Ubiquitous & Pervasive Computing: A Technology-driven Motivation

Friedemann Mattern

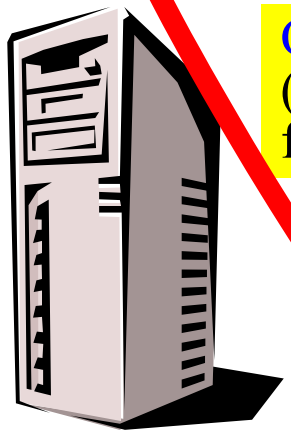
ETH Zürich

Hardware Trends

Computing: A Clear Trend

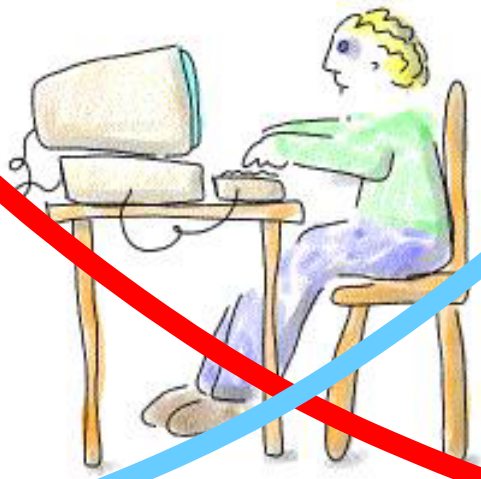
Size

Number

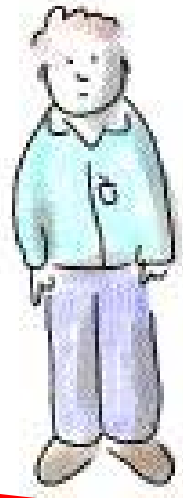


One computer (mainframe) for many people

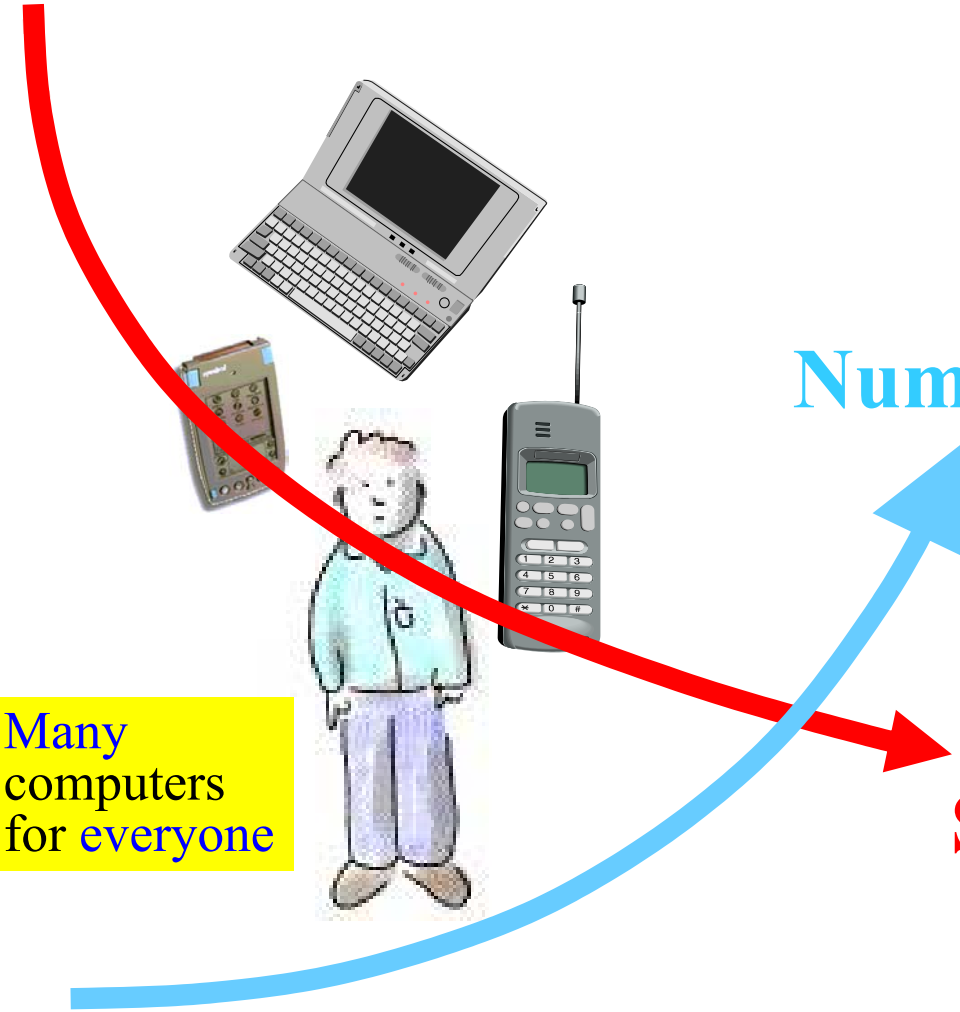
One computer (PC) for everyone



Many computers for everyone



The Trend... What Next?

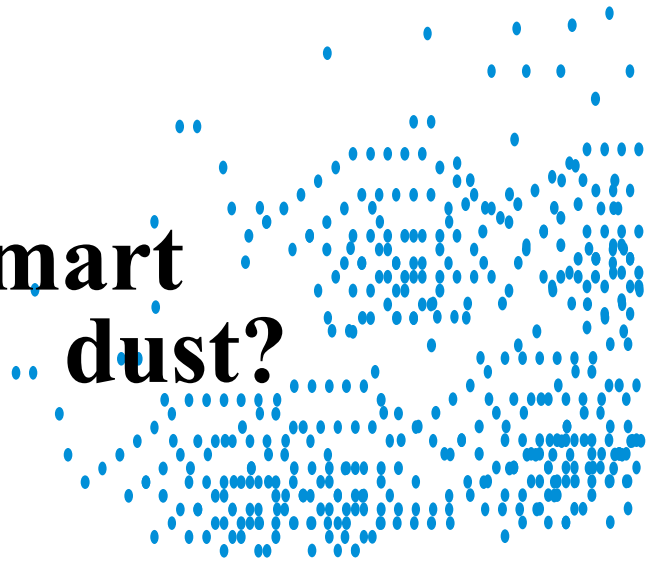


Many computers for everyone

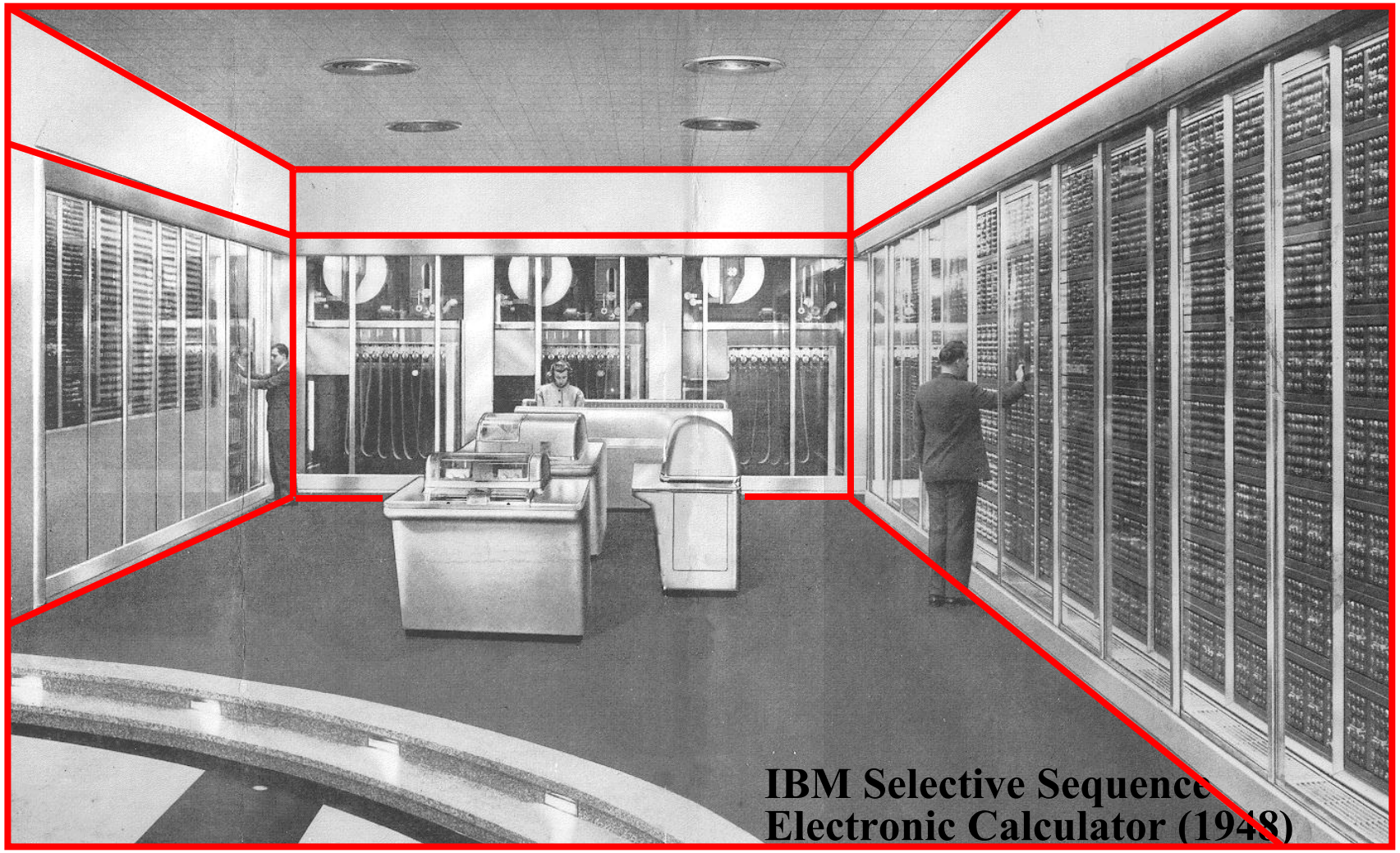
Number

Size

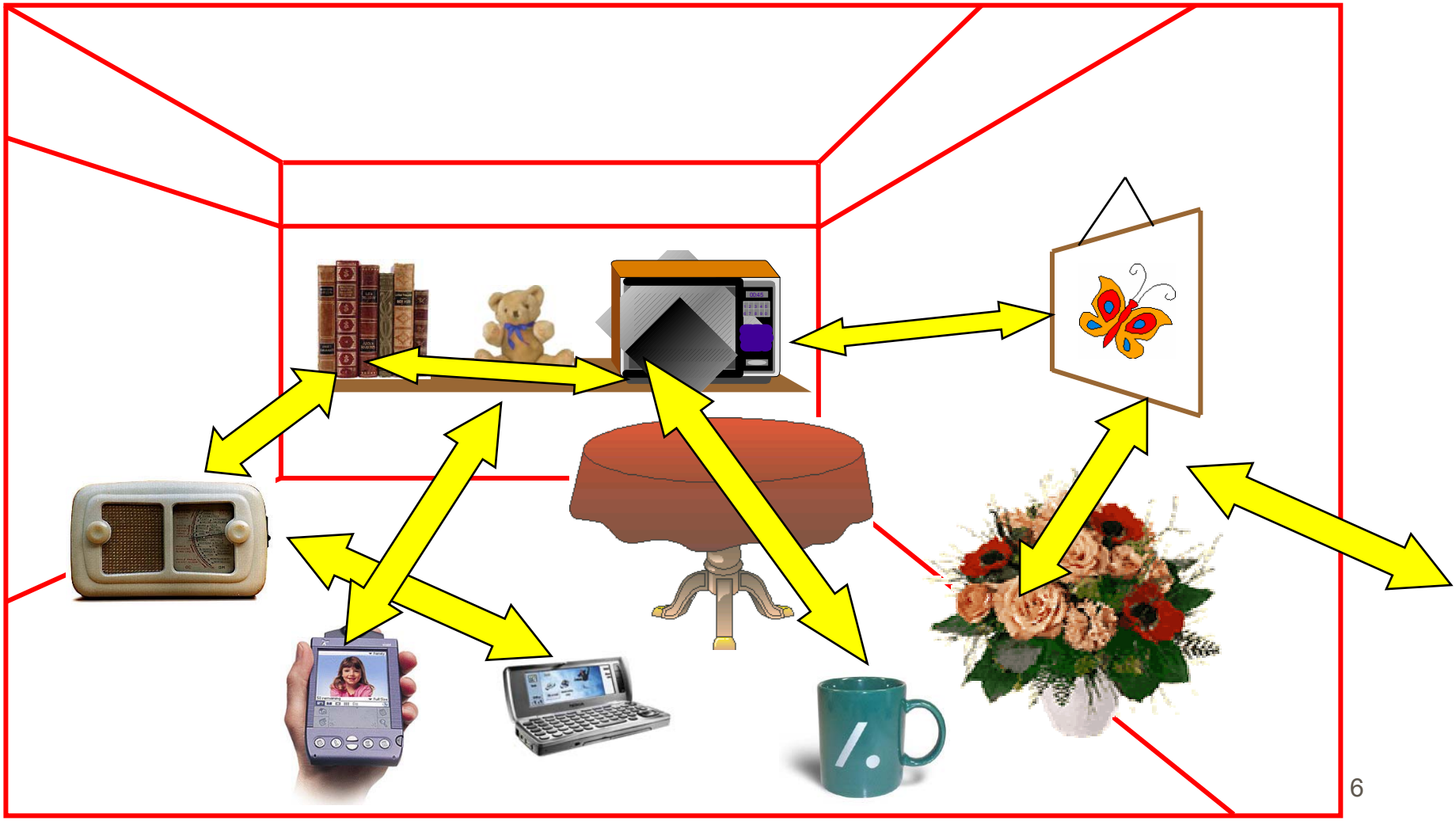
smart dust?



„Yesterday's Computers Filled Rooms...“

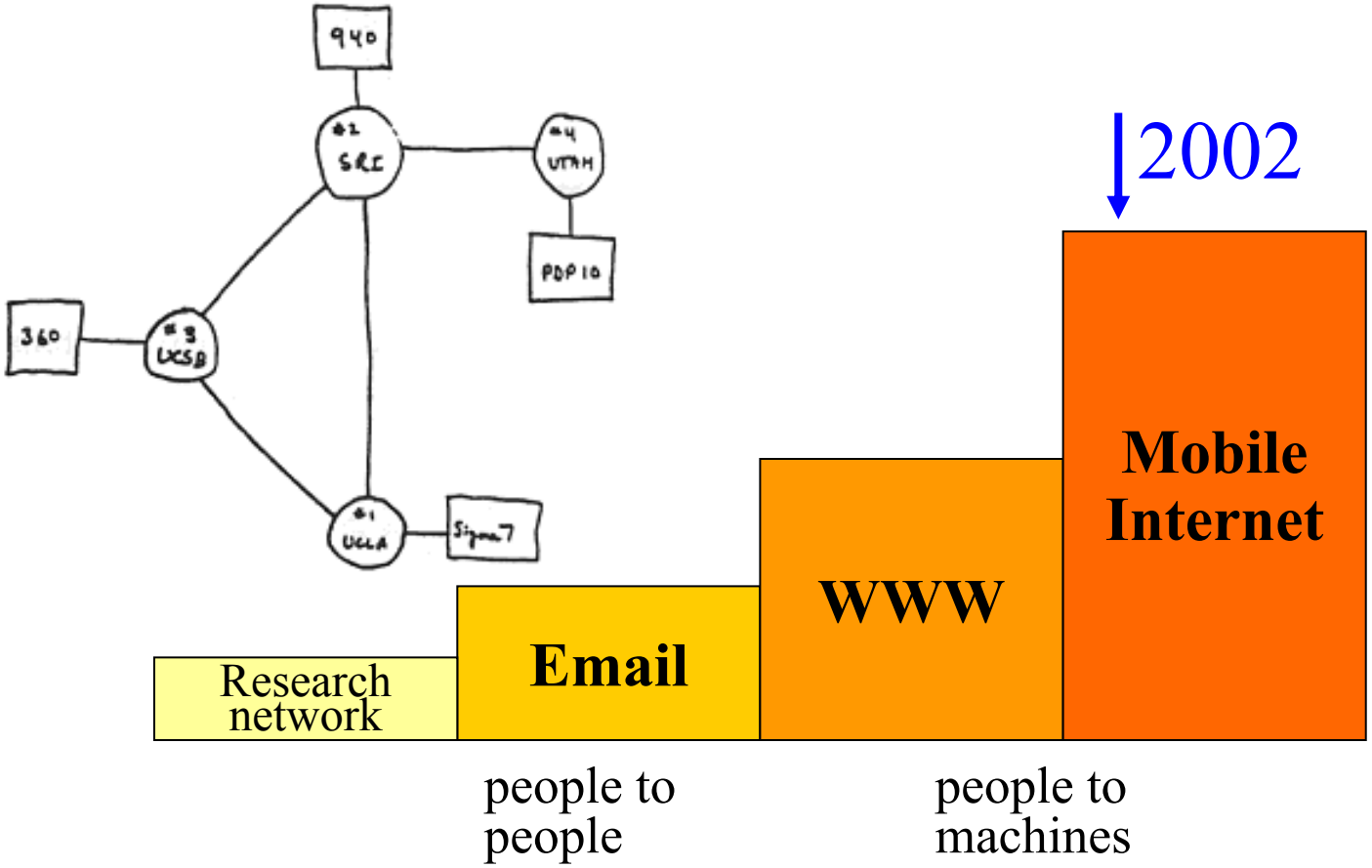


„Yesterday's Computers Filled Rooms - So Will Tomorrow's.“



Internet Trends

The Qualitative Growth of the Internet



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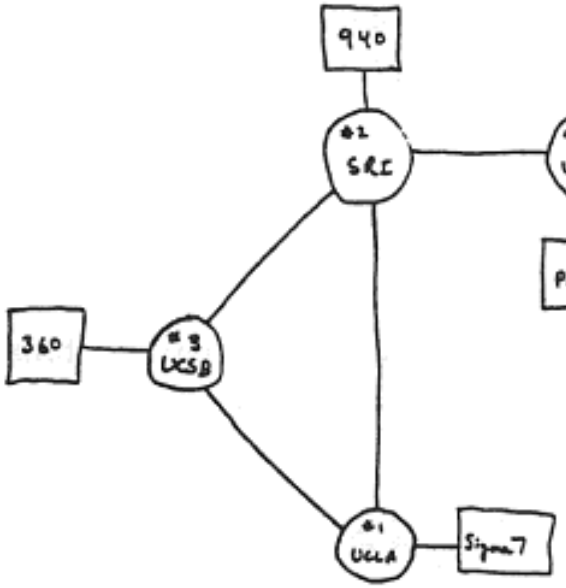


