Ubiquitous Sensor Networks
and Ambient Intelligence —
Technology Focusing on Society’s Woes

Emeritaatsviering Prof. H. De Man
September 19, 2005

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A New Age for Micro-Electronics Systems

• The Waning Days of the Moore’s Law of Old
  – A Time of Technology Convergence
  – A Time of Extreme Miniaturization
  – A Time of Ubiquity

• A Time for New Computational Paradigms
  – Making Technology Tackle New Problems
  – Making Technology Work Towards Improving our Daily Lives
Electronics Becoming Smaller and Cheaper

Moore’s law and cost

Moore’s law and size
Leading to System Miniaturization

“smart dust”

System-on-a-Chip/in-a-Package enabling True System Integration
Add Ubiquitous Connectivity . . .

Wireless galore
And a New Paradigm Emerges

Bell’s Law: A New Computer Class Every 10 Years

Source: R. Newton
A Short Intermezzo

Hugo’s Illustrious Career Has Impacted Virtually Every Stage of This Roadmap
The 1970s

The Early Days of Integrated Components
Integrated Signal Processing Becoming Reality

The 1980s

**A unified computer aided design technique for switched capacitor systems in the time and the frequency domain**

by

J. Rabaey

Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor in de Toegepaste Wetenschappen

April 1983

The Diana simulation family (K.U. Leuven)

1. Diana.mm (Arnout, Regem, H. Demarest)
   - Mixed mode simulation of LSI: logic, timing, circuit
   - Now also: register transfer

2. Diana.sc (Rabaey, Vandewalle, Demarest)
   - Multilevel simulation of d.c.-networks

3. Diana.dsp (Clausen, Vandewalle, Demarest)
   - Simulation of d.s.p.-networks in time and frequency domain (including finite w.t.-effects)
Cathedral-II:
A Silicon Compiler for Digital Signal Processing

CATHEDRAL-II — a computer-aided synthesis system for digital signal processing VLSI systems

by Prof. H. De Man,
Katholieke Universiteit Leuven
Prof. J. Rabaey
University of California, Berkeley
and J. Vanhoof, G. Goossens, P. Six and L. Claesen
IMEC
From Computation to Ambient Intelligence

Moving to New Computational Paradigms

Ultra-low Power Computation and Communication enables Ambient Intelligence

SOC '03 - Grenoble

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and the PicoRadio Group
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Ambient Intelligence: Giga-Scale Dreams and Nano-Scale Realities

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Senior Research Fellow IMEC
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Disappearing Electronics and the “Ambient Intelligence” Concept

- An environment where technology is embedded, hidden in the background
- An environment that is sensitive, adaptive, and responsive to the presence of people and objects
- An environment that augments activities through smart non-explicit assistance
- An environment that preserves security, privacy and trustworthiness while utilizing information when needed and appropriate

Fred Boekhorst, Philips, ISSCC02
Sensing The Ambient: Wireless Sensor Networks

A collection of cooperating algorithms (controllers) designed to achieve a set of common goals, aided by interactions with the environment through distributed measurements (sensors) and actions (actuators).

$150$ millions sales in $2003$

$7$ billion in sales in $2010$

On World Emerging Wireless Research, Feb 2004
The purpose is inter-disciplinary, collaborative research on IT solutions to grand-challenge social and commercial problems affecting the quality of life of all citizens.

- Major new initiative started in 2001 jointly with UC Berkeley, UC Davis, UC Merced, and UC Santa Cruz
- Approximately 1000 researchers, including over 200 faculty from over 50 academic departments
- Many industrial partners
- Significant State, federal, and private support ($300 million over 4 years)
- CITRIS focuses on IT solutions to tough, Quality-of-life problems
Enabling Large Testbeds

- Golden Gate Bridge Net (Profs. Fenves, Culler)
- Masada (Prof. Glaser)
- Wild Fire Monitoring (Prof. Glaser, Sitar)
- Botanical Gardens (Prof. Culler)

