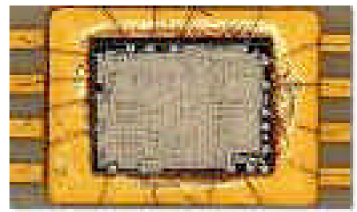
Designing Micro/Nano Systems
for a safer and healthier tomorrow

Giovanni De Micheli

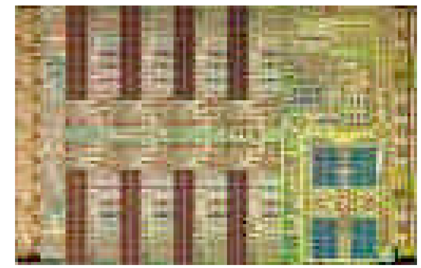
Quo vadis ?

- We came a long way …
  - 50 years of electronics

[Bell labs]

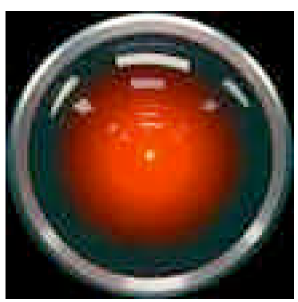


[Intel]



[IBM]

- … and where are we going?
  - The next 50 years



[Kubrick:2001]

How did we affect society ?

- From transistor radio …

[Motorola]

[IBM]

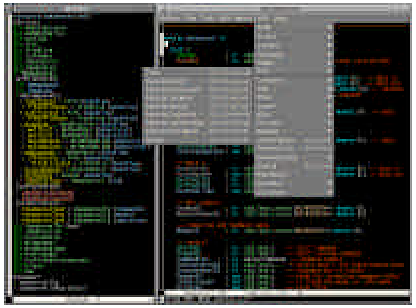
[Sony]

[Apple]

- Challenges:
  - More processing power needed
  - Less energy consumption desired
  - What is the technology of the future?
- Can we have a deeper impact into society?
  - Who will benefit?
    - Socially?
    - Economically? Which market sector?

How did we engineer products ?

- Electronic Design Automation (EDA)
  - Provides us with the enabling technology
  - Formal modeling, analysis, synthesis



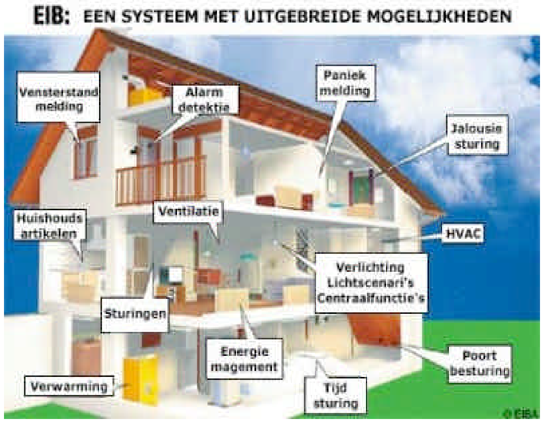
- But EDA
  - … is entangled in solving *deep submicron* issues
  - … missed opportunities at system-level design
  - … is still a small niche market

- Can we reposition DA as a central engineering task?
  - Broader in scope
  - Scientifically challenging
  - Attracting the best young researchers
  - Creating more value

The next fifty years…

- Ubiquitously-distributed electronics
  - Electronic circuits and systems distributed in clothing, car, home, office, environment…
- A global market affecting everybody’s everyday’s life
- Some audacious goals:
  - Break language barriers
  - Eliminate energy dependence
  - Link up every human
  - Better health, safety and longevity
  - Protect and monitor our environment

[Infineon]

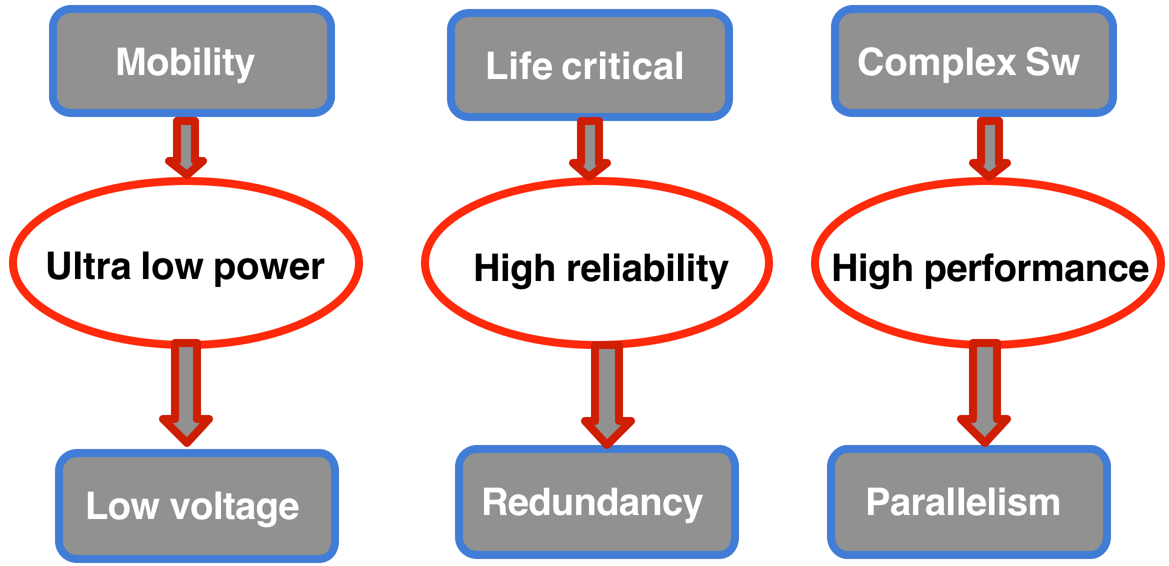


[QBUS Domotica]

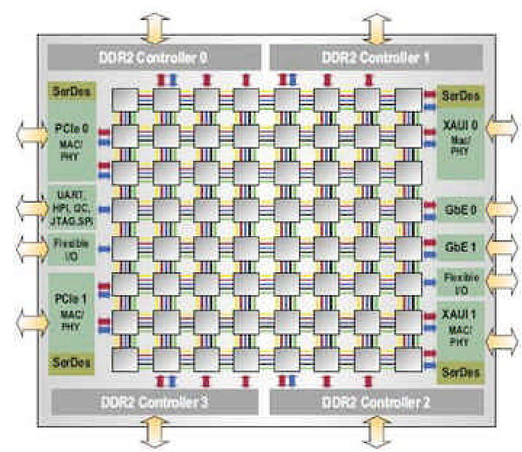
The way ahead

Redefining electronic chip design

- Requirements:



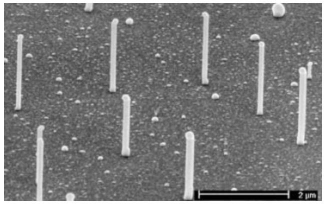
- From processors to multi-processors
  - Technology support
  - Systems and software redesign

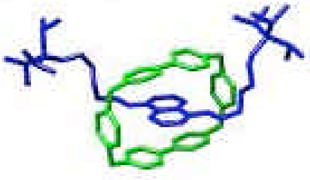


[Tilera]

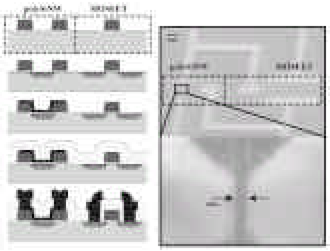
The fabrication technology support

- Beyond CMOS: a myriad of new ideas

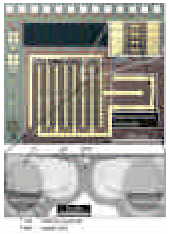




- Are these technologies apt/ready for system design?
- Can they mix and match with CMOS?


[Leblebici, EPFL]