2002

Mobile Internet

WWW

Email

Research network

people to people

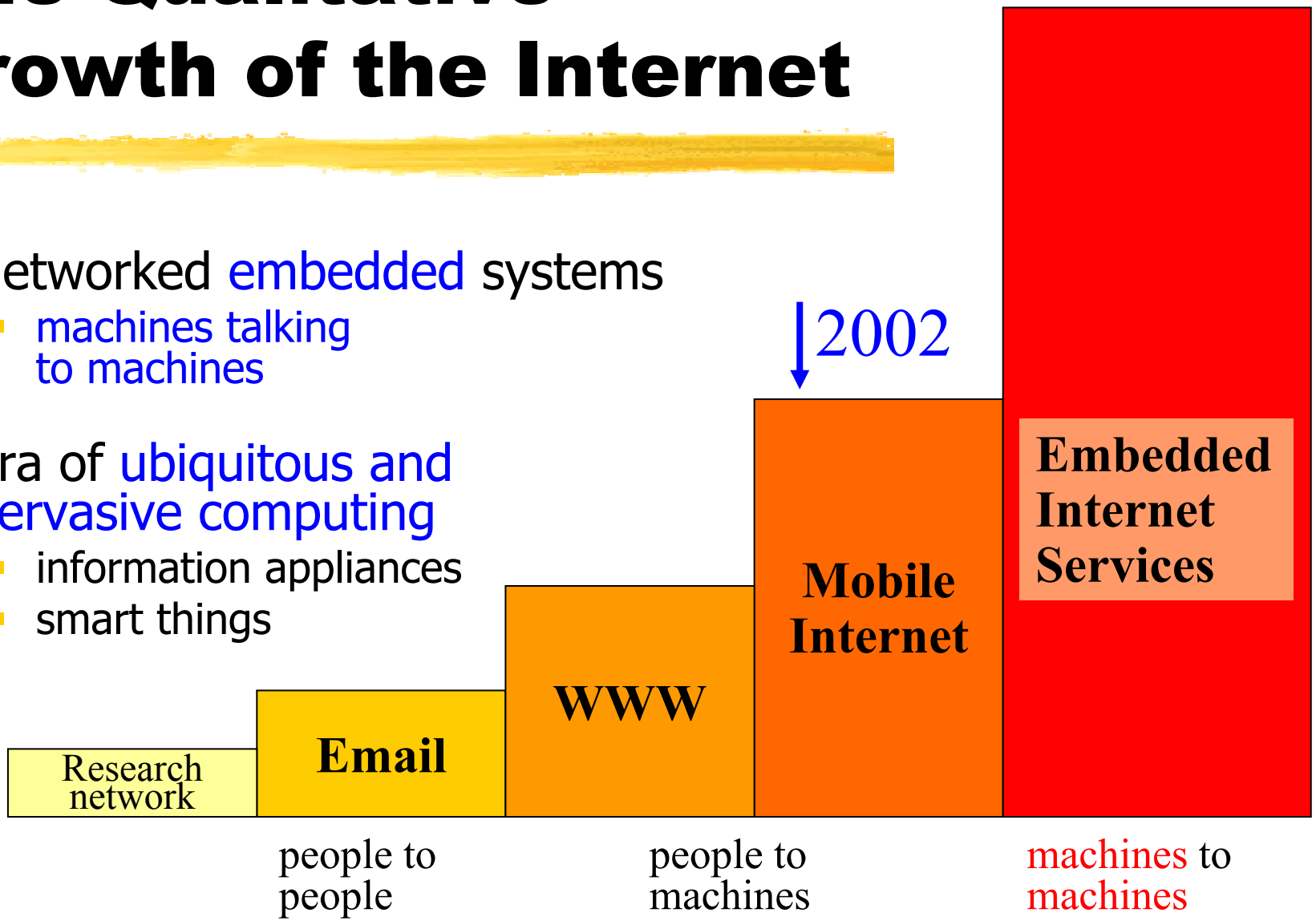
people to machines

Internet time line

?

The Qualitative Growth of the Internet

- Networked embedded systems
  - machines talking to machines
- Era of ubiquitous and pervasive computing
  - information appliances
  - smart things



Ubiquitous Computing

- Today, the Internet connects all *computers*

- Tomorrow everyday *objects* will become smart
  - embedded processors

- ...and they will all be interconnected
  - wireless communication

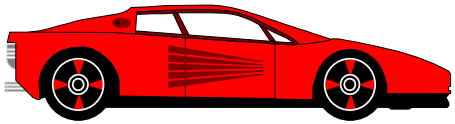
image source: “Die Zeit”

Everything Smart?

Embedded Computing Enables „Cooperating Smart Things“

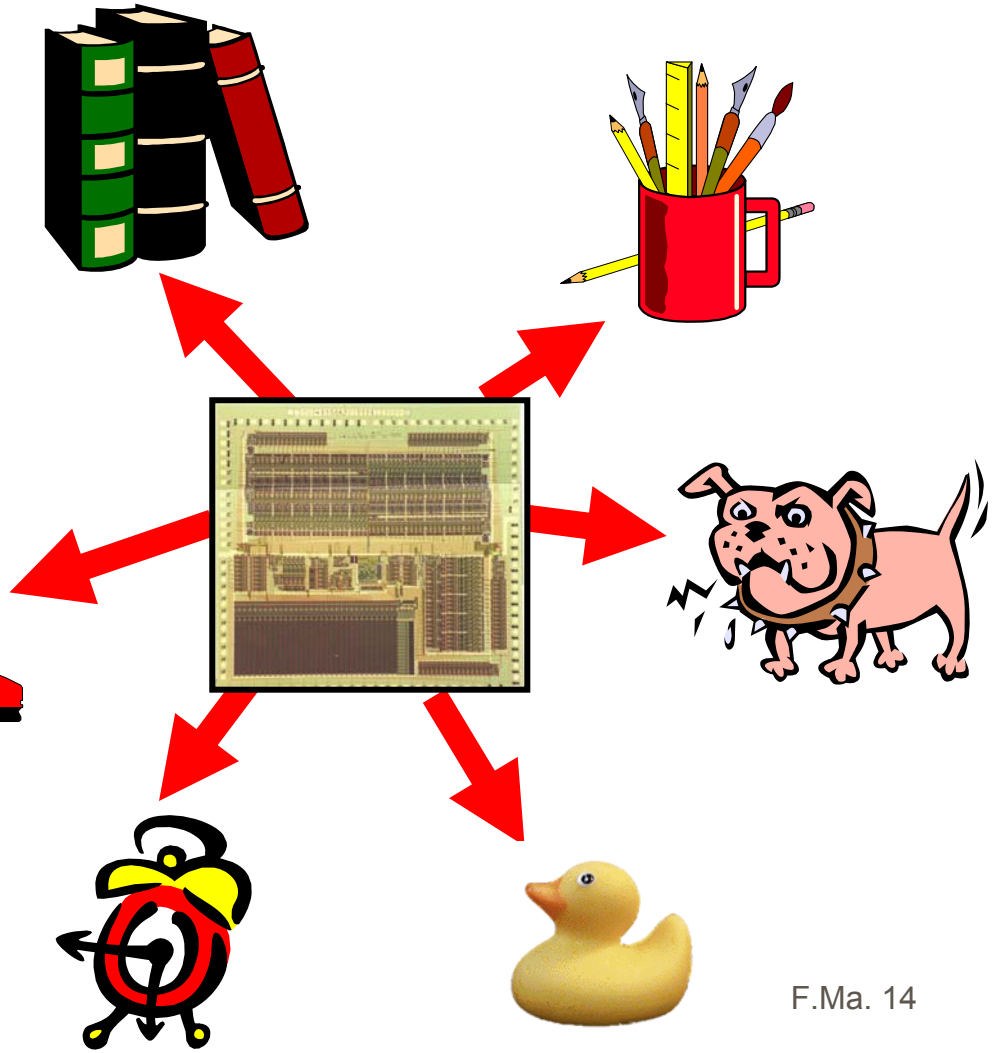
Real world objects are enriched with information processing capabilities

1. Embedded processors
   - in everyday objects
   - small
   - cheap
   - lightweight



2. Wireless communication
   - spontaneous networks

3. Sensors



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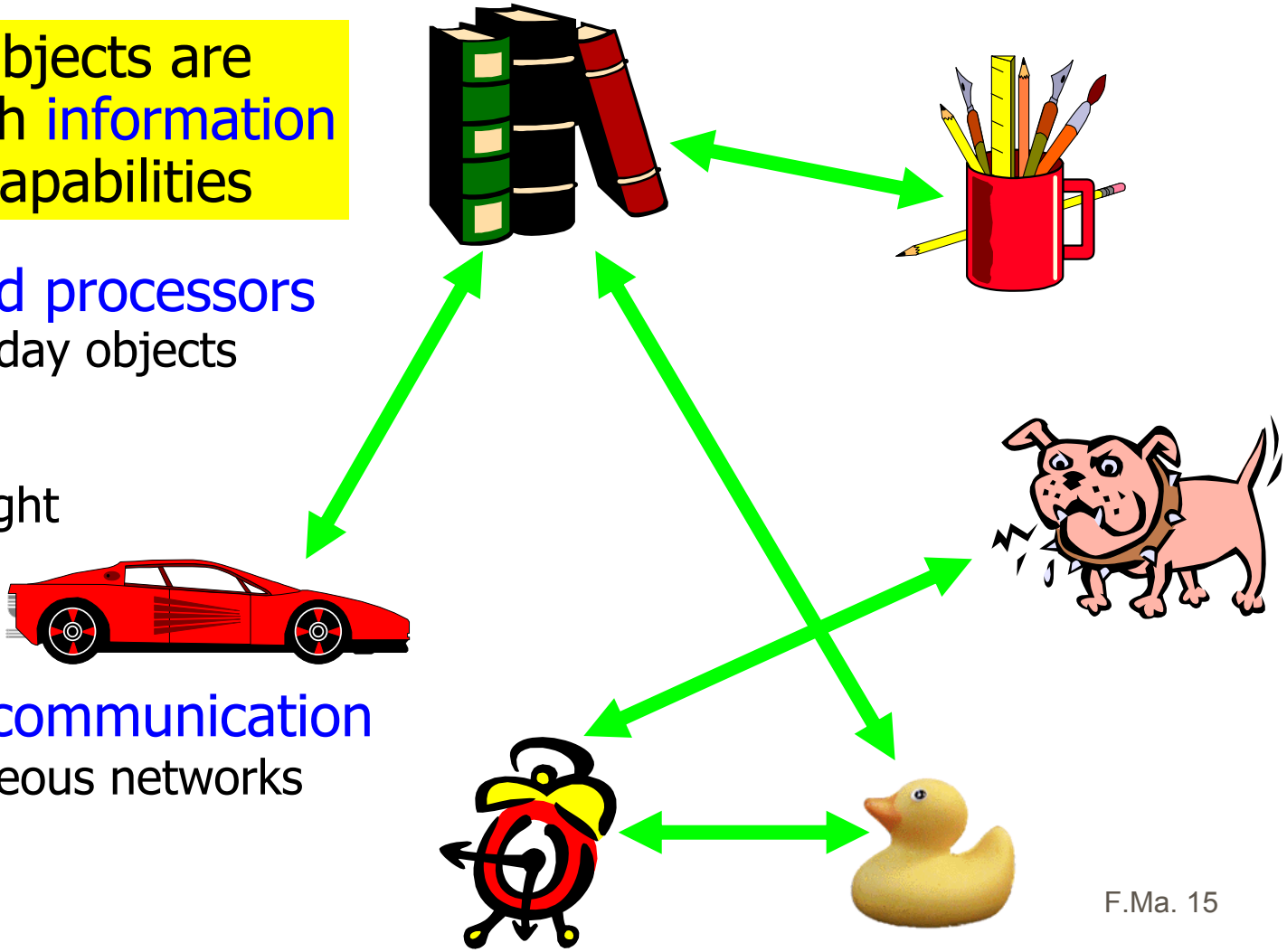
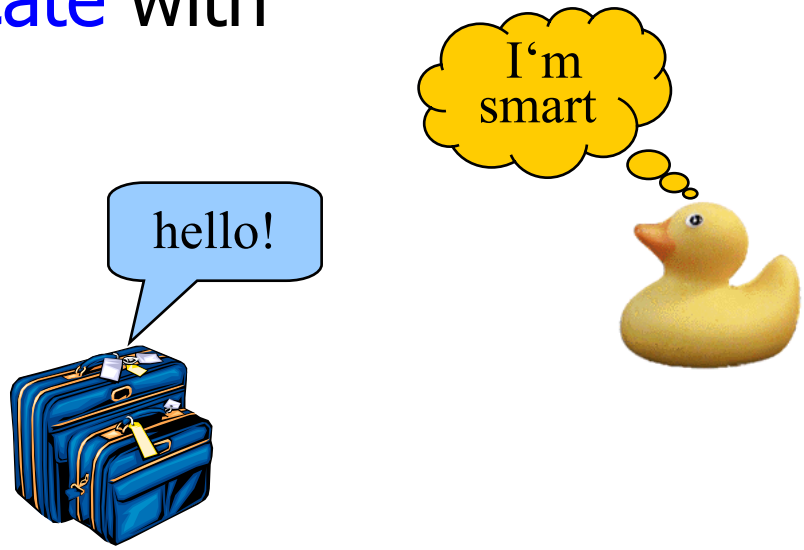
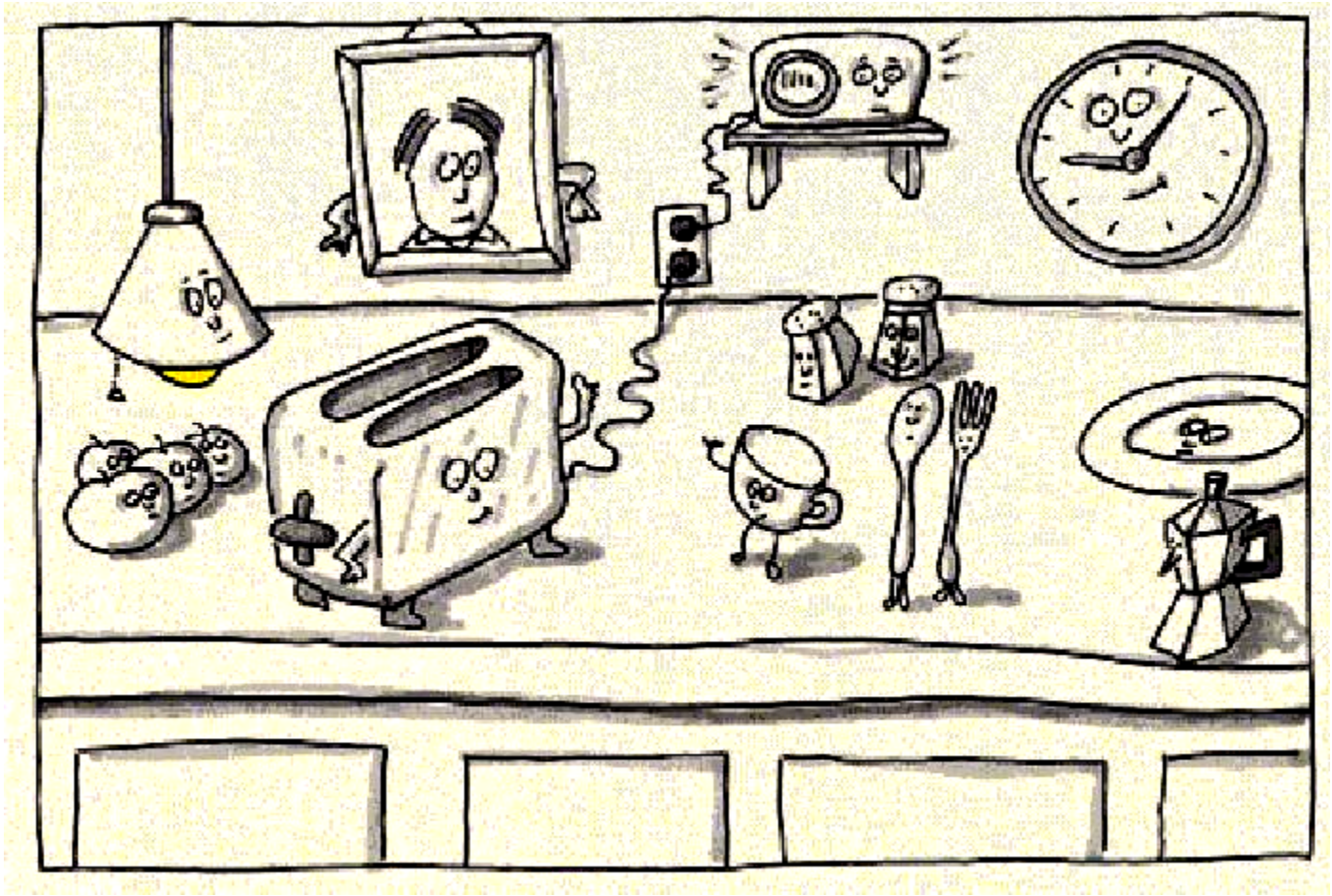


What If All Things Were Smart?

