



System Oriented Nanoelectronics

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Outline

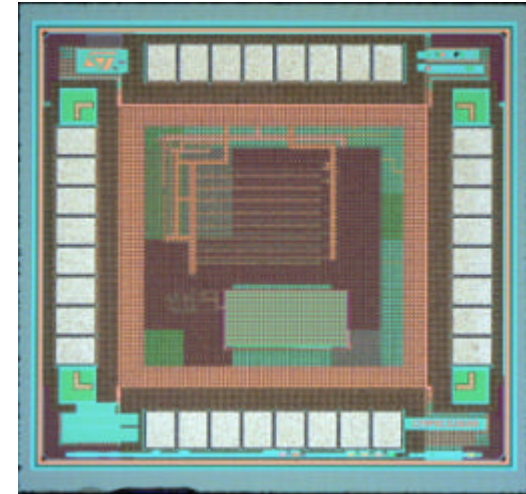
- ◆ Electronics Research at University of Turku
- ◆ I4Center
 - Research objectives
 - Strategy
 - Research areas
- ◆ An Example research topic: Integrated Self-Aware Nanoelectronics (INSANE)
 - Objectives
 - New approach and innovations
 - System design and analysis
 - Case studies

Electronics Research at University of Turku

- ◆ Jouni Isoaho / Communication systems
 - Telecommunication technology and applications, digital TV
 - Human and society interactivity, speech and language technology
 - Nano systems and telecommunication implementation techniques
- ◆ Hannu Tenhunen / Computer engineering
 - Nanoelectronics, embedded and reconfigurable systems
 - Asynchronous systems, fault-tolerance, formal methods
 - Ubiquitous intelligence in paper and packaging
- ◆ Ari Paasio / Microelectronics
 - Ultra low power analog electronics
 - Parallel analog systems and video processing
 - Clean-room technology, light on silicon and sensors
- ◆ Aulis Tuominen / Electronics productization
 - RFID and nanotechnology
 - Printable electronics and fuel cells
 - Lead-free soldering and electronics production technologies
- ◆ Johan Lilius / Embedded systems (Åbo Akademi University)
 - Embedded system design methodologies and digital TV

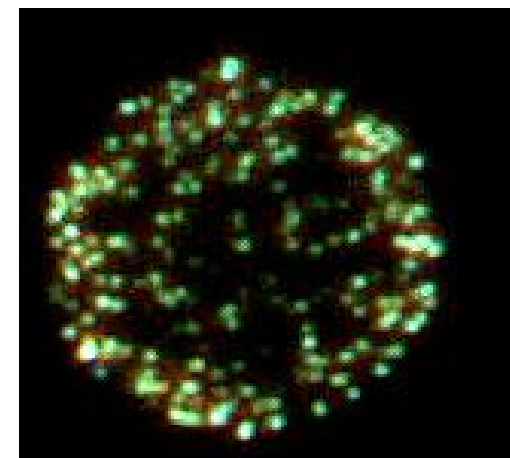
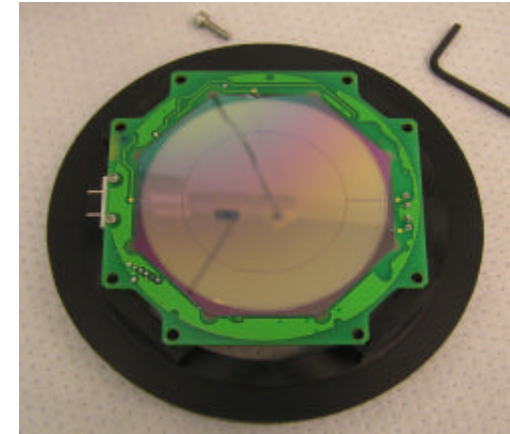
Integrated Circuit Design

- ◆ Imaging and image content analysis
 - Sensors, processor arrays, algorithms
 - » Dr. Laiho, Dr. Poikonen, Prof. Paasio
- ◆ RF and baseband communication circuits
 - UWB transceiver structures
 - » Dr. Tiiliharju
 - Fast Analog Viterbi etc.
 - » Dr. Laiho, Prof. Paasio
- ◆ Process mismatch compensation for nano scale devices
 - » Dr. Poikonen, Dr. Laiho



Microelectronics fabrication

- ◆ Production and development of particle or radiation detectors
 - Large area 20 cm^2 (diam. 5 cm)
 - Small leakage current density
 $< 50 \text{ pA/cm}^2$ @ 200 V
- ◆ Light from silicon & applications
 - Light emitting diode, nano-sized light dots, targeting towards Si-laser
 - Optical transmission (in biosystems nerve substitute)
- ◆ Processing facilities (clean room)
 - CVD, etching, sputtering
 - lithography



←→
10 μm

Productization of Innovative Research

◆<http://www.pir.utu.fi/>

- ◆ RFID, nanotechnology, printable electronics & printable fuel cells
- ◆ Lead-free soldering and reliability engineering by multivariate analysis
- ◆ rf-test beds & multitude data collection:
<http://www.simplexsolutions.info>

CONFERENCES

See details in:

next.utu.fi



NEXT 2007

25-27.10 Soul

 Ambassador Hotel
Korea

Institute for Intelligent Integration through Interaction (I4)

Why?

- ◆ Building an inclusive information society by research and technology development for the basic human needs of wellbeing:
 - personal health
 - social interaction and communication
 - safety and security

What?

