



Designing Micro/Nano Systems for a safer and healthier tomorrow

Giovanni De Micheli

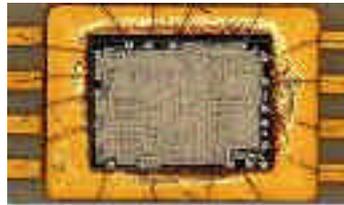


Quo vadis ?

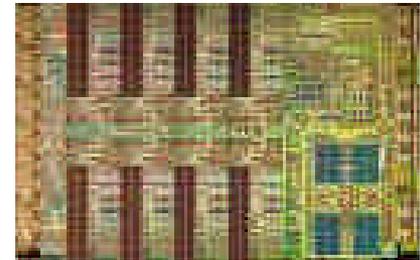
- We came a long way ...
 - 50 years of electronics



[Bell labs]

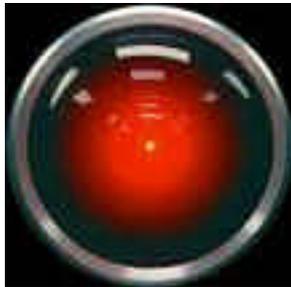


[Intel]



[IBM]

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



[Kubrick:2001]

How did we affect society ?

- From transistor radio ...



[Motorola]



[IBM]



[Sony]

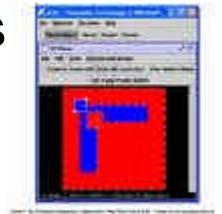
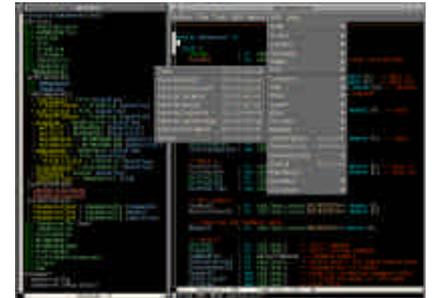


[Apple]

- 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]

EIB: EEN SYSTEEM MET UITGEBREIDE MOGELIJKHEDEN



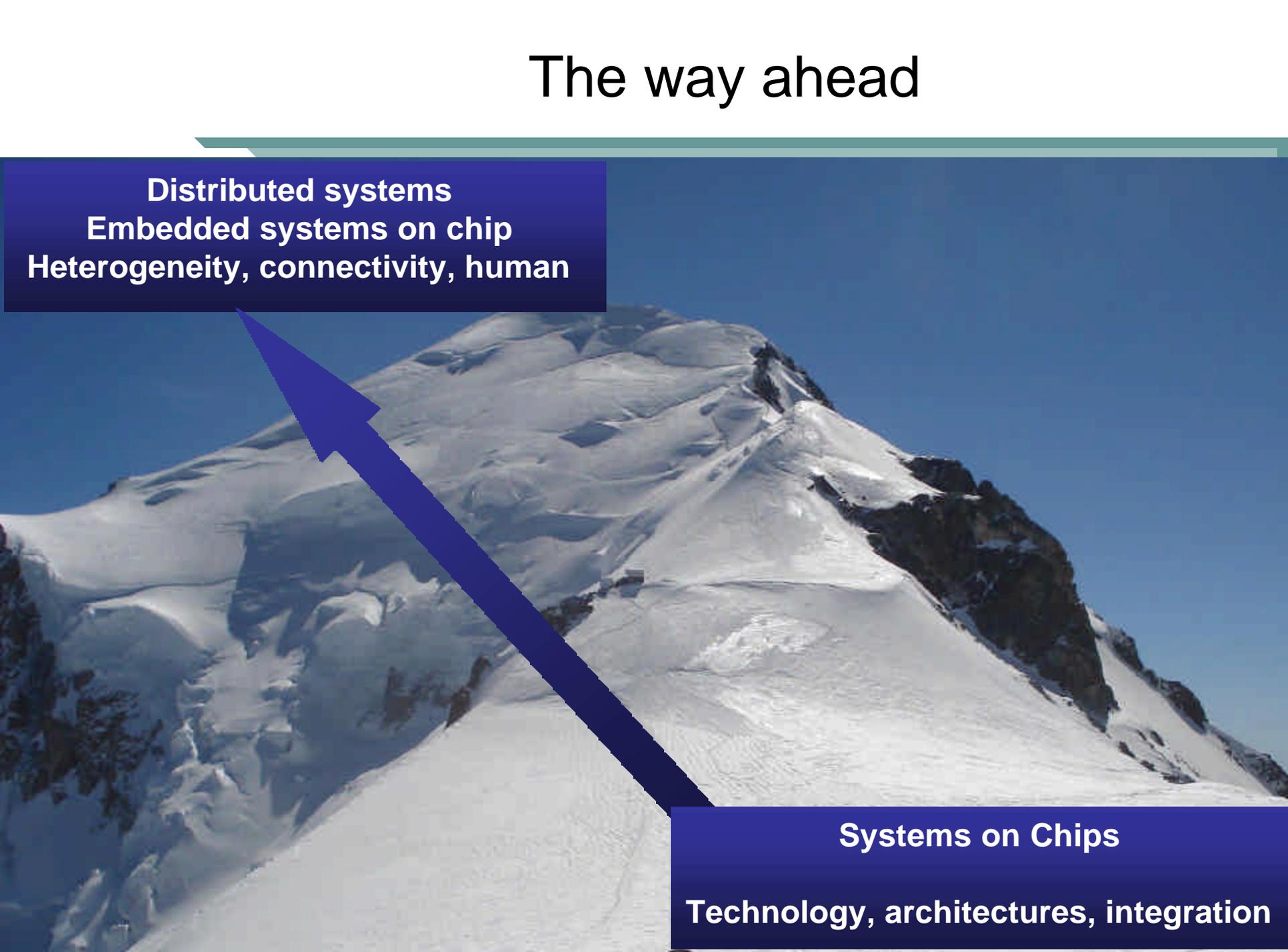
[QBUS Domotica]

The way ahead

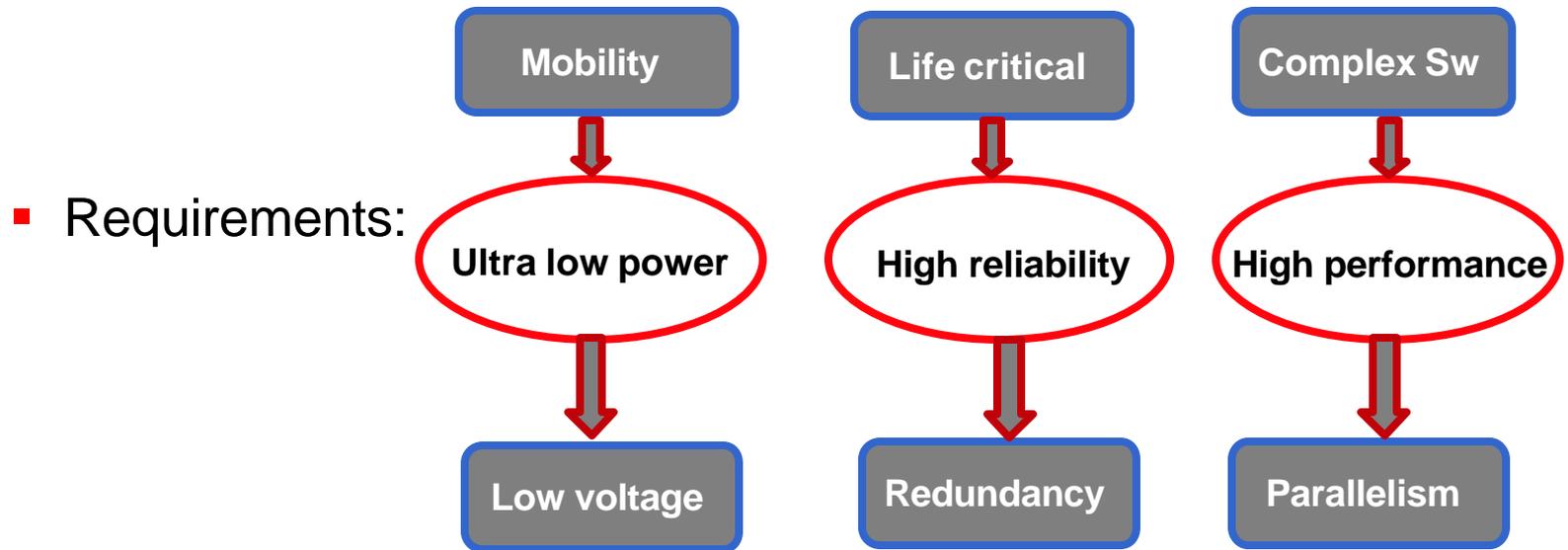
Distributed systems
Embedded systems on chip
Heterogeneity, connectivity, human