- And communicate with each other?



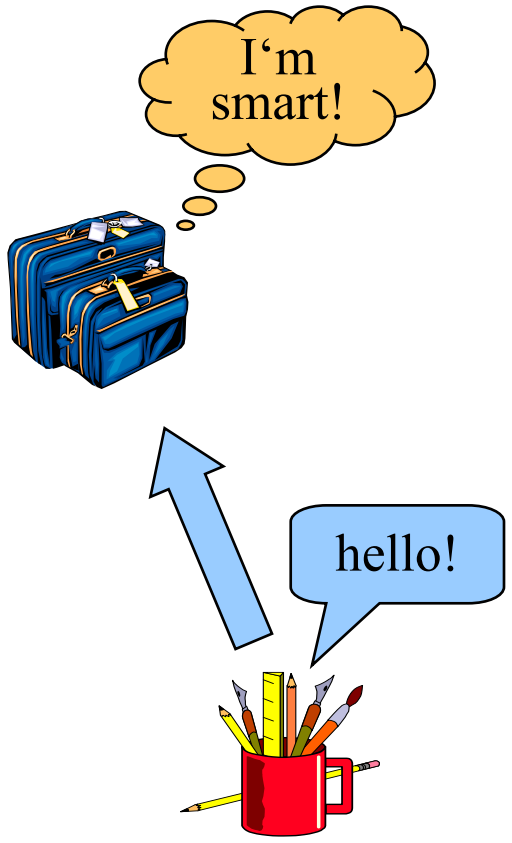
Smart Objects?



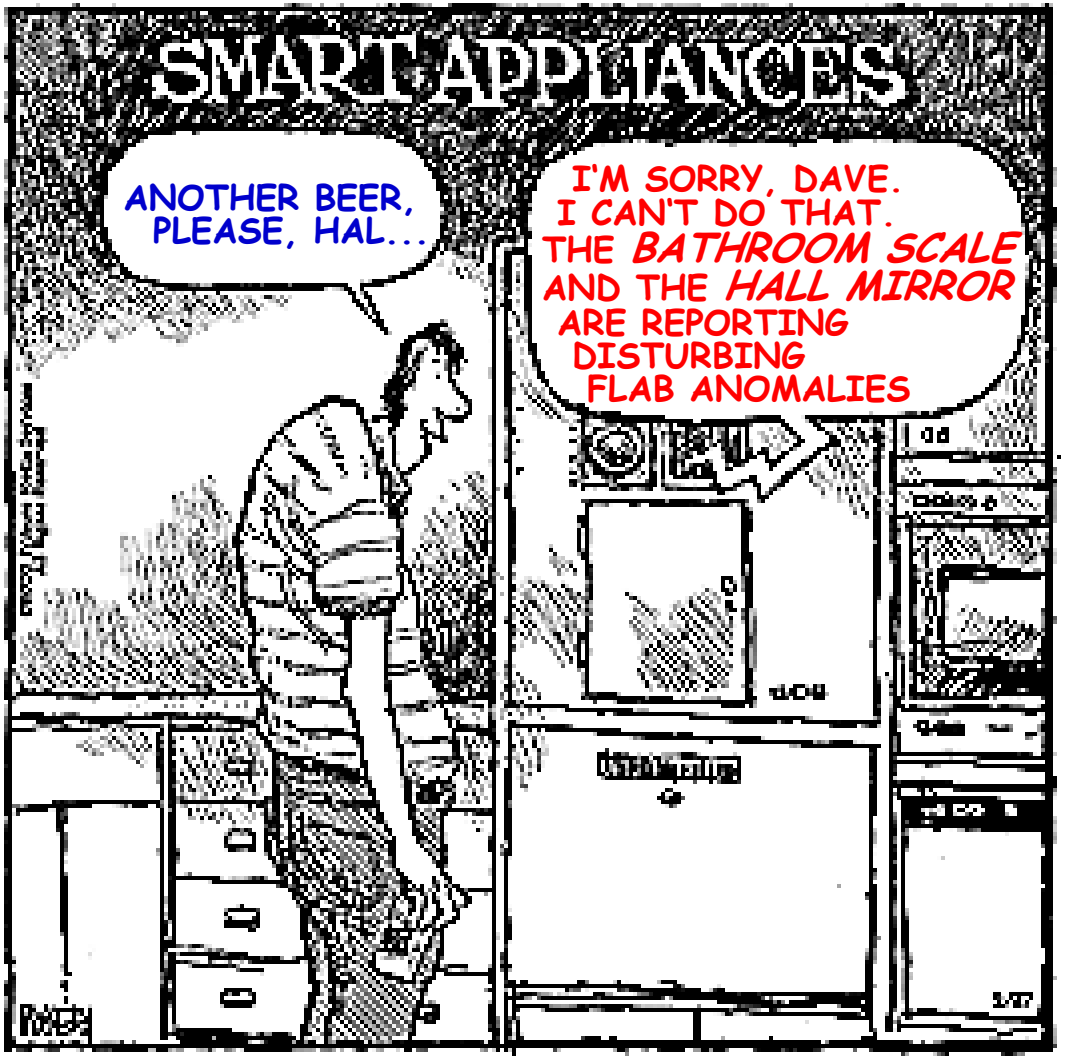
„A Dancing Toaster" (Rich Gold, XEROX PARC)

Smart Objects!

- Can remember pertinent events
  - they have a memory
- Show context-sensitive behavior
  - they may have sensors
  - → location / situation awareness
- Are responsive
  - communicate with their environment
  - networked with other smart objects

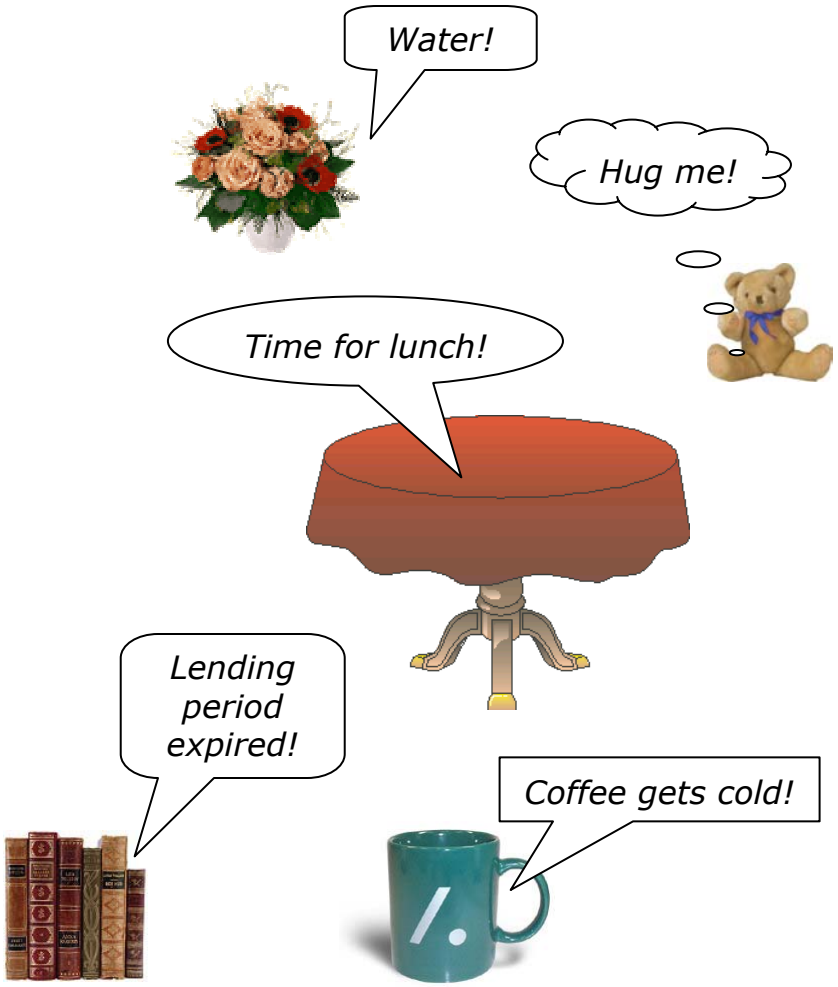


Networked with Other Smart Objects?



Cartoon by Jeff MacNelly

Happy Networking?



Calm Technology?

Calm Technology!

- Mark Weiser
  - 1952 - 1999
  - XEROX PARC

- The Coming Age of Calm Technology
  - *„As technology becomes more imbedded and invisible, it calms our lives by removing the annoyances while keeping us connected with what is truly important"*
- 1988 Notion of Ubiquitous Computing
  - *„In the 21st century the technology revolution will move into the everyday, the small and the invisible..."*
- The Disappearing Computer
  - *„The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."*

Disappearing Computer

- Information processing moves to the background
  - human centered: concentrate on the task, not the tool
  - the notion „computer as a tool" does no longer hold

- New picture of computing as an invisible, ubiquitous background assistance
  - specialized, invisible computers will become an integral part of the natural human environment
  - „computing without computers"

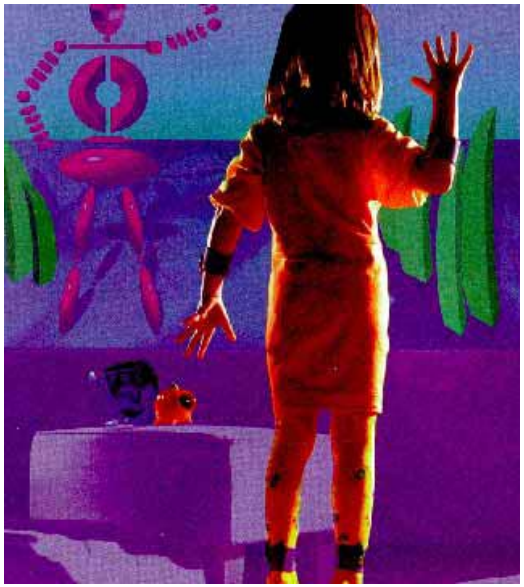


image source: Phillips

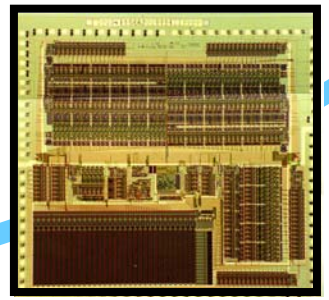
4 Reasons for Ubicomp

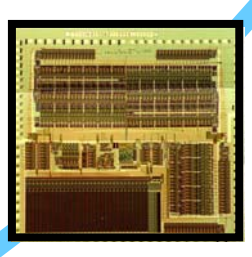
Four Reasons for Ubicomp

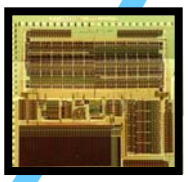
1

First Reason for Ubiquitous Computing: Moore's Law (1965)

- Processing speed and storage capacity double every 18 months
  - „cheaper, smaller, faster"
- Exponential increase
  - will probably go on for the next 10 years at same rate







Moore‘s Law
Electronics, April 19, 1965

Cramming more components onto integrated circuits

With unit cost falling as the number of components per circuit rises, by 1975 economics may dictate squeezing as many as 65,000 components on a single silicon chip

By Gordon E. Moore

Director, Research and Development Laboratories, Fairchild Semiconductor division of Fairchild Camera and Instrument Corp.

Moore‘s Law

The future of integrated electronics is the future of electronics itself. The advantages of integration will bring about a proliferation of electronics, pushing this science into many new areas.

Integrated circuits will lead to such wonders as home computers—or at least terminals connected to a central computer—automatic controls for automobiles, and personal portable communications equipment.

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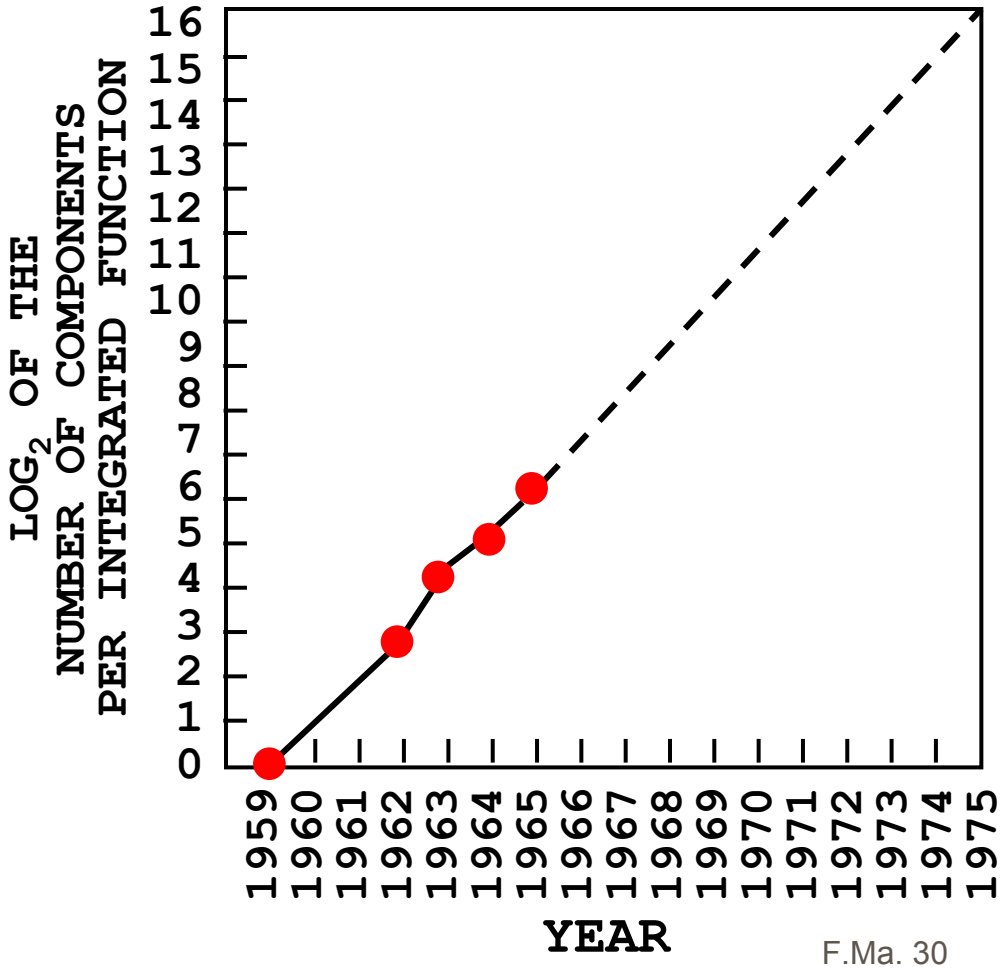
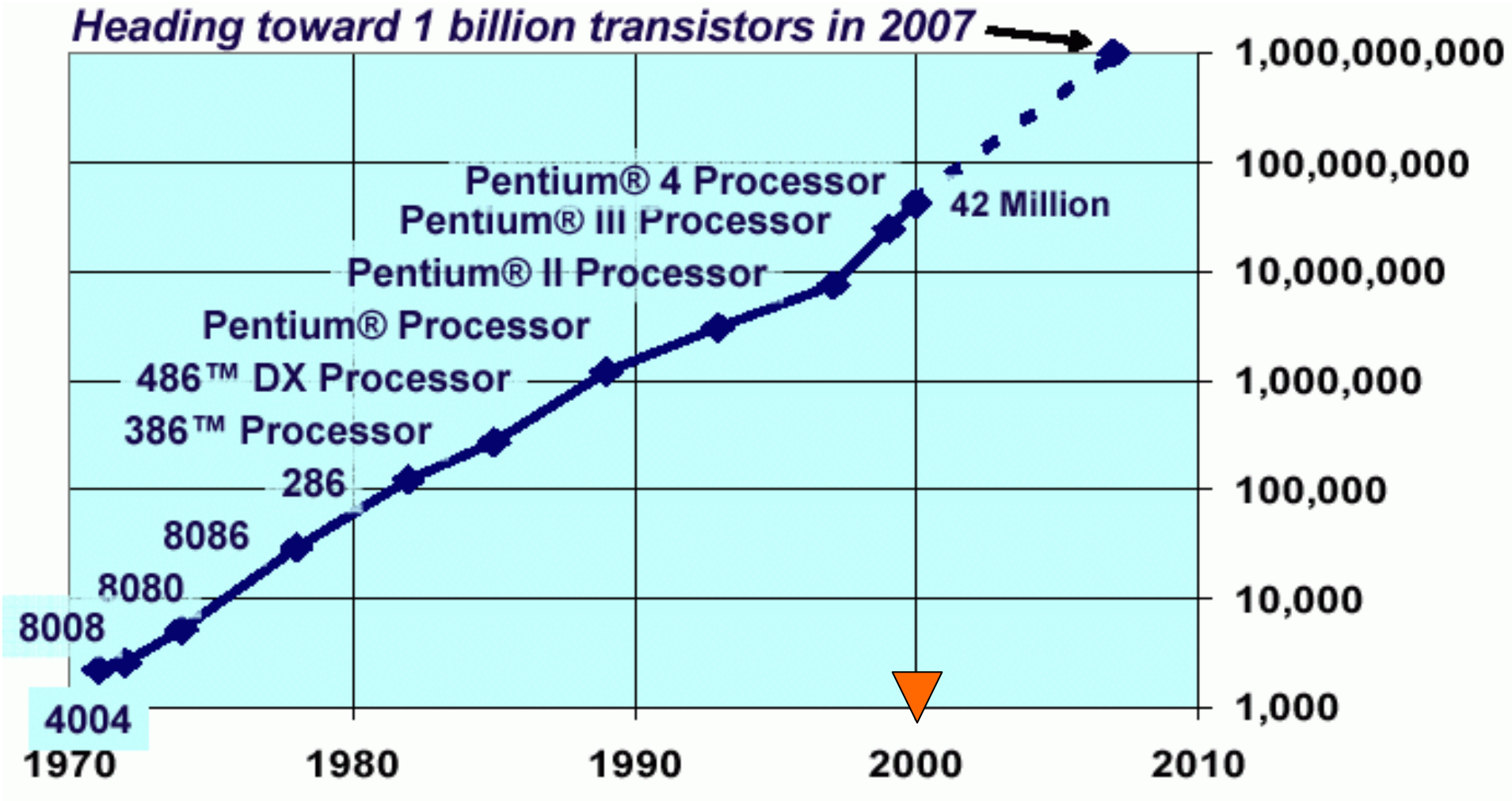
Moore's Law