- ◆ Interdisciplinary thematic areas
 - Integrated nano & embedded systems
 - Interactive communication systems
 - Intelligent health & safety technologies
 - Inclusive language & learning technologies

Who?

- ◆ Communication systems / Jouni Isoaho
- ◆ Computer engineering / Hannu Tenhunen
- ◆ Computer science / Tapio Salakoski

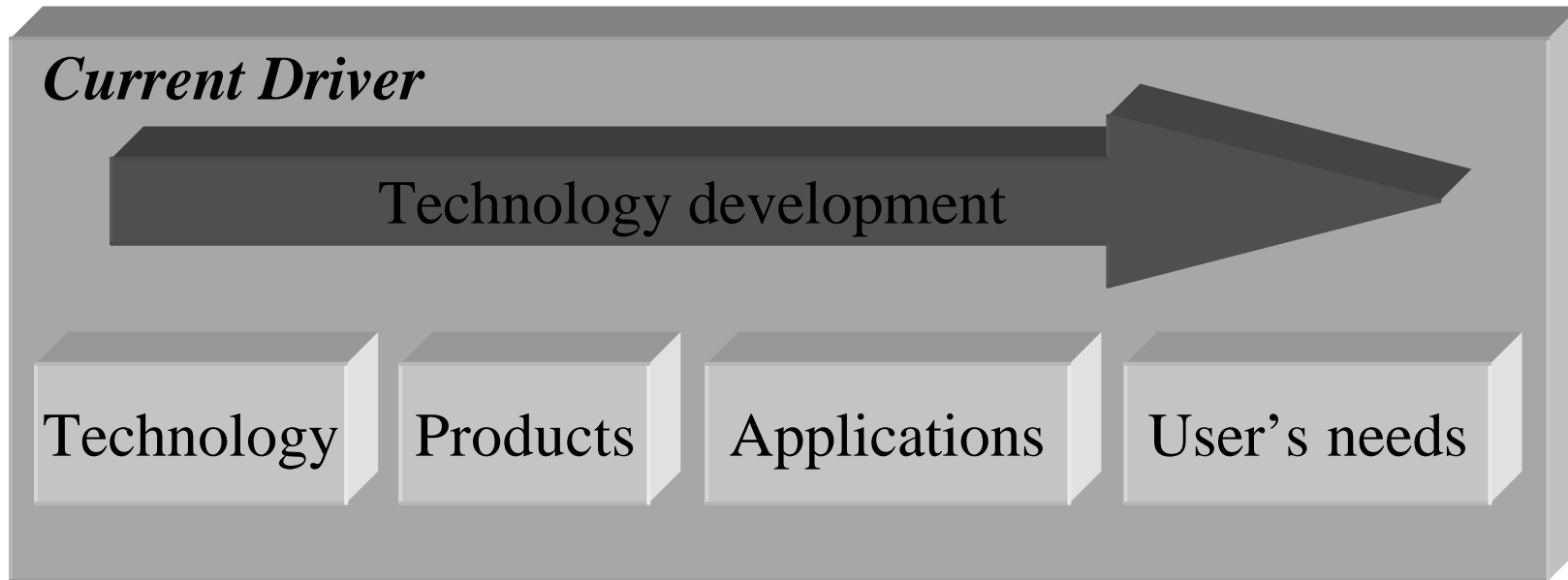
How?

- ◆ In open innovation systems, people integrate technologies creating not order but chaos; to support rather than suppress the creative trend, we have to **integrate human and machine intelligence through interaction**
- ◆ Inherent inter-disciplinarity and agile group interaction
- ◆ Interaction between social and technological innovations: individuals as technology drivers
- ◆ Interaction between scientific, human, and societal values -- a scalable system perspective

Values

- ◆ Interdisciplinary approach to thematic areas
- ◆ Integrated basic and applied research
- ◆ Interaction of human and technology, science and society
- ◆ Intelligent applications for inclusive information society
- ◆ Innovation through agile group interaction

Integration of Development Drivers



???

Inclusive Language & Learning Technologies

Projects: 2001 02 03 04 05 06 07 08 09 10 11

PUMS – New Methods and Applications of Speech Technology
 Finnish Funding Agency for Technology and Innovation (Tekes)
 6 universities, state research centre
 20 companies and organizations

Core Speech
 100th Anniv. Foundation for Finnish Technology Industry

IMPEd – Improving Math & Programming Education
 100th Anniv. Foundation for Finnish Technology Industry

BioText – Text Mining for Biological Data Management
 Finnish Funding Agency for Technology and Innovation (Tekes)
 University research lab
 Bioinformatics & langtech companies

Louhi – Text Mining of Clinical Records
 Finnish Funding Agency for Technology and Innovation (Tekes)
 3 university research labs, 2 hospitals, 4 private companies, other organizations

BioPIE – Parallel Architecture for Information Extraction in the Biomedical Domain
 Academy of Finland

Research focuses:

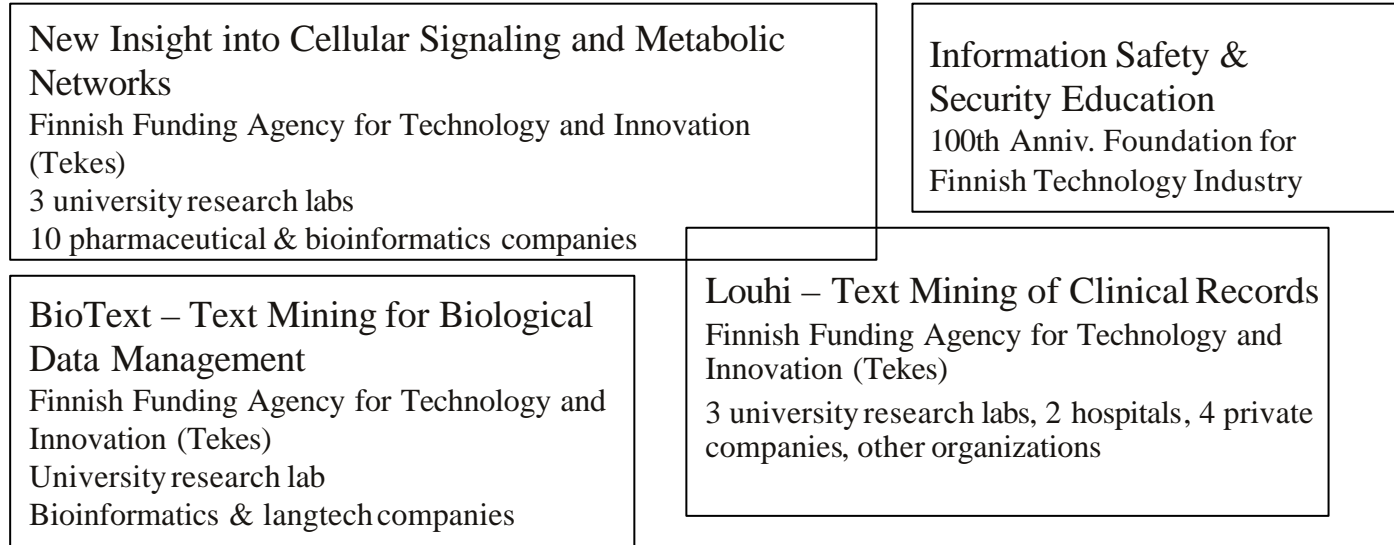
- ◆ BioNLP -- intelligent management of textual information in the biomedical domain
- ◆ Integrating speech and language technologies
- ◆ Applications for inclusive ICT-enhanced learning and human language based interaction

Key activities:

- Building the national cluster for multicultural interaction
- Living Labs

Intelligent Health & Safety Technologies

Projects: 2001 02 03 04 05 06 07 08 09 10 11



Research focuses:

- ◆ In silico data analysis for human regulatory networks
- ◆ Intelligent management of textual information for improved and individualized health care systems
- ◆ Personal Safety & Security technologies

Key Activities:

- ◆ International interdisciplinary education in Bioinformatics
- ◆ Multidisciplinary education in Information Safety & Security
- ◆ Better insight in life sciences through basic research in bio-ICT
- ◆ Turku Innovation Platform

Interactive Communication Systems

Projects: 2001 02 03 04 05 06 07 08 09 10 11

Semantic-driven Cooperative Vehicle Infrastructure Systems For Advanced eSafety Applications (COVER) / EU

Extension for Services to Wireless, Integrated, Nomadic, GPRS-UMTS & TV, Handheld Terminals (WING-TV) / CELTIC / TEKES (2006-07)

Giga Networks (GAP) / TEKES

Broadcasting for 21st Century (B21C)/Celtic/TEKES

Convergent Networks Laboratory (CoNetLab) / EAKR/TEKES

Dynamic Parallel Radio Structures for Cell Array Platforms (ArrayRadio) / Academy of Finland / TULE

Scalable Fault-Tolerant Software Defined Radio Platforms (SCARLET) / Academy of Finland

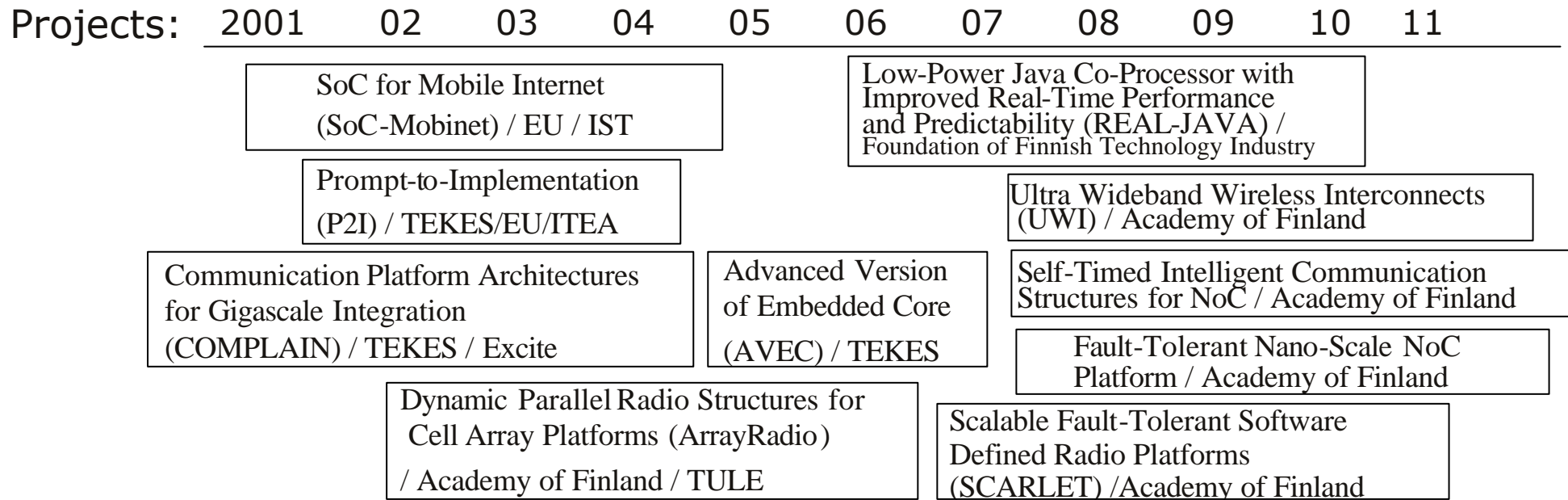
Research focuses:

- ◆ Interactive and application driven communication system design and development, support infrastructures
- ◆ Coding algorithms, system models, parallel systems and algorithms, MIMO, broadcast systems
- ◆ Self-aware, intelligent dynamic terminal implementations and design methods

Key Activities:

- ◆ Demonstration networks and living labs
- ◆ DVB standardization

Integrated Embedded and Nano Systems



Research focuses:

- ◆ Dynamically reconfigurable error-tolerant nano electronics, self-aware agents and components
- ◆ Physical system and performance modelling, noise analysis, functional system level modelling
- ◆ Platforms and components for nano systems, asynchronous / self-timed techniques

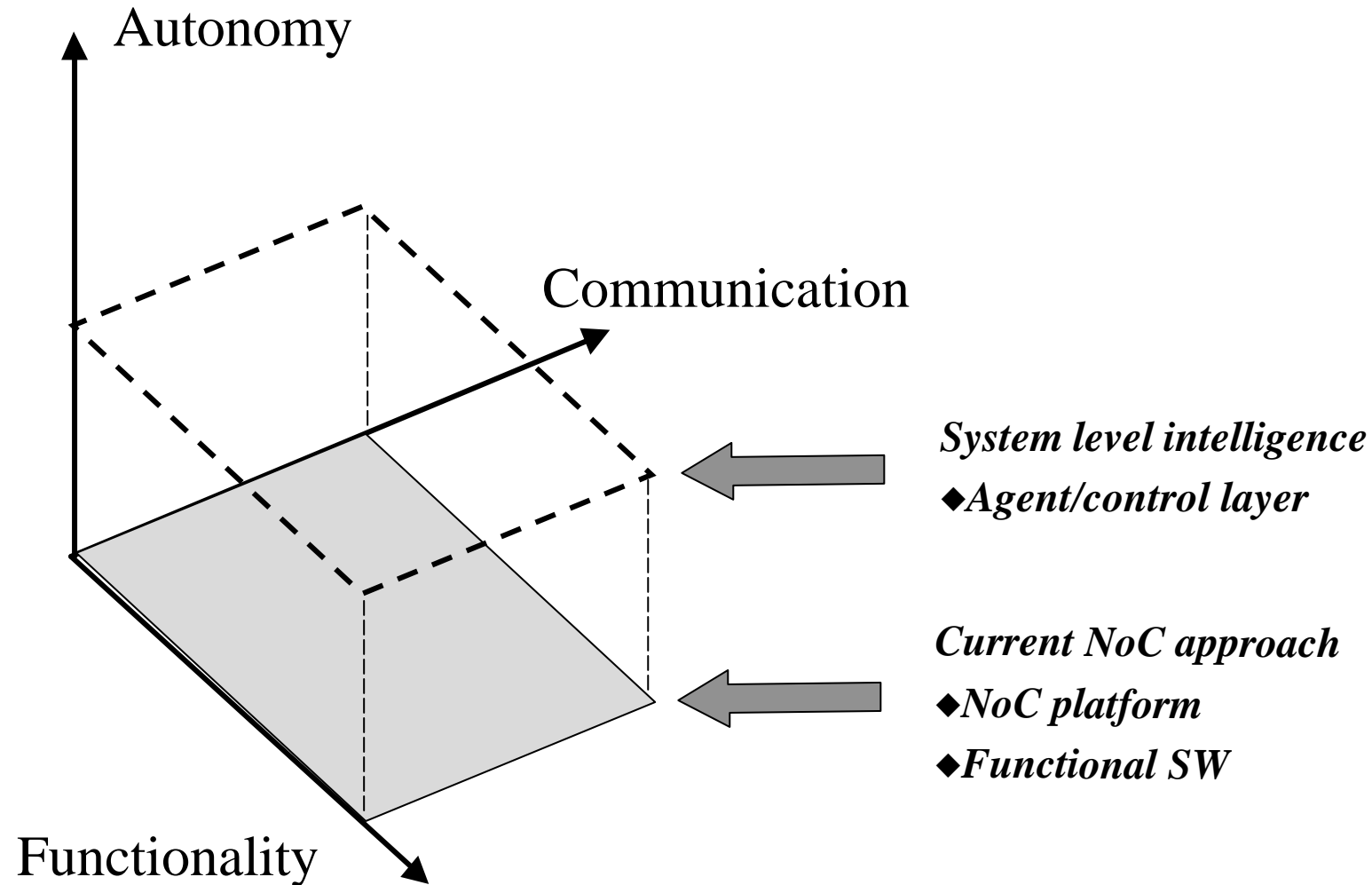
Key Activities:

- ◆ European roadmap on nanoelectronics beyond 2015
- ◆ MPSOC SRA to Artemis technology platform
- ◆ European scientific ecosystem in nanoelectronics
- ◆ Global educational platform in SoC
- ◆ Turku Innovation Platform