Systems on Chips

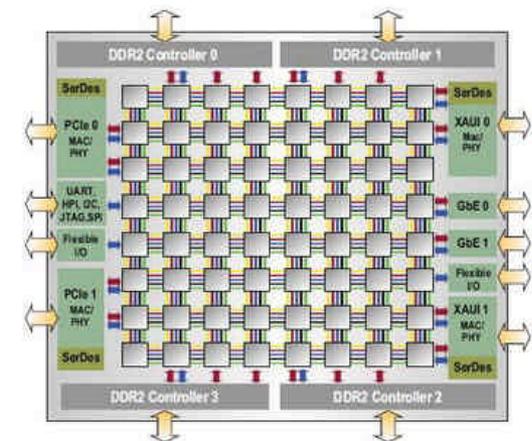
Technology, architectures, integration



Redefining electronic chip design



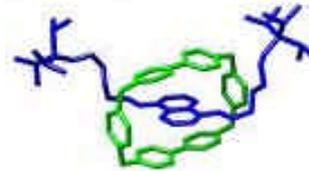
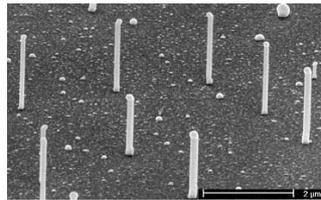
- From processors to multi-processors
- Technology support
 - Systems and software redesign



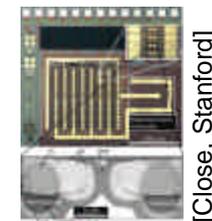
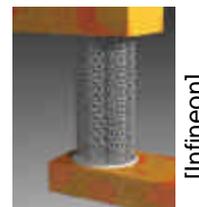
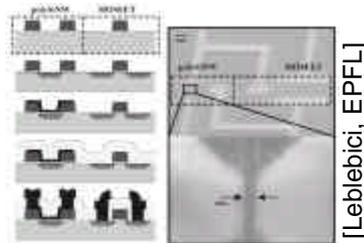
[Tilera]

The fabrication technology support

- Beyond CMOS: a myriad of new ideas



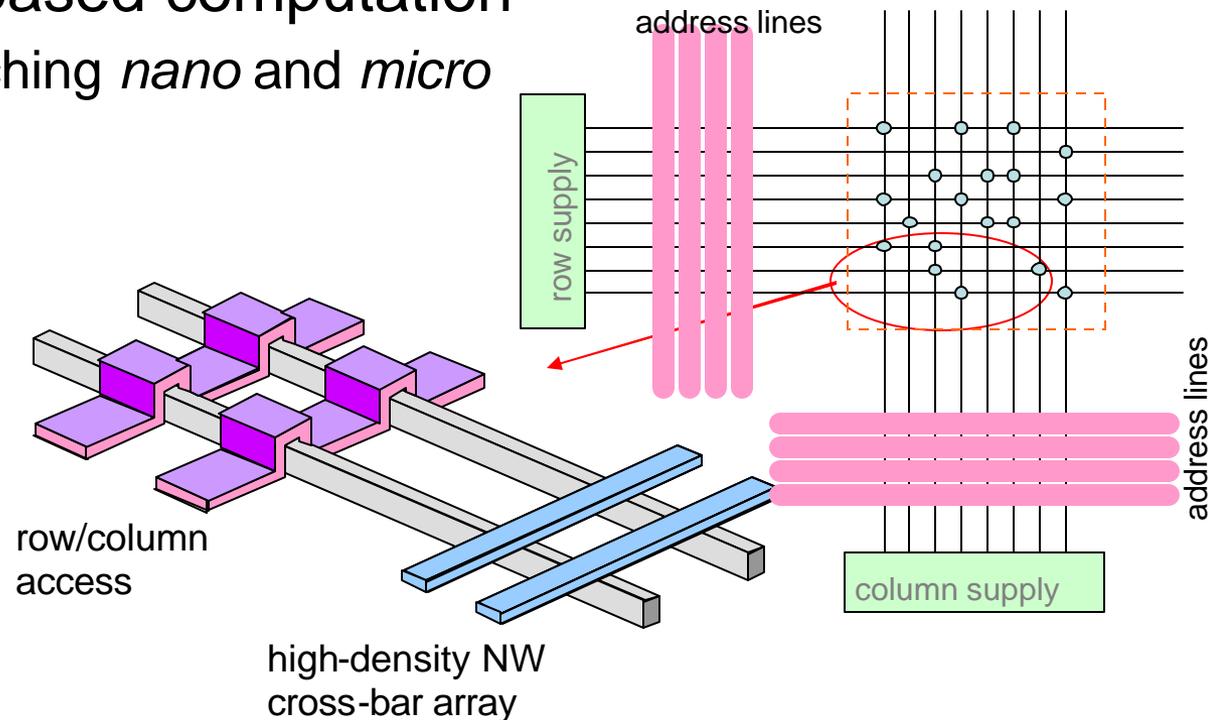
- Are these technologies apt/ready for system design?
- Can they mix and match with CMOS?



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

New computational structures

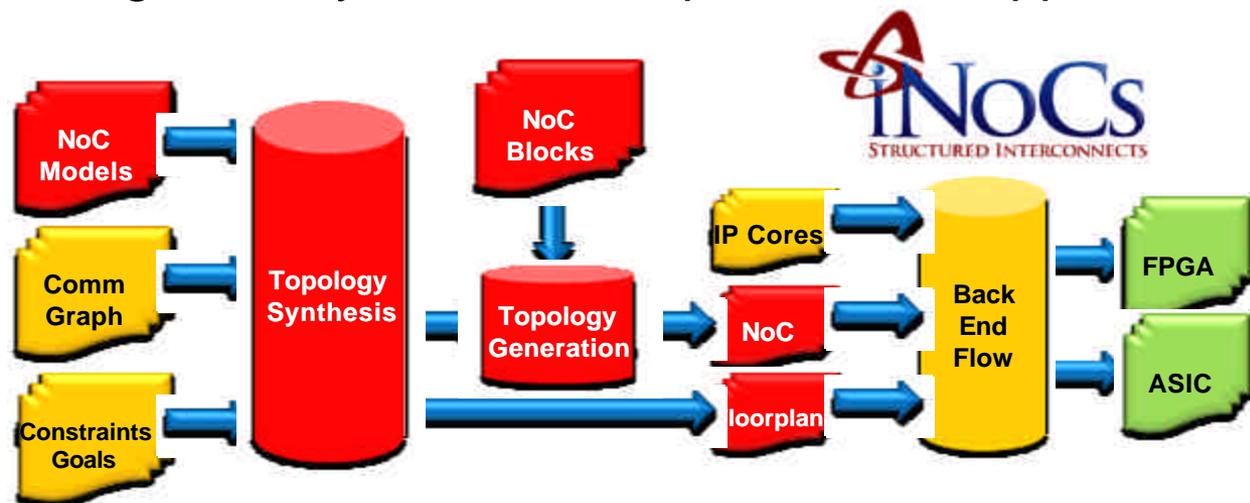
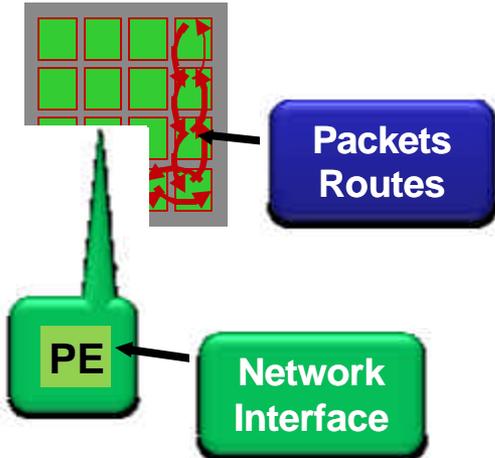
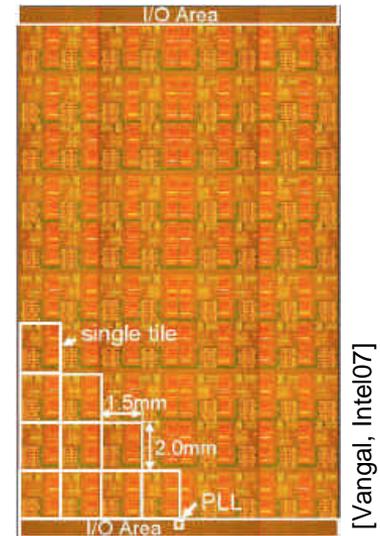
- Computation requirements
 - Predictable design
 - Fast design closure
- Array based computation
 - Matching *nano* and *micro*



[Benjamaa, Moselund, EPFL]

