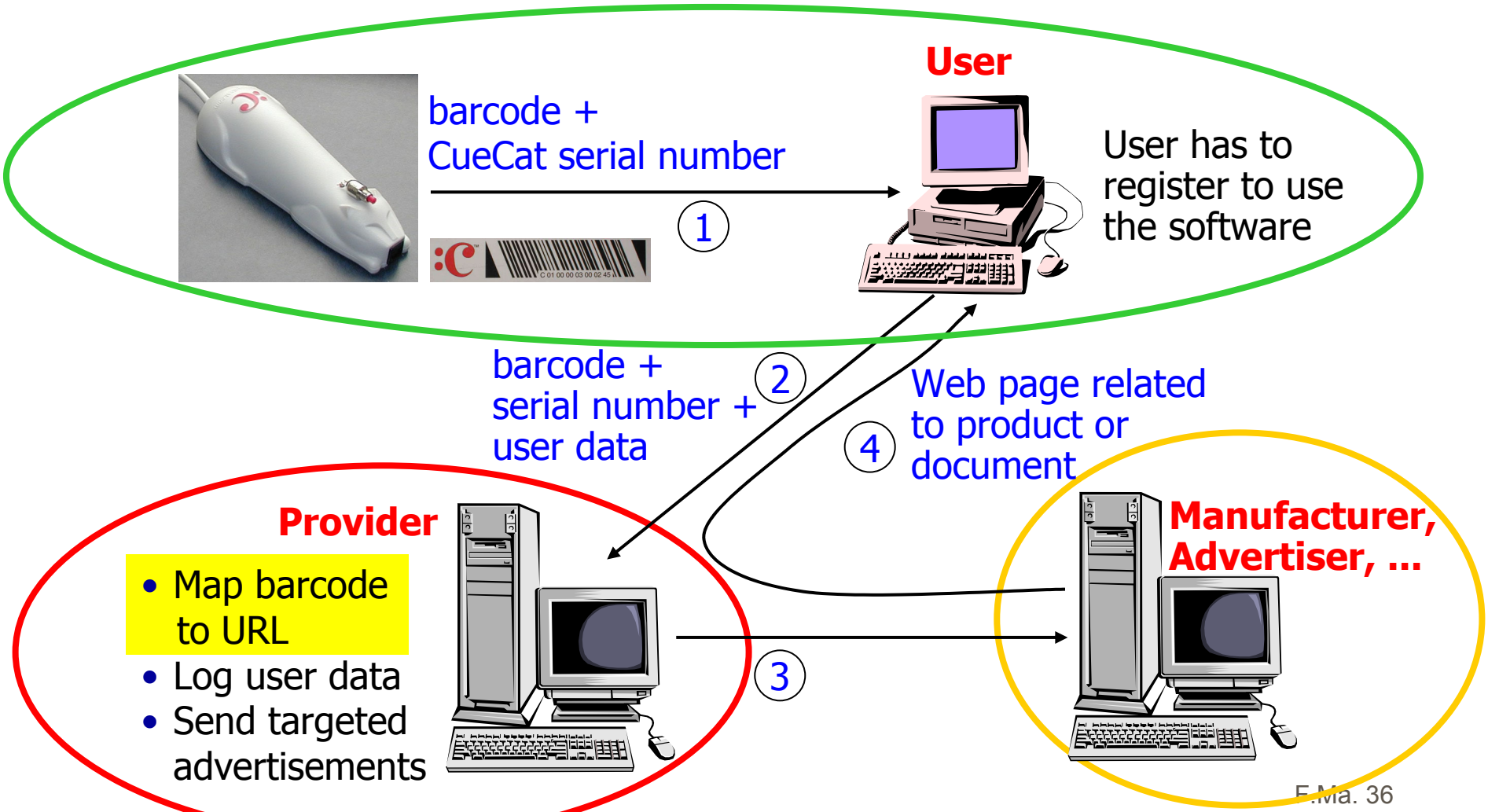


- Mobile scanner and pen, $89.90
- Allows to link from a printed page directly to the Web
- Scans barcodes on printed material
- No wireless communication yet
  - data well hooks up to computer for information transfer
  - up to 100 scans between downloads
- First release shipped Oct. 2000
  - still available today?

Example 3: „CueCat“ – *First Tries with Business Models*

- Bar code scanner (shape of a cat)
  - LED based; attaches to the computer via the keyboard port
- 10 million free scanners distributed in the US by the end of year 2000
  - 50 millions were planned for 2001
  - estimated cost of $ 5 - $ 10 per CueCat
  - someone willing to spend at least $ 0.5 Bio.
- Sends the Web browser directly to the „right“ location when scanning the bar code of an ad in a magazine
- Video

Mapping of Barcode to Web Page



Who?

- Who controls the information to be displayed?
- Who has the knowledge?
- Who „owns“ the mapping?
- What about privacy?
- Economic value?

Patent US5978773

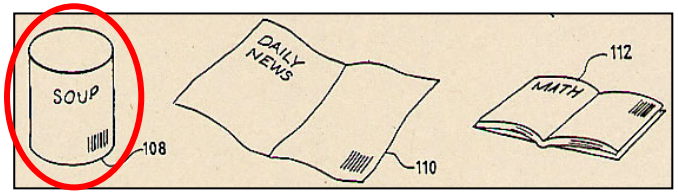
„System and method for using an ordinary article of commerce to access a remote computer.“

NeoMedia Technologies, Inc., Fort Myers, FL
Issued / Filed Dates: Nov. 2, 1999 / Oct. 3, 1995

Patent US5978773

„System and method for using an ordinary article of commerce to access a remote computer."

NeoMedia Technologies, Inc., Fort Myers, FL
Issued / Filed Dates: Nov. 2, 1999 / Oct. 3, 1995



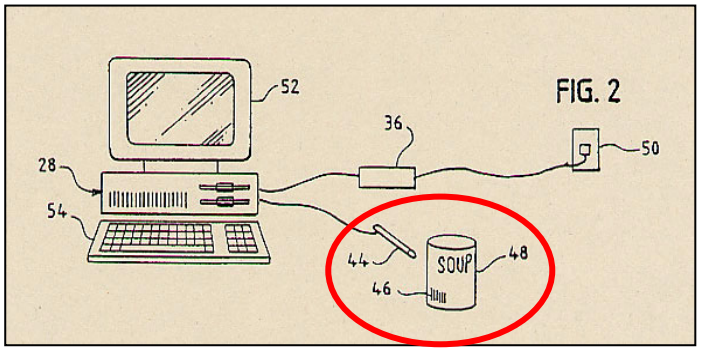


FIG. 2

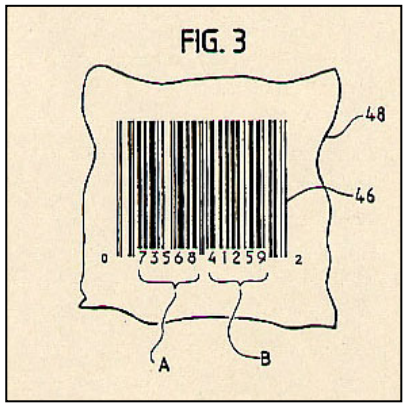


FIG. 3

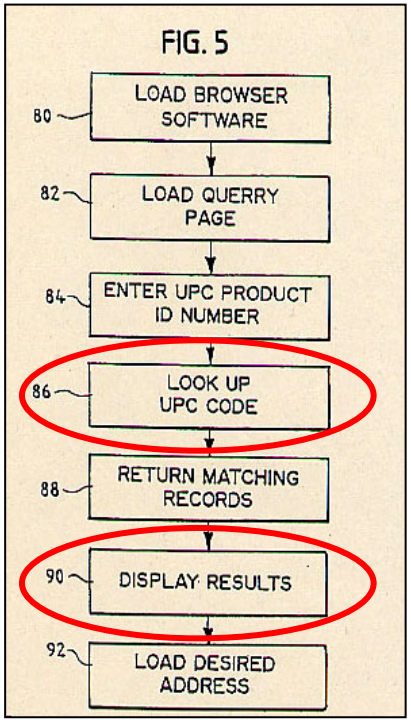


FIG. 5

Patent US5978773

„System and method for using an ordinary article of commerce to access a remote computer.“

NeoMedia Technologies, Inc., Fort Myers, FL
Issued / Filed Dates: Nov. 2, 1999 / Oct. 3, 1995

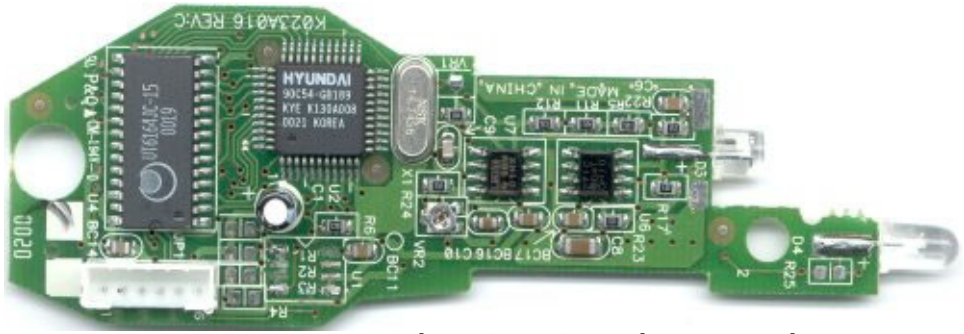
A system and method for using identification codes found on ordinary articles of commerce to access remote computers on a network. In accordance with one embodiment of the invention, a computer is provided having a database that relates Uniform Product Code ("UPC") numbers to Internet network addresses (or "URLs"). To access an Internet resource relating to a particular product, a user enters the product's UPC symbol manually, by swiping a bar code reader over the UPC symbol, or via other suitable input means. The database retrieves the URL corresponding to the UPC code. This location information is then used to access the desired resource.

