Politecnico di Milano

Embedded Systems: Introduction

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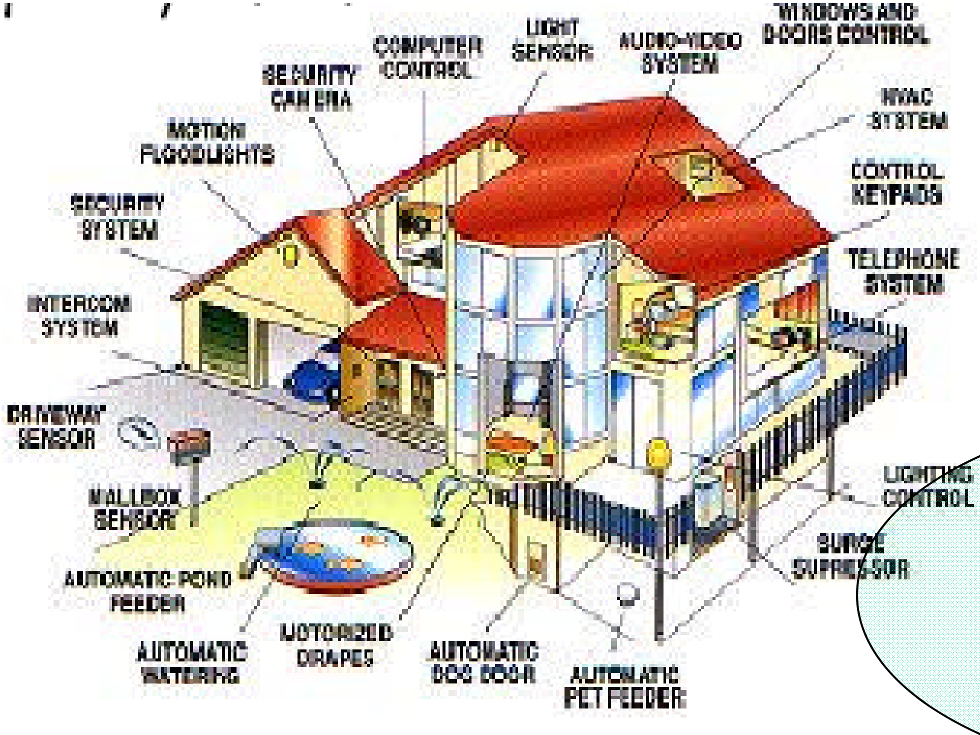
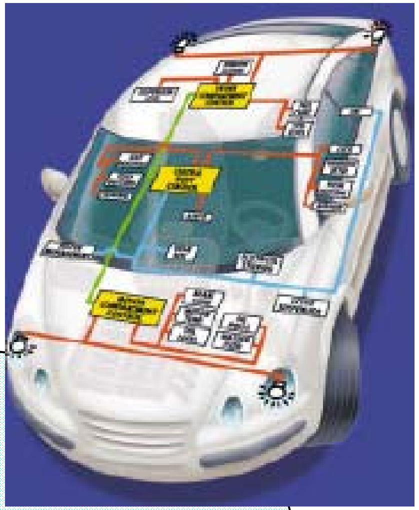
Embedded Systems Everywhere

www
gps
Frigidaire online refrigerator
SMART PAN
HOW IT WORKS...

Networked Embedded Intelligence

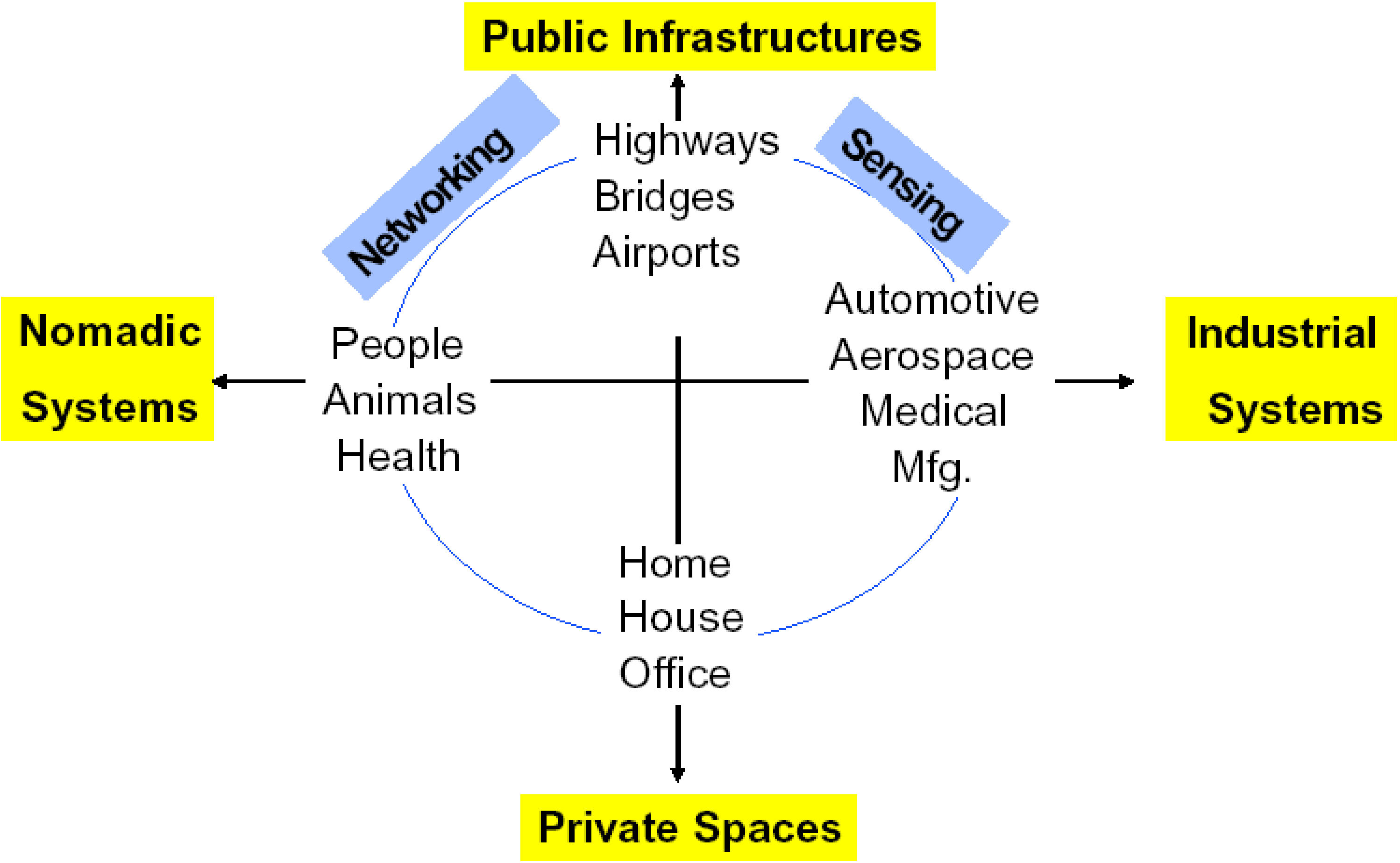
- Enabling transportation, infrastructure industries
- Leading to revolutions like the digital home
- Turning ambient dreams into reality
- Enabling sensor networks improving our quality of life