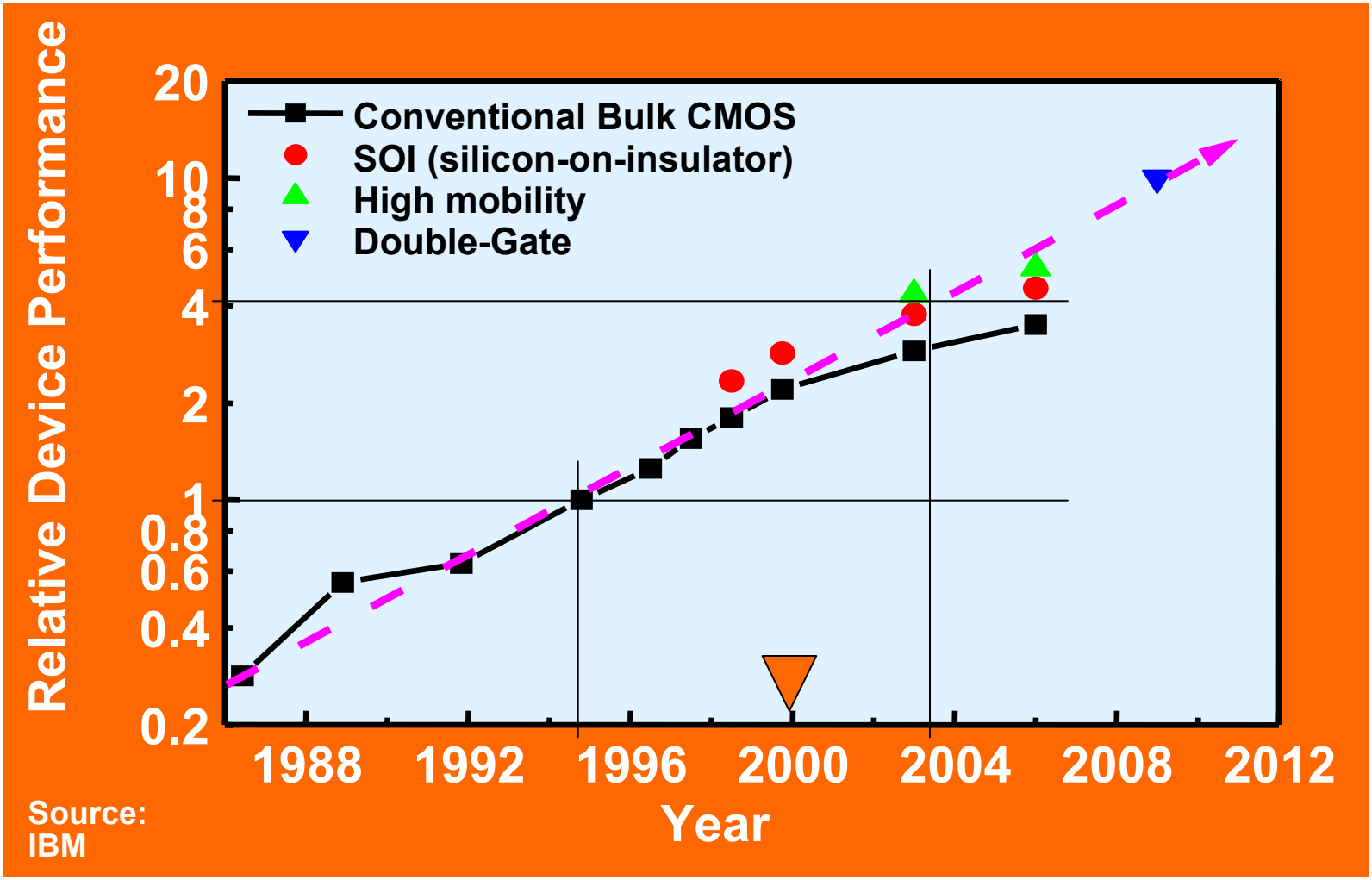
The complexity for minimum component costs has increased at a rate of roughly a factor of two per year (see graph on next page). Certainly over the short term this rate can be expected to continue, if not to increase. Over the longer term, the rate is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least 10 years. That means by 1975, the number of components per integrated circuit for minimum cost will be 65,000.



Transistors Per Die



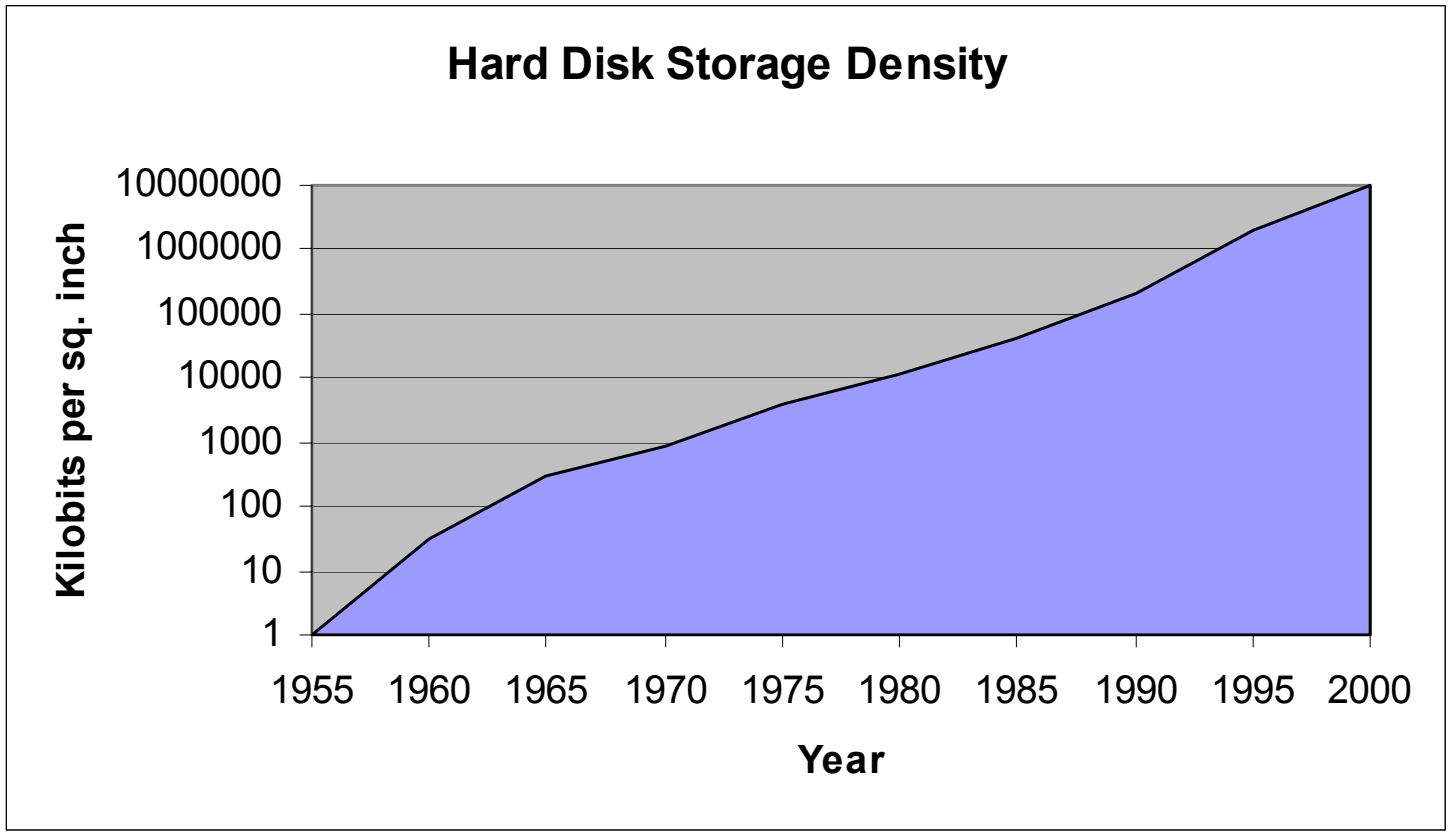
Example: CMOS Performance Increase



SIA Roadmap 1998

Year	1999	2002	2005	2008	2011	2014
structural size (nm)	180	130	100	70	50	35
cost / transistor	1'735	.580	.255	.110	.049	.022
clock [MHz]	1250	2100	3500	6000	10000	16900
chip size [mm^2]	340	430	520	620	750	900

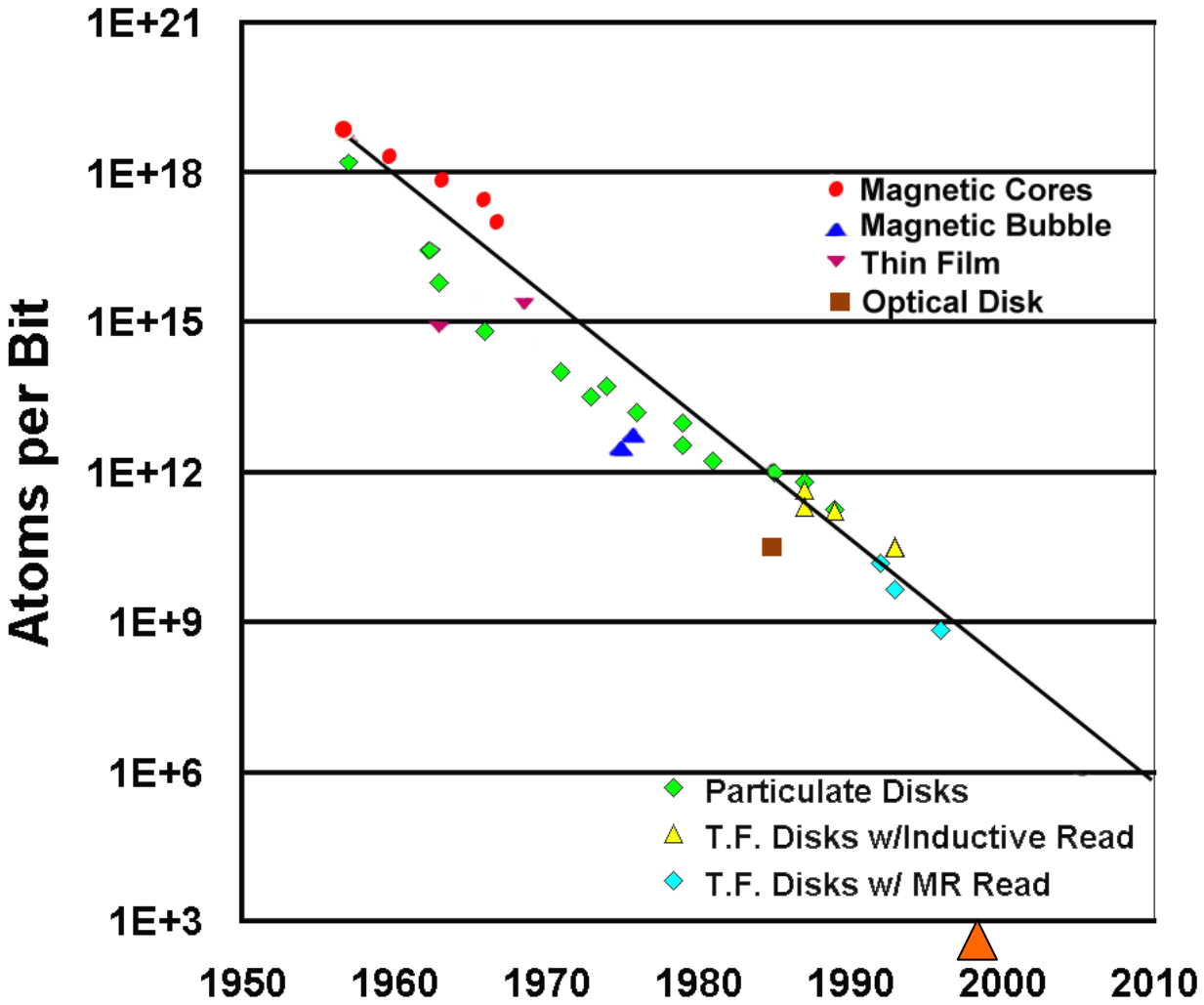
Disk Storage Density



Scientific American, May 2000

A 1GB disk drive in a compact flash card format (2001)

Bit Storage Density

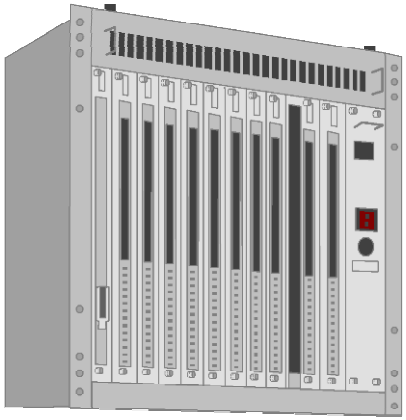


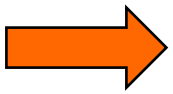
Generalized Moore's Law

- Most important technology parameters double every 1 – 3 years:
  - computation cycles
  - memory, magnetic disks
  - bandwidth

Problems:
- increasing cost
- energy

- Consequence: scaling down





WatchPad1.5 Functions

Bluetooth module (band joint)

IrDA port

Piezo speaker bottom

320x240 B/W LCD

Touch panel

Accelerometer on board

Battery terminal (right side)