CueCat Revenue Model

- „Our revenue model is being the gate keeper between codes and their destination online“
  - software in the user‘s computer links to the provider
  - code is encrypted by the scanner
  - scanner adds its serial number
  - provider keeps mapping from bar code to URL as its property
- Business risk: “Our right to keep information collected in our databases may be challenged in the future.”

CueCat Reverse Engineering

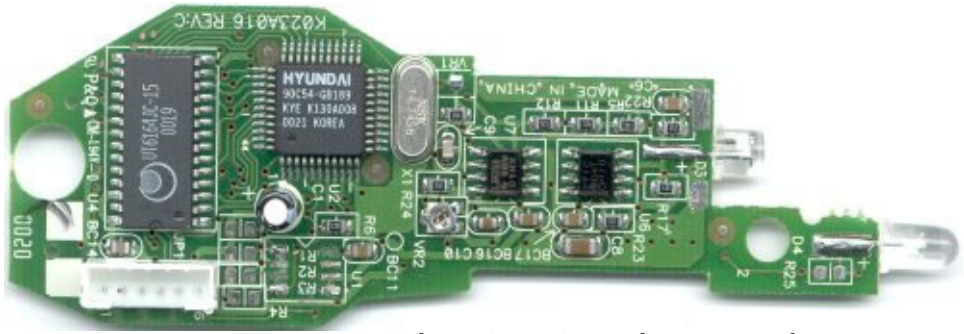
- Hackers know
  - how to decrypt the code
  - how to avoid sending the serial number



The CueCat dissected

CueCat Reverse Engineering

- Hackers know
  - how to decrypt the code
  - how to avoid sending the serial number



The CueCat dissected

- Provider doesn't like
  - reverse engineering
  - open bar code directories for products
  - free applications (e.g., download amazon.com information from ISBN numbers on books)
  - LINUX drivers

- „Our revenue model is being the gate keeper between codes and their destination online"

The „Digital Millennium Copyright Act“

- Many people believe that the reason for the XOR "encryption" is an attempt to bring the output of the CueCat under the Digital Millenium Copyright Act. Using/writing your own software for the cuecat would then be illegal.

The „Digital Millennium Copyright Act“

- Many people believe that the reason for the XOR "encryption" is an attempt to bring the output of the CueCat under the Digital Millenium Copyright Act. Using/writing your own software for the cuecat would then be illegal.

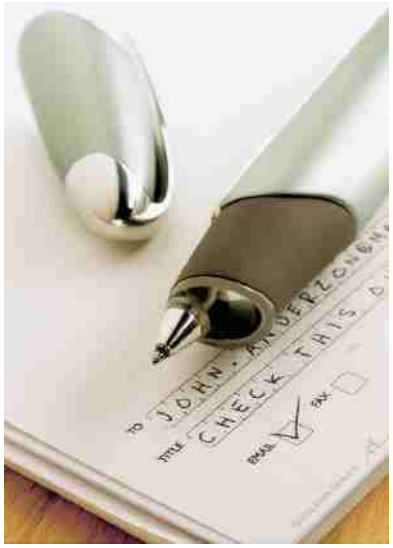
- U.S. Congress passed the Digital Millennium Copyright Act on October 12, 1998.

  It makes it a crime to circumvent anti-piracy measures built into commercial software. It outlaws the manufacture, sale, or distribution of code-cracking devices used to illegally copy software. It does permit the cracking of copyright protection devices, however, to conduct encryption research, assess product interoperability, and test computer security systems.

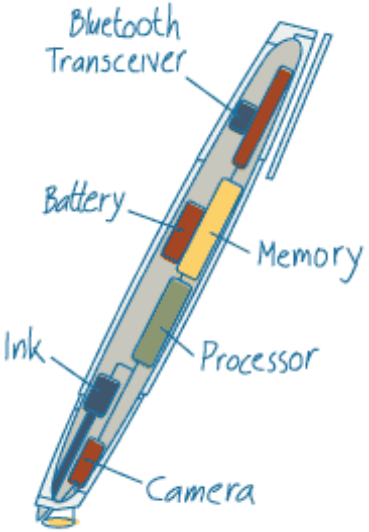
A Recent Example: The Anoto Pen

- Uses paper with a pattern of small dots, slightly dislocated from a strict grid
  - 2x2 mm determine exact location
  - appears as a faint grey shade on the paper
- Pen calculates its position
  - illuminates pattern with infrared
  - reads 100 picture frames / s
  - ink from pen not visible
- Sends the calculated positions to other devices via Bluetooth
  - together with the pen ID (useful in e-commerce, e.g. when ordering a product)

Anoto Pen


TO JOHN ANDERSON
TITLE CHECK THIS
EMAIL
FAX

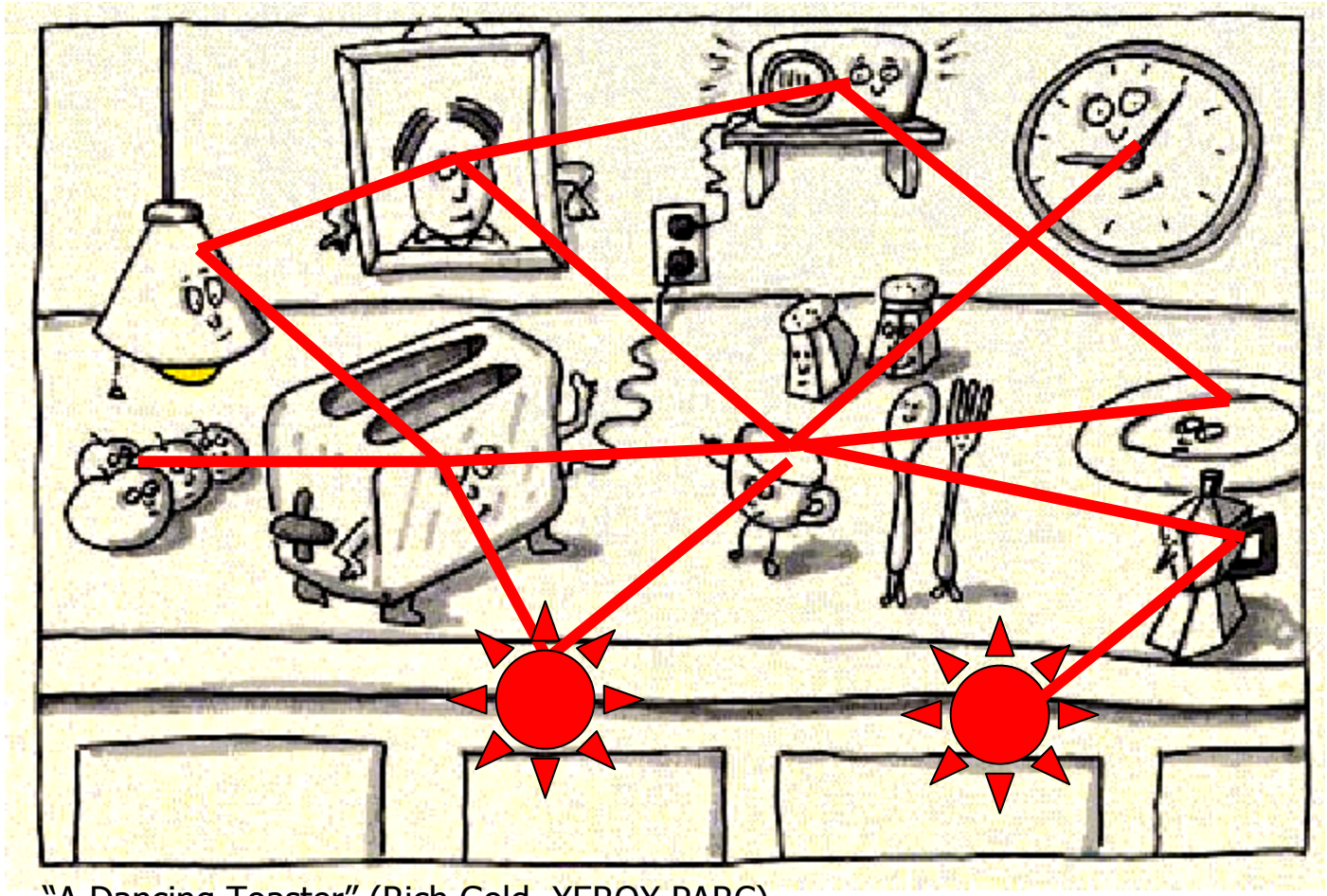

© Anoto AB 2000


Bluetooth Transceiver
Battery
Memory
Ink
Processor
Camera

Outline

- The Vision
- Linking Atoms and Bits
- Bridging the Gap
- Our Contributions
- Applications
- Implications

Infrastructure for Smart Objects



"A Dancing Toaster" (Rich Gold, XEROX PARC)

Why Infrastructures at All?

- Consider infrastructures in the real life
  - examples: electricity, roads,…
  - just there or even invisible
  - "open platform"
  - makes life easy (e.g., deployment of new services)

- Internet infrastructure
  - Domain Name System (DNS registry)
  - services: cooperating routers, time servers,...
  - IP, TCP,…: common formats / protocols
  - Web standards (platform for other applications)

Extend the Internet to everyday objects

Why Infrastructure for Smart Objects?

How do we organize billions of mobile smart objects that are highly dynamic, short living,…?

- Guarantee
  - security
  - privacy
  - availability
  - reliability

for **applications** built with smart objects

Why Infrastructure for Smart Objects?

How do we organize billions of mobile smart objects that are highly dynamic, short living,…?