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



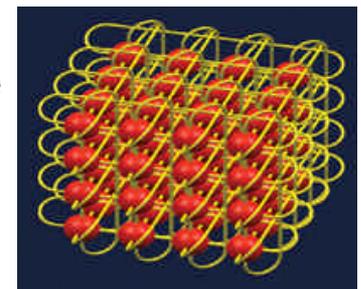
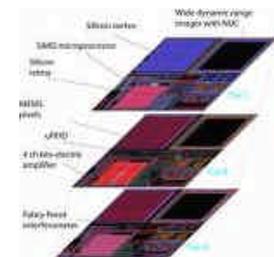
(c) Giovanni De Micheli

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



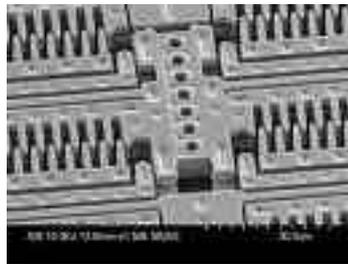
[Fraunhofer]



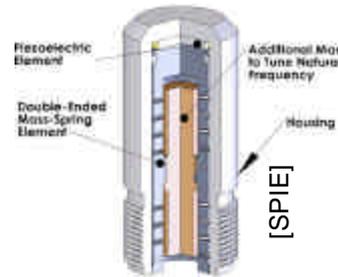
[IBM]

Heterogeneous integration

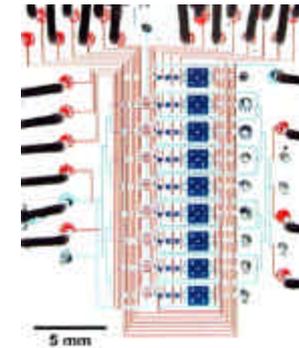
- Electrical and mechanical parts
 - Microactuators, scavengers, microfluidics



[Sandia]



[SPIE]



[Quake, Stanford]

- Electronics meets the living world



[Un. Missouri]

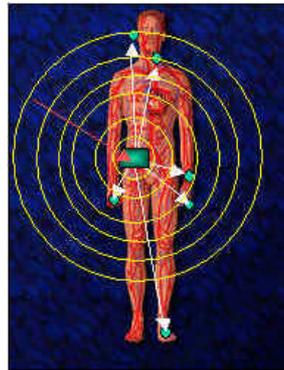


[RSC]

- Universal co-design

The micro and macro world

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



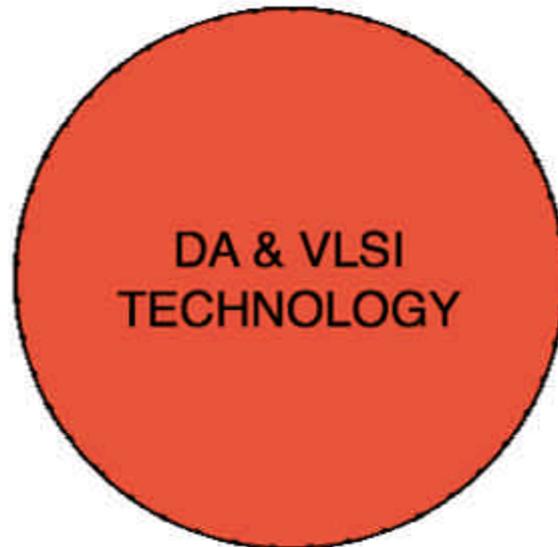
- Information production and consumption
 - The challenge of effective, correct and dependable SW
- Avoiding system-level failure
 - Safety-critical applications
 - Application, system and communication SW