Ubiquitous
Low Power
High performance
Interconnected

Four main application contexts



Public Infrastructures

Highways
Bridges
Airports

Networking

Sensing

Nomadic Systems

People
Animals
Health

Automotive
Aerospace
Medical
Mfg.

Industrial Systems

Home
House
Office

Private Spaces

Embedded Systems 10 years from now

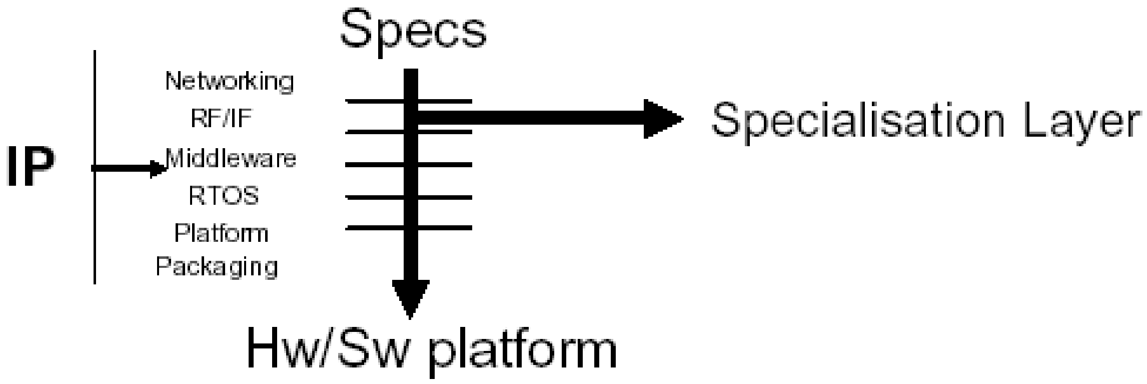
- Networked: from working in isolation towards communicating, networked, distributed solutions
- Secure: threatened by enormous security issues, challenging its technical and economical viability
- Complex:
  - Giga-complexity enabled by nano-technology
  - Complex through heterogeneity
  - Transducer devices
    - Sensors: Biosensors, MEMS, NEMS
    - Actuators/Interactive Screens/Displays
    - Speech input device/Handwriting input devices
  - Computing devices: more software than hardware, application domain specific, reconfigurable
  - Communication: protocols, standards, RF
- Low power: scavenging power