- Guarantee
  - security
  - privacy
  - availability
  - reliability

for **applications** built with smart objects

- Provide services
  - location („where am I?“)
  - context („are we in a meeting?“)
  - event delivery („tell me when... happens“)
  - brokering („find something that…“)
  - directory
  - registry
  - …

for smart objects

More Infrastructure Tasks

- Enable — for communities of smart objects
  - spontaneous networking
  - cooperation among smart objects
  - communication
  - mobility
  - service creation
  - service discovery ("is a service available that ...?")
  - ...

Challenge for practical computer science research!

- Facilitate linking the real world to the virtual world

Open or Proprietary Infrastructure?

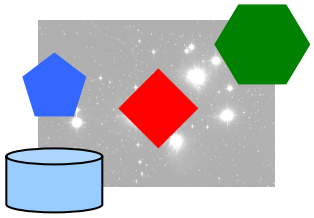
- Will we ever get a common infrastructure for smart objects?
  - scalable
  - extensible
  - ...

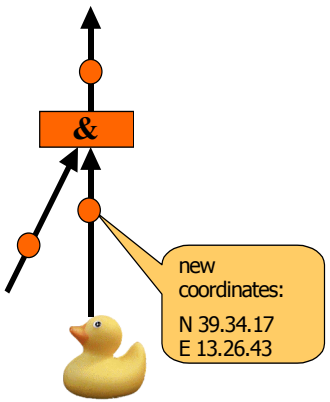
Is it realistic or a dream?

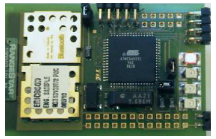
- Will it be open?
  - based on common, open standards
  - analogous to the Internet and its protocols

What Are We Doing at ETH?

- General infrastructure for Ubiquitous Computing
  - smart counterparts for real-world objects
  - event-based middleware for smart objects
- Communication and service environment for Smart-Its
  - → *Oliver Kasten*
- Privacy
  - → *Marc Langheinrich*
- Scenarios, social & economic consequences
  - → *Vlad Coroama*

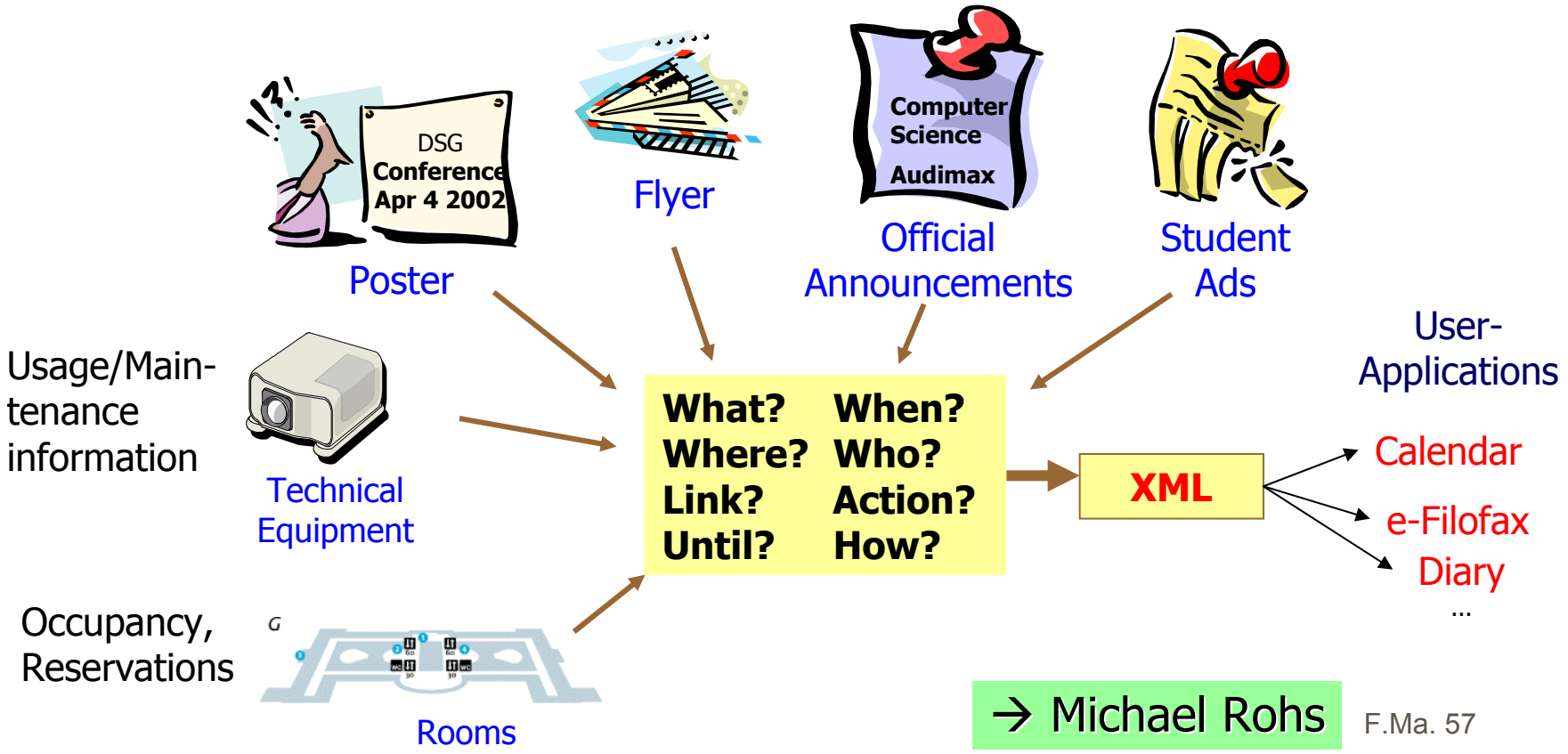






Project „Entry Points to the ETH World Infostructure“

- Responsive objects interweave the physical campus infrastructure with the infostructure



Research Project „Living in a Smart Environment“

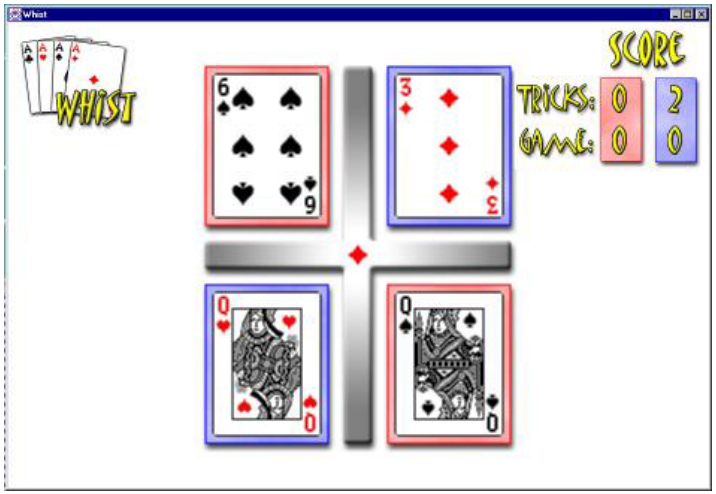
- Vision of an all-encompassing computarization and networking of „all“ objects soon feasable
  - could have dramatic impact
- Consequences of Ubicomp?
  - social
  - economic
  - privacy
  - perception of the world
  - everyday life, work, home,...
- What possibilities and alternatives do we have when shaping a „smart“ world?

- Gottlieb Daimler- & Karl Benz Foundation
- 7 groups (Germany, Switzerland)
- started Jan. 2002
- development of scenarios, showcases, prototypes