SYSTEM FAILURE

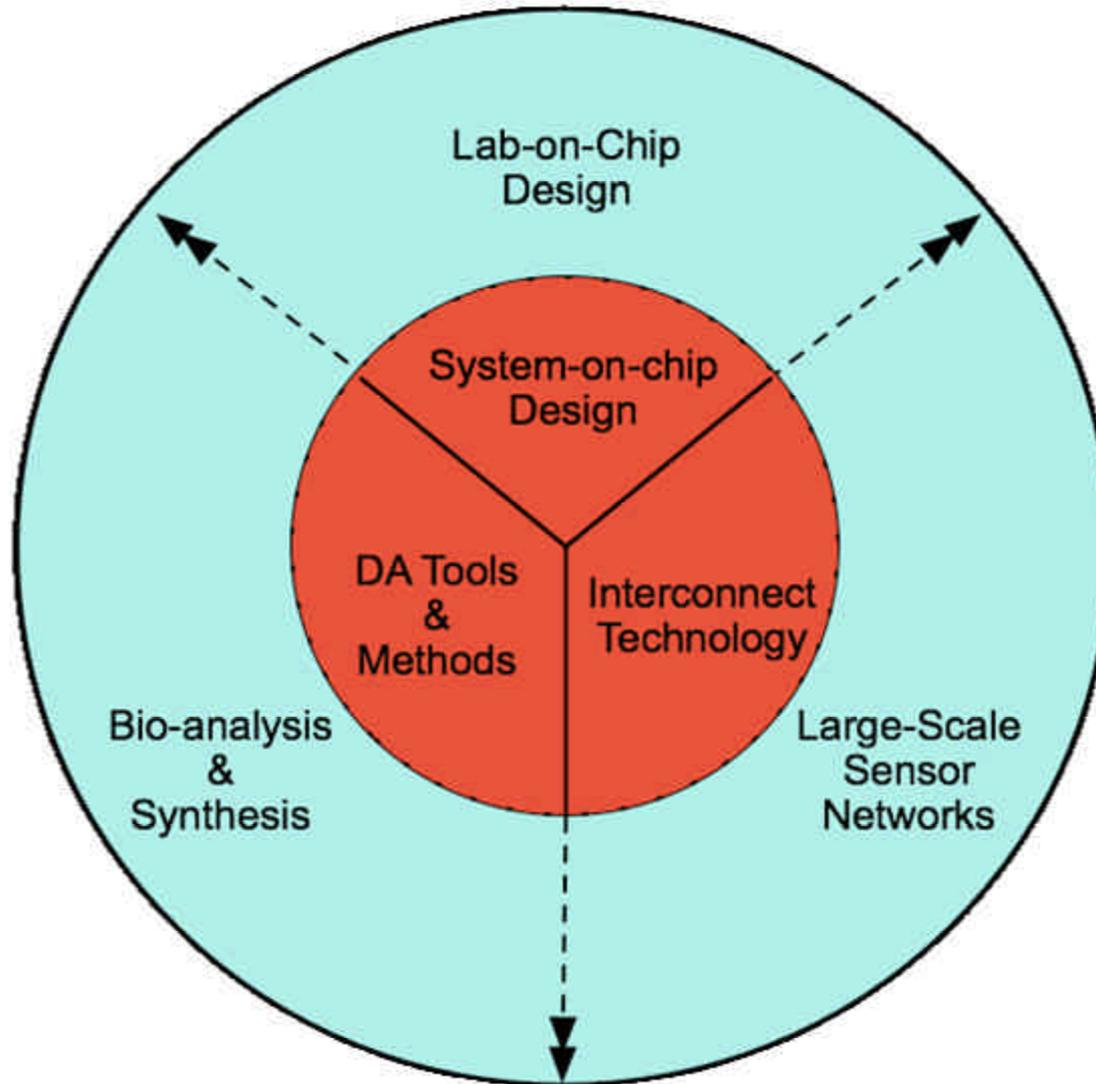
The enabling design technology

- 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

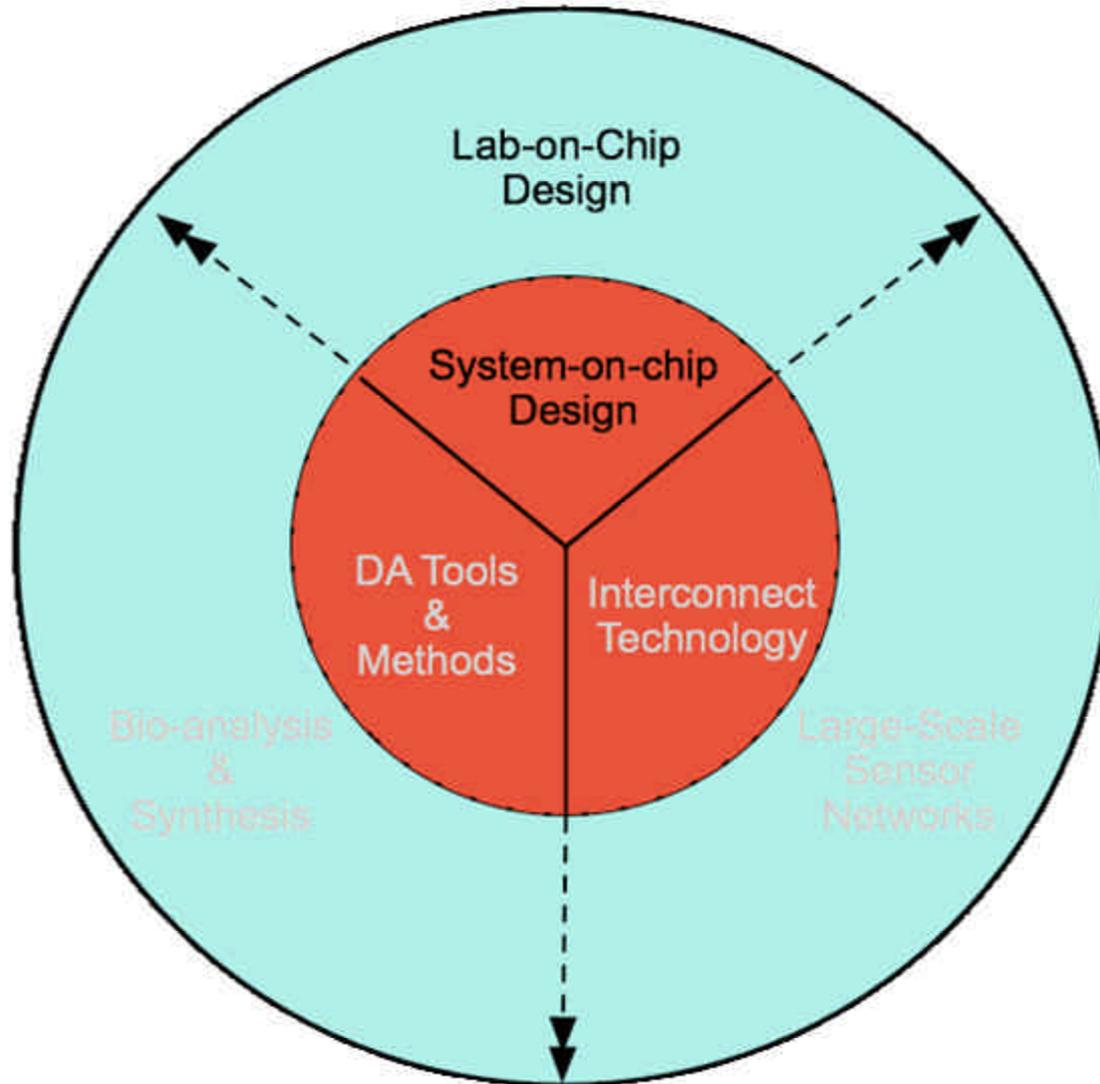
DA Evolution through three illustrative examples



DA Evolution through three illustrative examples



Lab-on-chip technology



Computer-aided diagnosis (CAD?)

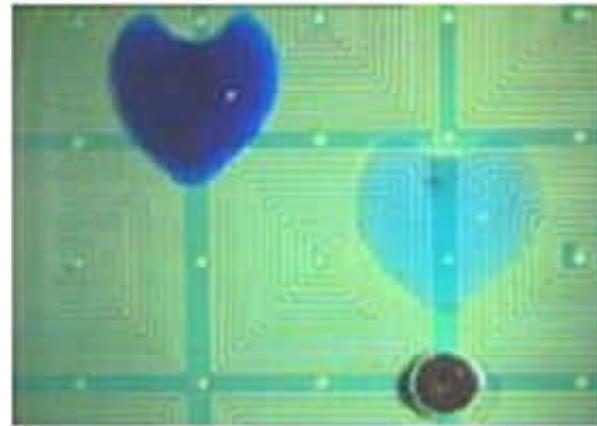
- *Lab on chip* at point of care
 - Perform biochemical test on the field
 - Faster, cheaper, more effective...
- How
 - The ultimate hybridization of technologies:
 - Microfluidic: sample transport
 - Sensors: binding proteins, DNA to probes
 - Low-noise electronics
 - Powerful data processing algorithms and software
- The promise of lab on chip is to revolutionize medical care and offer personalized medicine



(c) Giovanni De Micheli



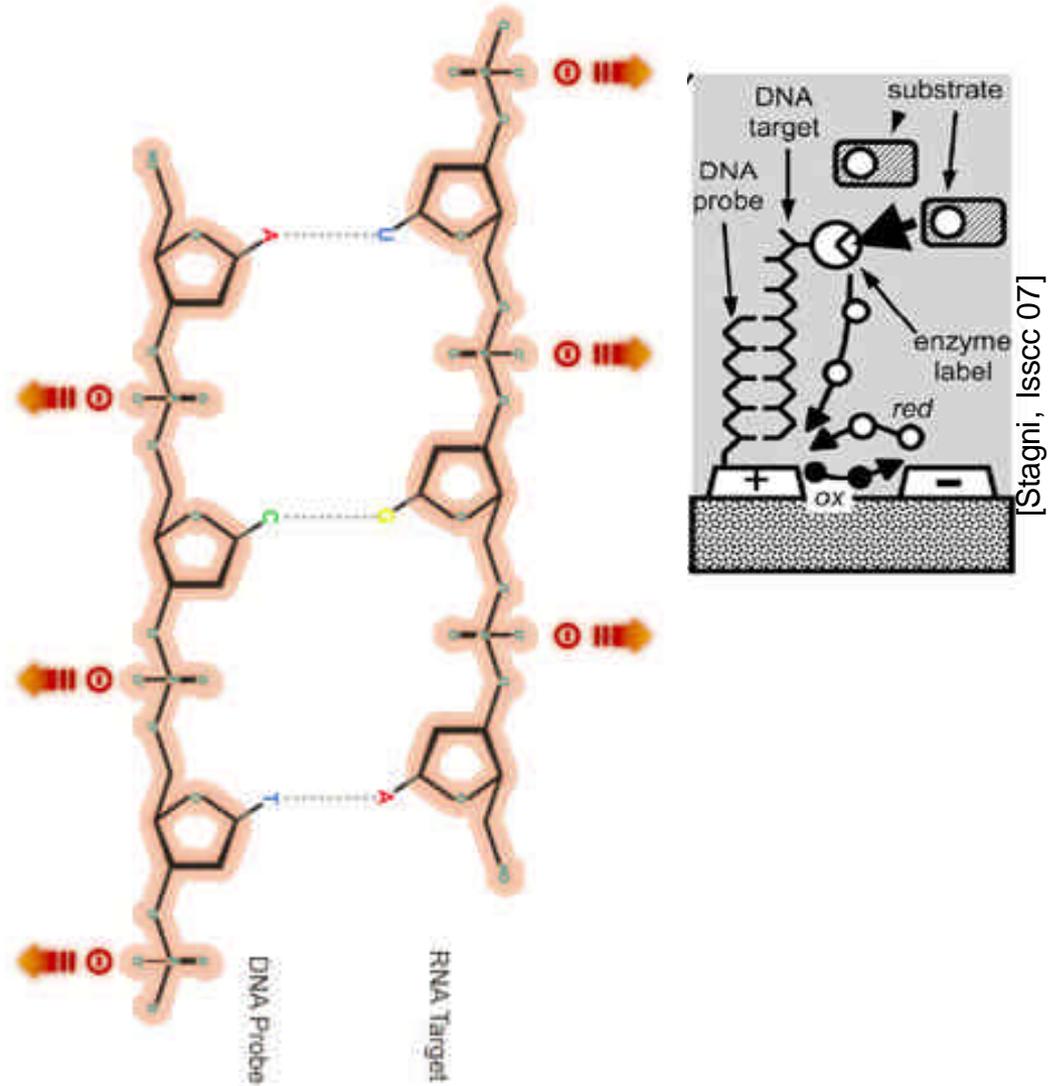
Sample transport



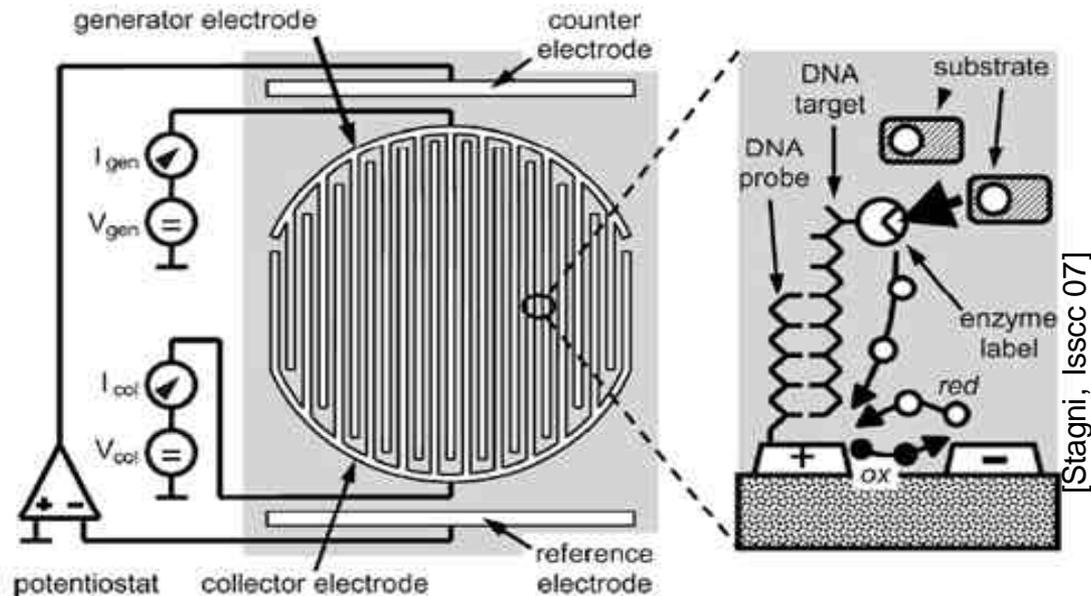
[Gijs, EPFL]