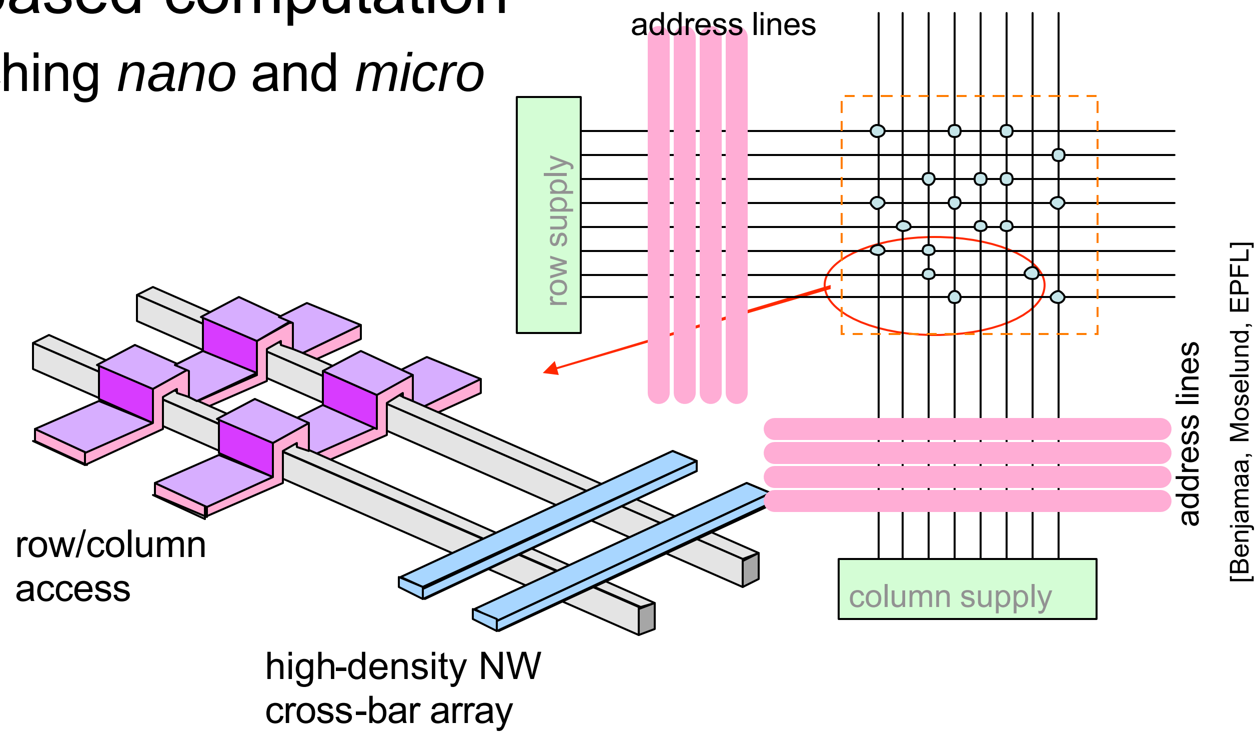

[Infineon]


[Close, Stanford]

- How do we design with these technologies?
  - Higher defect densities and failure rates

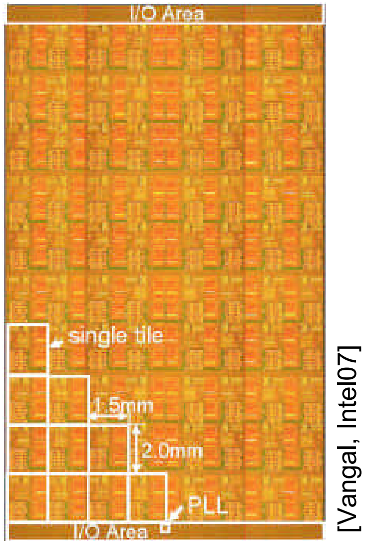
New computational structures

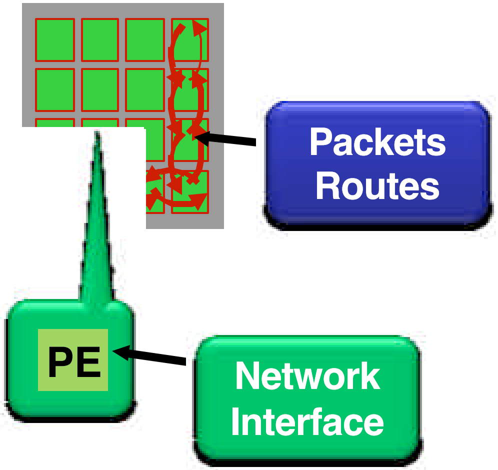
- Computation requirements
  - Predictable design
  - Fast design closure
- Array based computation
  - Matching *nano* and *micro*

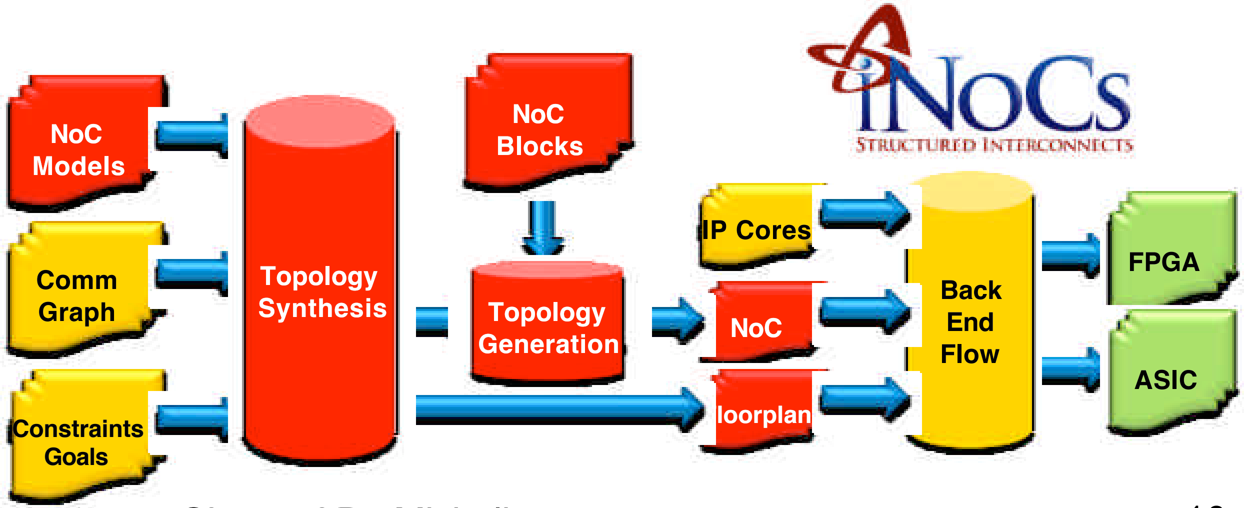


New communication structures

- Design requirements:
  - Predictable design
  - Fast design closure
- Network on Chip communication
  - Modular and flexible interconnect
  - Reliable on-chip communication
  - Structured design with synthesis and optimization support



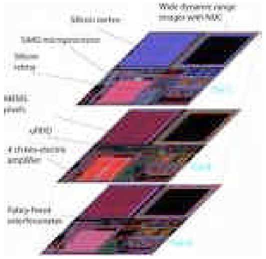


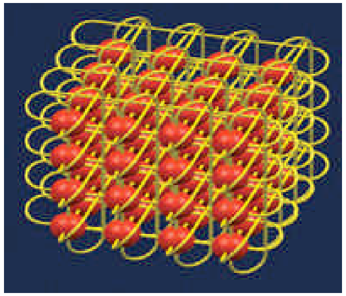


New packaging technology

- From planar to 3D integration
  - Chips have limited wiring resources
  - Electrical and manufacturing constraints limit heterogeneous planar integration
- *Through silicon vias* allow designer to stack:
  - Computing arrays
  - Memory arrays
  - Analog and RF circuitry
- 3D NoCs provide effective and reconfigurable means of realizing communication

[Fraunhofer]

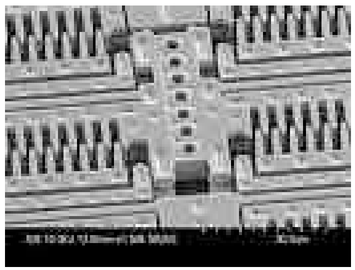




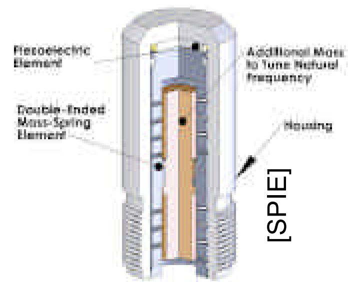
[IBM]

Heterogeneous integration

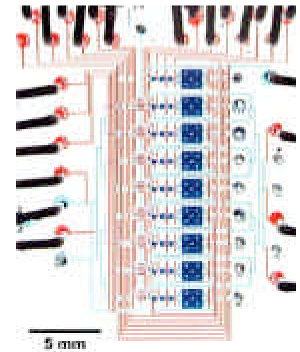
- Electrical and mechanical parts
  - Microactuators, scavengers, microfluidics



[Sandia]



[SPIE]



[Quake, Stanford]

- Electronics meets the living world

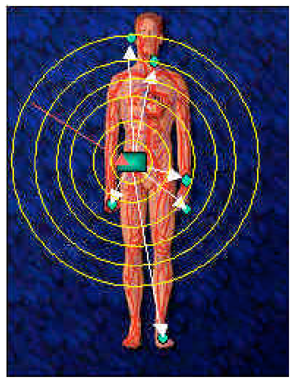
[Un. Missouri]

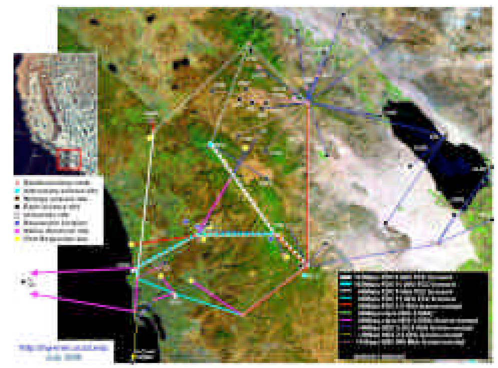
[RSC]

- Universal co-design

The micro and macro world

- Chips embedded in environment
  - Local sensing, processing and communicating





[HPWREN, UCSD]