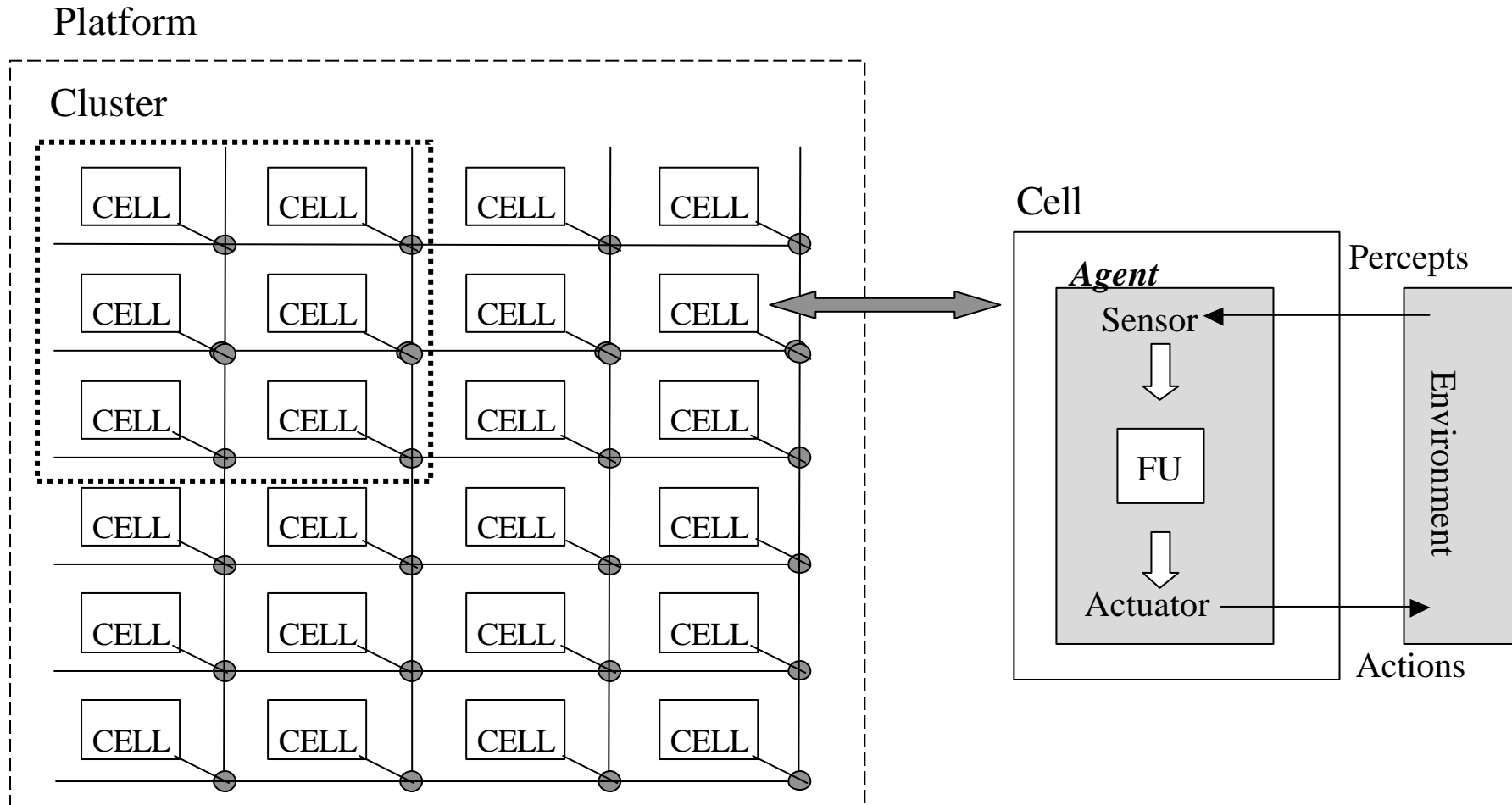
Objectives To Nano Systems Design

- ◆ The implementations of future nanoscale electronics systems can be based either on advanced CMOS-style technologies ranging 0.1 – 0.01 μm , or completely new, emerging technology approaches.
 - In either case the strategic issue is scalability towards and beyond gigascale integration in three domains:
 - (a) architectural and system scalability with respect to complexity,
 - (b) performance scalability with respect to geometrical scaling in underlying device and circuit structures
 - (c) design effort scalability with respect to increased functionality.
- ◆ More error-prone manufacturing due to finer scale technologies
 - How to build robust, error-free and highly scalable systems, when basic building blocks can be defective due to static and dynamic errors or failures.
- ◆ Noise, clocking and performance problems due to current system approaches towards higher performance demands
- ◆ **Key issues:**
 - **modularity** (regular structures, local control and design)
 - **concurrency** (high performance, low noise, local communication)
 - **reconfigurability** (platform life-time, redesign cycles)
 - **fault tolerancy** (high yield, chip/wafer level scalability)