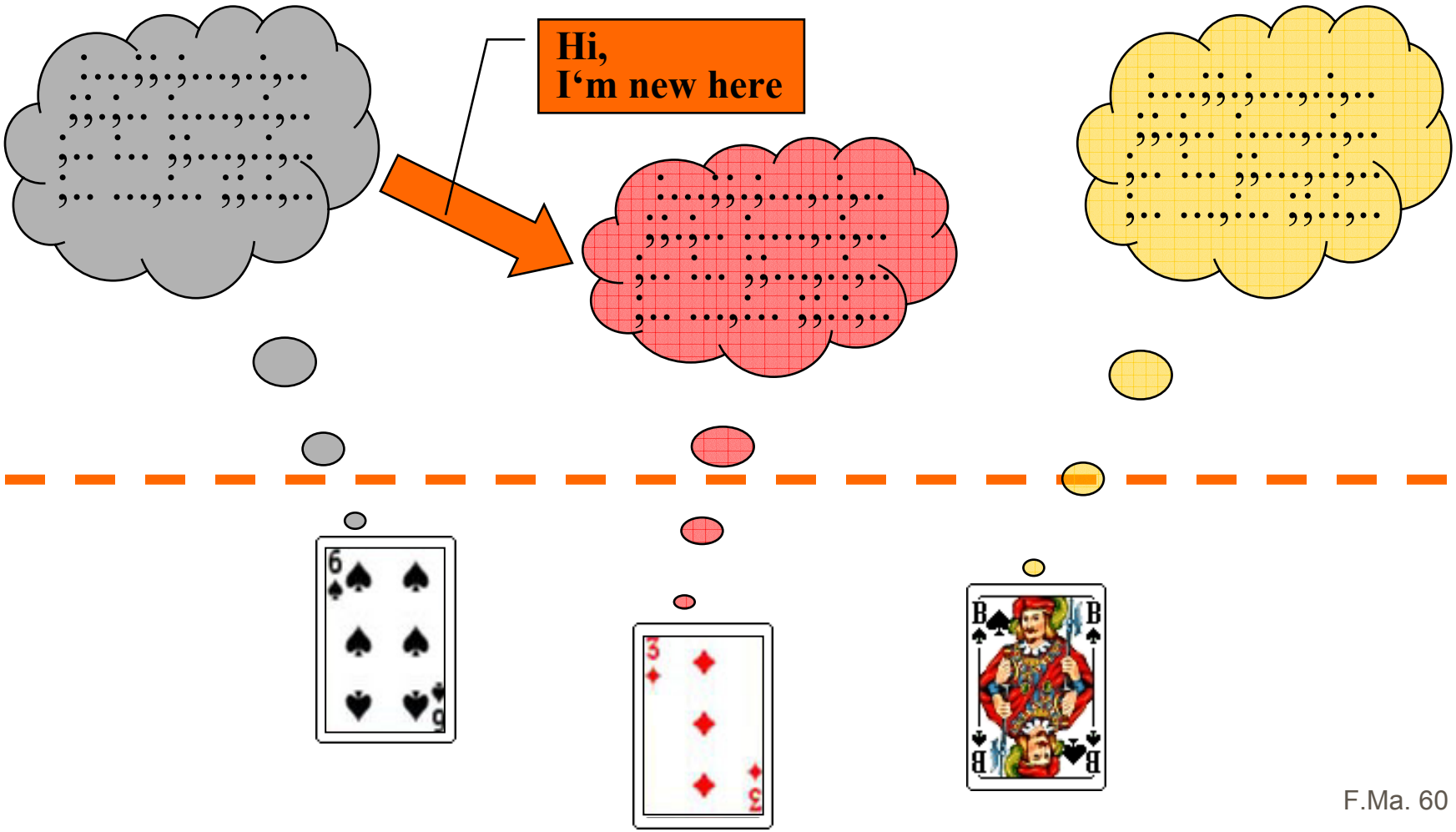
→ Vlad Coroama

Smart Playing Cards

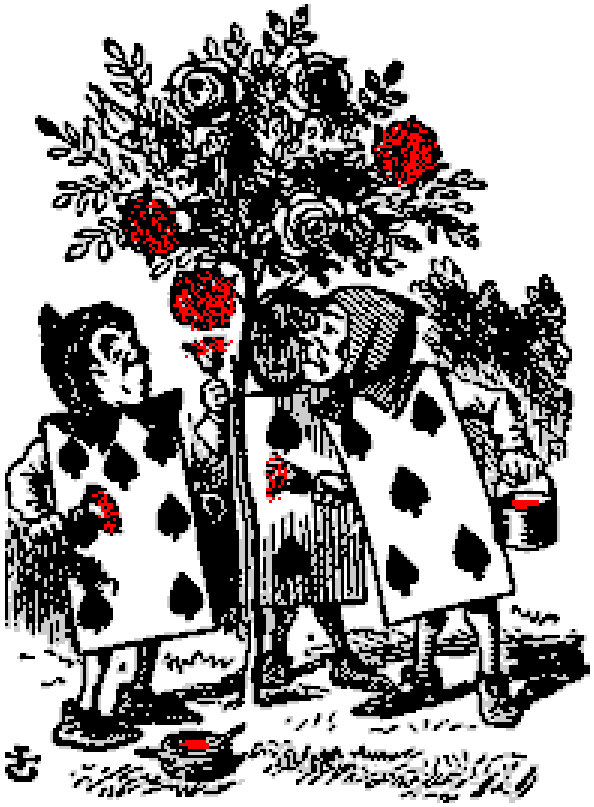
- Support people playing a card game by an unobtrusive smart environment
  - playing cards equipped with RFID labels
  - RFID antenna is placed under the table
- Features:
  - count score
  - determine winner
  - hints for beginners
  - cheat alarm
- Display:
  - wireless PDA
  - nearby screen



Card Proxies as Virtual Counterparts



Cards as Personalities



Alice in Wonderland

- What do playing cards remember?
  - all their games?
- What do they communicate?
- How do they react?

Outline

- The Vision
- Linking Atoms and Bits
- Bridging the Gap
- Our Contributions
- Applications
- Implications

Ubicomp - Applications?

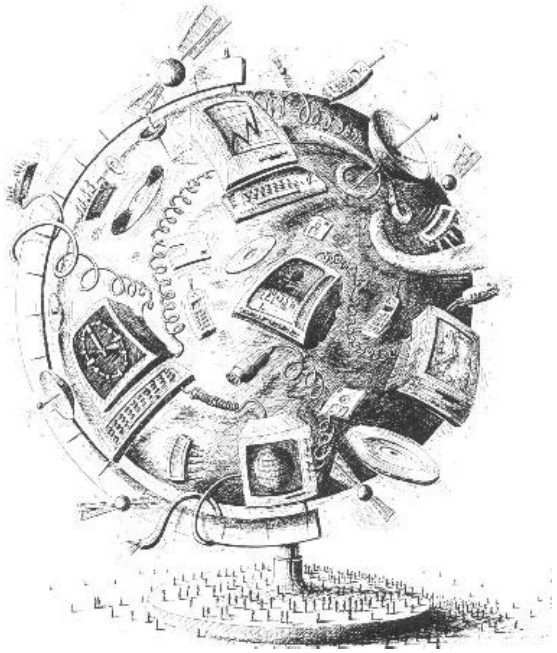
„We are always very bad at predicting how a given technology will be used and for what reasons"

-- Bran Ferren, Chief Disney Imagineer

Economic Impact of Ubicomp?

(„Couple E-business with Star Trek Technology“)

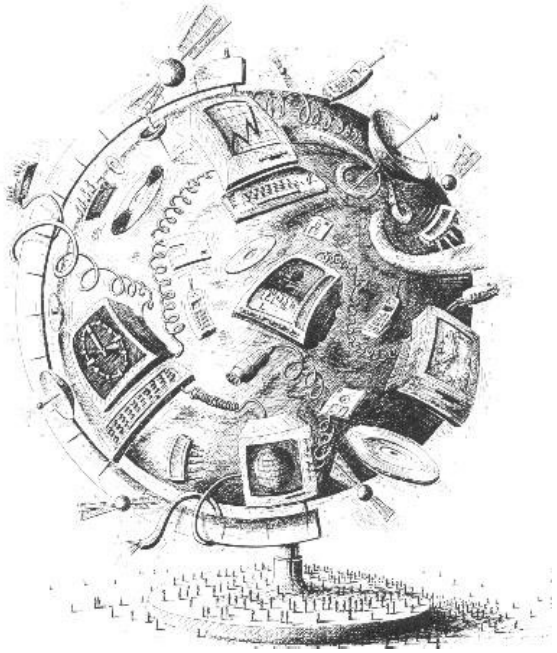
- Products that are fully integrated in information systems
  - e.g., supply chain optimization
- New digitally enhanced products
  - e.g., cooperating toys,...
- New services („e-utilities“)
  - e.g., management of smart devices at hom management of personal privacy,...



Economic Impact of Ubicomp?

(„Couple E-business with Star Trek Technology“)

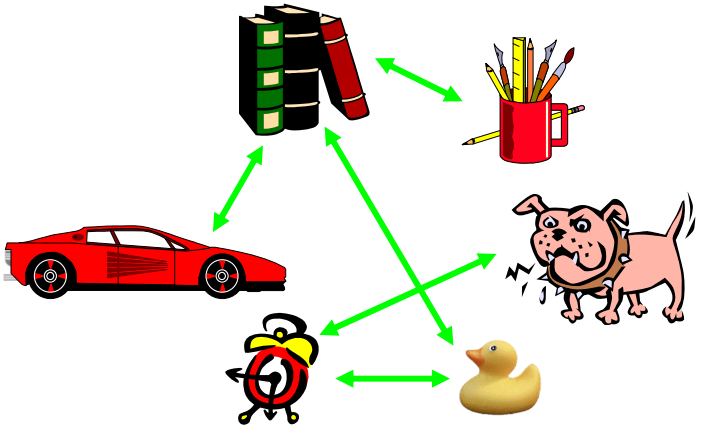
- Products that are fully integrated in information systems
  - e.g., supply chain optimization
- New digitally enhanced products
  - e.g., cooperating toys,...
- New services („e-utilities“)
  - e.g., management of smart devices at home, management of personal privacy,...



- Detailed and timely knowledge of product location and life cycles, individual and dynamic prices for goods,...
  - car insurance depends on usage patterns,...
  - higher taxes if product is transported by plane
  - milk bottle reduces its price with its age

Imagine an „Internet of Things“

- „Silent commerce“ (*Intershop*)
  - the ability of objects to conduct business transactions directly with other objects

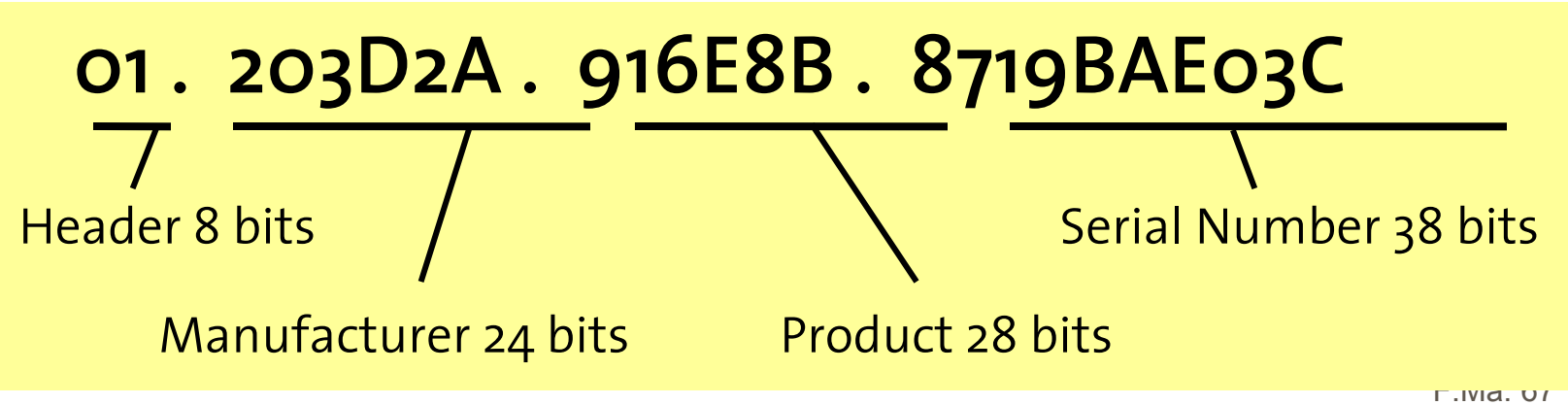


- „Imagine that...
  - your products, your inventory or any of your physical assets could sense the characteristics of their environment, know their location and tell you about it
  - your products were self monitoring and could tell you when they were about to go outside of acceptable boundaries for temperature
  - you could identify and track every product as it moves along your value chain, from the factory all the way to the consumer
  - ...“ (*Accenture*)

Electronic Product Code (ePC)

- Identification of single object instances, not object classes
- Based on RFIDs
- Developed by MIT Auto-ID
- Cheap (goal: $0.05 per label)

- ontology?
- infrastructure?
- distributed architecture?