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

Sensing

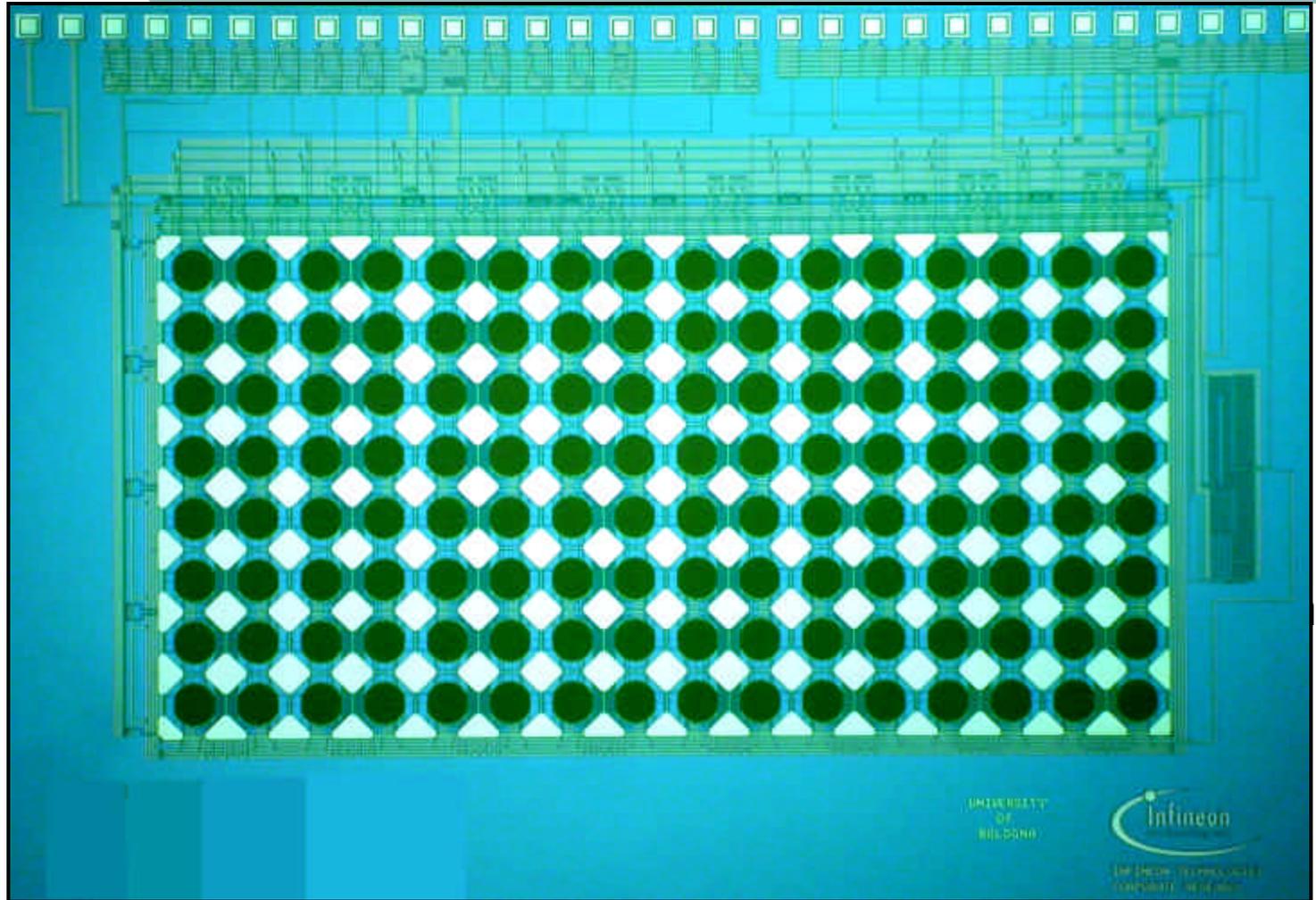


Sensing



- 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]

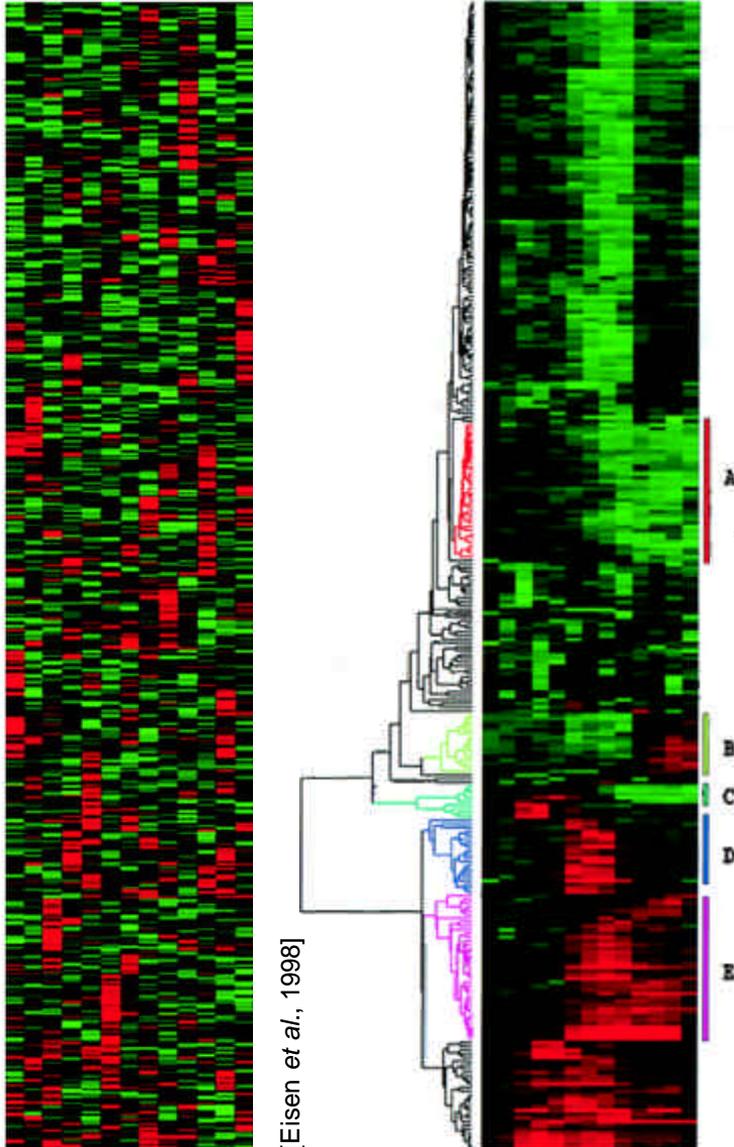
- Array detectors yield a matrix of expression levels

Data mining and interpretation

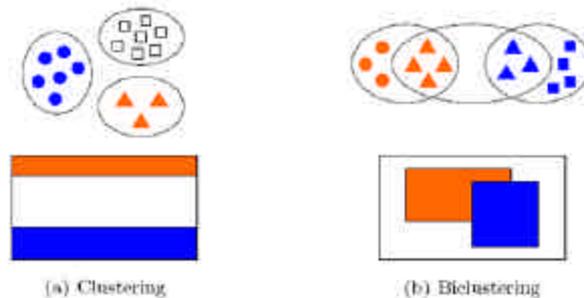


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Data interpretation and clustering



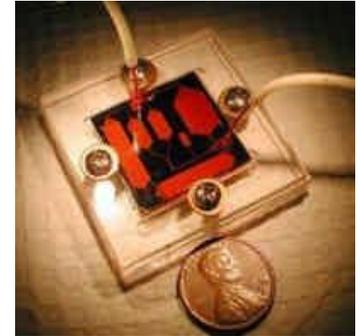
- Grouping similar objects together
 - Detecting gene variations consistent with the sample choice
 - Inference of specific conditions
- Bi-clustering on large data sets
 - Simultaneous cluster of subsets of rows and columns
 - Gene and samples