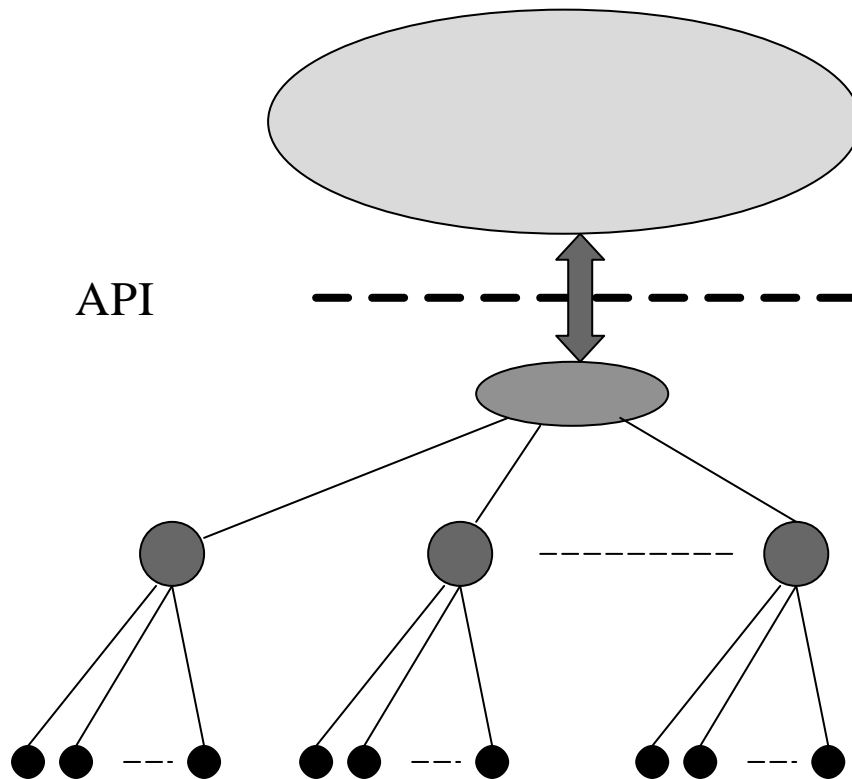
Adding of a New Layer to Implementation Platforms



Platform Hierarchy



Agent Hierarchy



Application agent

- Recognise application needs for system reconfiguration (change of functionality, performance enhancement)

Platform agent

- Forms interface between application and platform

Cluster agent

- Performs reconfiguration if necessary (application needs, fault-tolerance)

Cell agent

- Routing, cell diagnostics

INSANE: Innovative Aspects

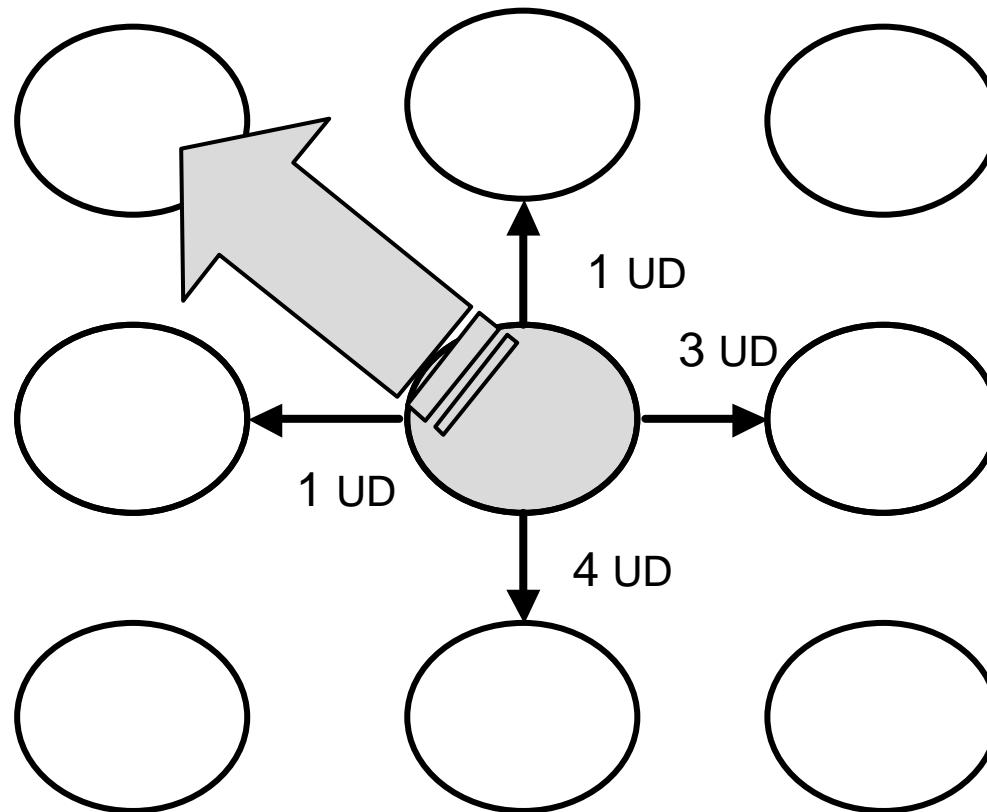
Key aspects for successful nano-regime NoC designs are **build-in fault-tolerancy, flexible use of resources, and easy scalability**. In order to solve these demands there are several innovative issues, which need to be covered.