Embedded Systems Design: not Business as usual…

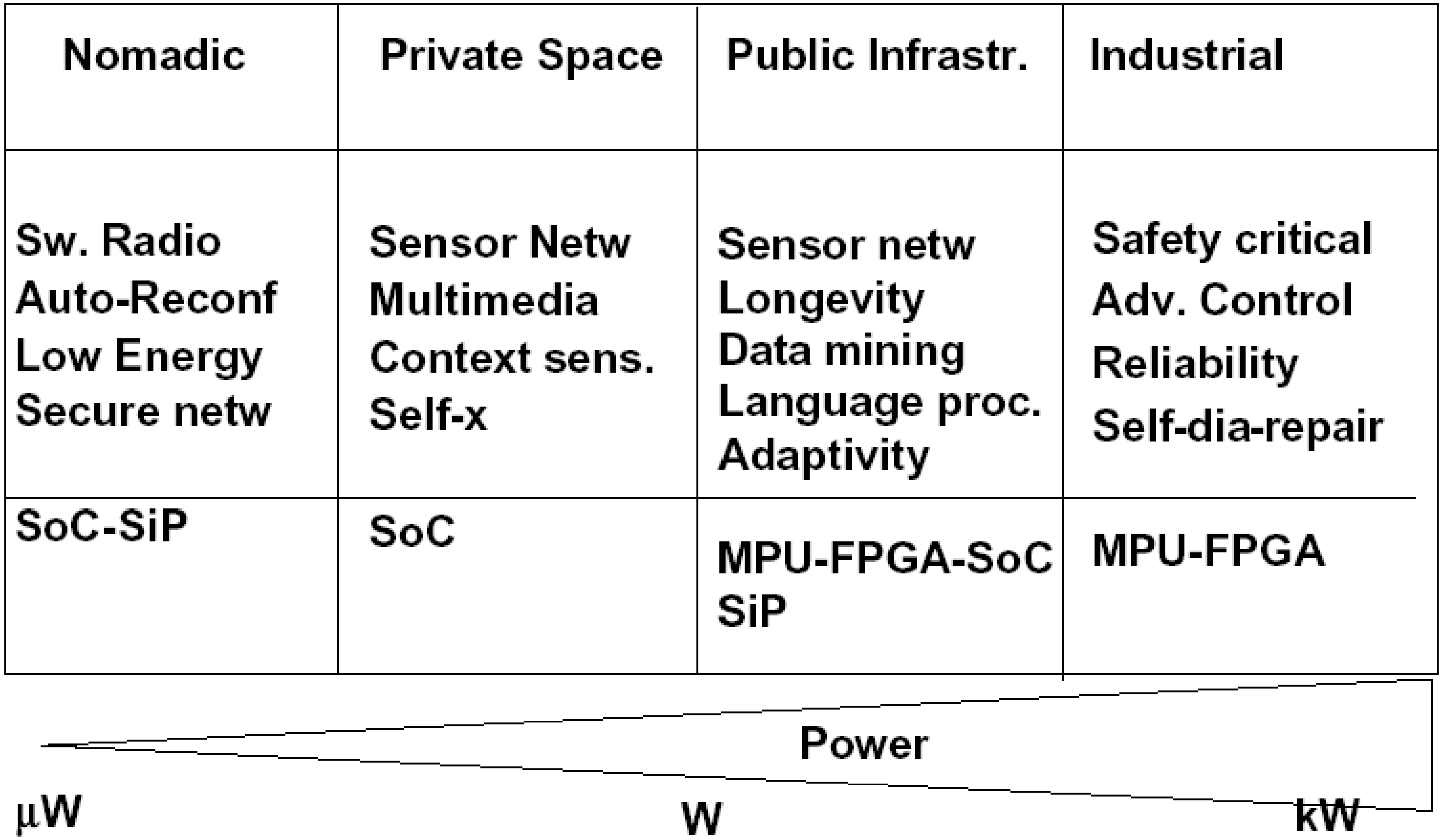
- **Embedded Systems require a holistic approach to design, manufacturing, and skill creation in a distributed industrial context (eco-alliances)**
- **Embedded systems are complex by nature:**
  - **GLOBAL TECHNICAL SYSTEMS: networked-sensingintelligence**
  - **(hw/sw)-actuation = MULTI-DISCIPLINARY**
  - **OPERATING on an EMBEDDING ENVIRONMENT IN AN APPLICATION DOMAIN with its own requirements and expertise**

Embedded System Characteristics

- **Multi-disciplinary by nature: EE + CS + DOMAIN**
- **Hard constraints: real-time, low cost, low energy yet complex software on dedicated distributed platforms, short t.t.m., security, ease of use ...**
- **Requires global system approach based on application domain expertise**
- **Products result from eco-alliances in domain Traverses many layers of abstraction (vertical)**



Each application context has specific requirements and technologies…



Nomadic	Private Space	Public Infrastr.	Industrial
Sw. Radio Auto-Reconf Low Energy Secure netw	Sensor Netw Multimedia Context sens. Self-x	Sensor netw Longevity Data mining Language proc. Adaptivity	Safety critical Adv. Control Reliability Self-dia-repair
SoC-SiP	SoC	MPU-FPGA-SoC SiP	MPU-FPGA