Others:
Duck Island habitat monitoring
The “Smart” Home — A Prime Target

- Security
- Environment control
- Energy management
- Object tracking/inventory
- Advanced user interfaces
- Sense of presence and space
Demand Response and Energy Management

Make energy prices dependent upon time-of-use

- Advanced thermostats operate on required level of comfort, energy cost, weather forecast and distributed measurements to offload peak times
- Appliances energy and cost aware

In collaboration with CEC
Home Layout for HealthCare Delivery

Flexible Communications

Hospitals

Electronic Patient Record Repositories

Knowledge Databases

High-Performance Computers

Data Processing Algorithms

Electronic medical records and knowledge database

Home LAN

Home education, diagnosis and treatment

Television

Living Room

Set-top box

Patient vital signs monitor with wrist display

* T/R: Transmitter/Receiver

Fully Distributed Network of Healthcare Information Resources
The Implementation Challenge: How to Make Electronics Truly Disappear?

From 10’s of cm³ and 10’s to 100’s of mW

To 10’s of mm³ and 10’s of µW
Meso-scale low-cost wireless transceivers for ubiquitous wireless data acquisition that

- are fully integrated
  - Size smaller than 1 cm³
- are dirt cheap ("the Dutch treat")
  - At or below 1$
- minimize power/energy dissipation
  - Limiting power dissipation to 100 µW enables energy scavenging
- and form self-configuring, robust, ad-hoc networks containing 100’s to 1000’s of nodes

The PicoRadio Project
What can one do with 1 cm³?

Energy Storage

<table>
<thead>
<tr>
<th></th>
<th>J/cm³</th>
<th>µW/cm³/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro Fuel cell</td>
<td>3500</td>
<td>110</td>
</tr>
<tr>
<td>Primary battery</td>
<td>2880</td>
<td>90</td>
</tr>
<tr>
<td>Secondary battery</td>
<td>1080</td>
<td>34</td>
</tr>
<tr>
<td>Ultra-capacitor</td>
<td>100</td>
<td>3.2</td>
</tr>
</tbody>
</table>
What can one do with 1 cm³?

Energy Generation

<table>
<thead>
<tr>
<th>Source</th>
<th>µW/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar (outside)</td>
<td>15,000</td>
</tr>
<tr>
<td>Air flow</td>
<td>380</td>
</tr>
<tr>
<td>Human power</td>
<td>330</td>
</tr>
<tr>
<td>Vibration</td>
<td>200</td>
</tr>
<tr>
<td>Temperature</td>
<td>40</td>
</tr>
<tr>
<td>Pressure Var.</td>
<td>17</td>
</tr>
<tr>
<td>Solar (inside)</td>
<td>10</td>
</tr>
</tbody>
</table>
Towards a sub-100 µW Node

“The Art of Creativity”

Ultra Low Power Compute Nodes

Innovative energy sources

Novel miniature wireless transceivers

Integrated Sensors

“Anchor Spring flexure Comb fingers”

Integrated Sensors
Towards a sub-100 μW Node

“Innovative Packaging”

“2.5/3D Integration”

Picotubes (Philips “sand” modules)

“Wireless Attanets”

Self-assembly
Sensor Nets: Challenges to be Addressed

- Complex distributed system behavior
- System development, deployment, configuration and management
  - Ease of use (see Theo Claasen presentation)
- Reliability
  - Power in the numbers
- Privacy/security/legality
Extrapolating into the Future

Paintable Computing

Each node fitted with a wireless comm system which supports network connectivity to spatially proximal nodes.

- communication radius < 2 cm
- node size < 2 mm²

Ultra-dense networks of unreliable components providing very reliable computation and communication
Providing innovative human – environment – computer interfaces
Summary and Perspectives

- Sensor and actuator networks offer great potential to tackle some of society’s woes
  - Numerous experimental deployments all over the world

- Require truly interdisciplinary research effort covering all corners of the academic spectrum (engineering, humanities, life sciences)
- Present a first glimpse on truly distributed computing and emerging computational paradigms for the post-silicon age.
Hugo,
Congratulations and Thanks
for an Amazing Lifetime of
Innovation, Education and Inspiration!