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

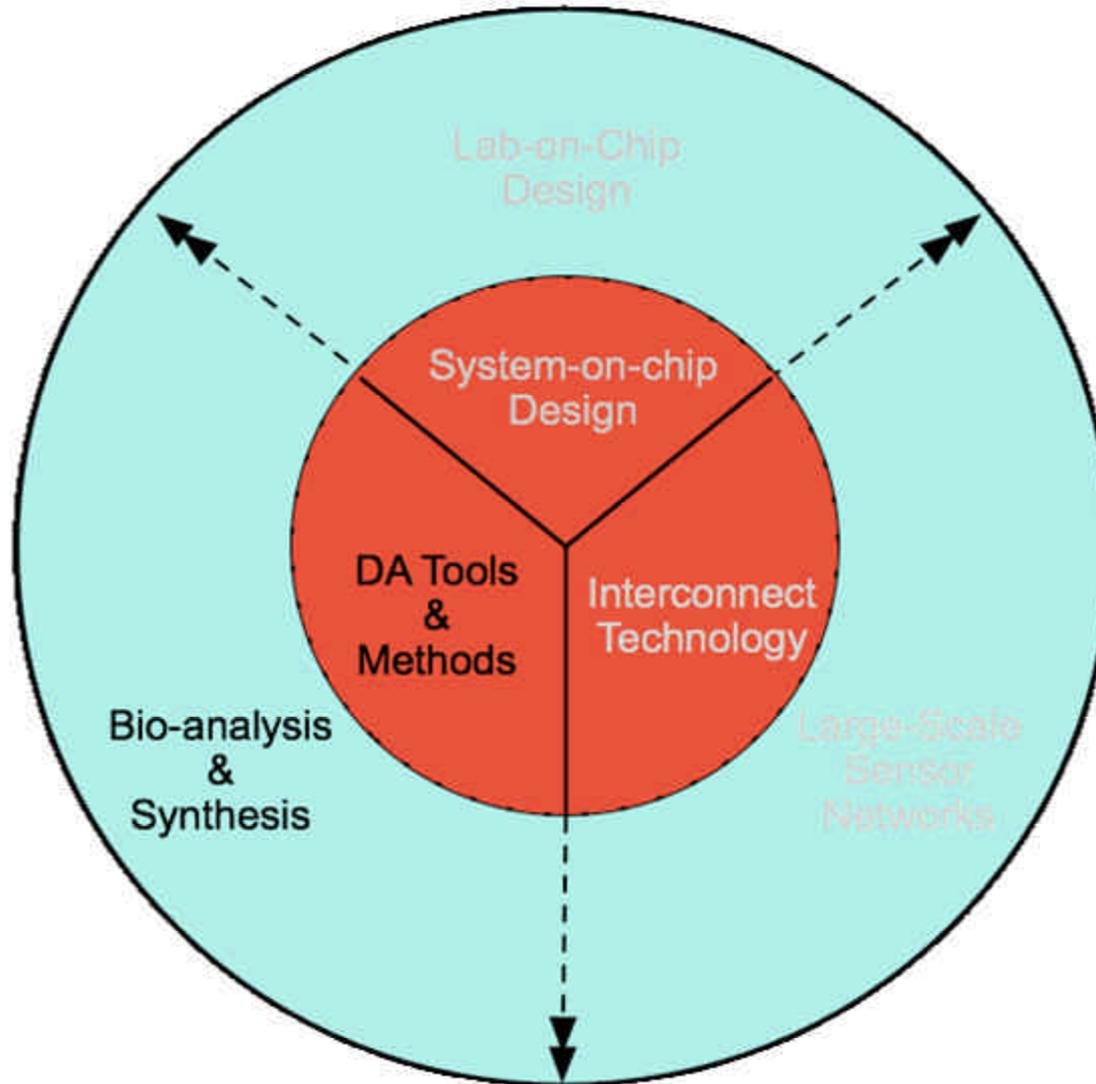
Global *Lab on Chip* objectives

- 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?



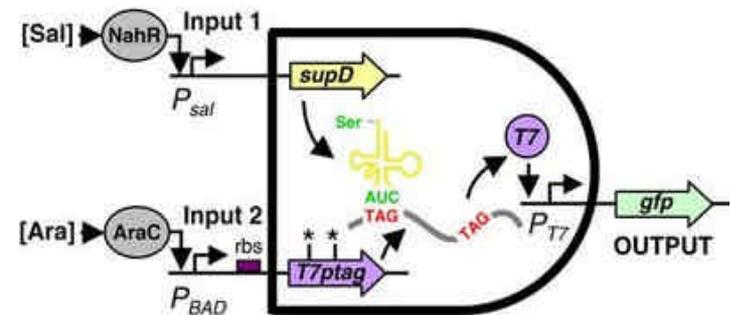
[Schuler, Cornell]

Bio analysis and synthesis



Analysis and synthesis

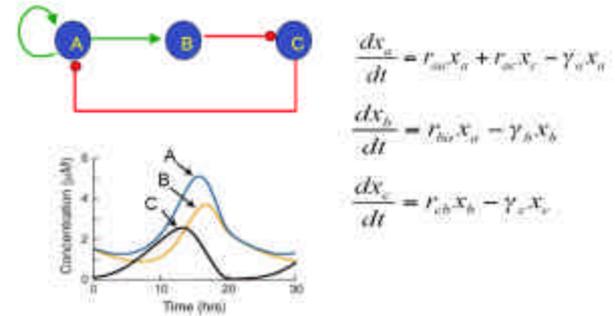
- Analysis - understand biological mechanisms
 - Comprehend in full the value of the *omics*
 - Genomics, proteomics, transcriptomics
- Synthesis - modify/create new realities
 - Synthesize drugs that alter genetic/metabolic pathways
 - Pharmacogenomics
 - Synthesize biological compounds that support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



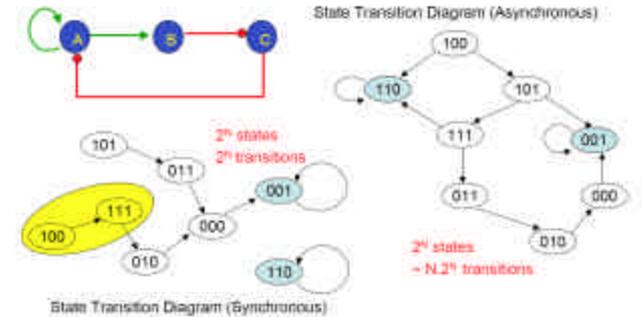
- Multiple abstractions are needed for analysis and synthesis

Abstractions

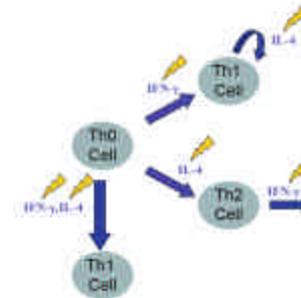
- Bio-chemical abstraction
 - Event timing
 - Differential equation models