Microphone

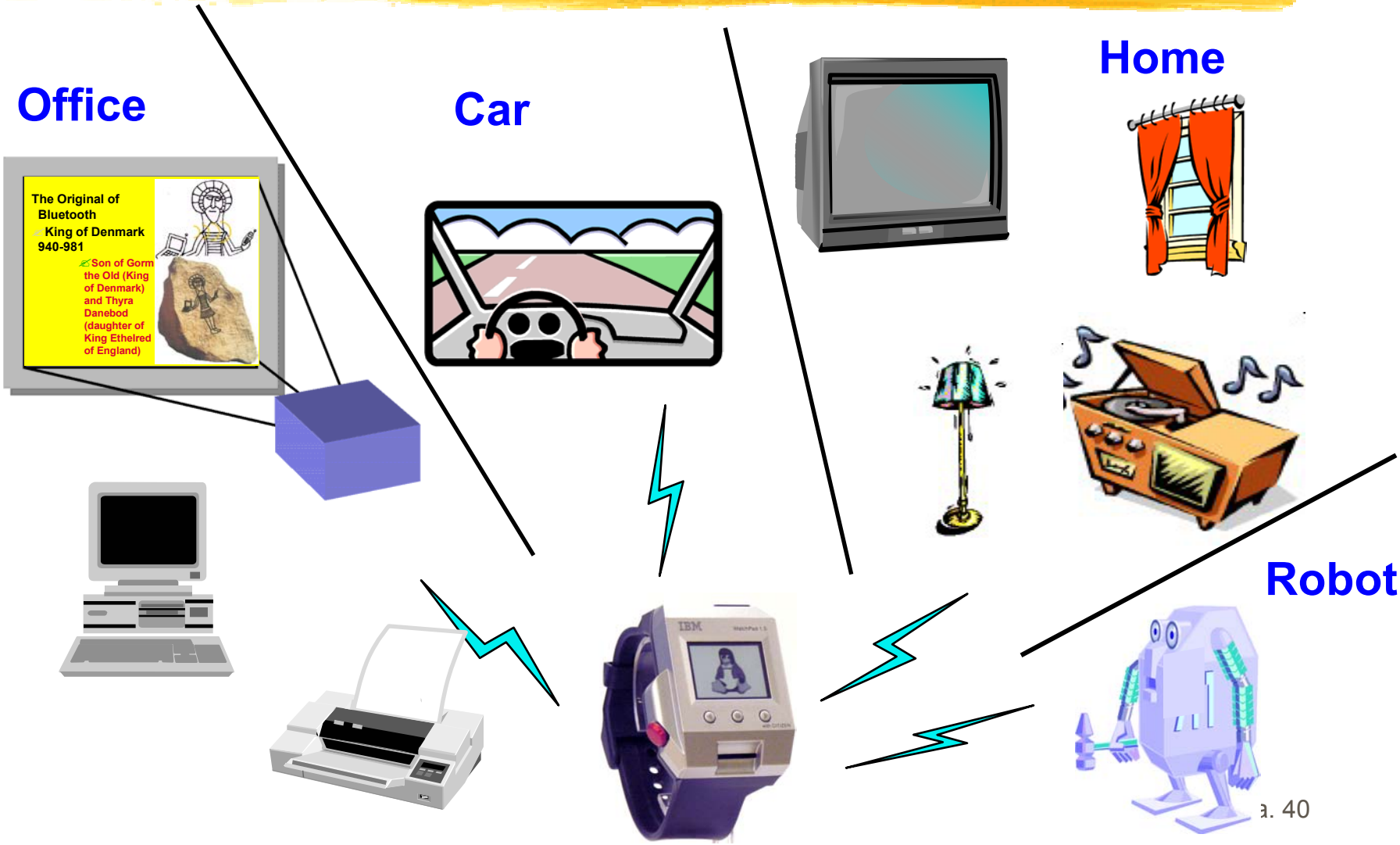
Stem switch

3 Buttons

Vibrator around here

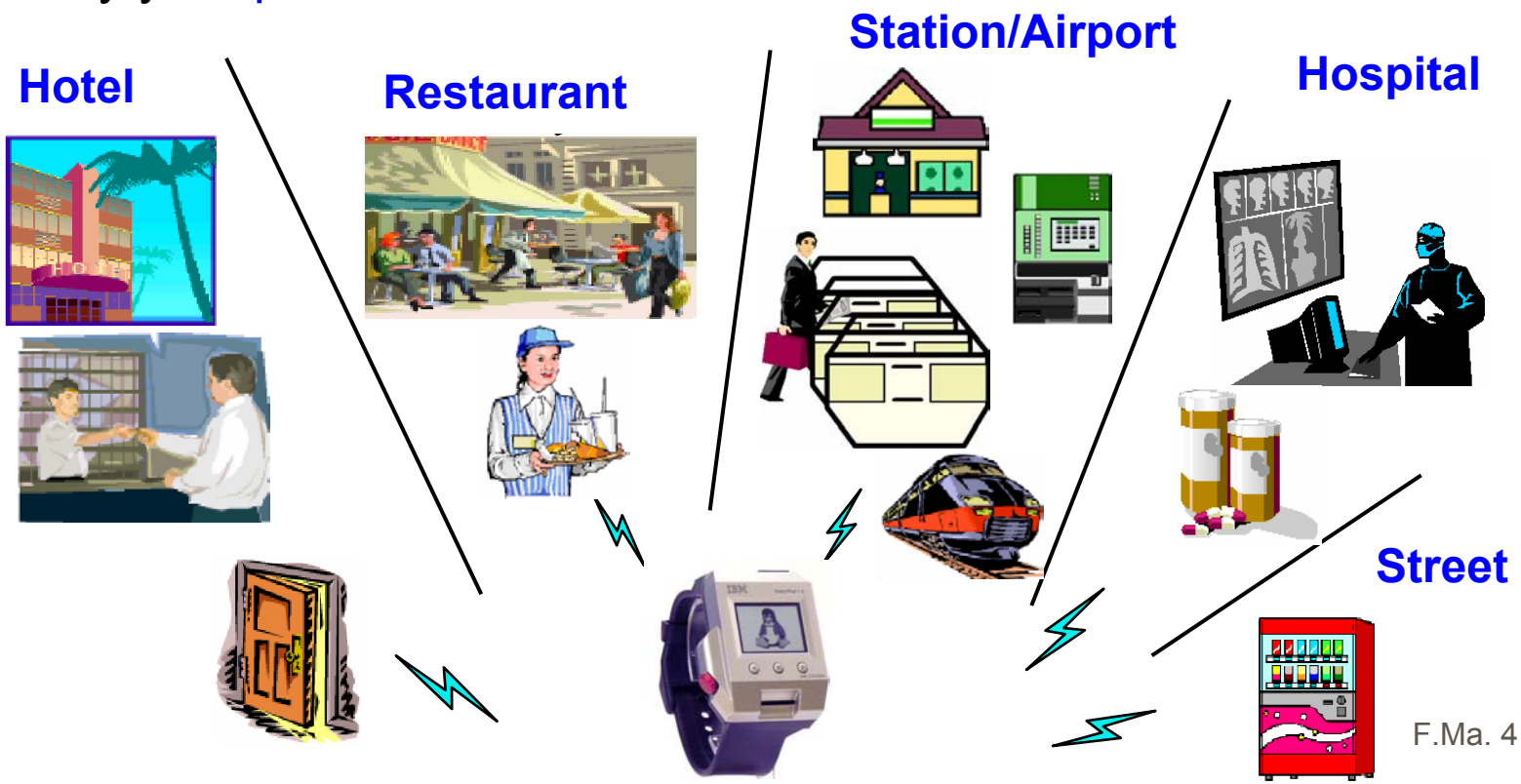
Fingerprint sensor

Use as a Universal Remote Controller



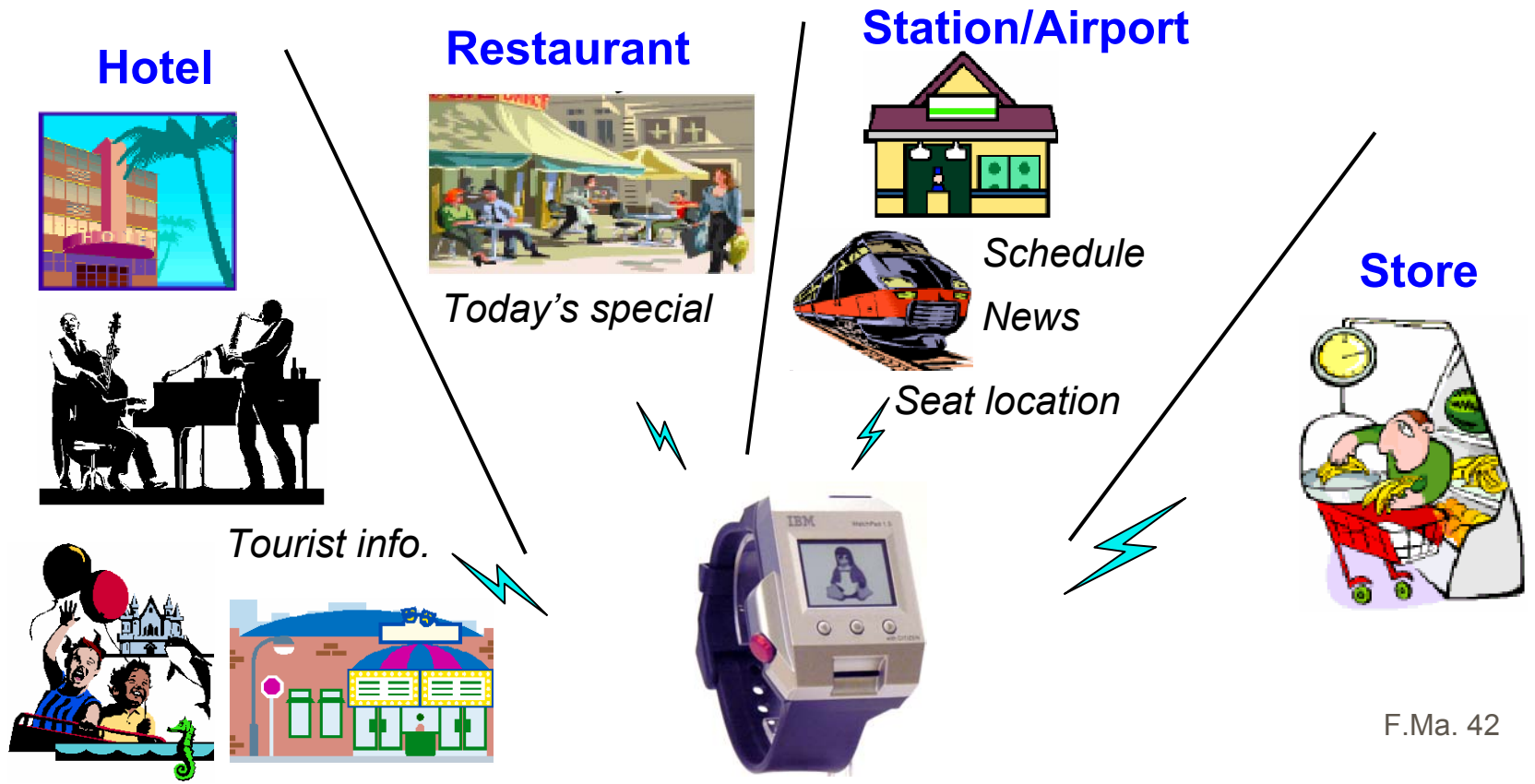
Use as a Personal Identificator

- Automated check-in at hotel and air counter
- Cashless payment at restaurant and station
- Medical history and prescription retrieval
- Specify your preference

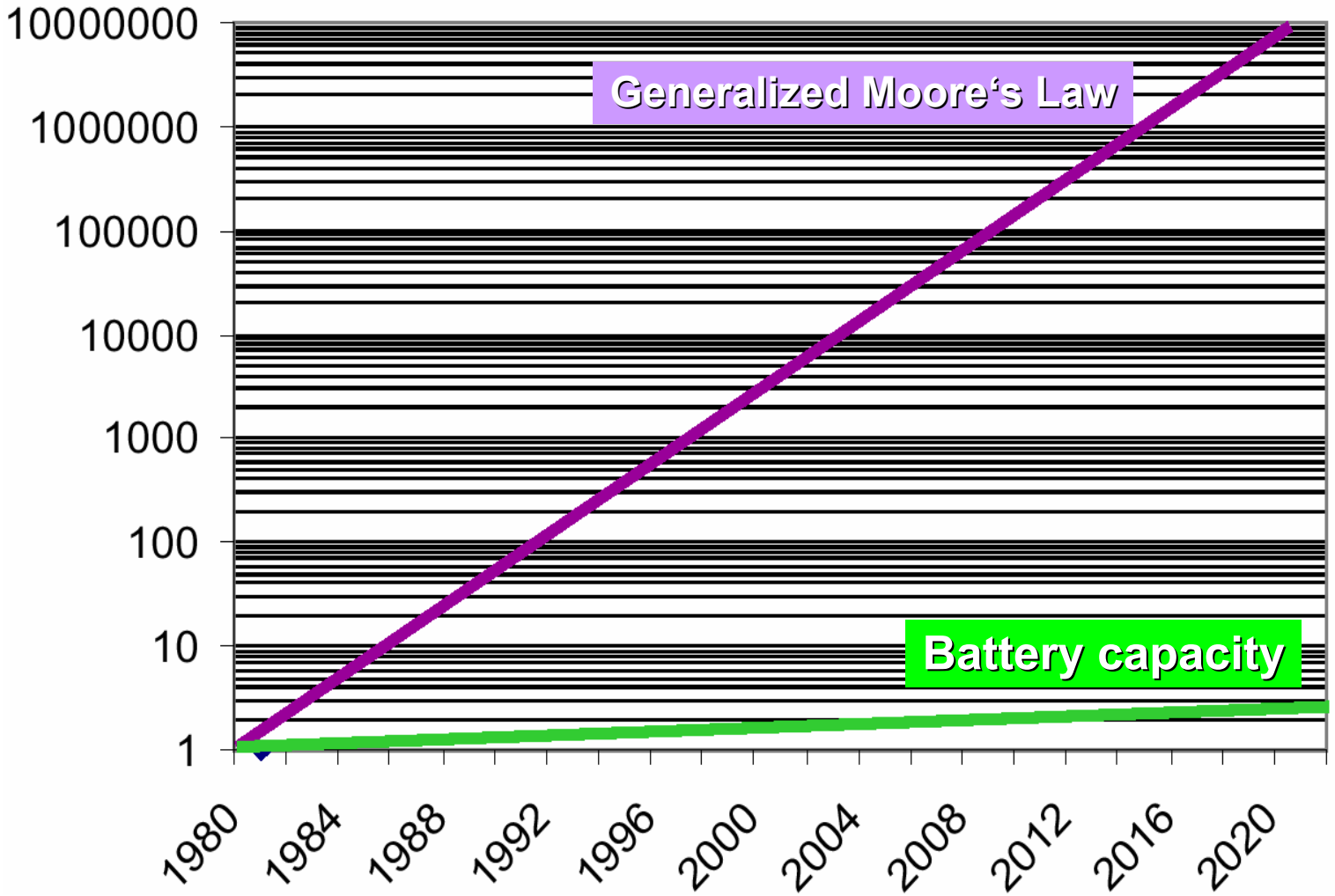


Use as a Display for Location Based Services

- Provide personalized advertisement and offering information
- Timetable and flight schedule at station and airport
- Navigate you at stations



Energy Crisis: Not Everything Obeys Moore‘s Law!



Source:
Jan Rabaey

Barriers

Exponential increase of aircraft speed?

About Predictions (1955)

"Bei diesem besonders schnittigen Modell aus dem Jahr 1975 handelt es sich um einen eleganten Zweisitzer mit Heck-Atomantrieb; die Sitze befinden sich dicht hinter den Vorderrädern..."

How Accurate Were Previous Predictions?

- Moon colonies
  - → too expensive?
- Submarine towns
  - → … + unconvenient?
- Flying cars
  - → … + too dangerous?
- Paperless office
  - → too early?

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- Moon colonies
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  - → … + unconvenient?
- Flying cars
  - → … + too dangerous?
- Paperless office
  - → too early?
- Supersonic planes
  - → what about the Concorde?
- Home robots
  - → too early?
- Magnetic suspension trains
  - → too expensive?
- Controled nuclear fusion
  - → too optimistic?

Predictions in 1938

- In 1938 Arthur Train made some predictions about housing conditions 50 years later, in 1988 (in an article for the „Harper“ magazine):
  - air condition, color TV via coax cable and with remote control, radio clock, frozen food, mobile phone („pocket radio“), PC / PDA („photoelectric tabulating machine“), synthetic textiles,...

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  - But also: synthetic air, roll of films instead of books and „the roof of the house is used as the landing field for the family's collection of airplanes of assorted sizes",...

Predictions?