The M-Lab

www.m-lab.ch

- „Mobility and Ubicomp Lab"
- ETH Zurich together with the University of St. Gallen (HSG)
  - collaboration with MIT Auto-ID Center (electronic product code,...)
- Identifying and designing effective business applications based on Ubicomp technologies
  - life sciences, automotive, retail and logistics,...
  - from ideas to prototypes
- Currently 7 industrial partners:

SAP SI UBS swisscom mobile NOVARTIS SAP

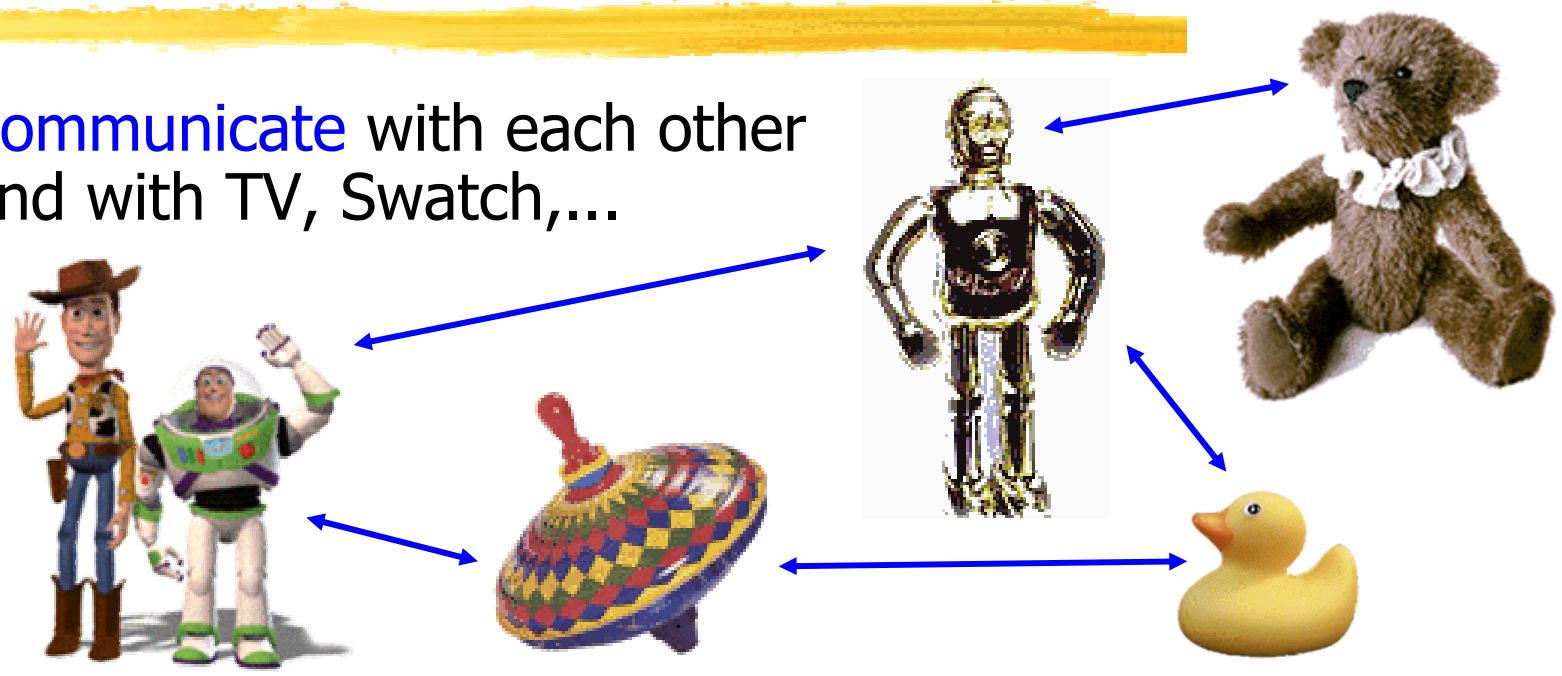
The M-Lab

- Ubicomp in healthcare

- Smart toolbox
- PML (Product Markup Language) together with MIT
- Spare part management with RFID
- Abstraction layer and programming library for different RFID systems
- ...

Example of an Application Domain: Smart Toys

- Communicate with each other and with TV, Swatch,...



- Internet via game console, home PC, „home gateway“
- Update during the night via the Internet
  - e.g., stories from yesterday‘s TV show for speaking dolls

Smart Toys

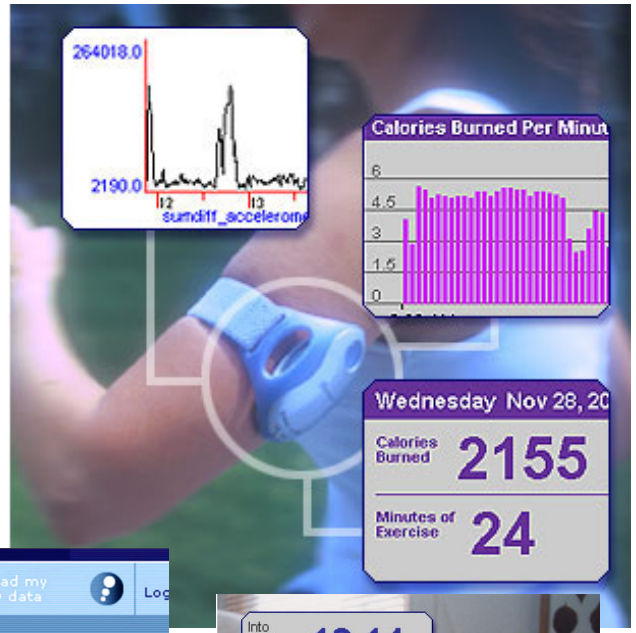
- Access to WWW and large external data bases
  - e.g., language dictionary
- Networked fan communities
  - „my toy" --> marketing
- Remote execution server for compute intensive tasks
  - e.g., speech recognition
- Avaters for family members
- Babysitting, health monitoring
- New games when toys interact

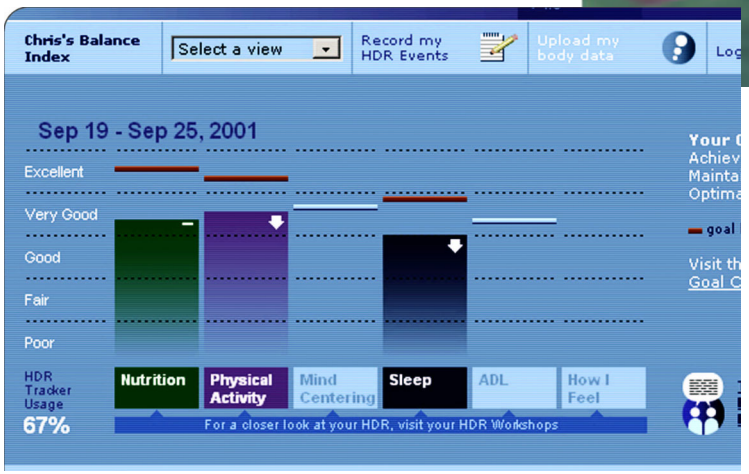
Another Important Application Area: Healtcare

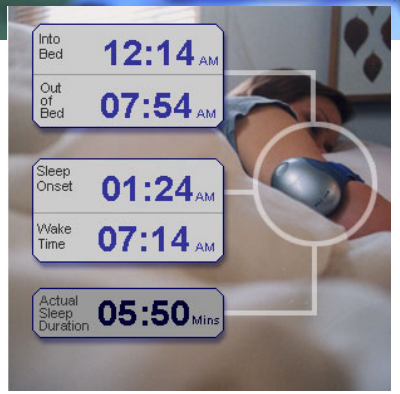
Wearables to collect medical data

Bodymedia

- Communication platform for wireless transmission of body function data
- Bodymedia translates raw sensor data to „lifestyle data“ (available on the Web)