- ◆ **Self-design.** Current design methodologies are meant for the actual design phase itself having no systematic support for self-design. The division of responsibilities between the design phase and the execution is different than what has been proposed so far. The systematic usage of the workflow concept is borrowed from practice on the Internet, but its introduction and usage in the present context is new. We also believe that it provides for the necessary conjunction between concepts at the system level and electronic design. A rough characterization of Quality of Service (QoS) distinguishes 'best effort' vs. 'guaranteed performance'. The workflow allocation allows in principle for exchange between use of resources and timing. Tasks that are more critical can be given more resources.
- ◆ **Unlimited Scalability.** Currently NoC concepts are typically referred as scalable, but their scalability is heavily limited by yield and inefficient design methodologies. The concepts presented will allow for a systematic path towards 'unlimited scalability' as it puts in place what is needed for a system to operate (given workflows) under even severe conditions of failure. In order to tackle scalability problems in system and algorithm level we use highly modular approaches with autonomous control concepts instead of typical sequential type algorithmic solutions and complex global control structures.
- ◆ **Design layers and abstractions.** Here we add a new layer above the traditional NoC approach, which provides application functionality and communication resources. The purpose of this layer is to provide system level intelligence to ensure dynamic use of resources and reliable implementations in non-robust technology basis. This layer is implemented using an agent function, which is added to an application function in order to compose a component abstraction that interacts with environment through sensors and actuators. Typically, component implementations have fixed instances as in our approach they must be seen as functional resources, which can dynamically mapped and scheduled. Therefore, our proposal requires the introduction of a 'meta-design' level, which decides on the physical layout of resources on the chip given the applications, and their rate one wants to run, and given the likelihood of failure - we propose to develop principles for this meta-design layer.

Analysis Overview

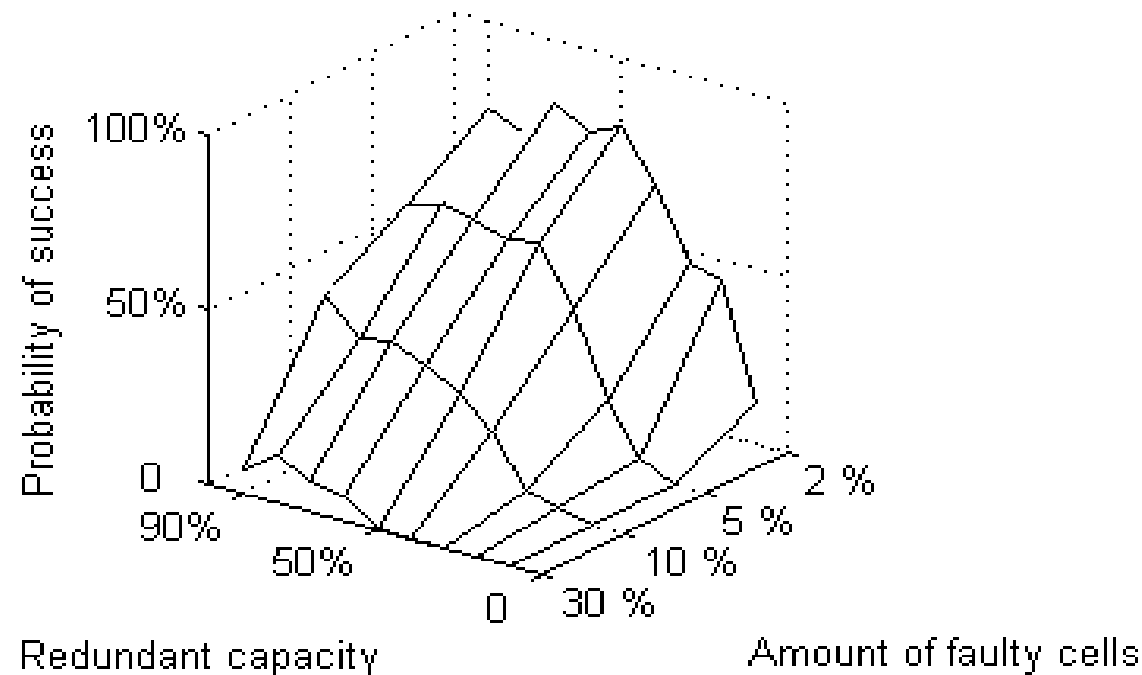
- ◆ System solutions
 - Impact of faulty cells to success of reconfiguration (as a function of amount of redundancy and communication requirements) shown as example
 - Similar manner we are analysing
 - » Impact of faulty routers
 - » Impact of interconnect topologies
 - » Impact of communication latency requirements
- ◆ Logic level
 - Inter-agent communication
 - Reconfiguration of cells (recognitions of faults, change specification or optimise performance)
 - Radio application
- ◆ Physical level
 - Impact of technology variations to on-chip communication solutions
 - » Noise and technology variation tolerant asynchronous links
 - Cross-talk, power-supply noise and clocking mutual impact to each other

Reconfiguration Studies (1)



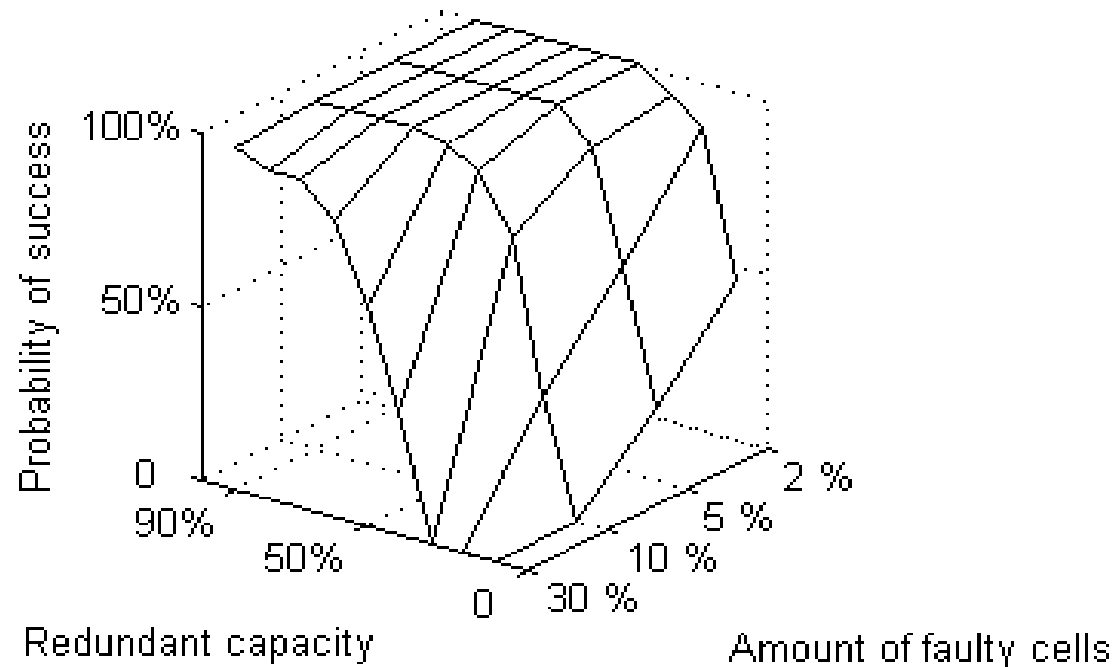
- ◆ Example of latency requirements to logical neighbors and only possible replacement cell. UD=unit distance