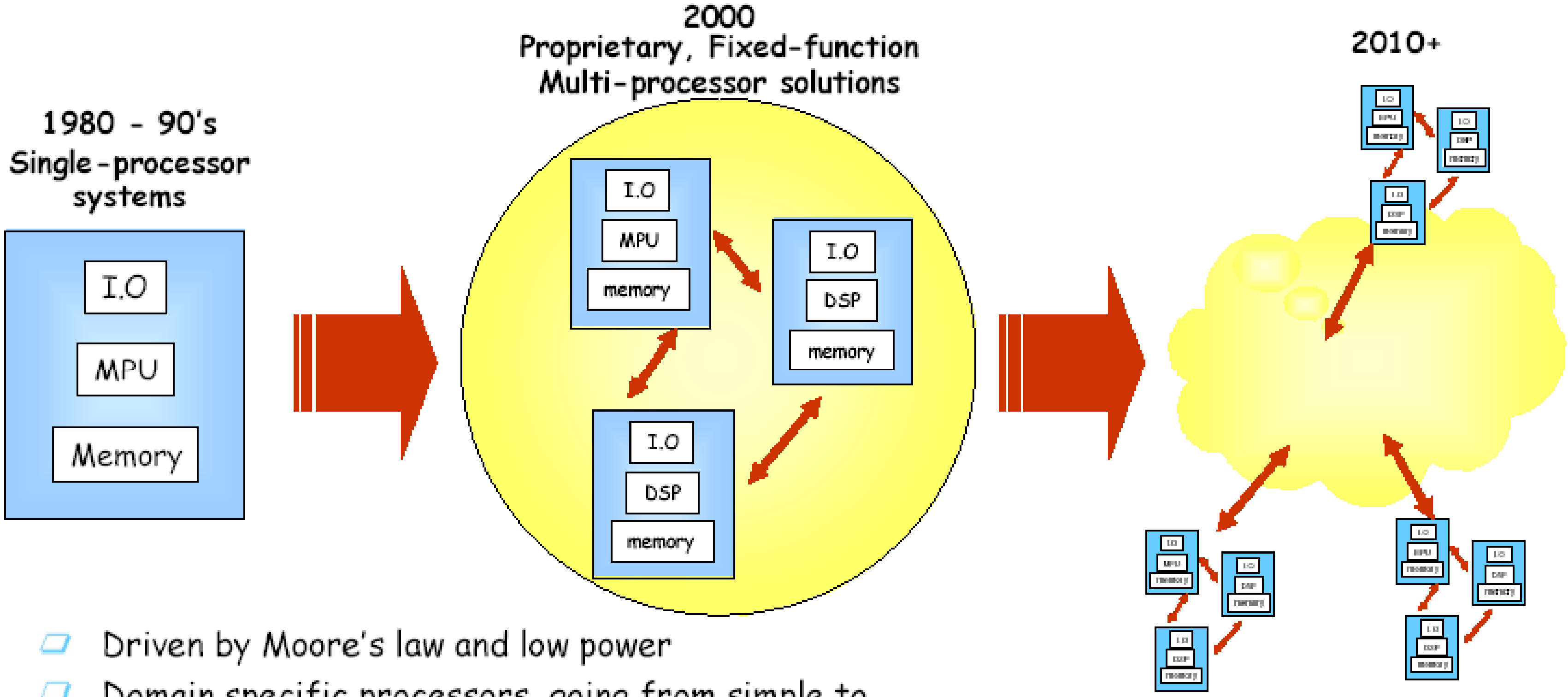
Power
µW
W
kW

Where has Moore's law brought us?

- Moore's law has had almost 40 years of validity
- The Semiconductors Industry Association (SIA) roadmap for process technology predicts the progress to go on for at least the next 10 – 15 years
- The theoretical limit for transistor gate length on silicon is around 1.5nm.
  - Today's 65nm CMOS process has a gate length of 42nm:
    i.e **28X larger** than the theoretical limit!
  - In 32nm, the gate length is 21nm

    i.e. **14X above limit**
- The gate delay determines the fundamental speed of the logic. The theoretical limit is 0.04ps
  - Today's 65nm logic NAND2 is ~1ps, i.e. **24X slower**!
- Transistor density, i.e. the number of device which can be squeezed into a chip, reaches the limit around 1.8 billion Tx per cm².
  - Today's 65nm CMOS device is **7.5X larger**!
    (i.e. 750Kgate/mm^2 = 2.4M Tx/mm^2 = 240M Tx/cm^2)
- Performance as measured by clock speed, fell off Moore's Law during the last decade, thanks to Multi Processors computing architectures.

Chip: Architectural evolution

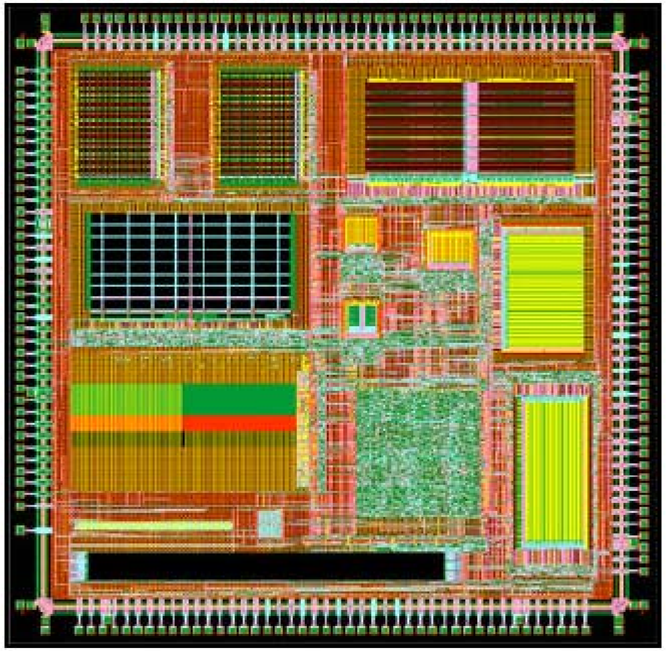


- Driven by Moore's law and low power
- Domain specific processors, going from simple to massive parallelism
- Software methods should cope with multi-processor networked architectures

Networked (ad-hoc, opportunistic), reconfigurable "processor ecosystem"

System consequences: Design complexity and costs

- IC complexity has grown faster than design efficiency: design crisis
  - The answer was reuse
  - Three generations of re-use
    - Standard cell and automatic synthesis: sea of gates
  - IP block reuse: sea of IP
  - Architecture reuse: platforms
- Design costs are increasing (for 90 nm: up to 20M€ / design)
  - Platform based design (SoC)
  - System in Package (SiP)