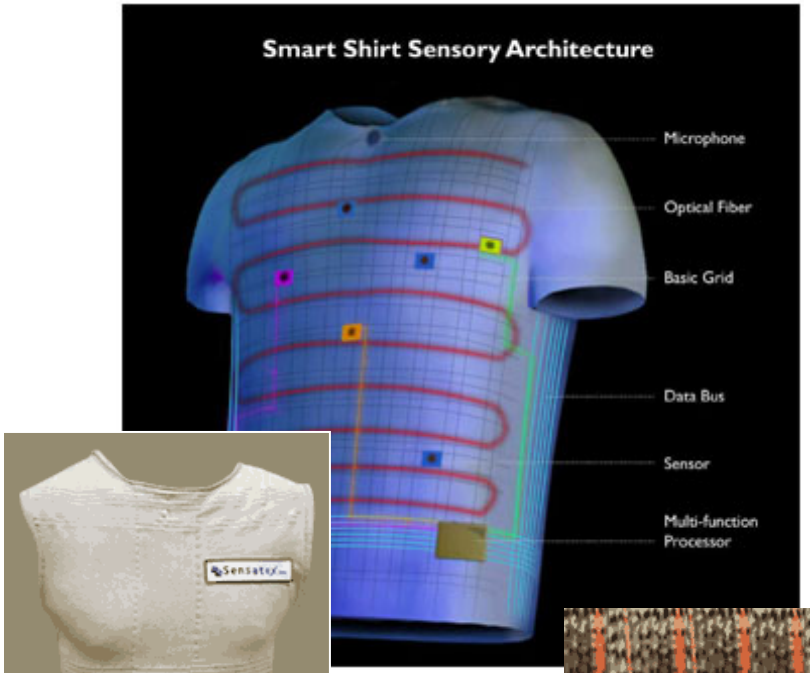






Sensatex Smart Shirt

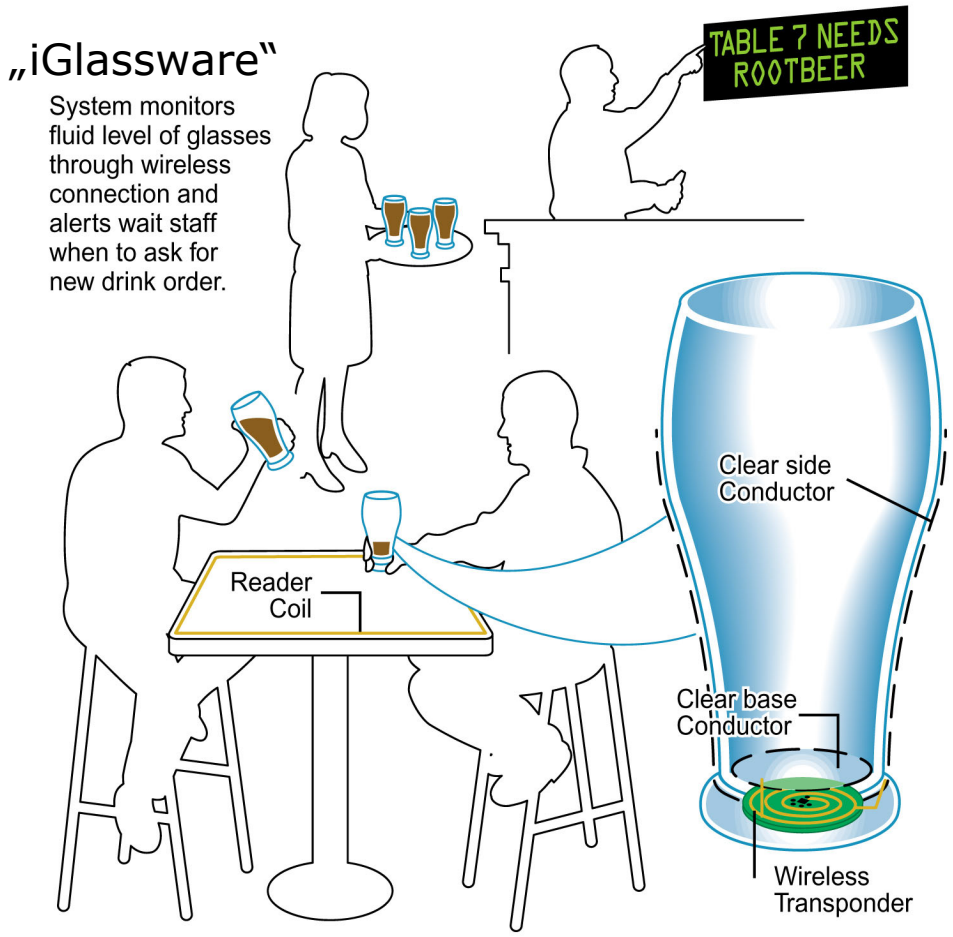
- Monitors continously vital signs such as heart rate, temperature, respiration activity,...
- Wireless communication with the Sensatex Health Center
- Comprehensive notification and audit systems for doctors and patients, but also for sportsmen and workers



Talking Medicine

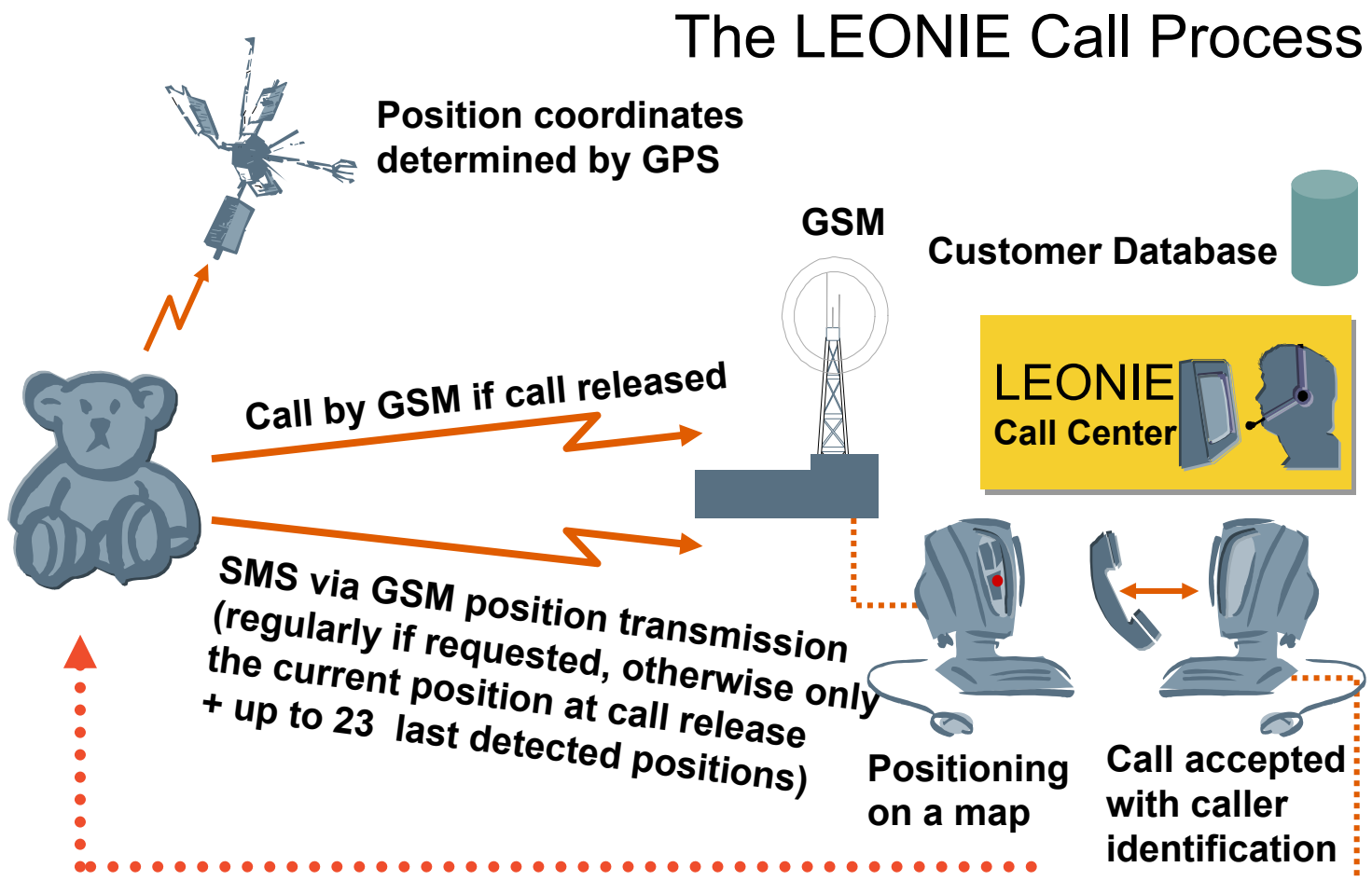
Helps partially sighted and blind persons to take the right medicine

Other, Unconventional Applications?