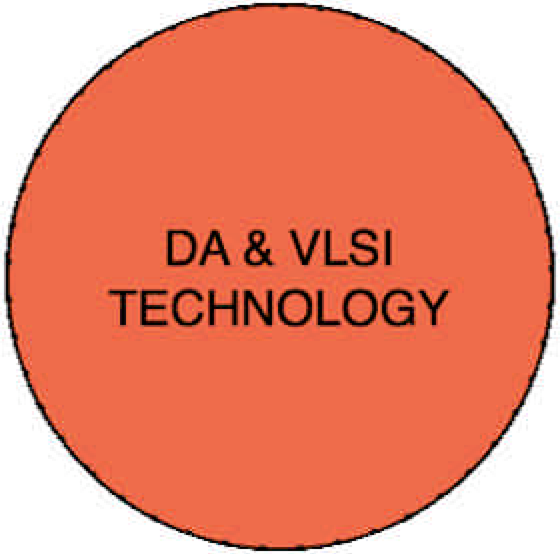
- Information production and consumption
  - The challenge of effective, correct and dependable SW
- Avoiding system-level failure
  - Safety-critical applications
  - Application, system and communication SW


SYSTEM FAILURE

The enabling design technology

- System-level design technology
  - Evolution of EDA
- Modeling, analysis, synthesis
  - The discipline brought by EDA enabled very complex chips to be successfully designed and operated
- A bigger perspective
  - How to engineer complex multivariate systems
  - Address all aspects of embedded system design
- Scientific and commercial value stems from the systems aspect

DA Evolution
through three illustrative examples



DA Evolution
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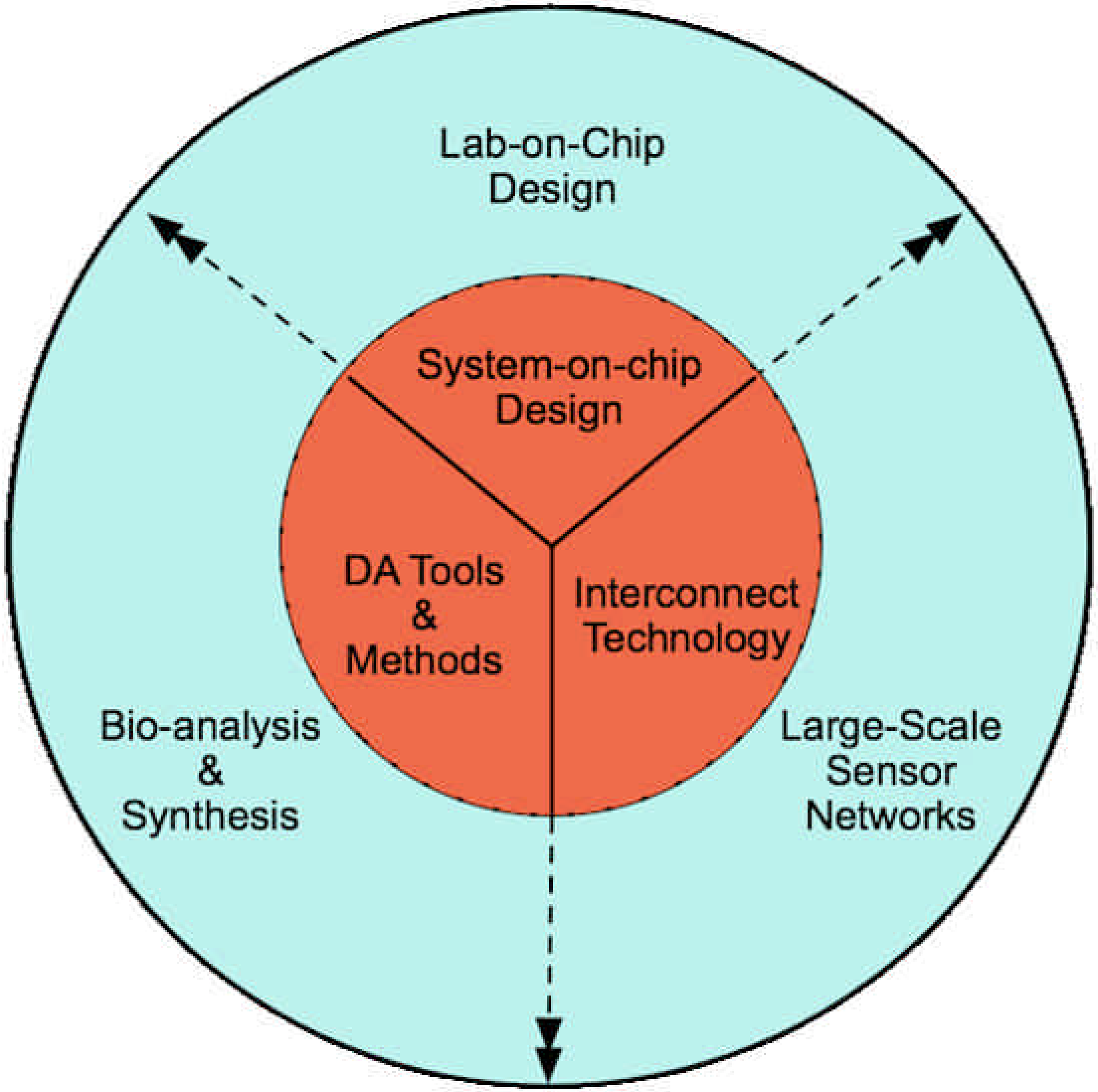
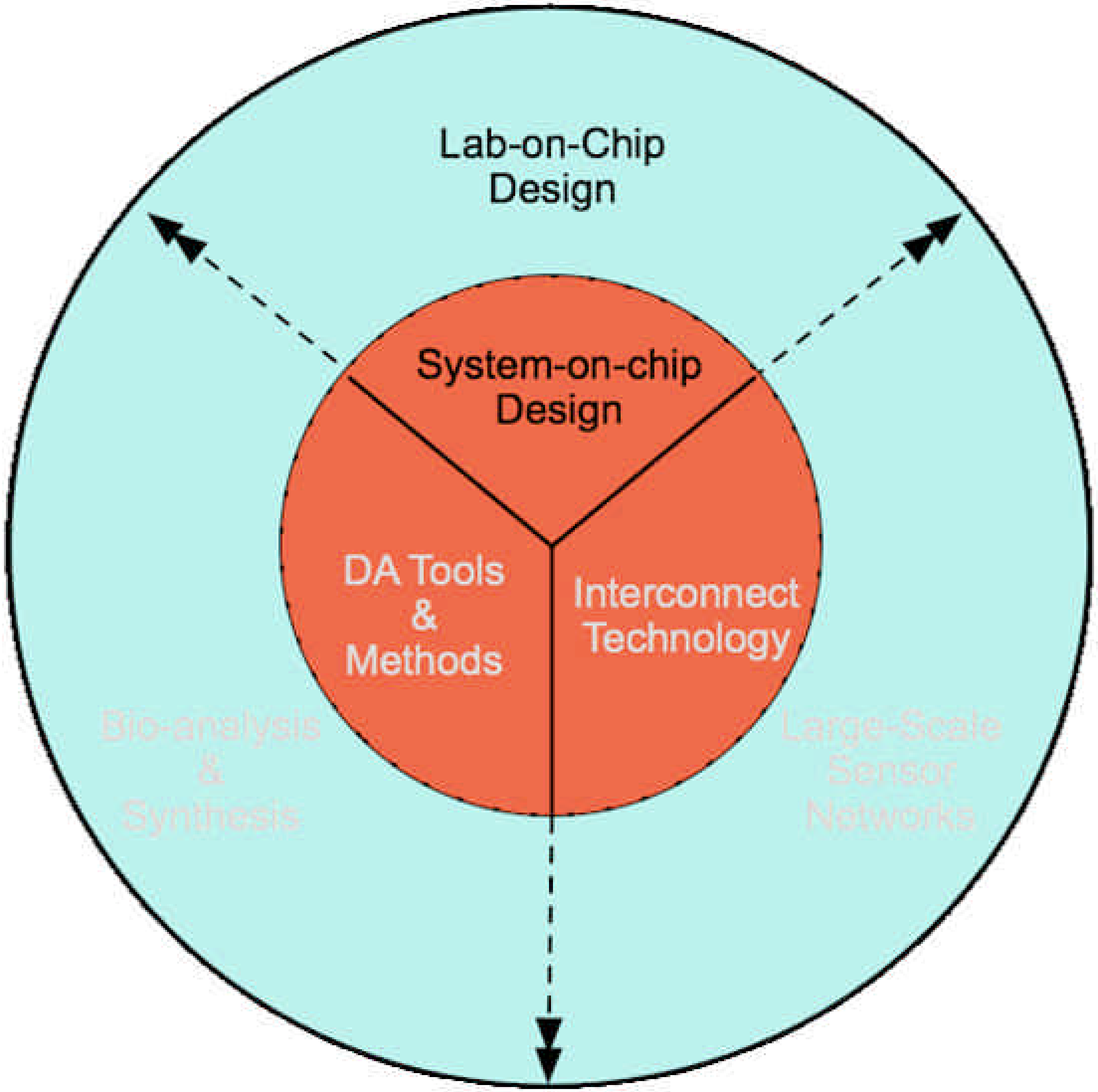


Lab-on-chip technology



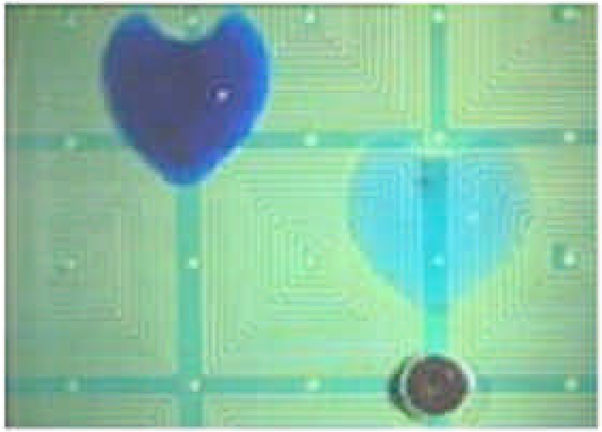
Computer-aided diagnosis (CAD?)