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

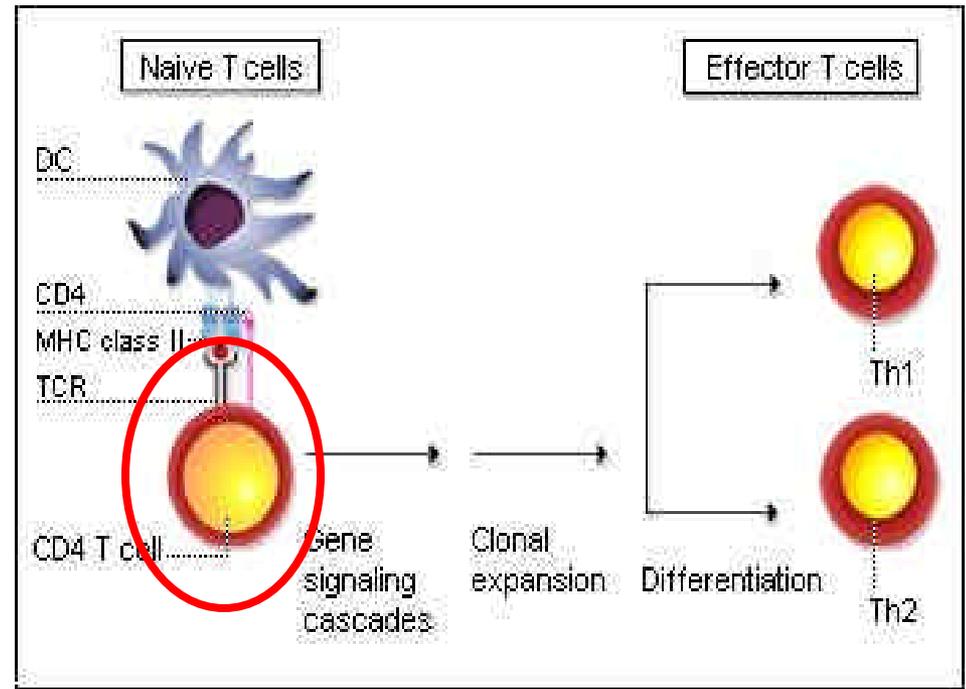


- Functional abstraction
 - Biological function
 - Input-output analysis

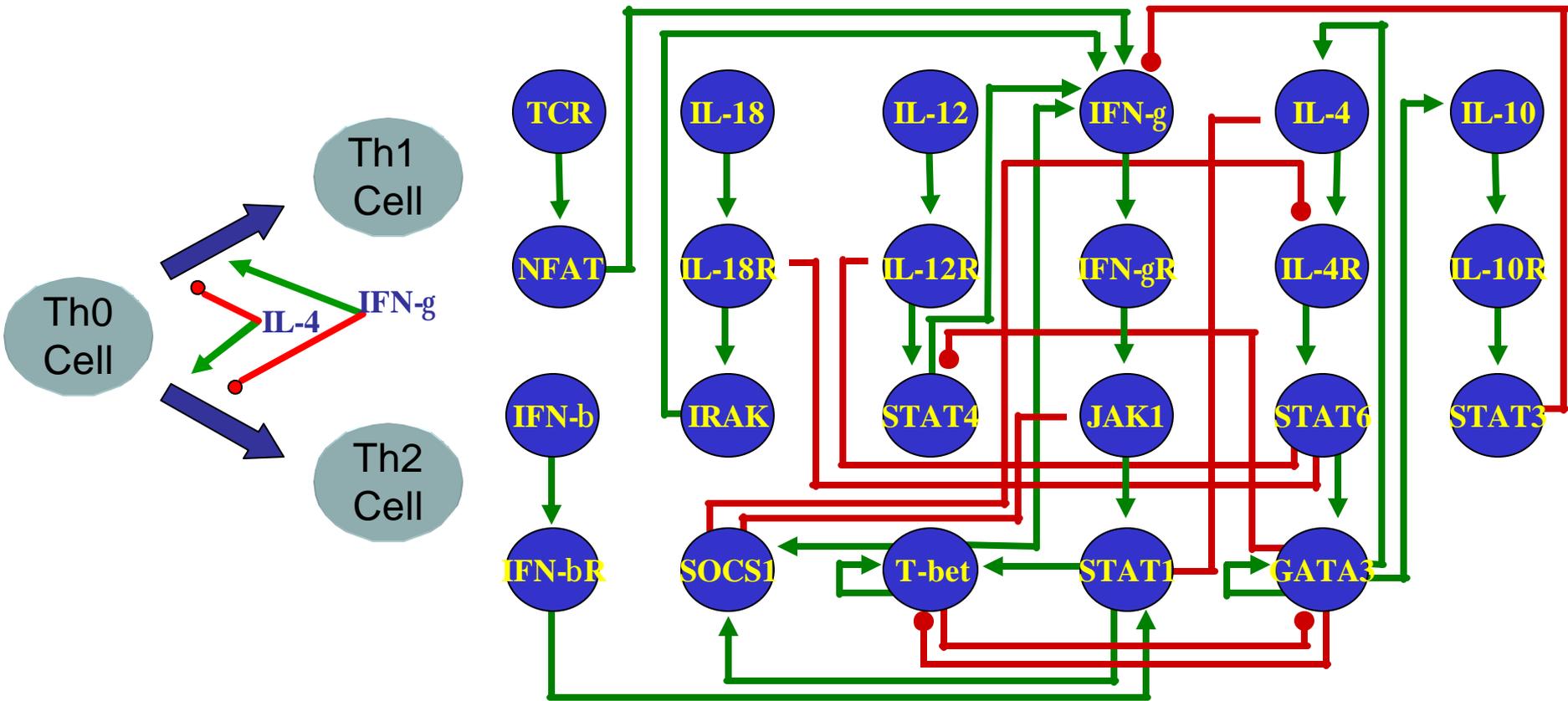


T-helper cells

- 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*



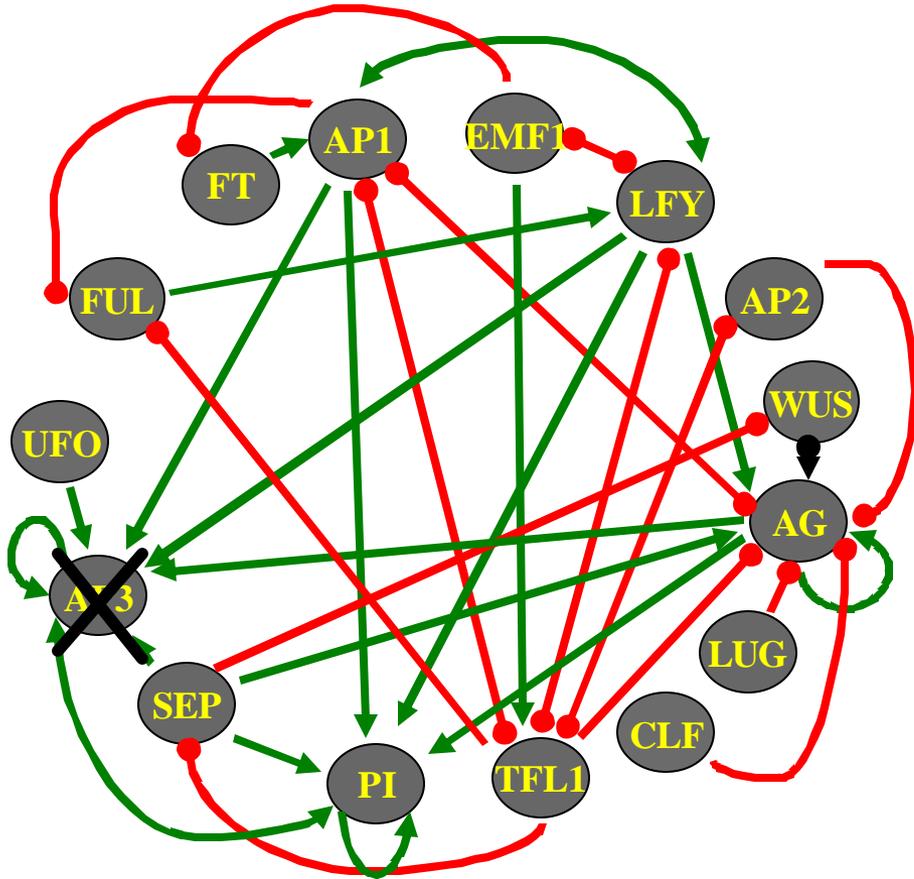
Functional and logic-level model of T-helper cell



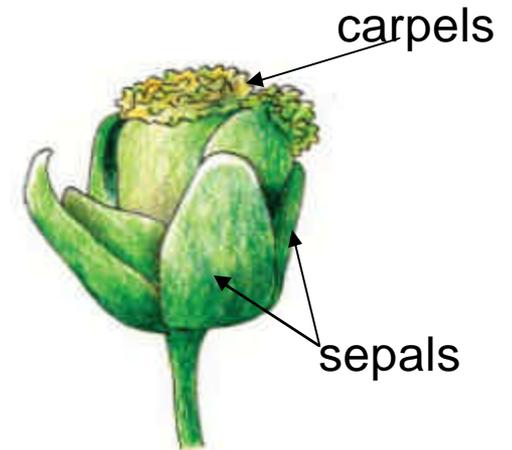
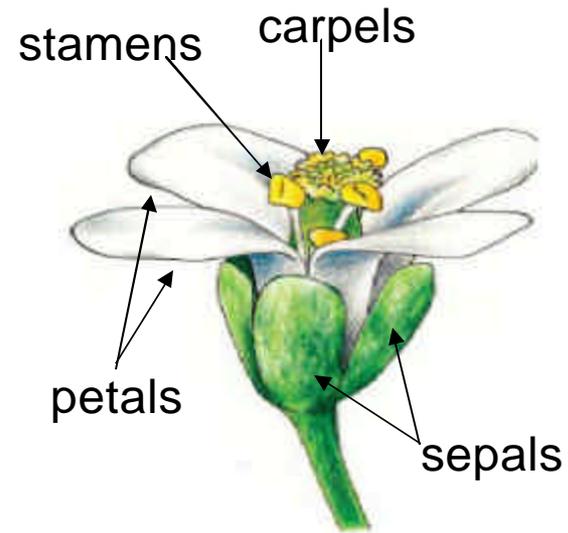
Issues

- 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*



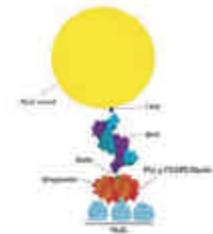
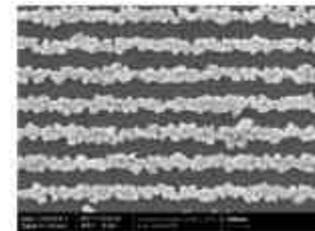
[Soto et al. *Plant Cell*, (16):2004]