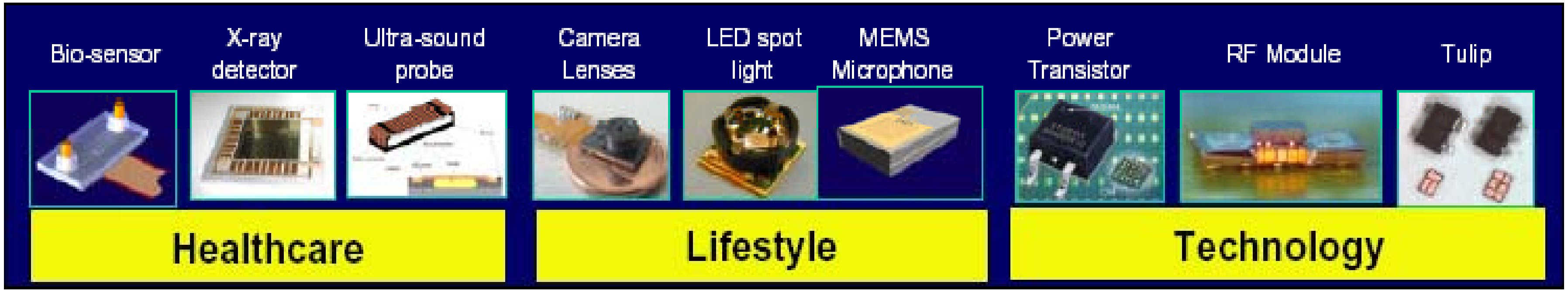


The critical discontinuity

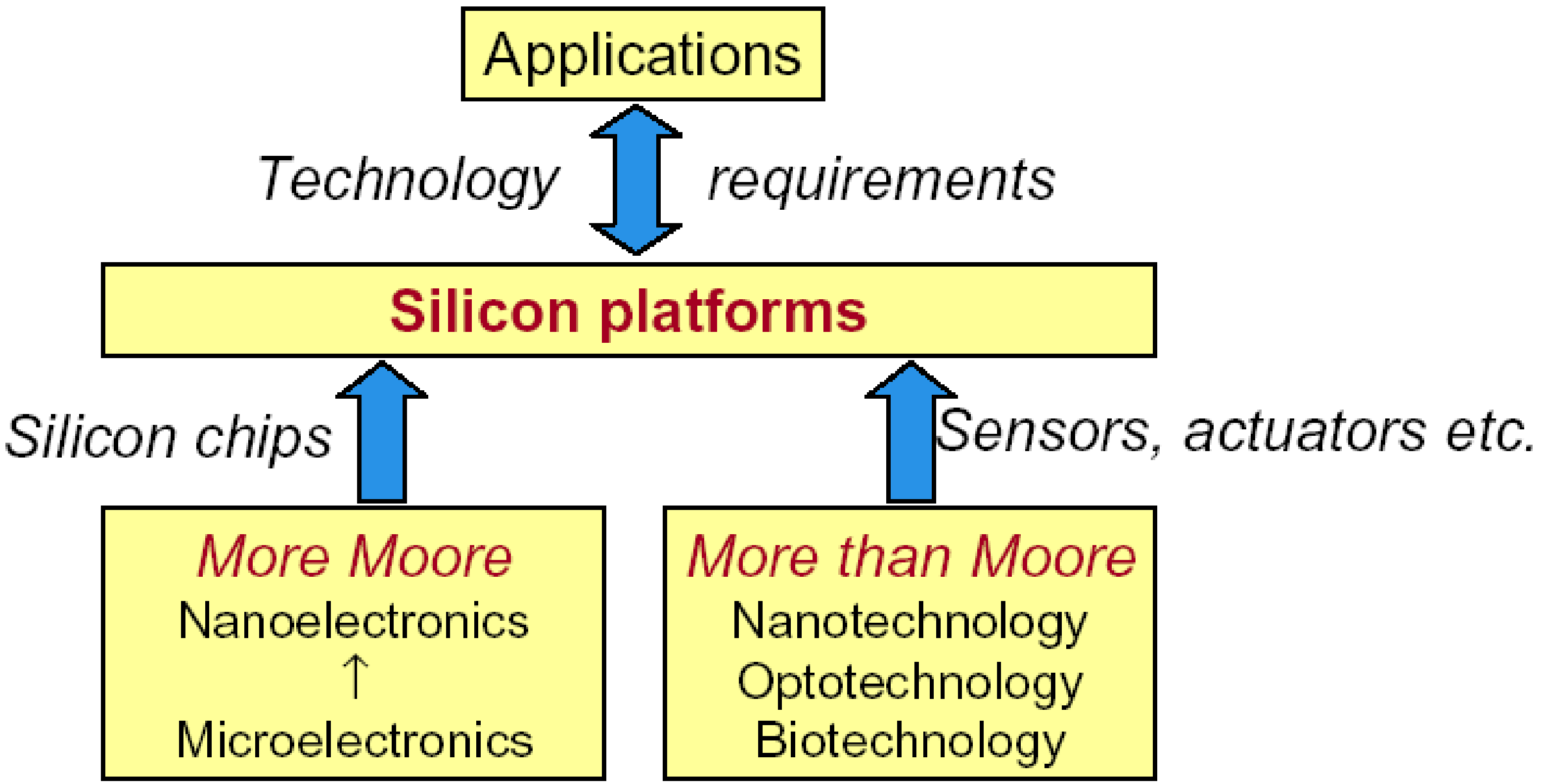
- Moving from closed to interconnected systems
- Moving from closed to open application platforms
- Moving from telecom standards [ATM/WAP etc...] to IP networks
- As a result we shall need
  - huge general purpose low power computing systems with standardized software platforms
  - Also, internet broadband connections will redefine the balance between locally run and web hosted applications

Long term technology trends

- System-on-Chip (SoC)
  - Focus on full integration and lowest cost per transistor
- System-in-Package (SiP)
  - Focus on lowest cost per function and for total system
- Complementing, not competing architectures
- Each requiring a different industrial approach
  - Advanced R&D / knowledge needed
  - Different manufacturing competences