- *Lab on chip* at point of care
  - Perform biochemical test on the field
  - Faster, cheaper, more effective…

[STMicroelectronics]

- How
  - The ultimate hybridization of technologies:
    - Microfluidic: sample transport
    - Sensors: binding proteins, DNA to probes
    - Low-noise electronics
    - Powerful data processing algorithms and software
- The promise of lab on chip is to revolutionize medical care and offer personalized medicine

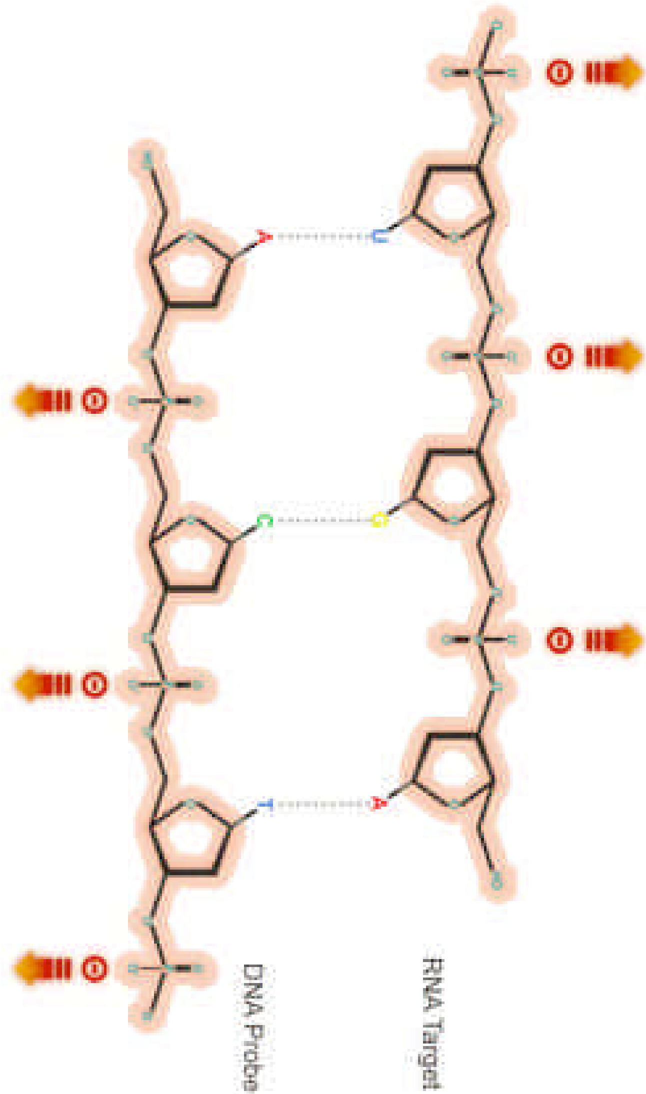
Sample transport

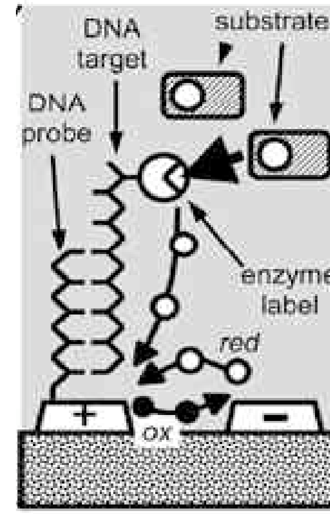


[Gijs, EPFL]

- Cell or sample transport, split and merge
  - On a 2-dimensional array
- Parallel scheduling and routing of multiple samples

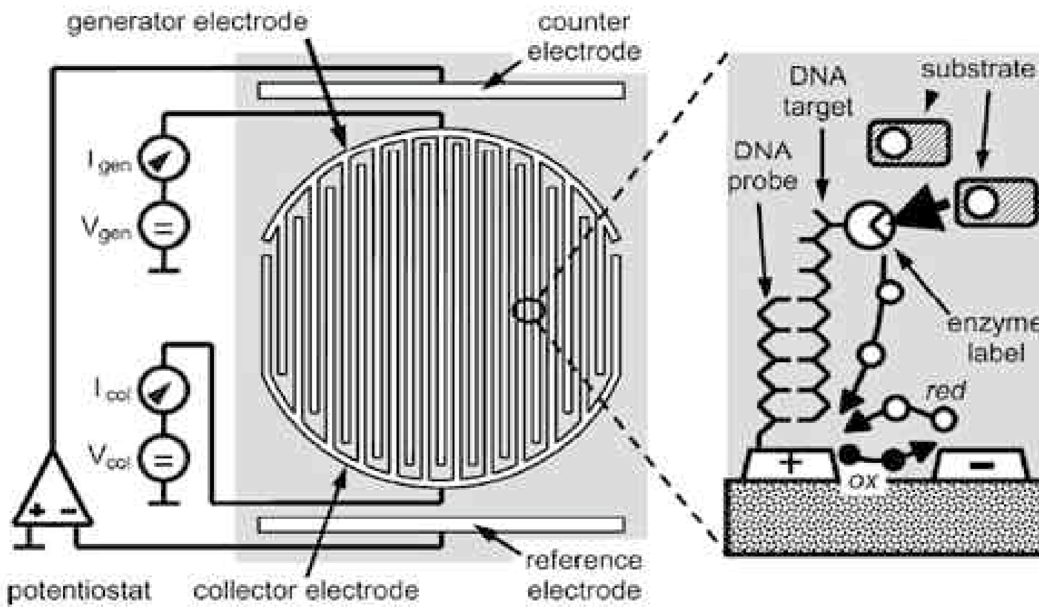
Sensing





[Stagni, Isscc 07]

Sensing

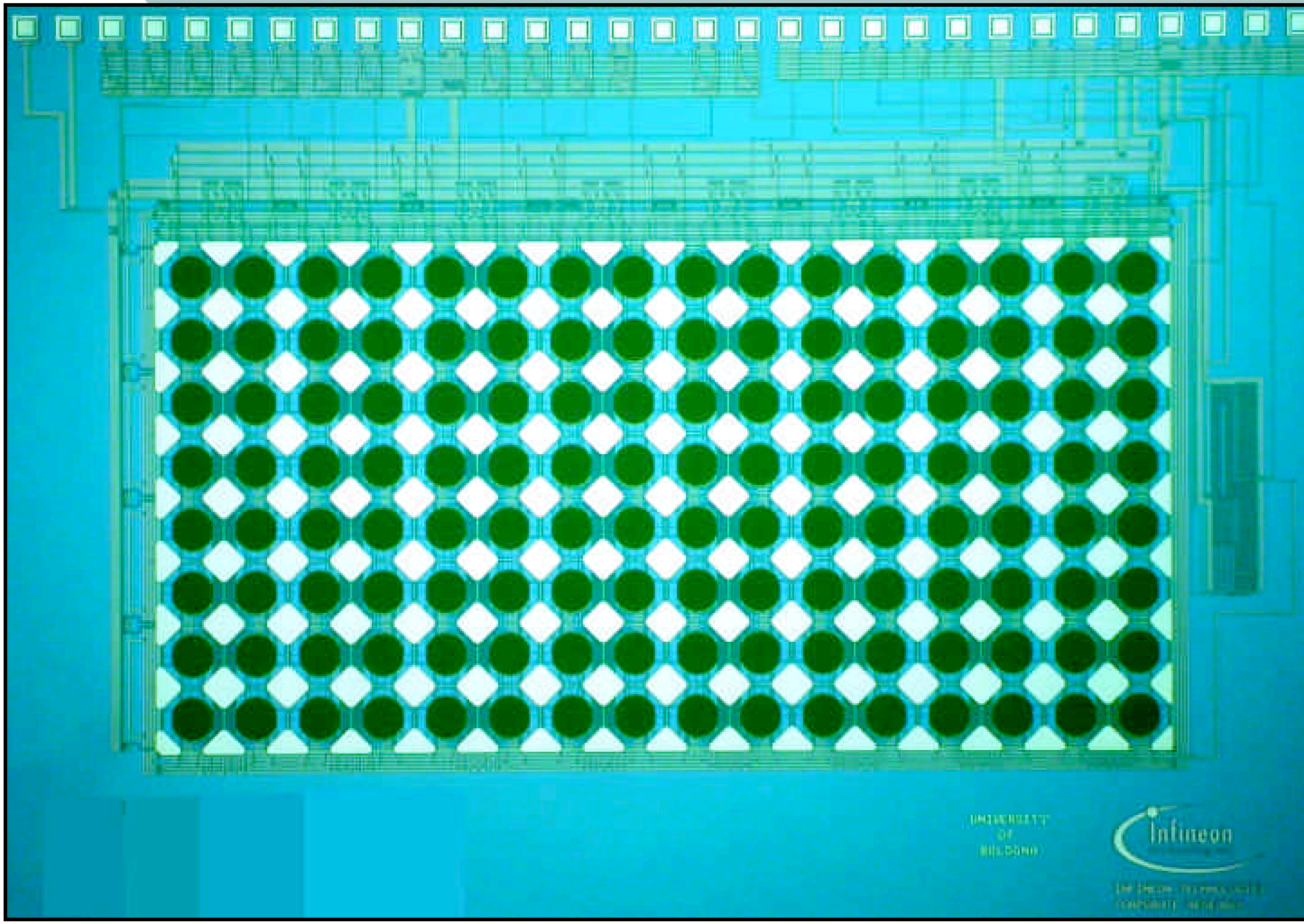


[Stagni, Isscc 07]