AP3 knockout

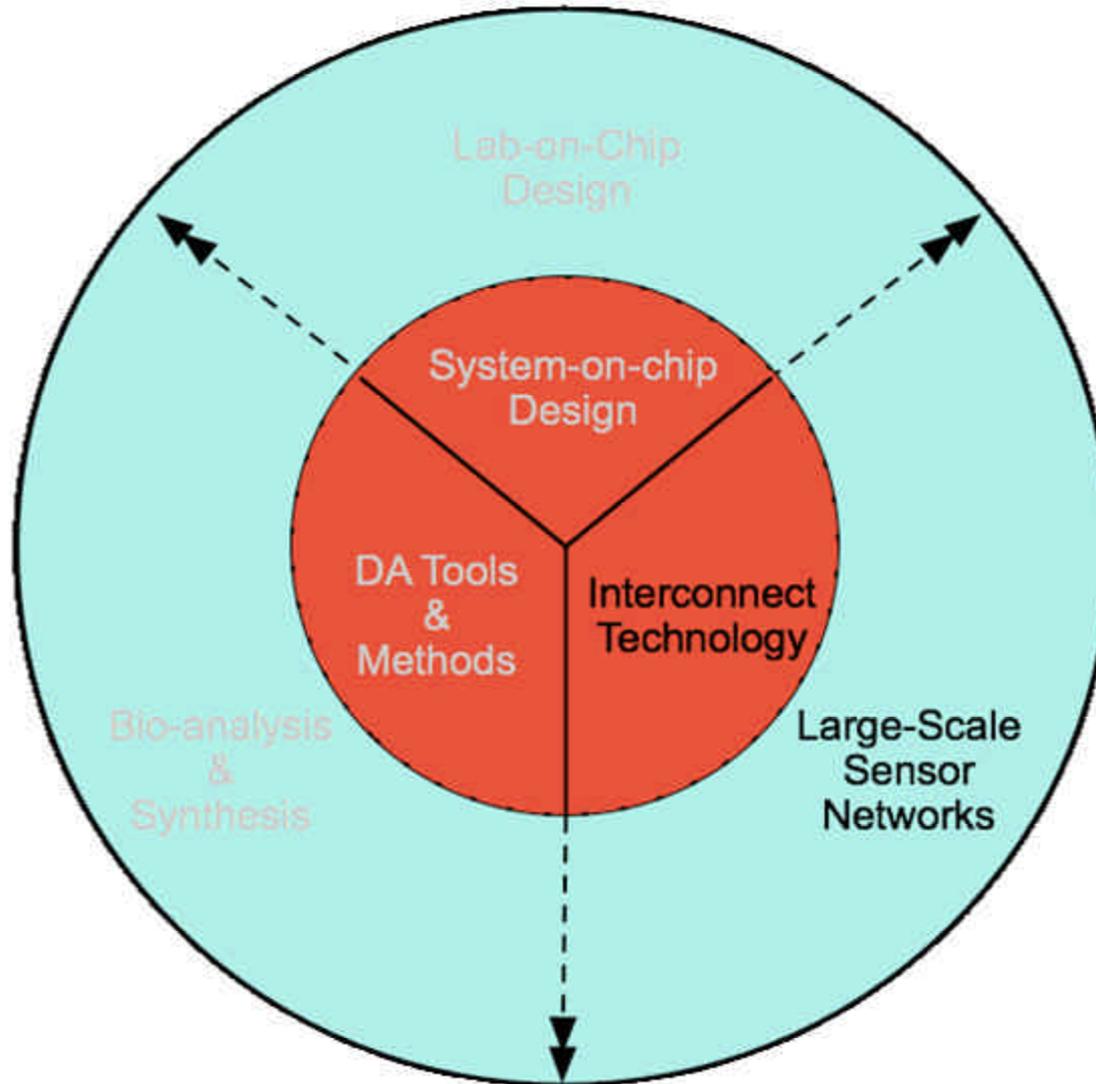
Bio analysis & synthesis objectives

- 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
- 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



[Thiele, ETHZ]



The quest for energy efficiency

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



[Perpetuum]



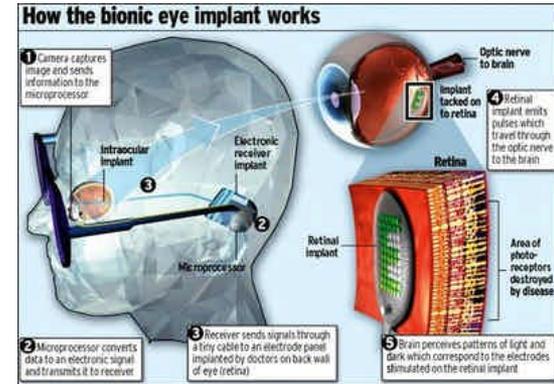
[Sandia]

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]

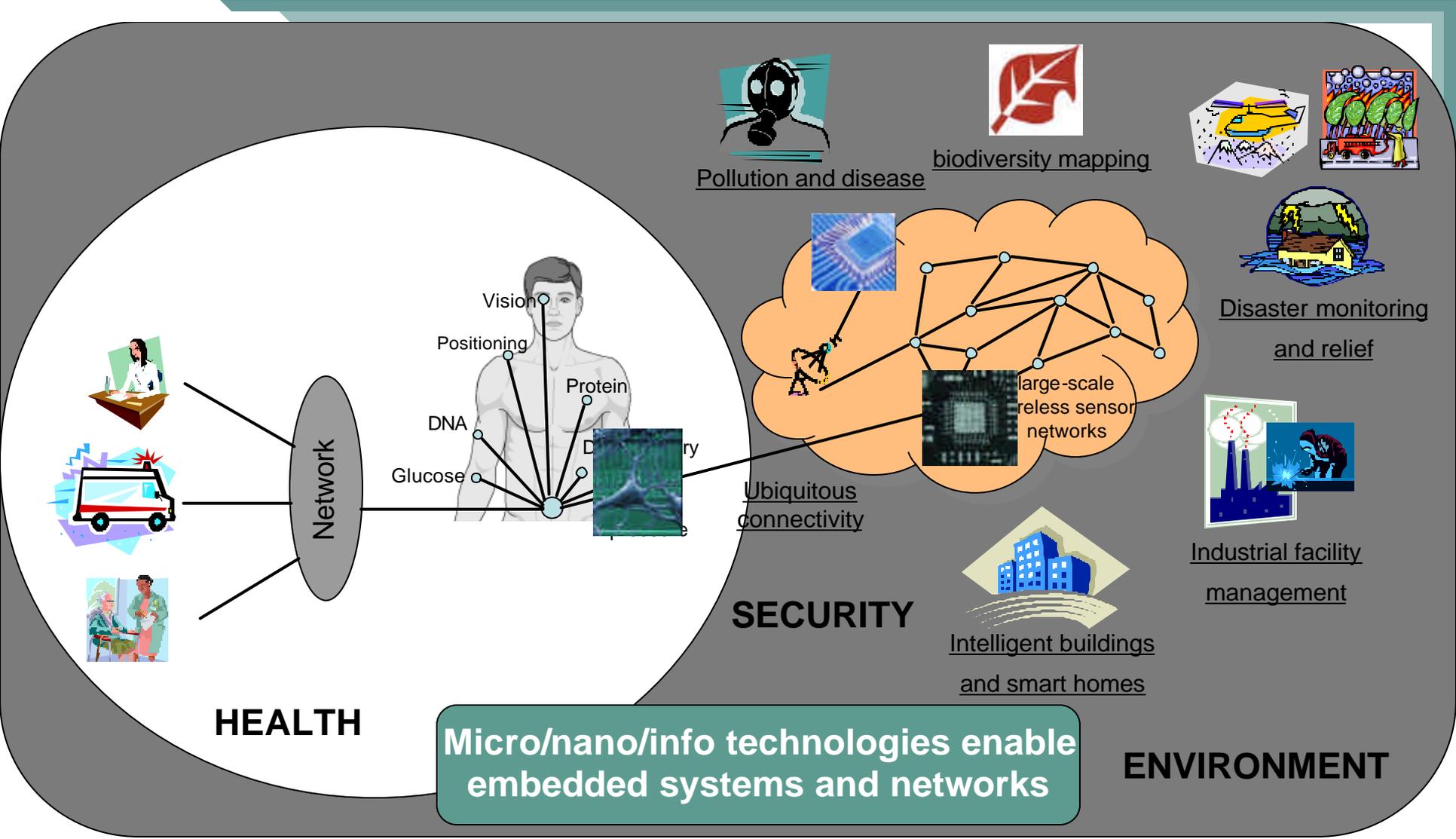


[Singapore Biopolis]

The



program



The humanitarian technology challenge



- 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