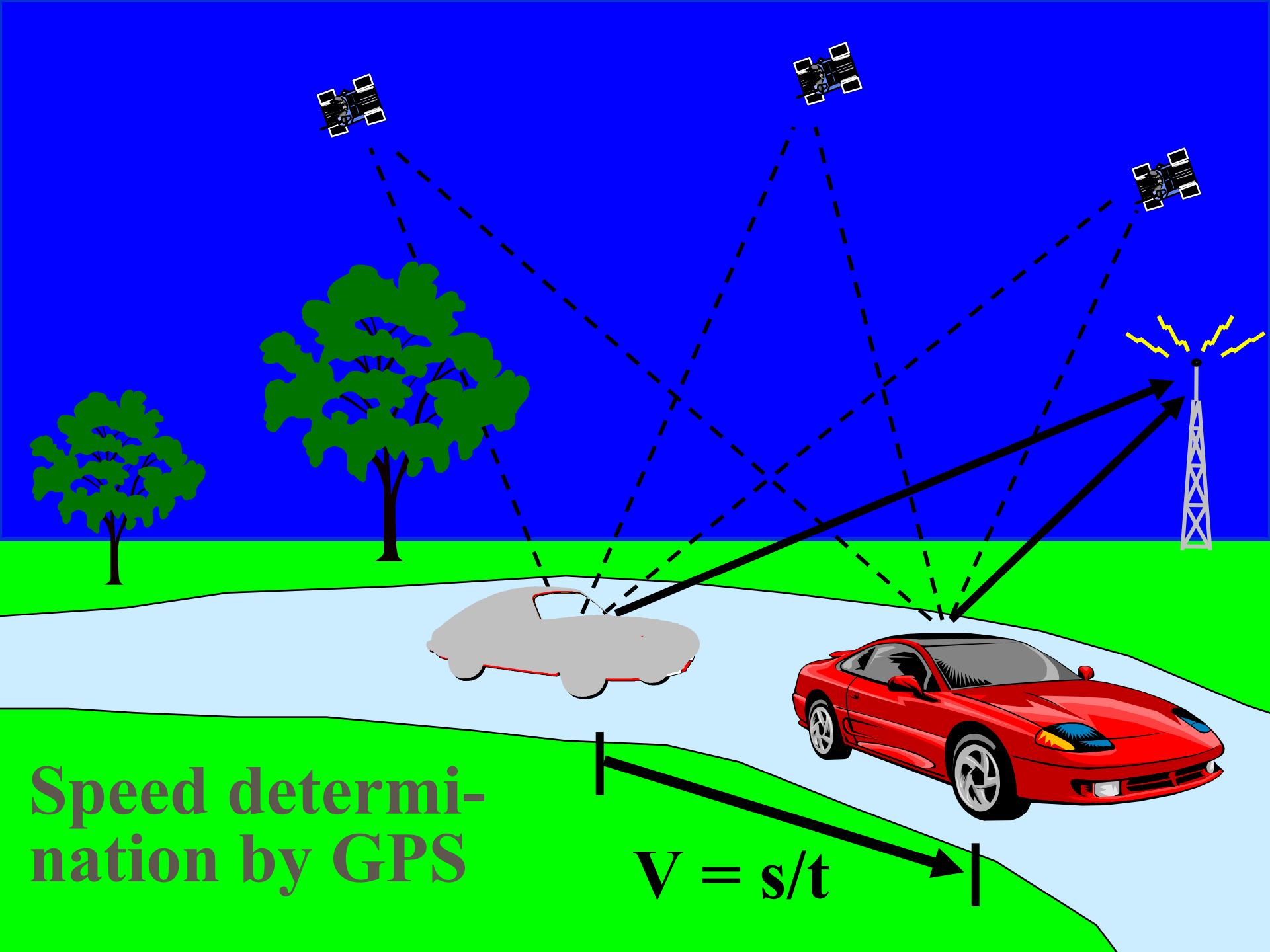
http://www.merl.com/projects/iGlassware/

Example of a Location-aware Application: The LEONIE Sytem



Example: Insurance Companies

- Autograph System
  - pilot 1998/99, Houston, TX
  - insurance rates depend on individual driving behavior (when, where, how often?)
  - GPS sensors send data to a service center
- Experience
  - 25% average fee reduction for customers
  - particularly successful with company car fleets


Speed determi-
nation by GPS
V = s/t

GPS System Used to Fine Driver for Speeding

HARTFORD, Conn. (AP, 07/03/2001) - The state Department of Consumer Protection is investigating a complaint against a rental car company that used satellite technology to track a New Haven customer's alleged speeding.

James Turner complained about Acme Rent-A-Car of New Haven for using his rented minivan's global positioning system to clock his speed. Acme billed Turner $150 for each of three alleged speeding violations last fall.

"It's a scary situation to be given speeding tickets by way of satellite, never having come into contact with a law enforcement agent," he said. "Who monitors this? Do they have someone in the back room monitoring where you go? I think there's some sort of privacy issues there."

Rental contracts inform potential customers about the global positioning systems, said Max Brunswick, a New Haven lawyer for Acme. ... Turner signed a contract stipulating that vehicles driven "in excess of posted speed limits" will be charged $150 each time, Brunswick said.

The devices also are intended to reduce car wrecks and track cars that customers fail to return, Brunswick said. Acme fines motorists who drive faster than 79 mph for two minutes or longer.

Outline

- The Vision
- Linking Atoms and Bits
- Bridging the Gap
- Our Contributions
- Applications
- Implications

Privacy in a Ubicomp World?

- Privacy is already a concern with the WWW
  - what do they do with my personal data?
  - are my page visits and mouse clicks analyzed?

- Much more dramatic in a ubicomp world!
  - many events of very elementary actions are registered
  - could be assembled to perfect profiles

Bought on **20 Aug 2001**; last travel: to **London** Sep 2003; contained shirt no. 1342 and 1349; was in **Hotel Atlantic**, **room 317** on 17 Nov 2002 ...

- information fusion
- data mining
- search engines

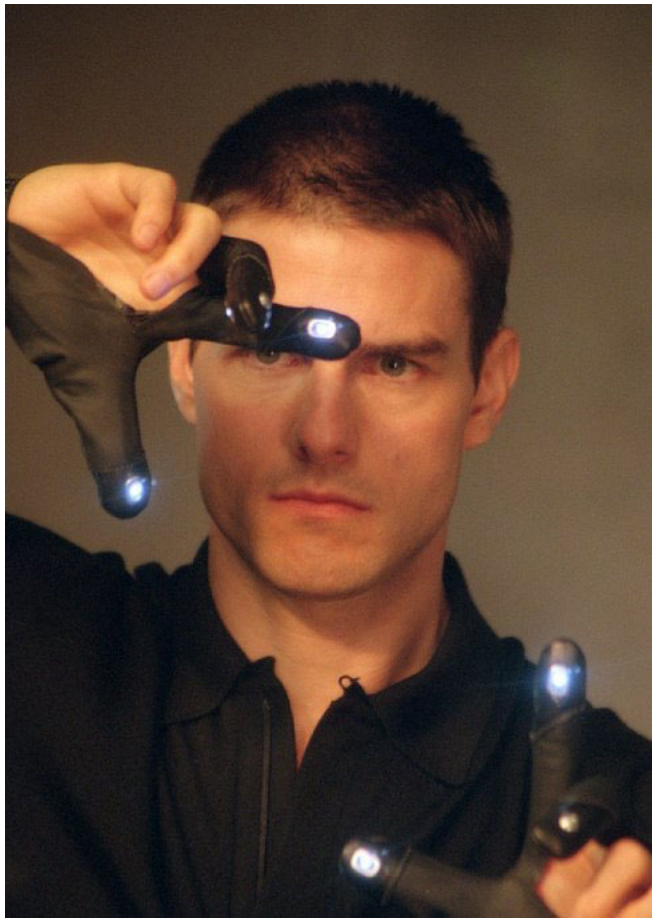
Privacy Challenges

- Unlimited coverage (sensors everywhere)
- Loss of awareness („invisible computing“)
- New types of data (location, health, habits, …)
- More knowledge through context
- Explicit notice, consent by user difficult
- …


TOM CRUISE
A STEVEN SPIELBERG FILM
MINORITY
REPORT

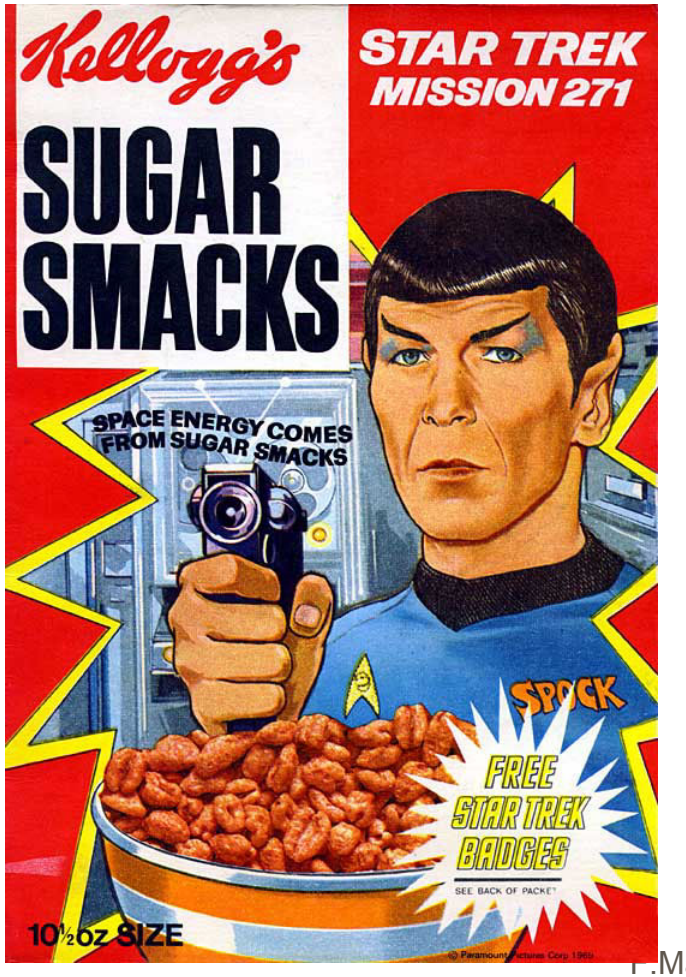
Minority Report (Steven Spielberg, 2002)

- Anderton (Tom Cruise) lives in a futuristic world (year 2054) that seems to respond to his every move.
- A key plot element is that iris scanners are completely ubiquitous in the world.
- „The futurists that I assembled around that table didn't agree with each other on every point, but one of the several things they did unanimously agree on was that the entire advertising industry is going to recognize us as individuals, and they're going to spot-sell to us". (Spielberg)



Minority Report (Steven Spielberg, 2002)

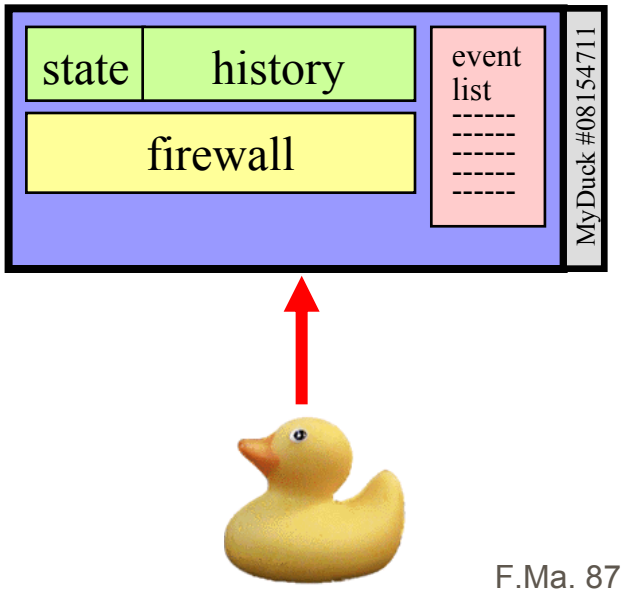
- New user interfaces
- Customized, animated ads
- Anderton pours a bowl of cereals at home, triggering the animated characters to sing the product's theme song. Frustrated because he can't make the characters shut up, Anderton flings the box at the wall.