- Non-labeled sensing techniques are based on an electronic reading of hybridization
  - Fully integrated system solutions
  - Lower cost

- Array detectors yield a matrix of expression levels

Sensing

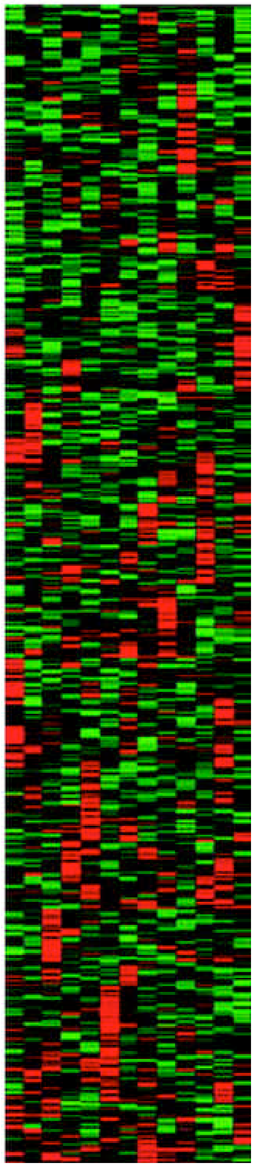


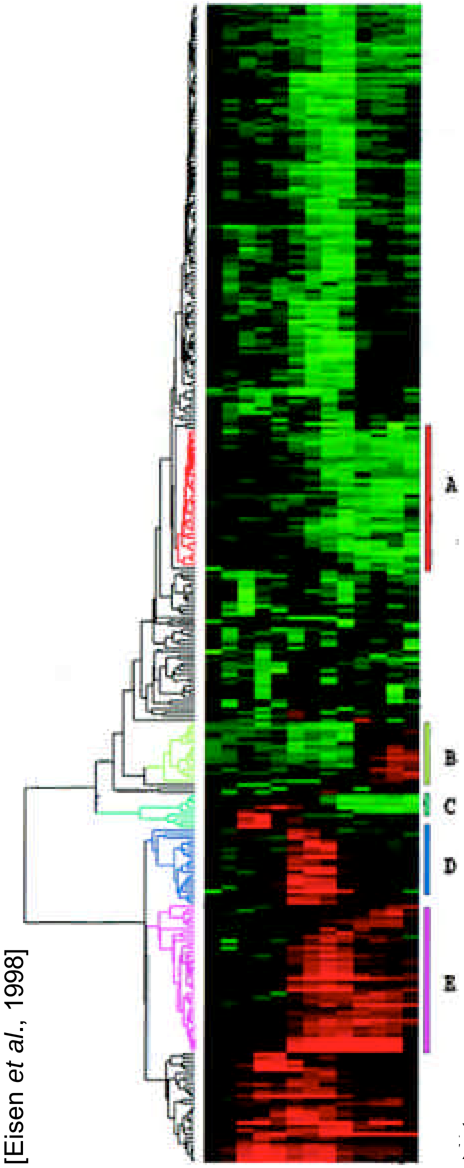
[Stagni et al., ISSCC]

- Array detectors yield a matrix of expression levels

Data mining and interpretation

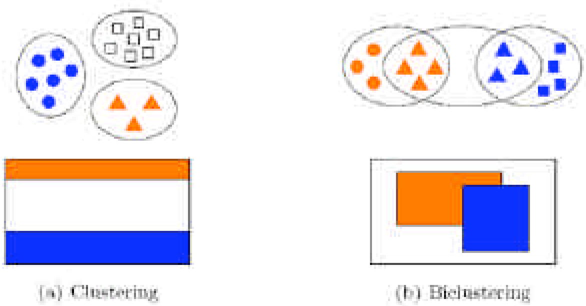
Data interpretation and clustering





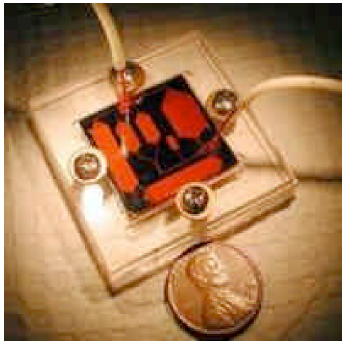
[Eisen *et al.*, 1998]

- Grouping similar objects together
  - Detecting gene variations consistent with the sample choice
  - Inference of specific conditions
- Bi-clustering on large data sets
  - Simultaneous cluster of subsets of rows and columns
    - Gene and samples



- Problem solved with ZDD technology
  - Fast and complete data interpretation

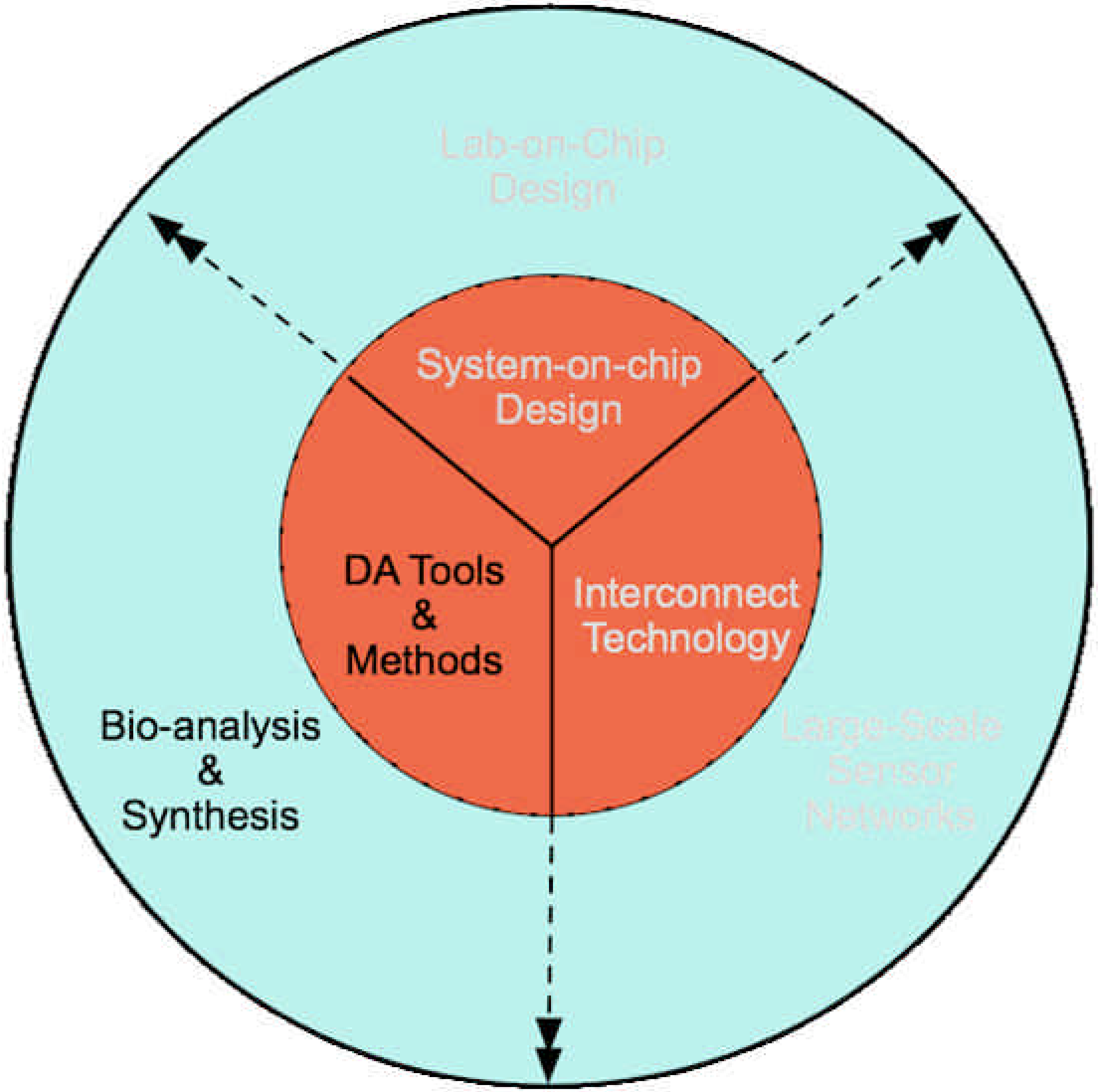
Global *Lab on Chip* objectives



[Schuler,Cornell]

- Bio-discovery
  - New biological mechanisms
- Medical practice
  - Better diagnosis via genetic information
  - Linking genetic data to clinical traits and databases
- Micro-chemistry
  - Creating organic compounds by micro-reactions
- Support for experiments/tests on the field
  - Generic versus application-specific *lab on chips*
  - Programmable, field-programmable?