Applications in 2020: *Technology requirements*



Applications

Technology *requirements*

Silicon platforms

Silicon chips

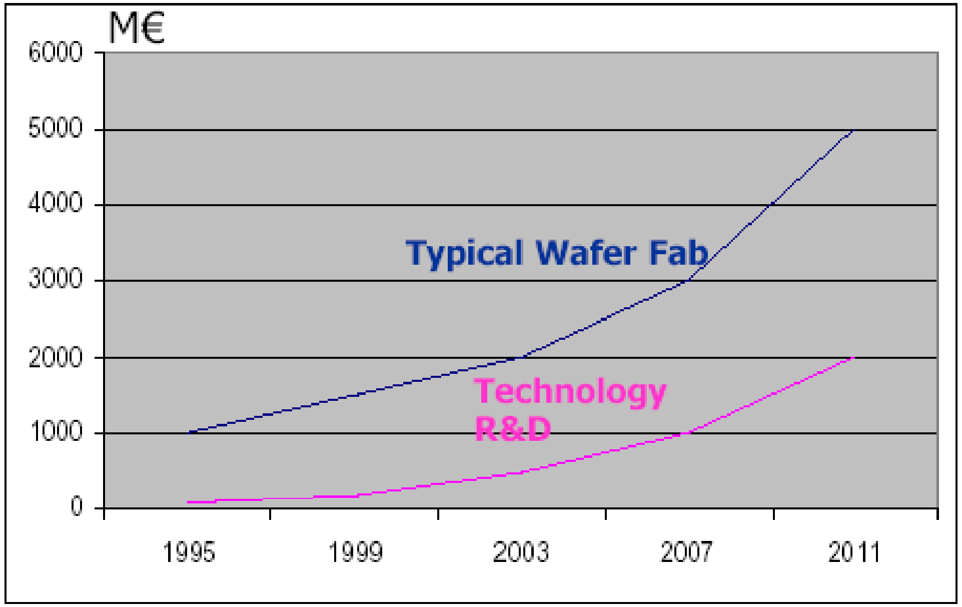
Sensors, actuators etc.

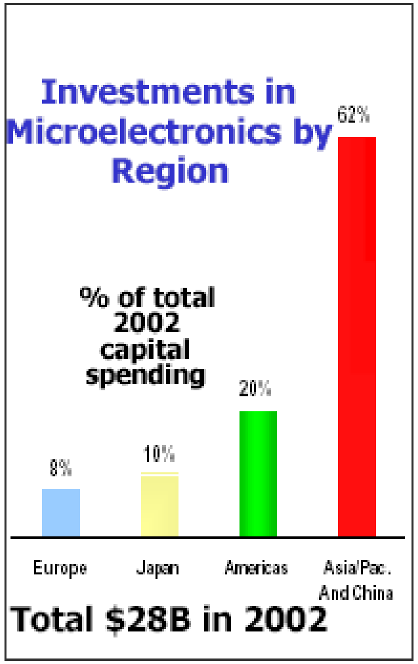
More Moore
Nanoelectronics
↑
Microelectronics

More than Moore
Nanotechnology
Optotechnology
Biotechnology

Leadership and Competitiveness

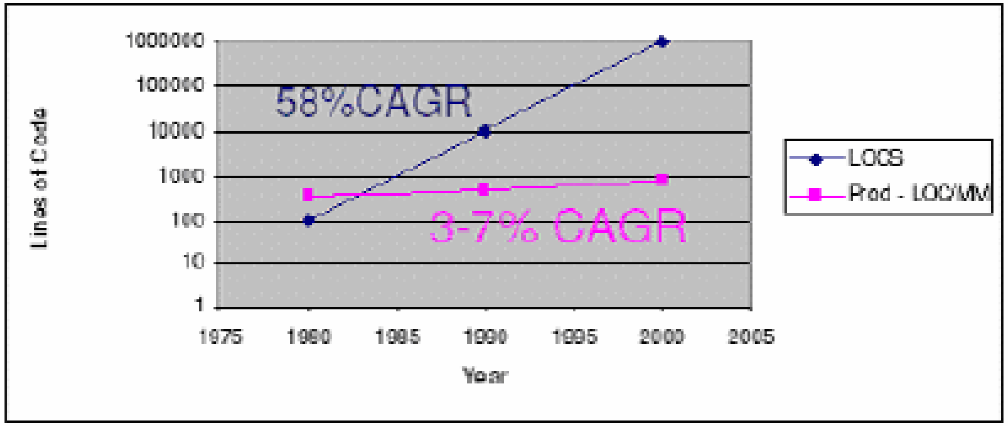
- Europe needs to quickly fill the gap on IP architectures and Computer Science
- Polimi courses?