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

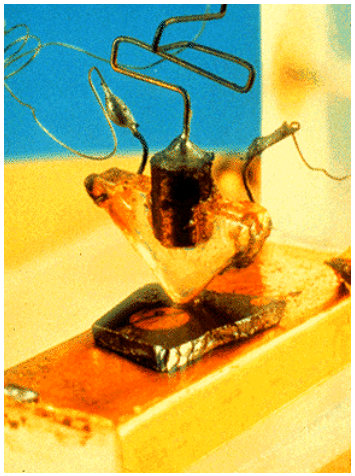
-- Bran Ferren, Chief Disney Imagineer

Four Reasons for Ubicomp

2

2nd Reason: New Materials

- Whole eras named after materials
  - e.g., „Stone Age“
- More recently: semiconductors, fibers
  - information and communication technology

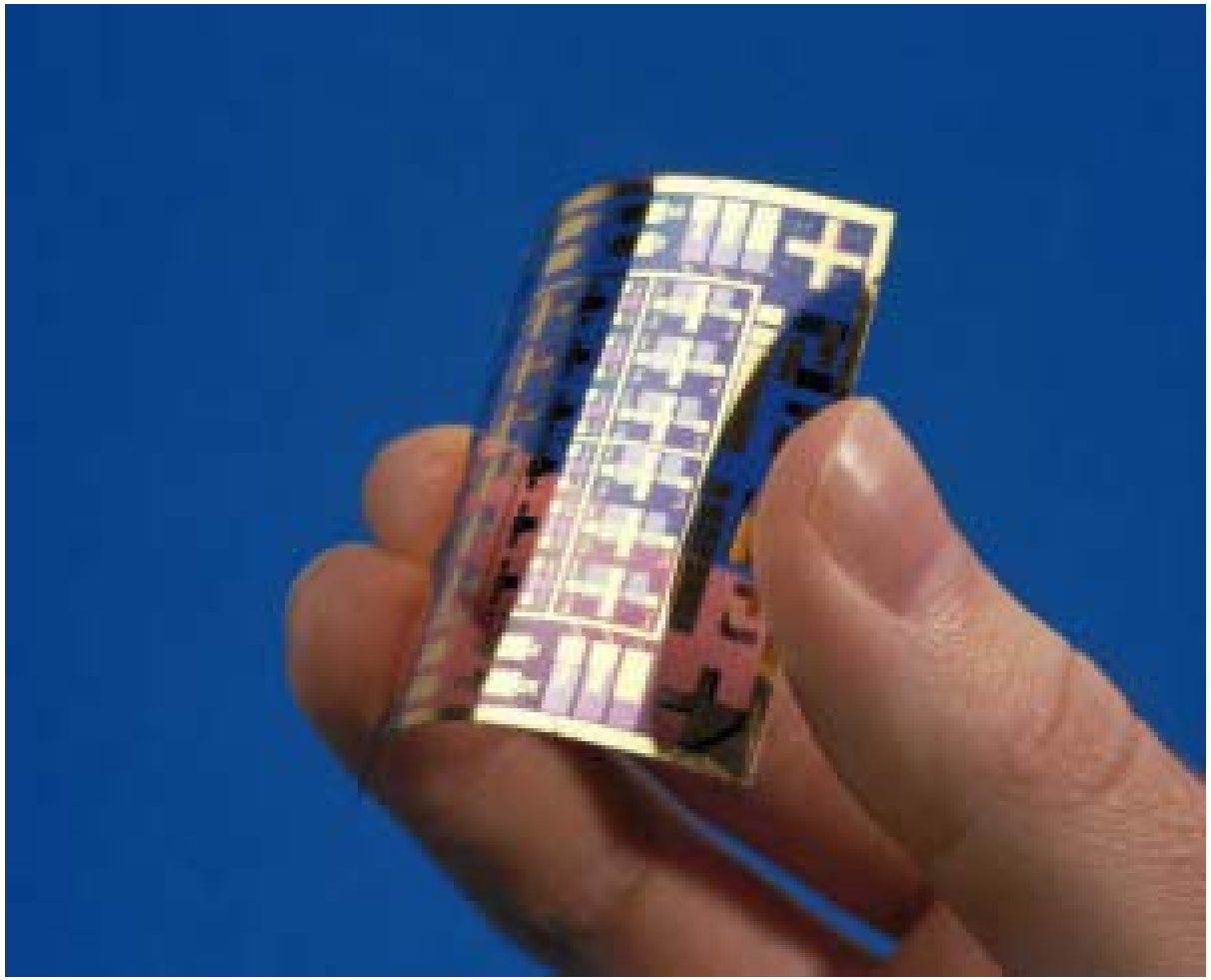


first transistor, 1947

- Organic semiconductors
  - → change the external appearance of computers
- „Plastic“ laser
  - → opto electronics, flexible displays,…
- …

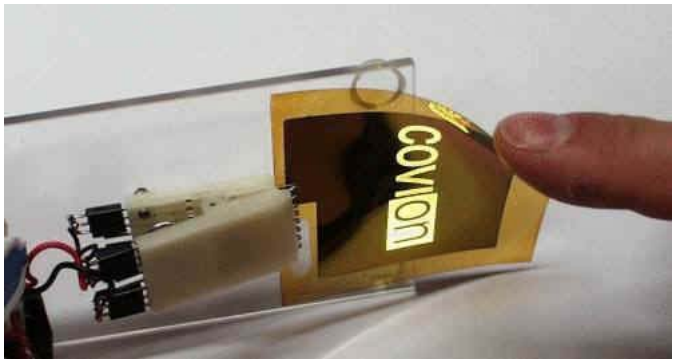
Flexible Substrates

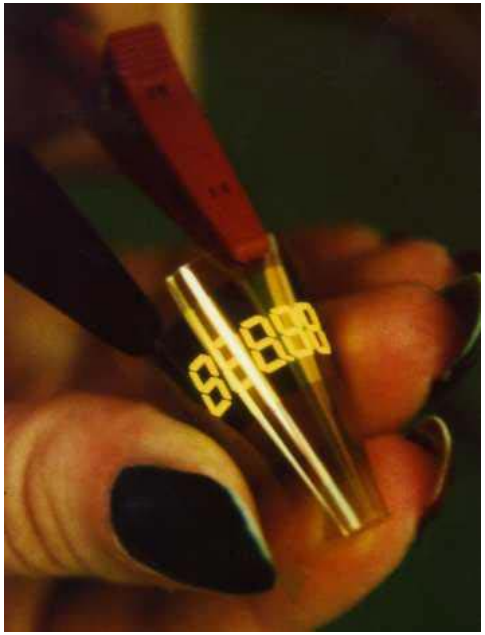
Flexible Substrates



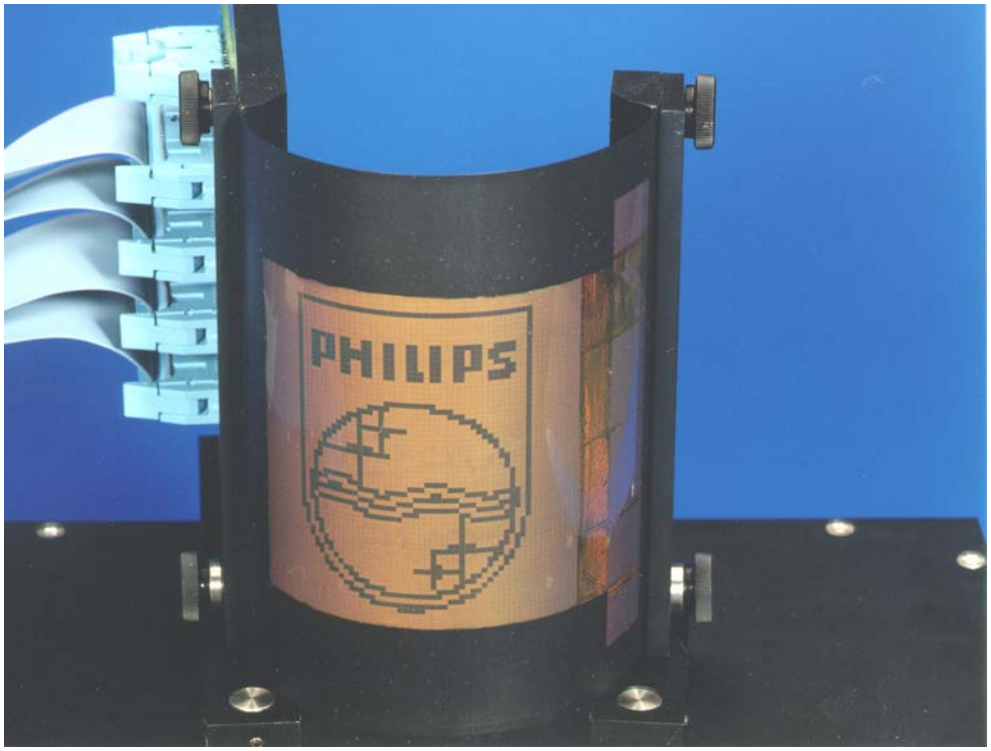
Light Emitting Polymers

- Organic semiconductors
- Plastic displays (~ 1 mm thick)
- Applications are emerging
  (e.g., curved or flexible displays)



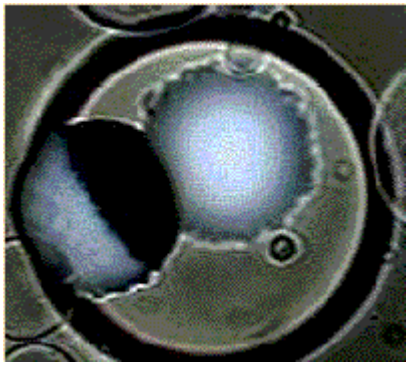


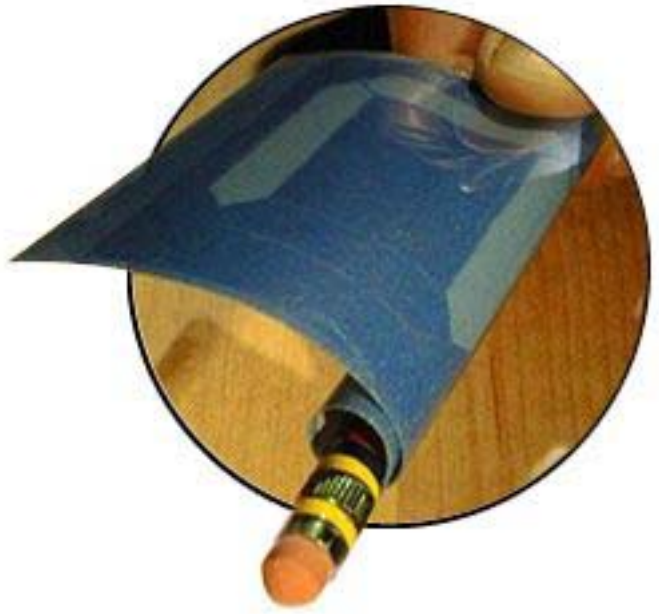
Flexible Display Prototypes (2001)



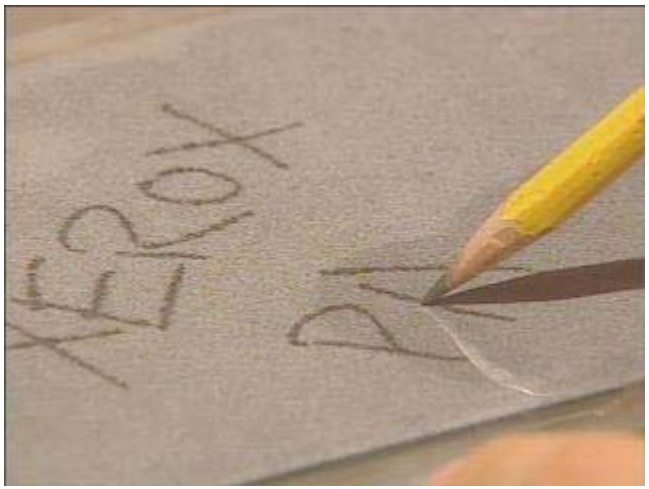
Another Example: Smart Paper, Electronic Ink

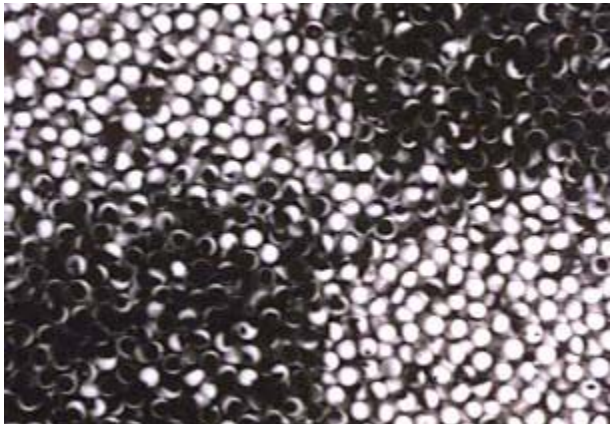
- Electronic ink
  - micro capsules, *white* on one side and *black* on the other
  - oriented by electrical field
  - substrate could be an array of plastic transistors
- Potentially high contrast, low energy, flexible
- Interactive: with magnetic pen





Smart Paper, Electronic Ink

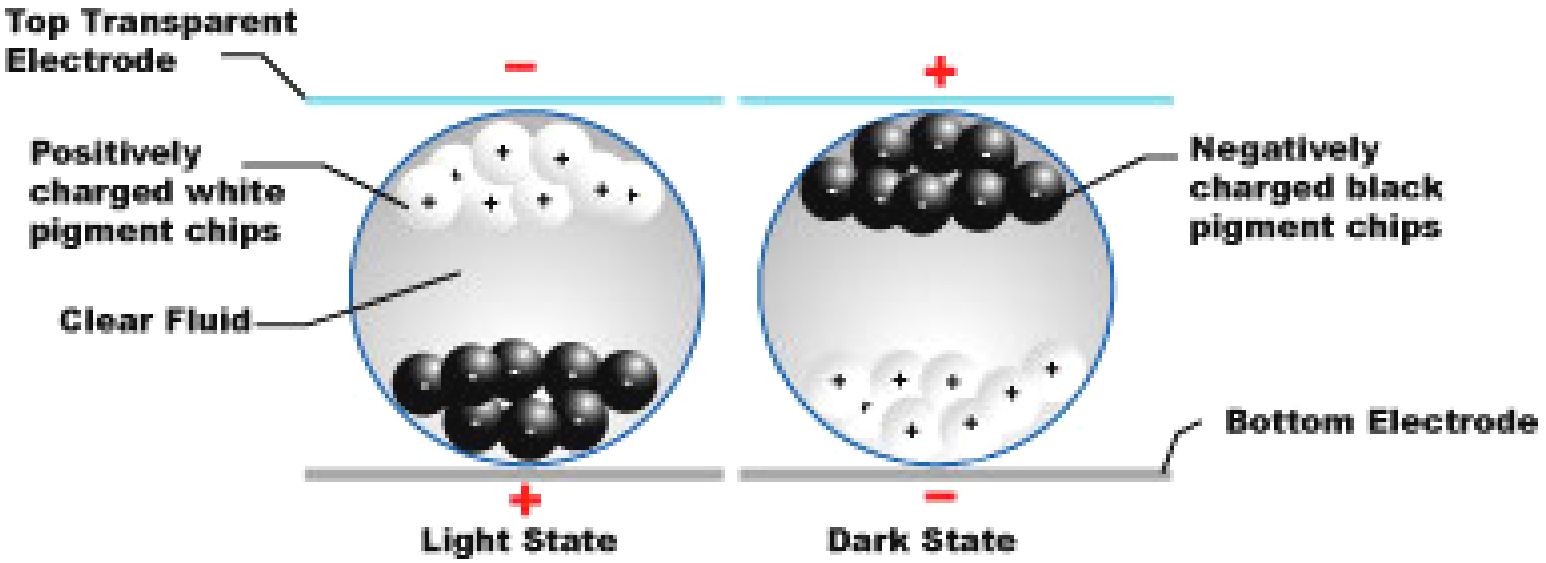




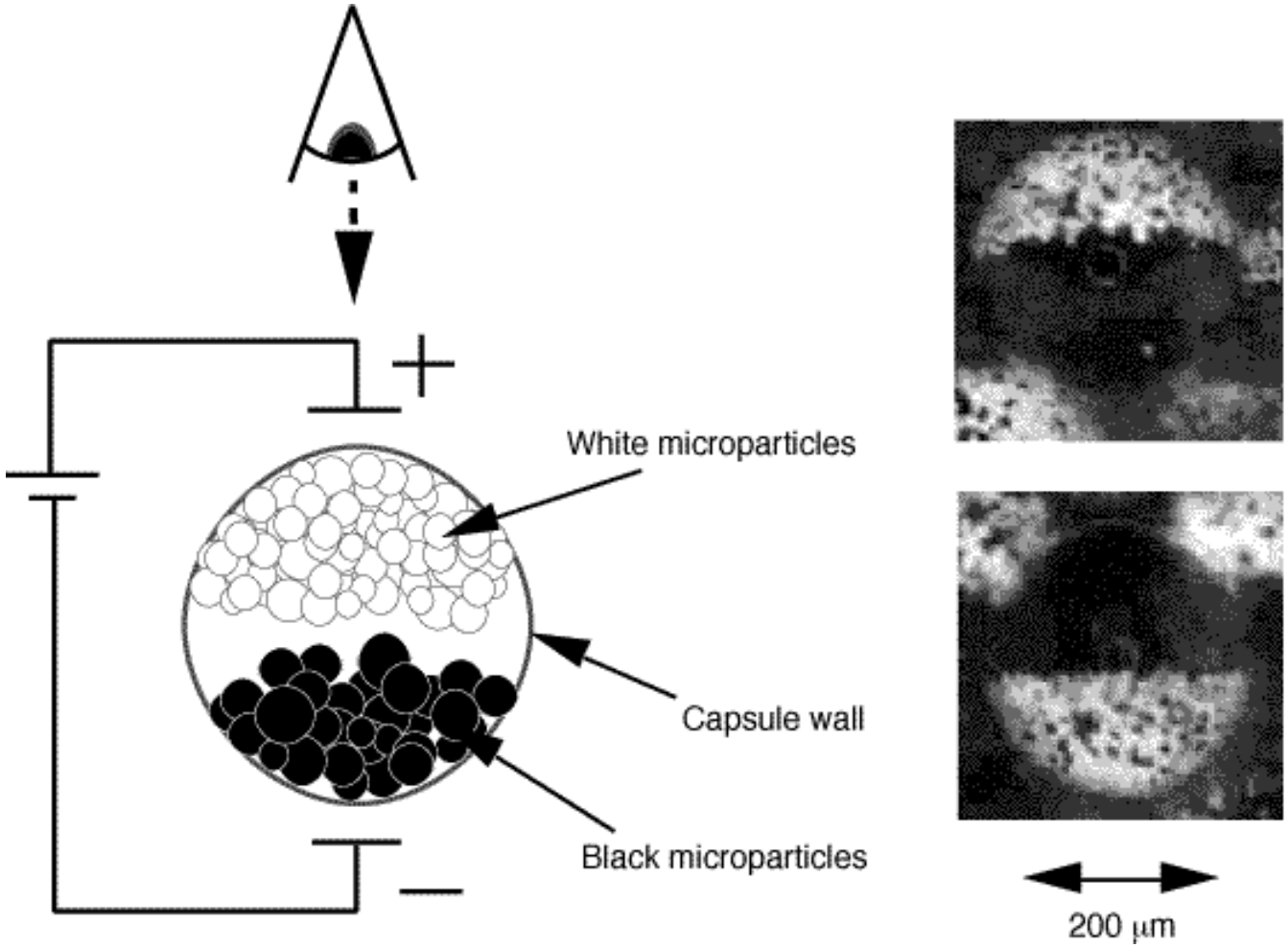
Detailed view of the micro capsules

An electronically charged pencil rotates the "pixels"