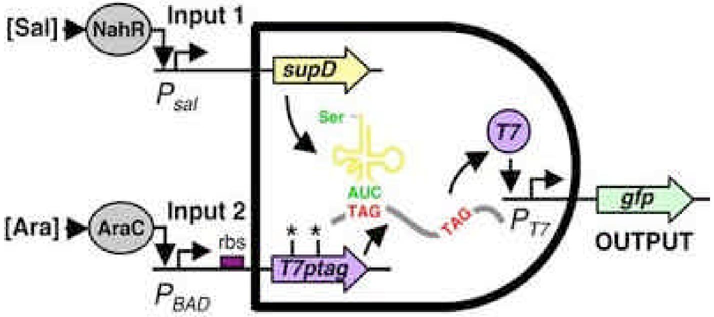
Bio analysis and synthesis



Analysis and synthesis

- Analysis - understand biological mechanisms
  - Comprehend in full the value of the *omics*
    - Genomics, proteinomics, trascriptomics
- Synthesis - modify/create new realities
  - Synthesize drugs that alter genetic/metabolic pathways
    - Pharmacogenomics
  - Synthesize biological compounds that support computation
    - Synthetic biology

[Roche]

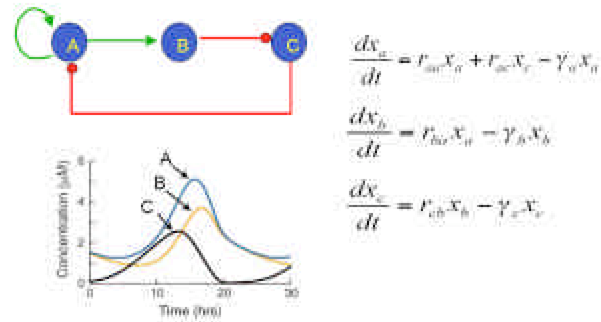


[UCSF,UCB]

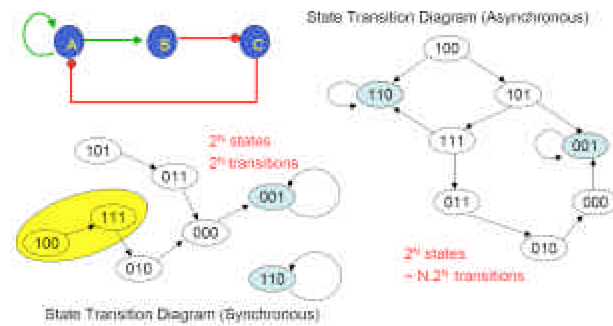
- Multiple abstractions are needed for analysis and synthesis

Abstractions

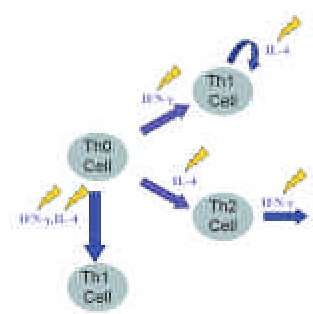
- Bio-chemical abstraction
  - Event timing
  - Differential equation models



- Logic level abstraction
  - Zero-delay model
  - Finite-state system
    - Synchronous, asynchronous

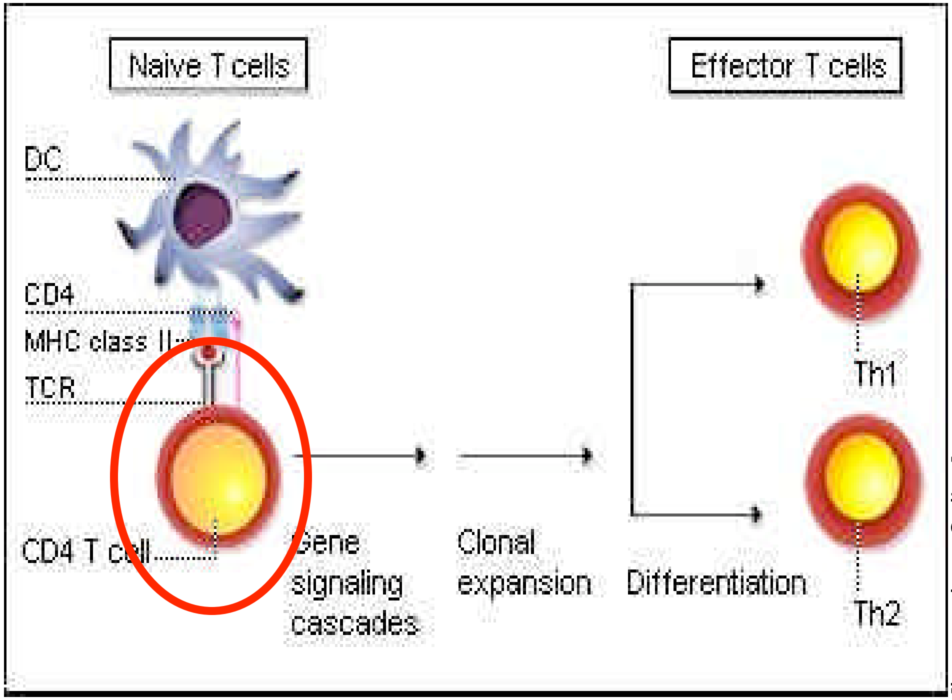


- Functional abstraction
  - Biological function
  - Input-output analysis



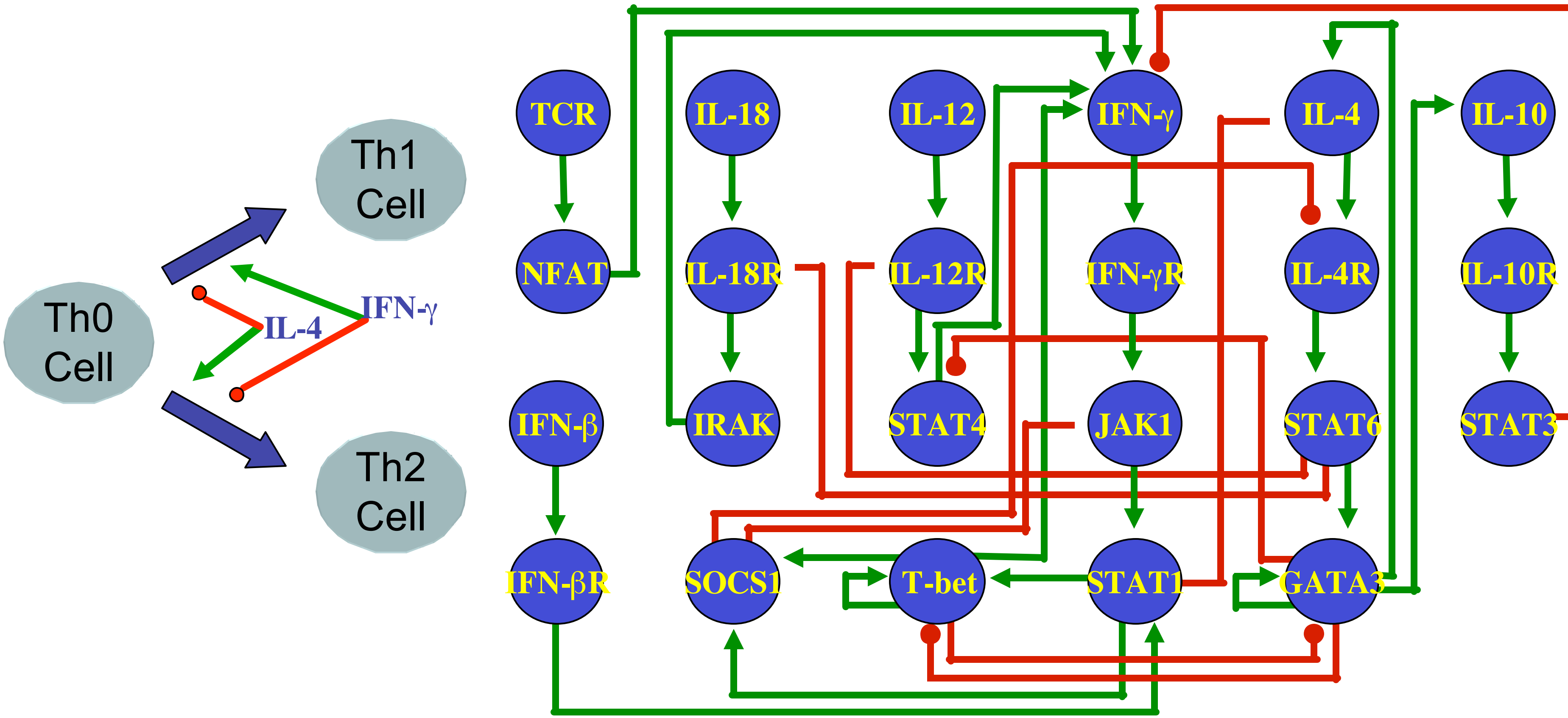
T-helper cells

- Observed behavior:
  - Precursor Th0 cells yield:
    - Effector Th1 cells
    - Effector Th2 cells
- Evolutions depends on specific gene expressions
- Evolution can be captured by a *gene regulatory network*