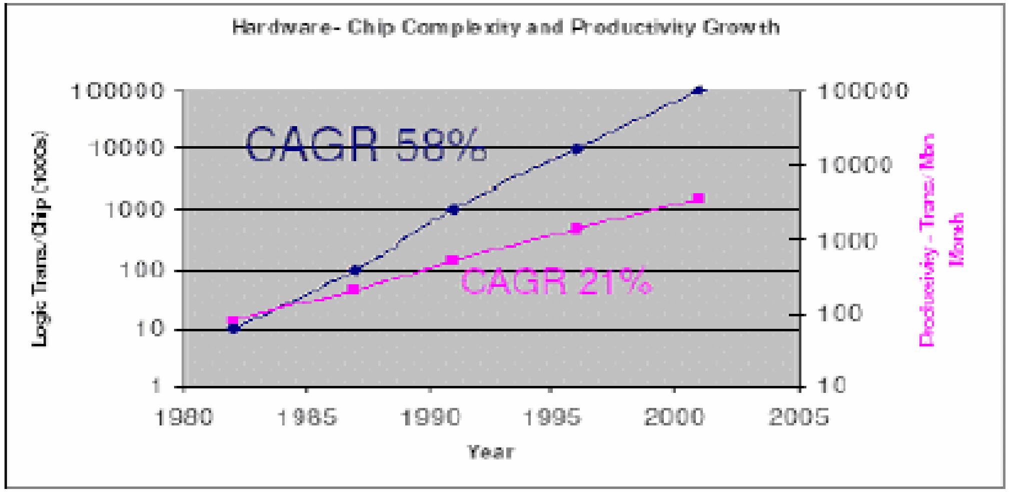


Complexity vs productivity growth

SW complexity & productivity growth

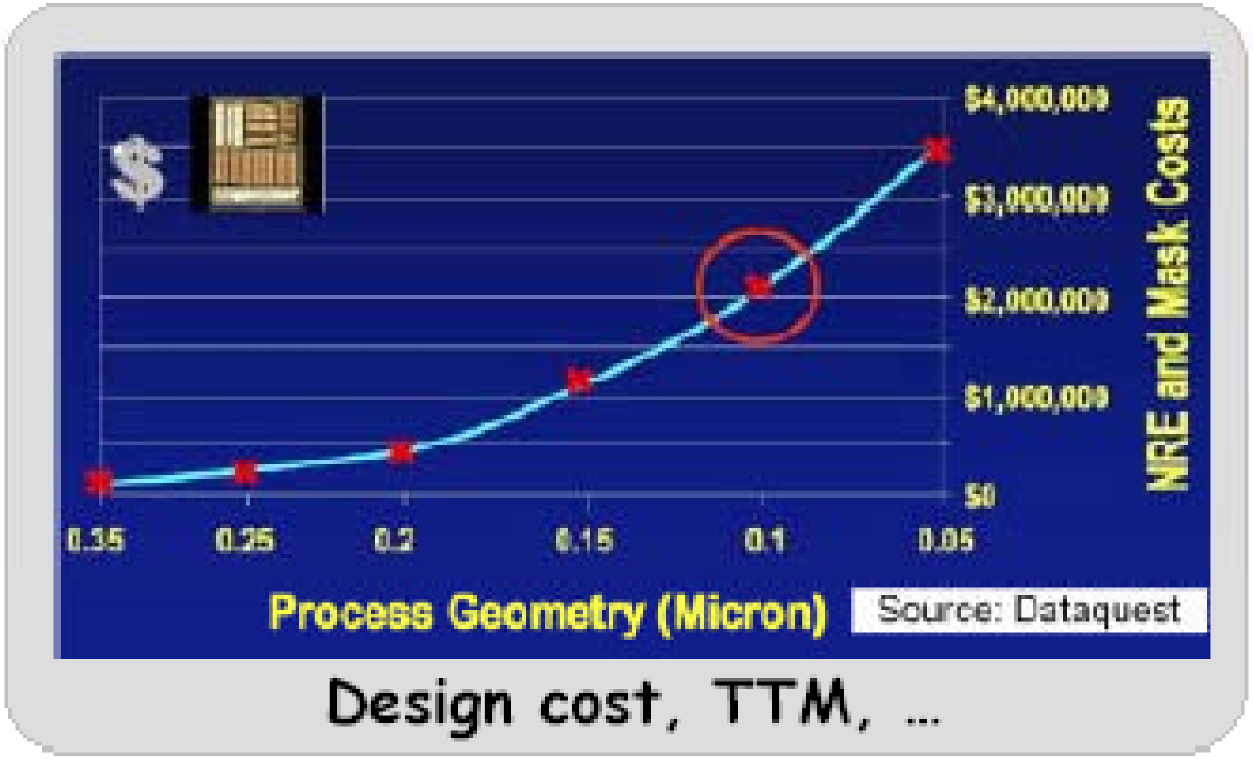


HW complexity & productivity growth



Nano-systems with Giga-complexity

- If design productivity increases in the next 5 years at the pace of the last 5 years, we will need 10-20 times bigger teams to design our future chips



Source: Dataquest

Design cost, TTM, ...

Some research directions

Software and compute architecture

Communication

Pheriferals

Design methodology: addressing complexity

Security

Compute architecture research

- Embedded systems are becoming computing networks: NOCs
  - major challenge for the engineering community, especially for SW developers: traditional SW programming methods do not work well for distributed highly concurrent platforms
- Focus should be the development of a network definition that is
  - agnostic to the processing element
  - independent of the application domain
  - unconcerned about location in the network
- At building block level: focus on domain specific processing units
  - Widely different programming models, from reconfigurable hardware to massively parallel processors
- The whole system architecture to be optimized for critical non-functional qualities, such as energy consumption

Software research

- Real time and embedded software technologies
  - Real time OS
  - Lightweight Middleware with QOS
- Platform independence
  - Address Software portability
  - Address the multiprocessor platform challenge
- Complexity
  - Model driven development allowing development at a higher level of abstraction
  - Verification and validation is increasingly becoming the bottleneck, topics include formal verification, modelling
- Address Standardization
  - Proven in the general purpose world: Linux, UML, XML
  - Embedded world is still a green field

Communication

- ES: Evolving from working in isolation towards communicating, networked, distributed solutions
- IP protocol demonstrated the power of a universal protocol
  - Reduces complexity in development, in validation
  - Ubiquitous, from data telecom network towards the phone [VoIP], the home network, enterprise etc…
  - Hossein Esambolchi (ATT CTO) says “IP is like a Pacman, it will eat everything by the end of the decade”.
- For Embedded systems we should:
  - Define and standardize a universal communication protocol
  - Address heterogeneous communication: Car environment talking to Mobile environment, talking to home environment, talking to www.
  - Address ad-hoc networks: communication established on an ad-hoc or opportunistic basis. Self discovering, self diagnosis, self organizing
  - Move towards several communicating objects forming one functionality