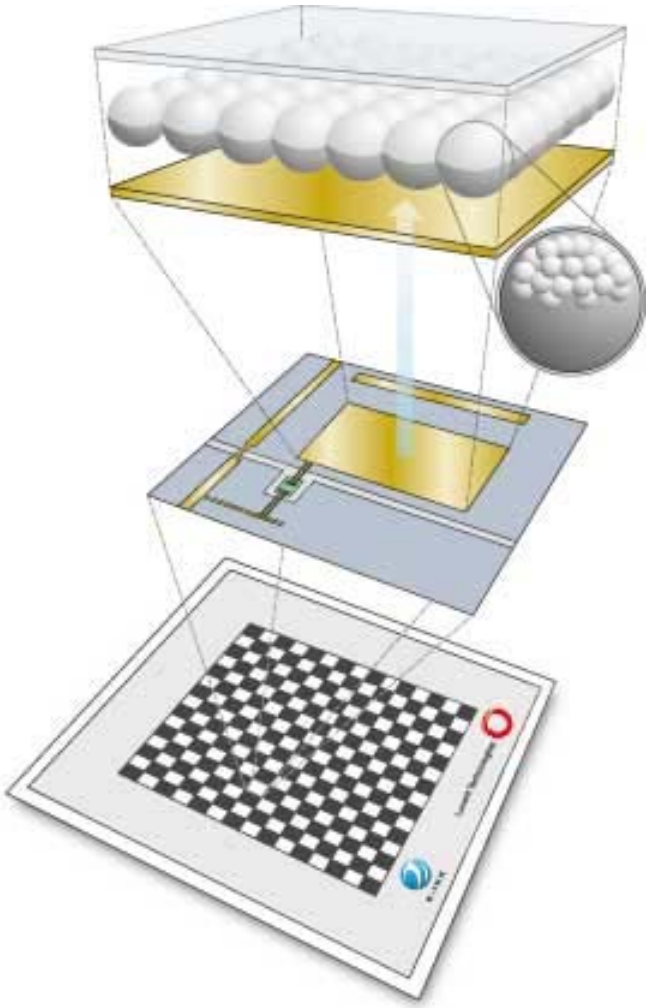
Electronic Ink

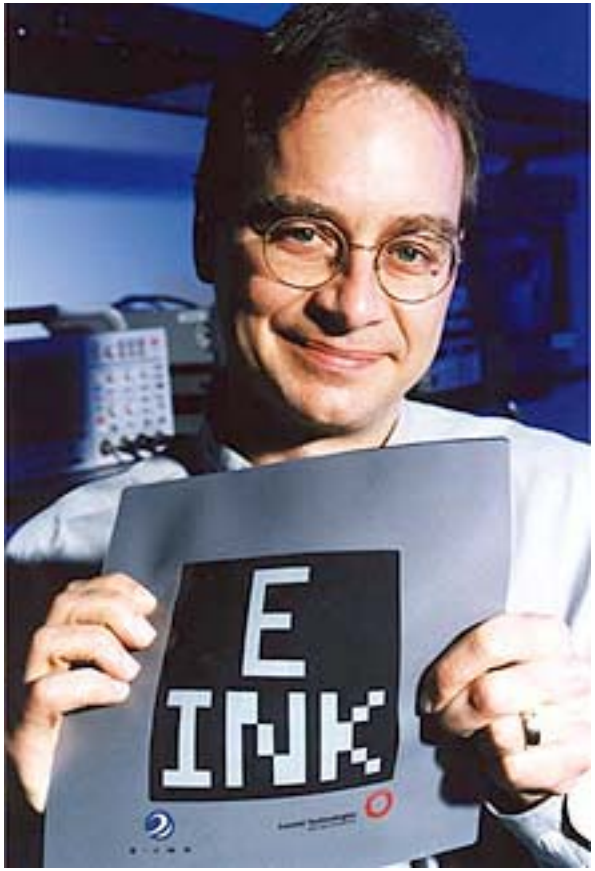


Electronic Ink



E-Ink





E-Ink: Cover Story and Evaluation Prototype

Smart Paper: Applications

This foldable and rollable interactive map
("*you are here*") is still science fiction, unfortunately

Four Reasons for Ubicomp

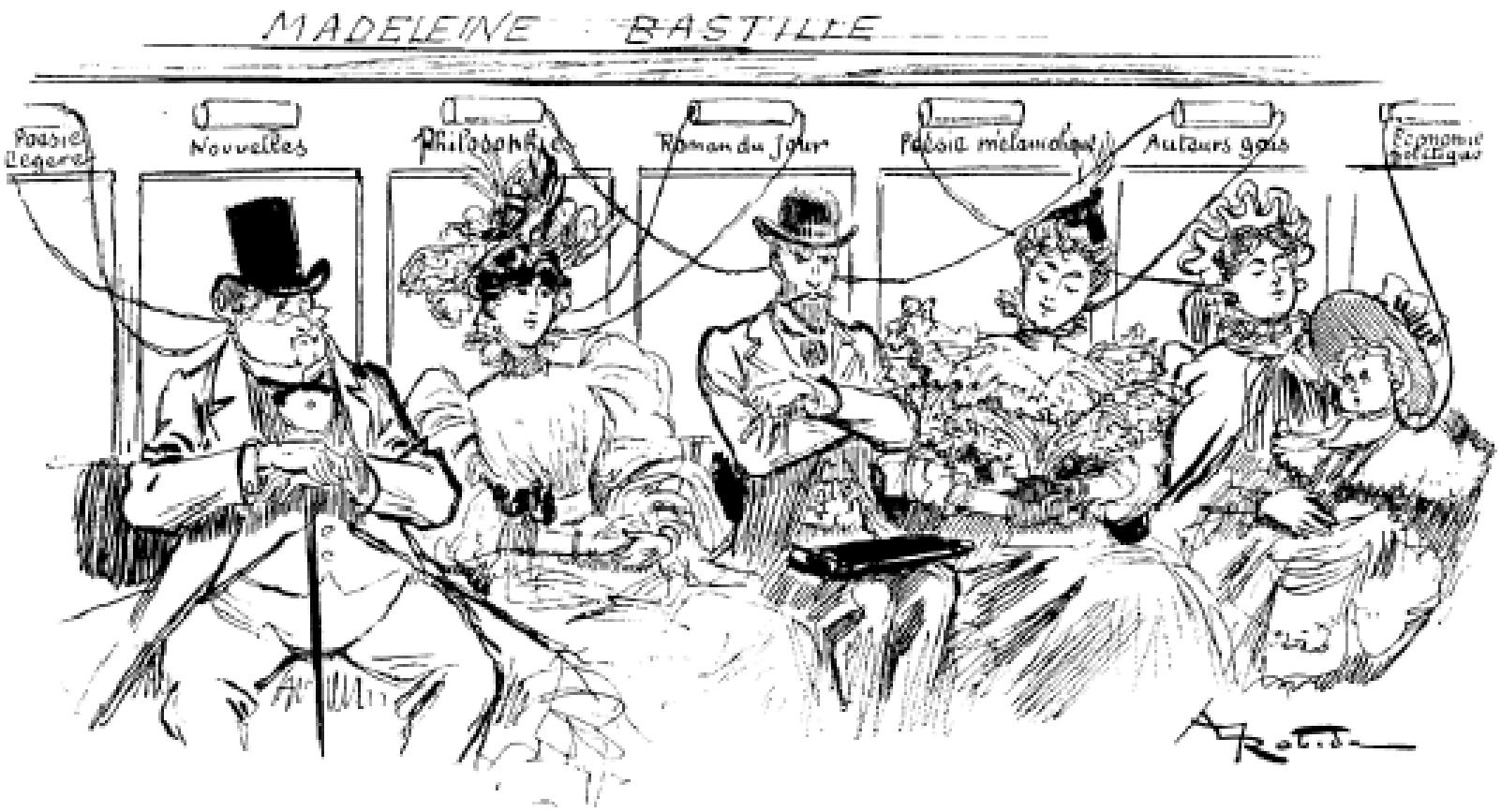
3

3rd Trend: Progress in Communication Technologies

Nostalgia

- Fiber optics: from Gbit/s to Tbit/s
- Powerline technique
  - coffee maker „auto-matically“ connected to the Internet
- Wireless
  - mobile phone: GSM, UMTS
  - wireless LAN (> 10 Mbit/s)
- Body area networks

Telecommunication and Information Everywhere – an Old Vision (1895)



Telecommunication and Information Everywhere – an Old Vision (1882)

O, du göttliches Telephon, was bist du eine praktische Erfindung! Da kann man in der Kneipe die Vorlesung hören und braucht das Trinken nicht zu versäumen.

Carl Stauber
„Die Zukunft des Telefons“

Telecommunication and Information Everywhere – an Old Vision (1882)

O, du göttliches Telephon, was bist du eine praktische Erfindung! Da kann man in der Kneipe die Vorlesung hören und braucht das Trinken nicht zu versäumen.

Im Generalstab: Der Feind zieht sich über den Fluß zurück. Sein linker Flügel ist umgangen. Die Schlacht scheint gewonnen!

Four Reasons for Ubicomp

4

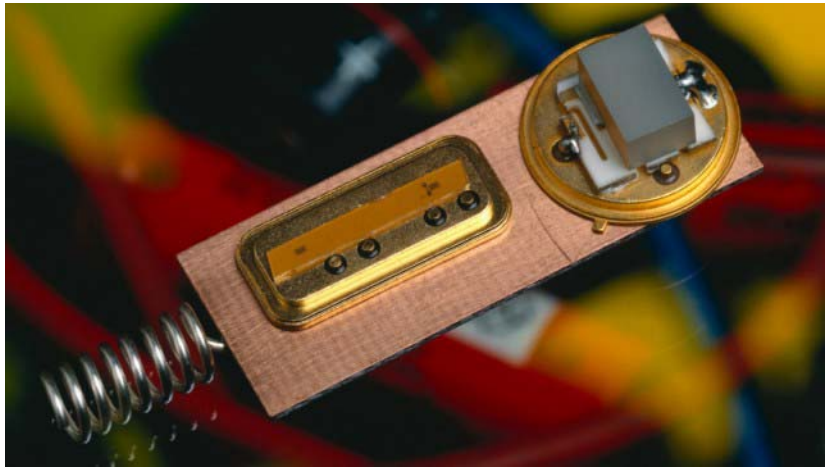
4th Reason: Better Sensors

- Very small cameras and microphones
  - pattern recognition, assisted by heuristics („user is in a meeting…“)
  - speaker recognition, speech controlled devices
- Fingerprint sensor on mobile objects
  - („we already know this guy“)
- Many other types of sensors (e.g., „location“)
- Autonomous perception of the user‘s environment
  - establishing contextual relations
  - recognition of objects

Example: Fingerprint Sensor

- CMOS silicon chip
- Thermal imaging
- 0.4 mm x 14 mm sensing area
- Finger "sweeping" interface

Example: Standalone Radio Sensors



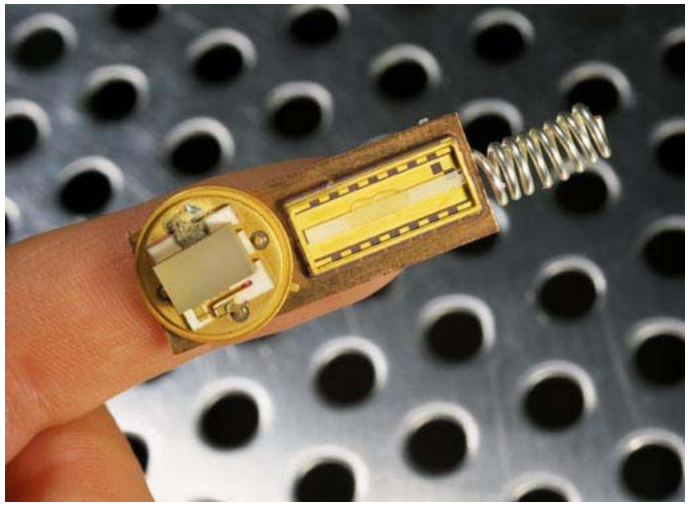


image source: Siemens

- No external power supply
  - energy from the actuation process
  - piezoelectric and pyroelectric materials transform changes in pressure or temperature into energy
  - RF signal is transmitted via an antenna (20 m distance)

Radio Sensors - Applications

- Mobile devices
- Wireless light switch
- Inventory control
- Fire detectors
- Temperature surveillance
- Remote control
- ...

The 4 (Technology-based!) Reasons for Ubicomp

- Moore's Law
- New materials
- Progress in communication technology
- Better sensors

Other reasons?

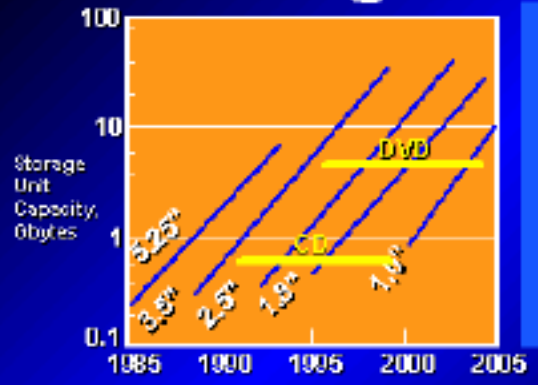
Technology Trends

Technology Trends

CPU (Cu, 1GHz)