[Immunology Online]

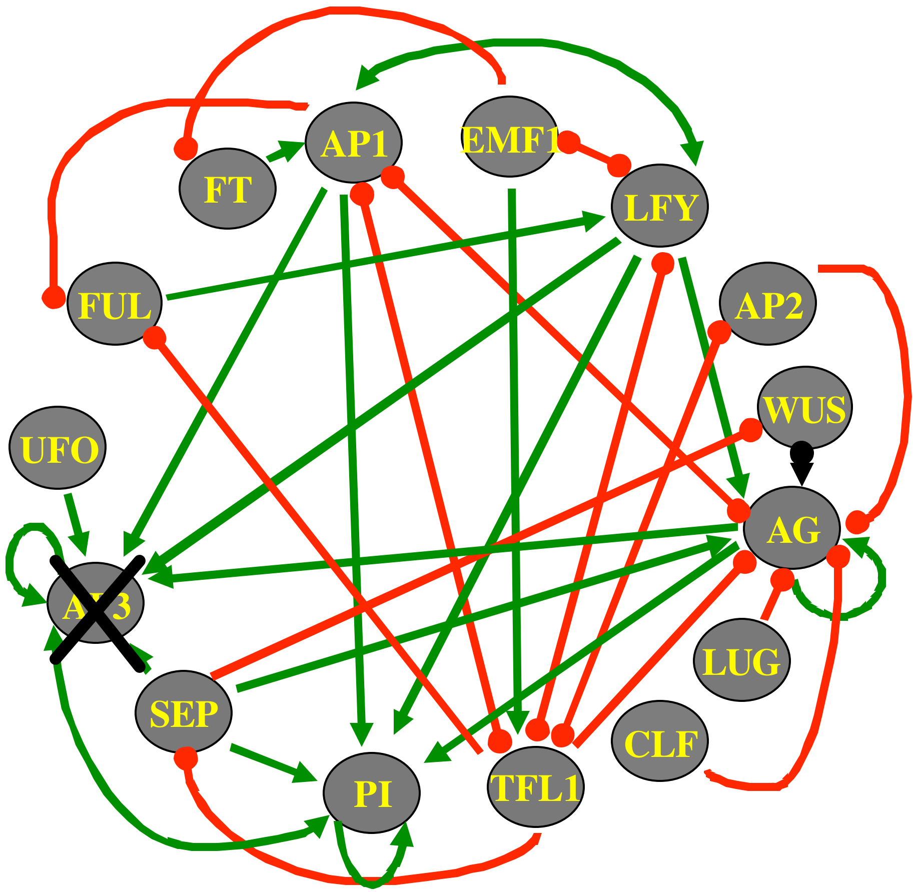
Functional and logic-level model of T-helper cell



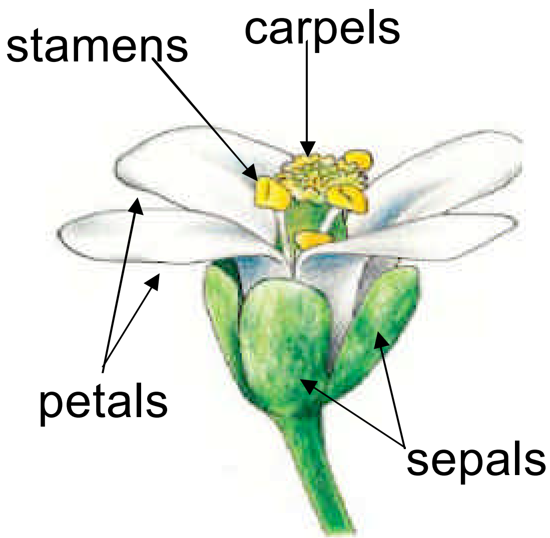
Issues

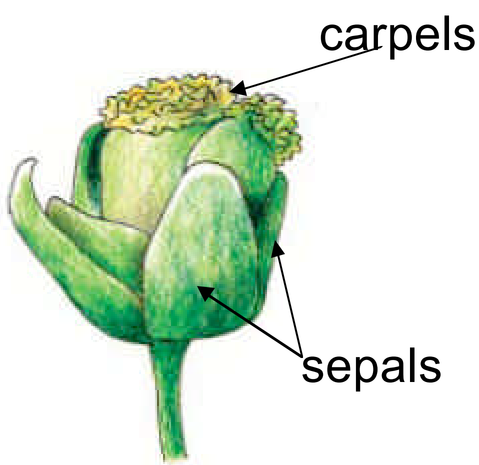
- Orthogonalization of concerns
  - Focus on terminal behavior independent from timing
- Simulation versus traversal
  - Steady state is often the objective
  - Implicit methods can handle large amount of data
- Modify system by perturbation
  - Knock-out experiment *in silico*
    - Silence a gene
  - Stuck-at 0 (déjà vu?)

Knock-out example: *Arabidopsis Thaliana*



[Soto et.al. *Plant Cell*, (16):2004]

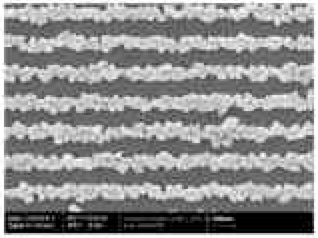




AP3 knockout

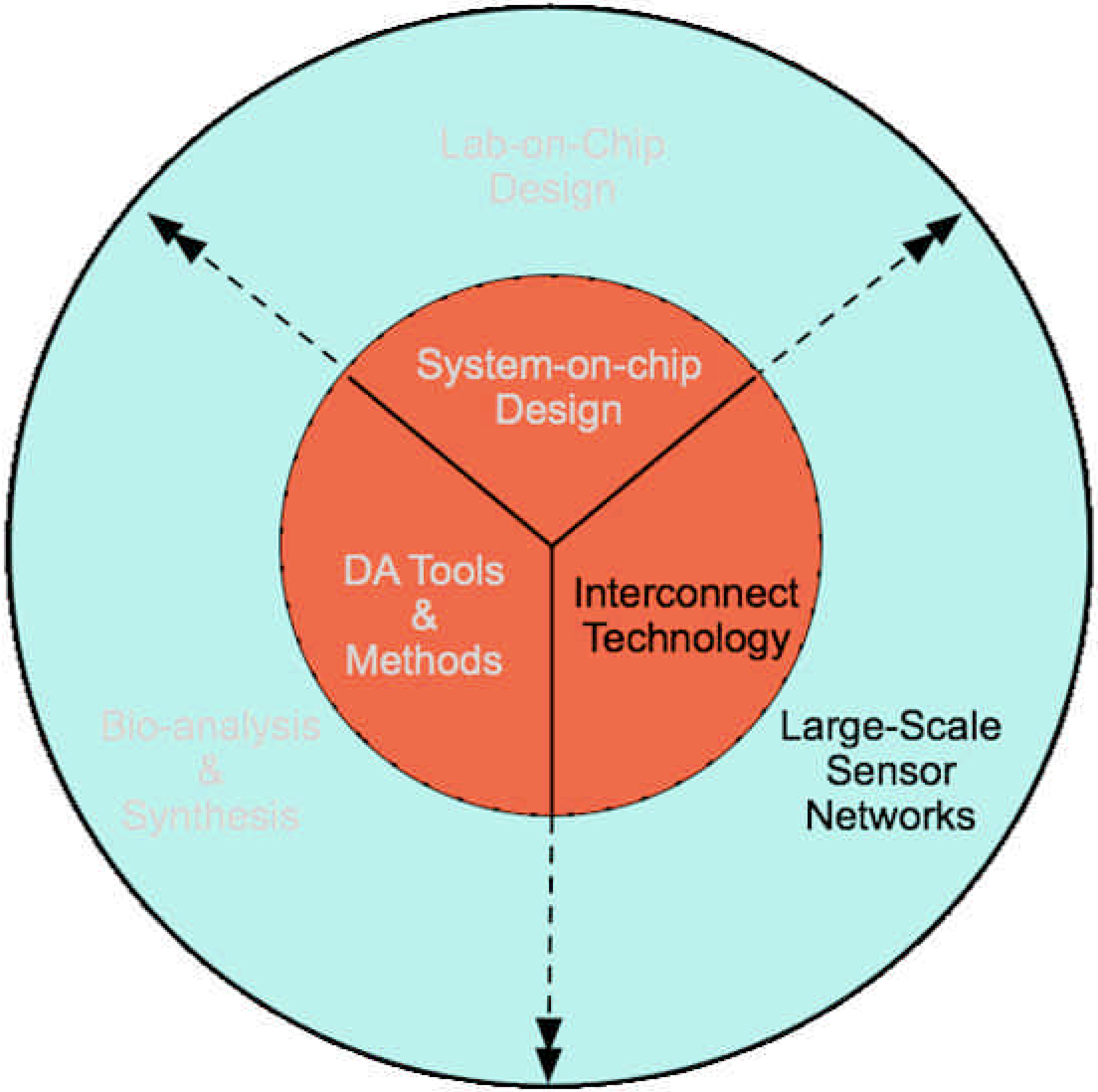
Bio analysis & synthesis objectives

- Pharmacogenomics
  - Develop drug therapy, cognizant of patient genotype
  - Study effects of altering genetic/metabolic pathways
- Synthetic biology
  - Engineer systems based on biological components
  - Abstraction: libraries, synthesis process
- Biology-driven computation
  - Devise computational processes performed by DNA
- Biologic scaffolding
  - Construct nano structures/circuits using DNA composition