Peripherals

- Transducers, sensors and actuators are essential enabling technologies for embedded systems,
  - interface to/shield from a sometimes harsh, rugged environment,
  - requiring various types of technologies
- Research agenda includes
  - Cost effective, integrated sensors and actuators, based on a wide range of new technologies: MEMS, NEMS, BIOsensors,…
  - Output & Power devices in nm CMOS
  - Communication interfacing technology: wired, RF, optical…
- Should be
  - Capable of living in the harsh environment: mechanically and thermally robust
  - Low power: autonomous, power scavenging
  - Fail safe, degrading gracefully, reliable

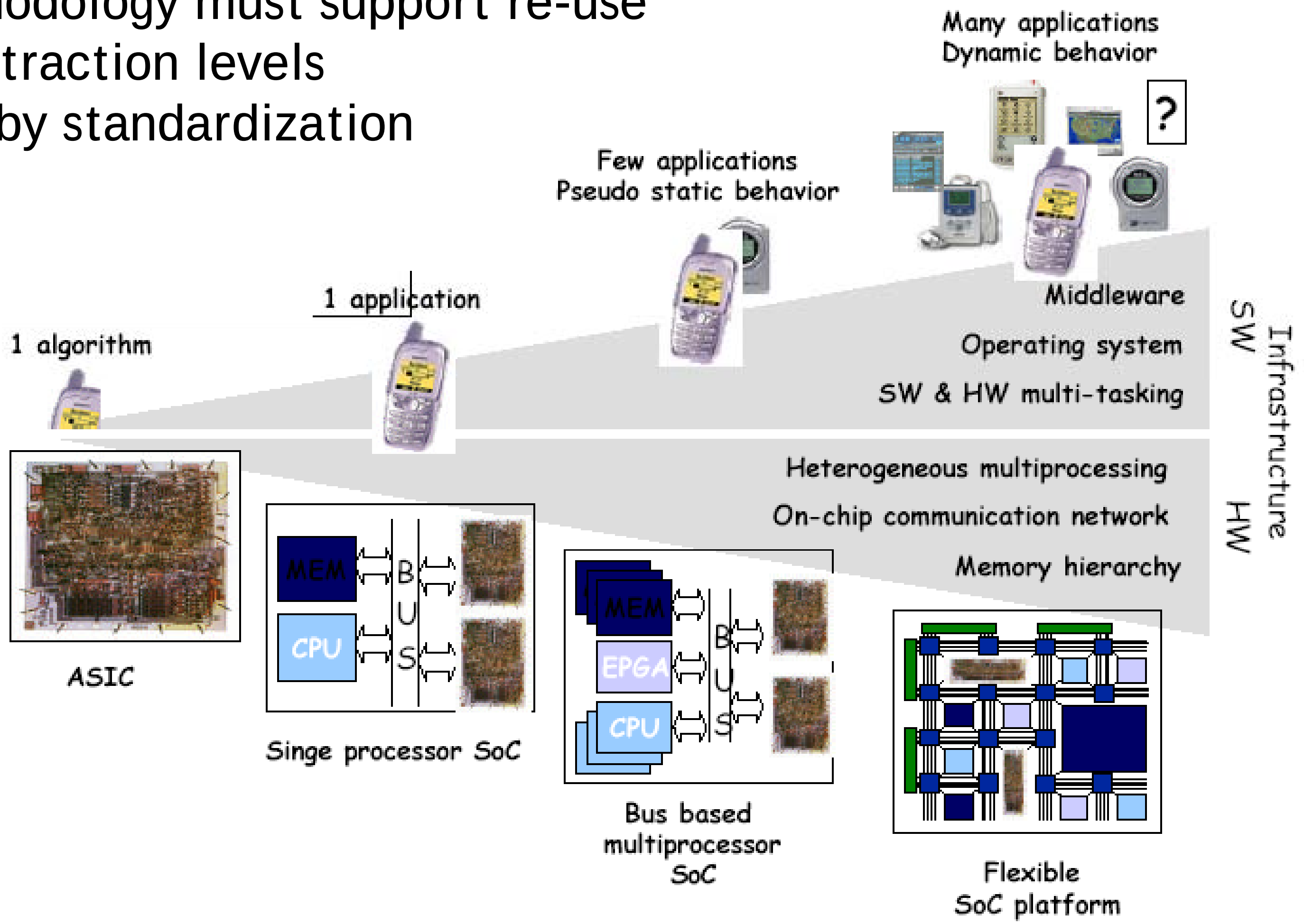
Design methodology: addressing complexity

- Quick design exploration: translate quickly applications into architectures
- Formal approach to capture user requirements
- Automation: link to final implementation should be fast:
  - Model based design -> design activity will be done at higher abstraction level where models can be verified and manipulated
- Formal synthesis and formal verification,
  - supported by the definition of clear layers of abstraction, masking implementation details
- Design methodologies must support heterogeneous systems,
  - abstracting the hell of physics,
  - including exotic technologies like MEMS, Biosensors, all in one design flow

Platform based design

Design methodology must support re-use

- at high abstraction levels
- supported by standardization



Security

- Management of rights (DRM) for a connected device will be fundamental to almost all future devices and SOCs
  - "Cisco VP of strategic Technology believes the DRM is THE fundamental factor that will drive their business (internet traffic) to the next level."
- Individual devices are easy targets for disruptive attacks in open, ad hoc wireless networks
- Widespred diffusion of intelligence/data (e.g., into smartcards) can become a new source of attacks (like DPA)
- Challenges:
  - The basis for any security solution is a trusted infrastructure, putting challenges towards all components of an embedded system
  - Standardization
  - Global end to end security management