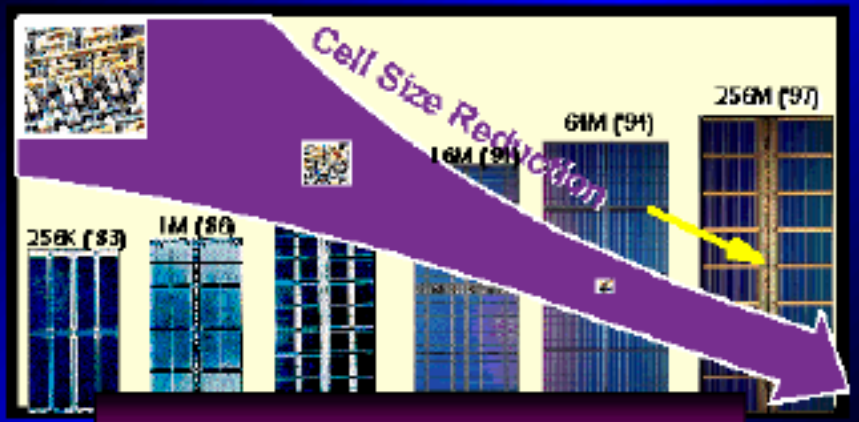
Speed: +69%

Storage



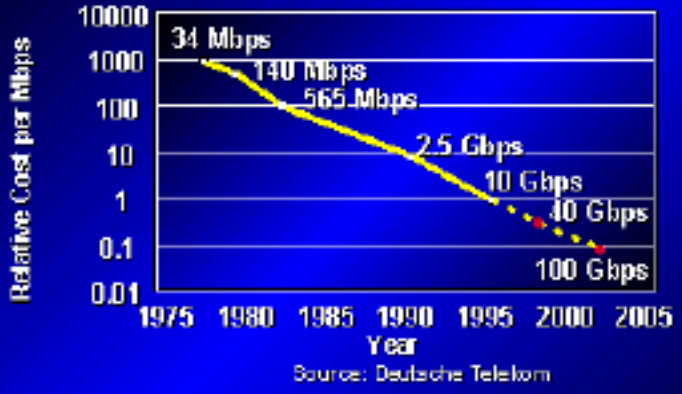
Density: +65%

DRAM Evolution



Bits/Chip: +59%

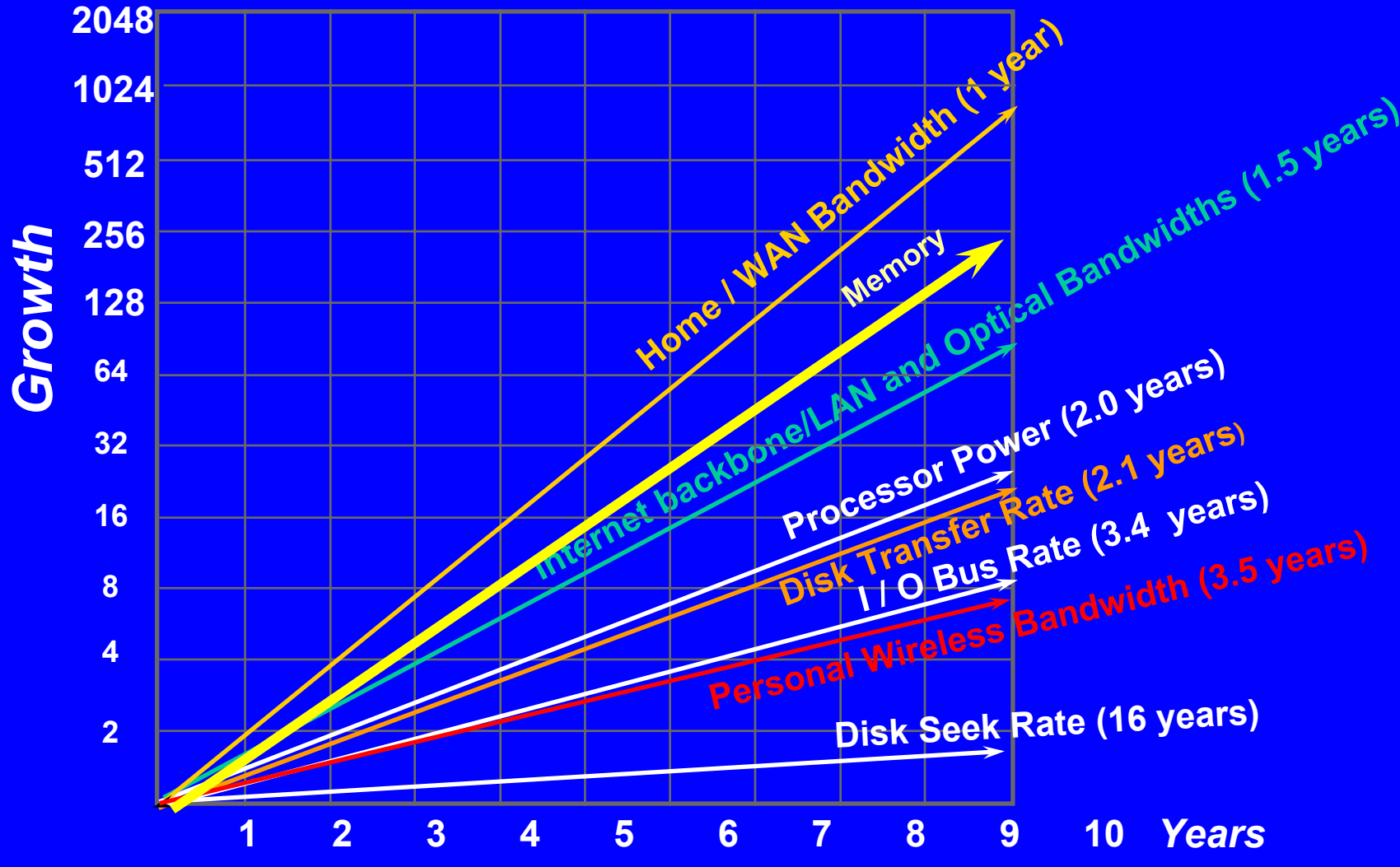
Network



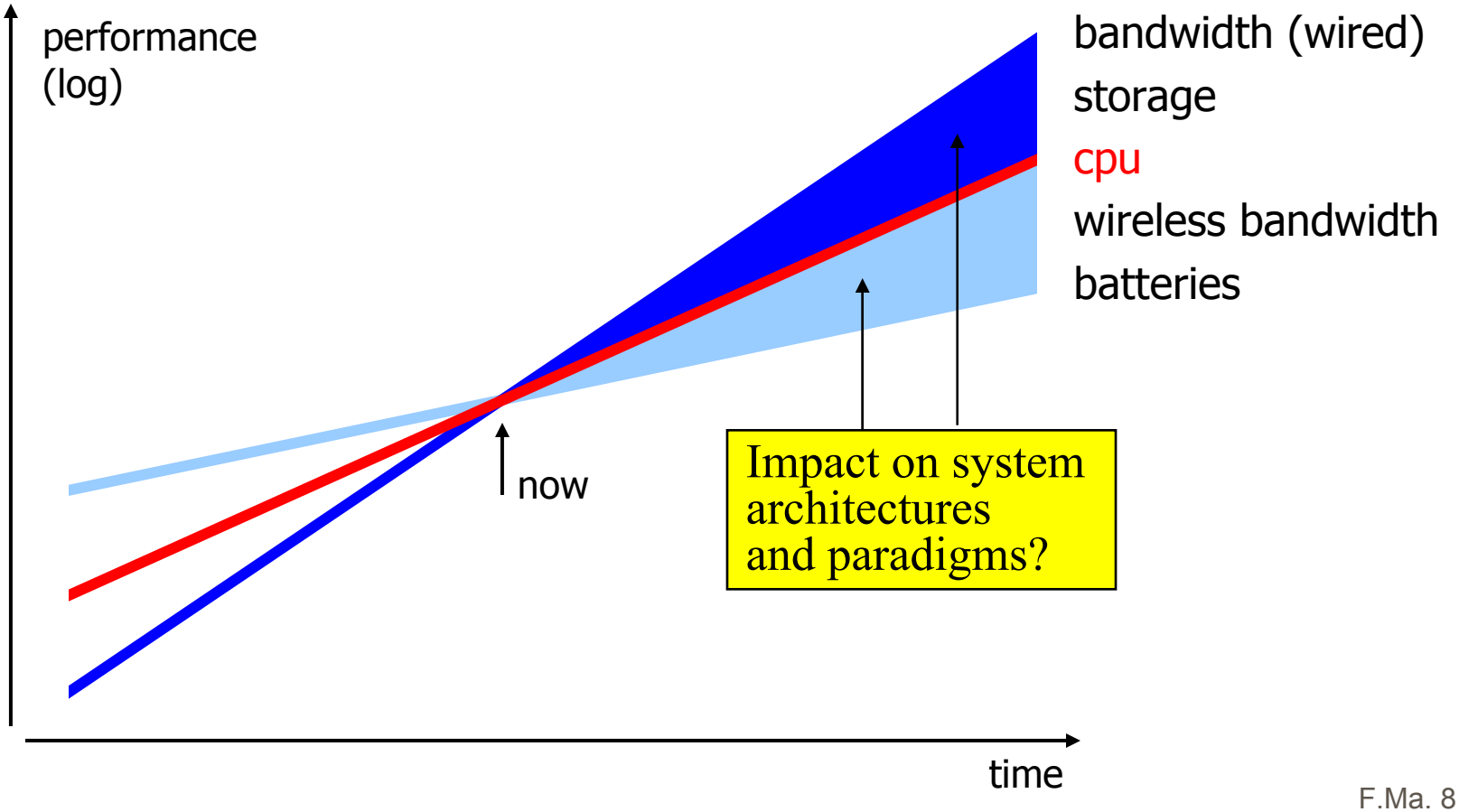
Speed: +151%

image source: IBM

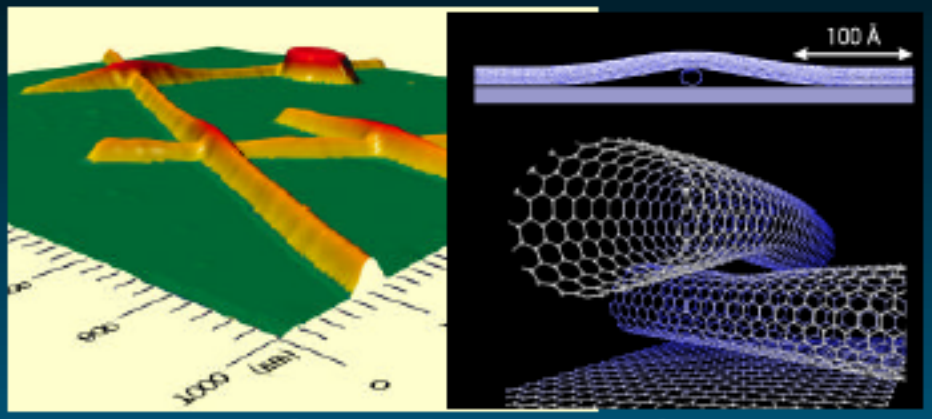
Evolution Speed of Crucial Technologies



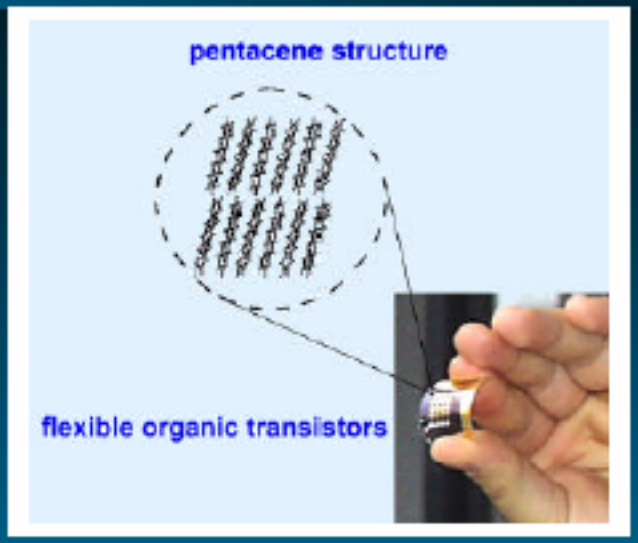
Diverging Growth Factors



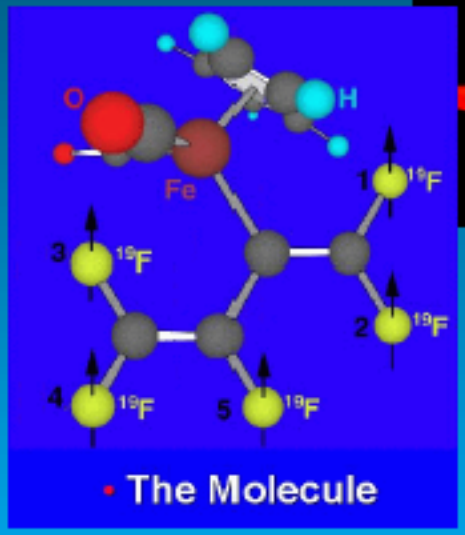
Alternative Devices

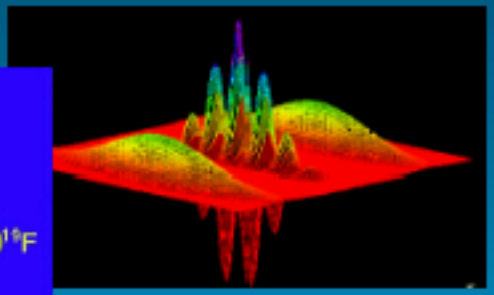


Carbon Nanotubes



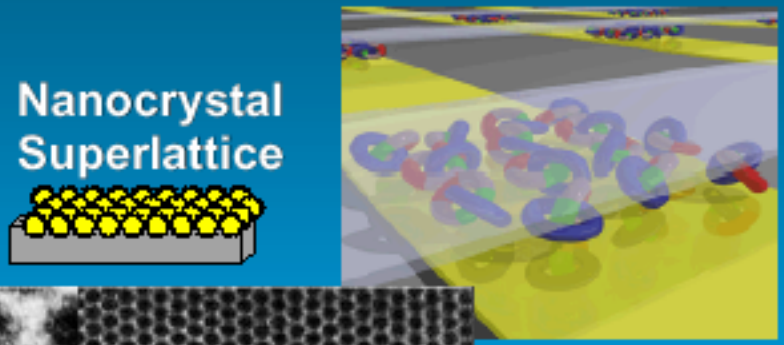
Organic Transistors

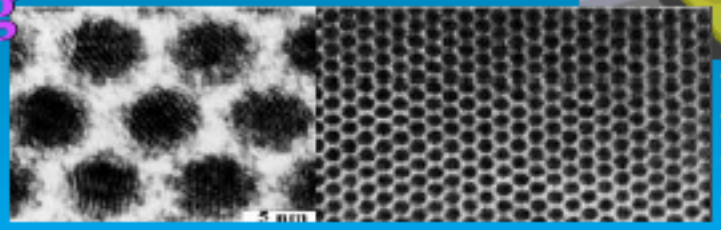




Quantum Computing

Nanocrystal Superlattice





Molecular Devices

image source: IBM

Consequences?

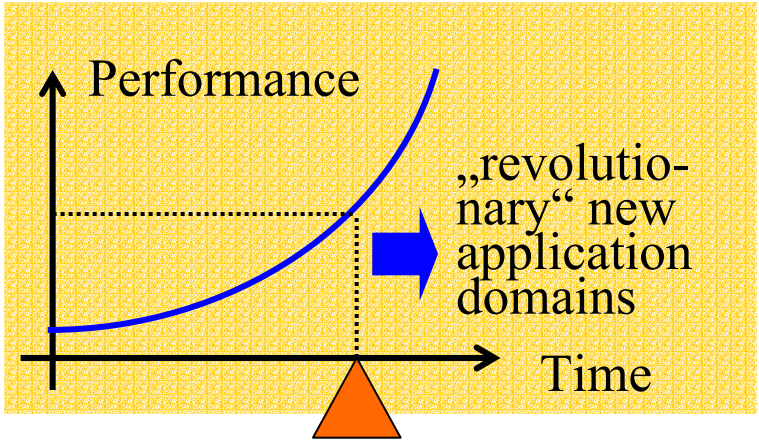
All Trends Together Lead to a New Era

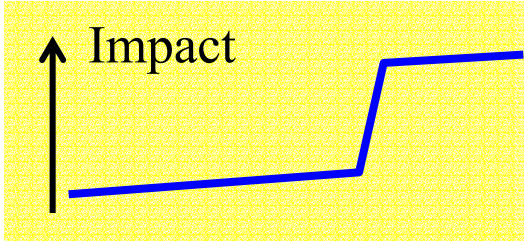
- Progress in
  - computing speed
  - communication bandwidth
  - material sciences
  - sensor technology
  - computer science concepts
  - miniaturization
  - energy usage
  - battery technique
  - display technologies
  - price
  - ...

→ Pervasive Computing
→ Ubiquitous Computing
→ Ambient Intelligence
→ Disappearing Computer
→ Invisible Computing

Impact: Evolution vs. Revolution

- Technology and science have a major impact on our society and the world we live
  - historically: industrialization, electricity, trains and automobiles, electronic mass media
  - implies therefore eventually also ethical questions
  - social adaptation to technical impacts needs some time since this is an evolutionary process (willingness to learn, generational aspects,…)





Ron Rivest: The Digital Revolution Reverses Defaults

- What was once hard to copy
  is now trivial to duplicate
- What was once forgotten
  is now stored forever
- What was once private
  is now public

Conclusions

- Ubiquitous computing technologies will have a major impact on our society and the world we live
- Economic, social, cultural consequences?
  - whole new industry to build and manage an intelligent infrastructure?
- Challenges
  - technical infrastructure
  - security, privacy, dependability
  - ...

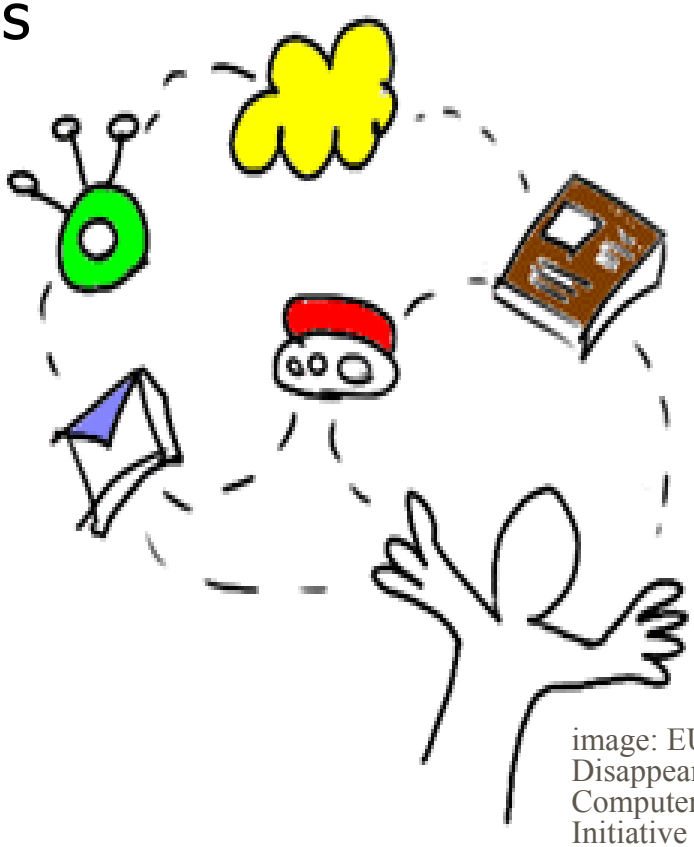


image: EU Disappearing Computer Initiative

*The Internet only connected computers, now we begin to **network all things***

Ubiquitous & Pervasive Computing: A Technology-driven Motivation

Friedemann Mattern

ETH Zürich

The End