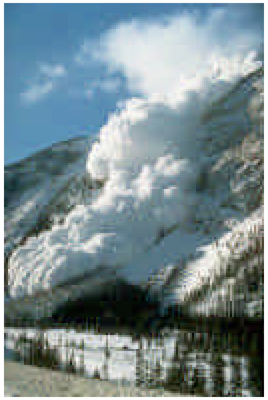
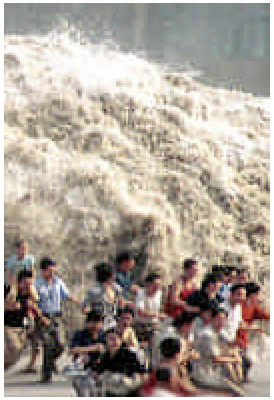
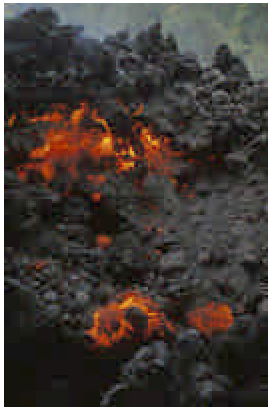
[Vörös, ETHZ]

Environmental monitoring and control



The environment

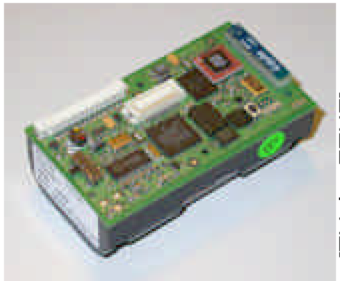
- We are embedded in the environment
  - Many inconvenient truths


- What are the challenges of wireless sensor networks to monitor/control the environment ?
  - Massive amount of data to process
  - Distributing and powering the nodes
  - Providing redundancy to tolerate local failures

Engineering environmental systems

- Integrated sensing, computation, communication and embedded software
  - Local vs. global data processing and communication



[Thiele, ETHZ]

- The power of data abstraction
  - Data reduction and integration
- The distributed intelligence approach
  - Reason and act locally with (some) global information
  - New computational paradigms, as compared to classical supercomputer approaches

The quest for energy efficiency


[Perpentum]

- Distributed wireless systems must (eventually) be autonomous
  - Energy harvesting from the environment
    - Mobile and fixed applications
  - Convert unused (degraded) energy into information
- Energy distribution systems must be efficient
  - Use information on the system to optimize energy distribution
    - Smart home, building, factory, …
    - Electric grid management
  - Convert information into energy savings

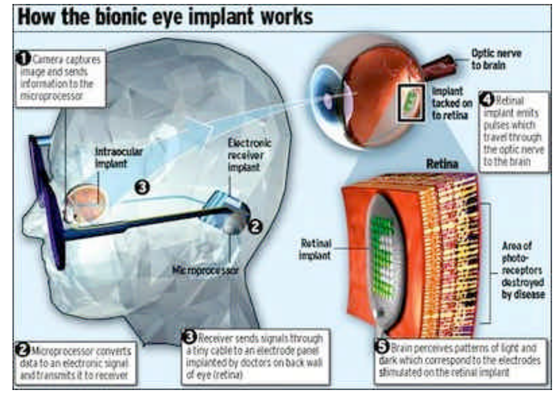

[Sandia]

- Mutual interaction: energy ? information
  - Policies for run-time energy/information management will play key role in system design

How do we interact with the environment?

- Physically

[Siemens]



[Second sight]

- Socially

[Google]

[Masternewmedia]

- How to design evolvable embedded environments with user interaction and immersion?

How do we interact with the environment?

[DATE 2058 @ 172.165….]

[Masternewmedia]

- How to design evolvable embedded environments with user interaction and immersion?

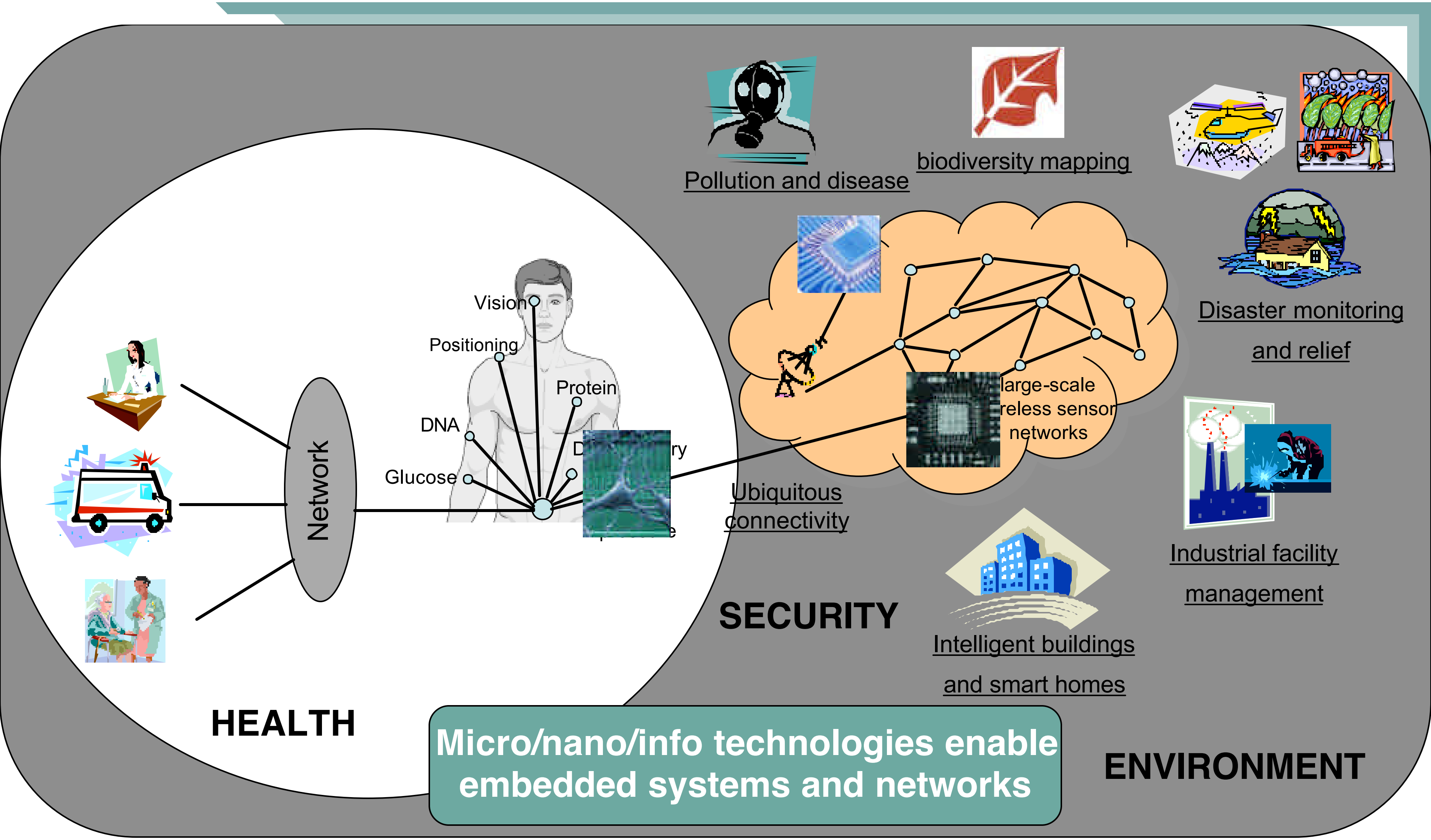
Cooperative engineering

- Bringing together engineer/scientists/doctors with different skills
  - Communication and vocabulary
  - Abstraction and modularity
- Collaborative workspaces

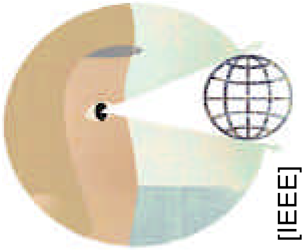
[Stanford Clark Center]

[Singapore Biopolis]

The nano-tera.ch program



The humanitarian technology challenge



[IEEE]

- A new partnership between the IEEE and the UN
- Identify technologies in the health/environment domain that can benefit developing countries
  - Food, water, health monitoring
- Using cellular technology to link data
  - Ubiquitous connectivity and local data processing
  - Autonomous or very low-power consumption because of limited availability of energy
- An ethical objective that can raise enthusiasm among engineers

Summary

- The road ahead has challenges and rewards:
  - Expanding our horizon is key to scientific viability and commercial profitability
- We need heterogeneous hardware design and the corresponding software infrastructure
  - Product/system design is an extremely complex task, because of the variety of facets and technologies involved
- System-level design technologies are crucial for system conception, design and management
  - Progress leads us beyond advanced silicon chip design
  - Scientific and financial benefits will stem from the system/service perspective

Thank you