Who Owns the Key?

- Who knows the mapping from object IDs to data (such as a product homepage)?
  - copyright? trade secret? intellectual property?
  - can one own such mappings?
  - e.g., are phone book entries common knowledge?

- Commercial value!
  - linking bar codes on ads to the "right" web site
  - customer profiles when "clicking" real-world objects



Ubiquitous Computing Criticism

- E.g., loss of control and loyalty:
  - "My refrigerator ... would refuse to open at certain hours of the day, having talked to my bathroom scale."
  - "If I exceed the speed limit, my car reports me, and if I try to park illegally, it refuses to turn off or to let me open the door."
  - "I want to disengage these features, but the car comes with a shrink-wrap agreement whose legalese implies that the purchaser has only licensed its capabilities without any true ownership."
  - ...
  - "I feel surrounded by enemies and traitors.„
- From: Robert Lucky: *Connections – Everything will be Connected to Everything Else*. IEEE Spectrum, March `99

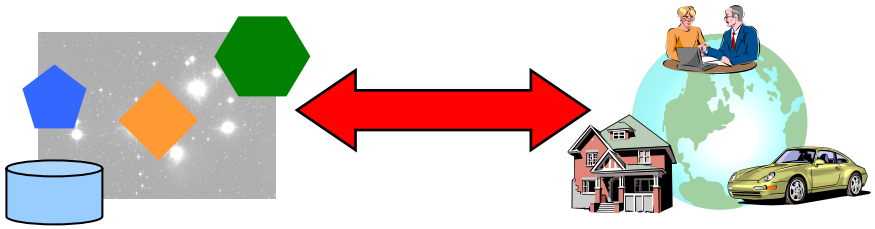
Consequences?

Have you ever thought of the cultural consequences when every object around us is both smart and connected?

-- Bernard Goldbach: Just Turn Me Off

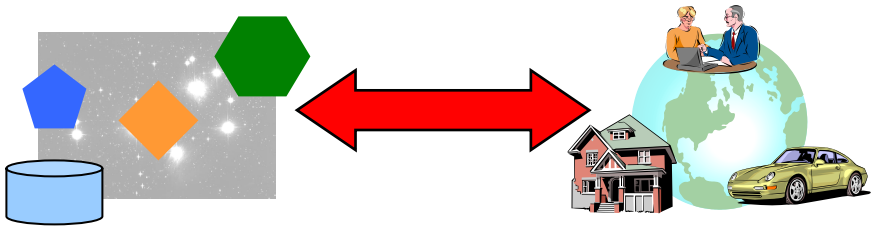
Two Worlds that Collide ?

- If there is tight interaction between the physical and the virtual world – what happens?
  - what is gained?
  - what is lost?

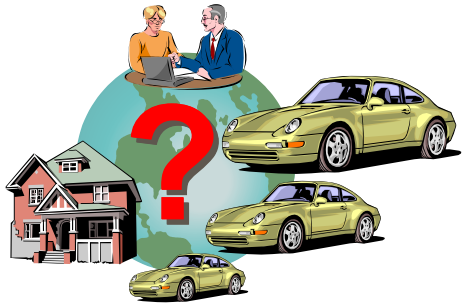


Two Worlds that Collide ?

- If there is tight interaction between the physical and the virtual world – what happens?
  - what is gained?
  - what is lost?

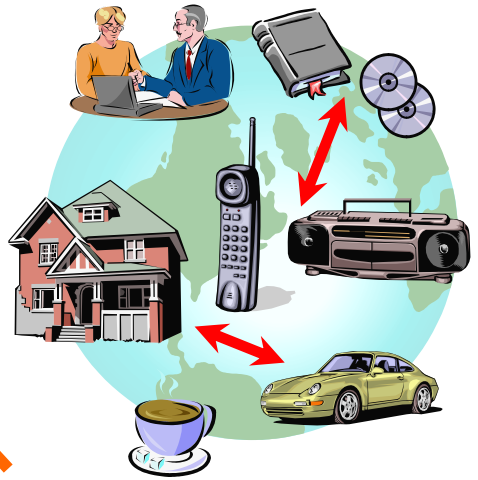


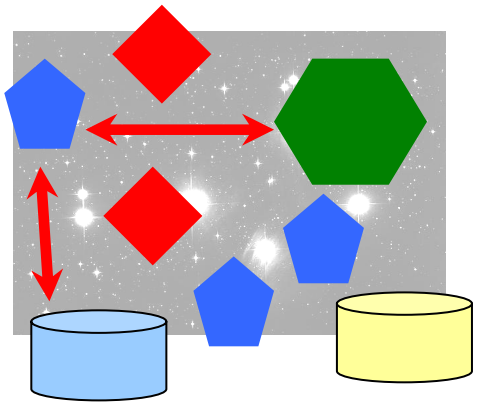
- Can we make a better world, or just better business?
- Which techniques are needed? Which are suitable?
- What are the limits?



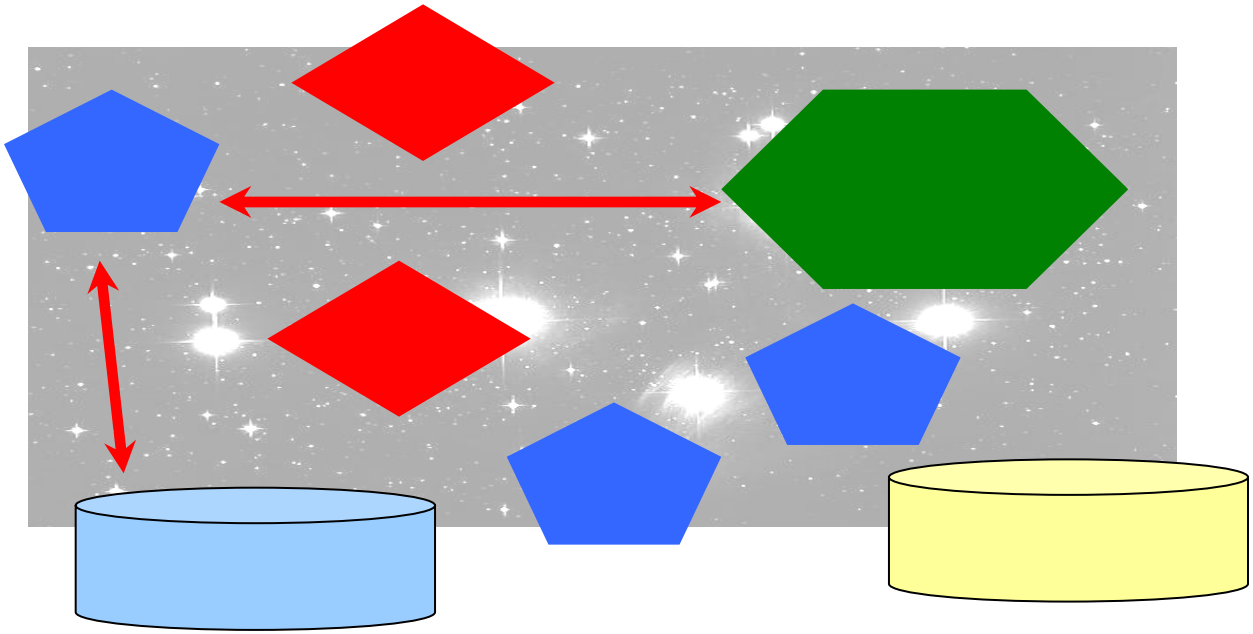
Challenges for Computer Science: „Computing Without Computers“

- Increasing importance of computer science
  - information processing moves to the background
  - computerizing and networking „all“ objects
  - cs has competence in organizational issues of complex, dynamic information spaces
    - object orientation, knowledge representation, semantics,...
  - good engineering principles are important
- New design issues
  - energy efficiency
  - scalability, reliability
  - mobility, cooperation
  - usability





Challenges for Computer Science



As we approach 2001, we are in the Information Age, not in the Space Age!

Randy Katz, UC Berkeley

International Conference on Pervasive Computing

Pervasive 2002

August 26-28, 2002
Zurich, Switzerland

ETH Zürich & IBM Research

www.pervasive2002.org

- System architectures and platforms for pervasive computing
- Middleware and pervasive computing infrastructures
- Mobile, wireless, and wearable technologies
- Innovative small computing and intelligent devices
- Emerging applications and mobile business issues
- Scenarios for information appliances
- Service discovery protocols
- Content distribution and delivery
- User interfaces for invisible and embedded computing
- Context awareness
- Security and privacy issues

- 20 papers (out of 160 submissions)
- Spinger LNCS
- 12 short papers
- Invited talks (Randy Katz, Ralf G. Herrtwich)
- 6 Tutorials
- Exhibition
- Conference dinner: boat tour on Lake Zurich

Physical-Virtual Integration, Ubicomp Applications & Implications

Friedemann Mattern

ETH Zürich