Reconfiguration Studies (2)



- ◆ Configuration success probability in function of redundant processing capacity in cells and amount of faulty cells in 5*5 mesh. Latency requirements are uniformly distributed to range [1..5]UDs

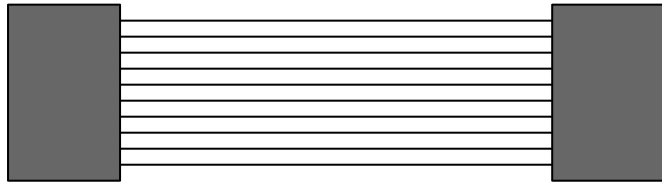
Reconfiguration Studies (3)



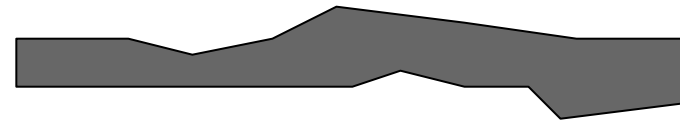
- ◆ Configuration success probability in function of redundant processing capacity in cells and amount of faulty cells in 5*5 mesh. Latency requirements are uniformly distributed to range [2..4]UDs

Physical Analysis of Mutual Effects

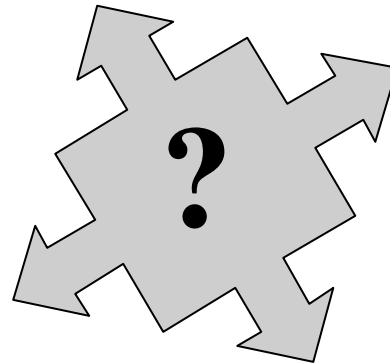
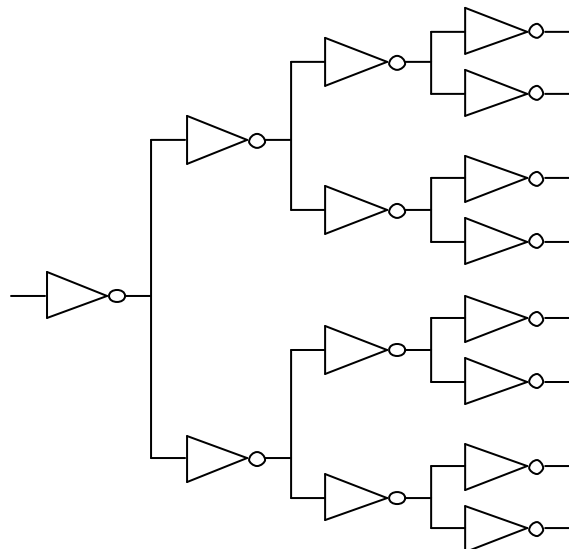
Cross-talk noise



Technology variation in wires and components

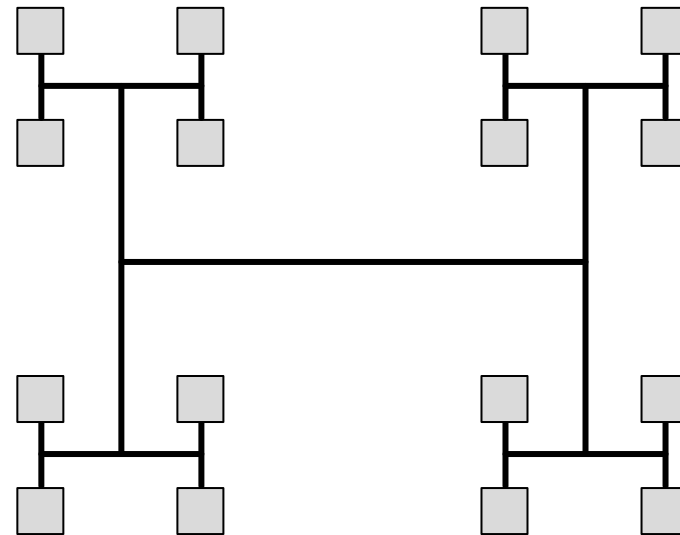


Clocking of cells



- ◆ **Mutual and accumulated effects**
- ◆ **Timing**

Power distribution network and noise



Dynamic Parallel Radio Structures for Cell Array Platforms

◆ Objectives

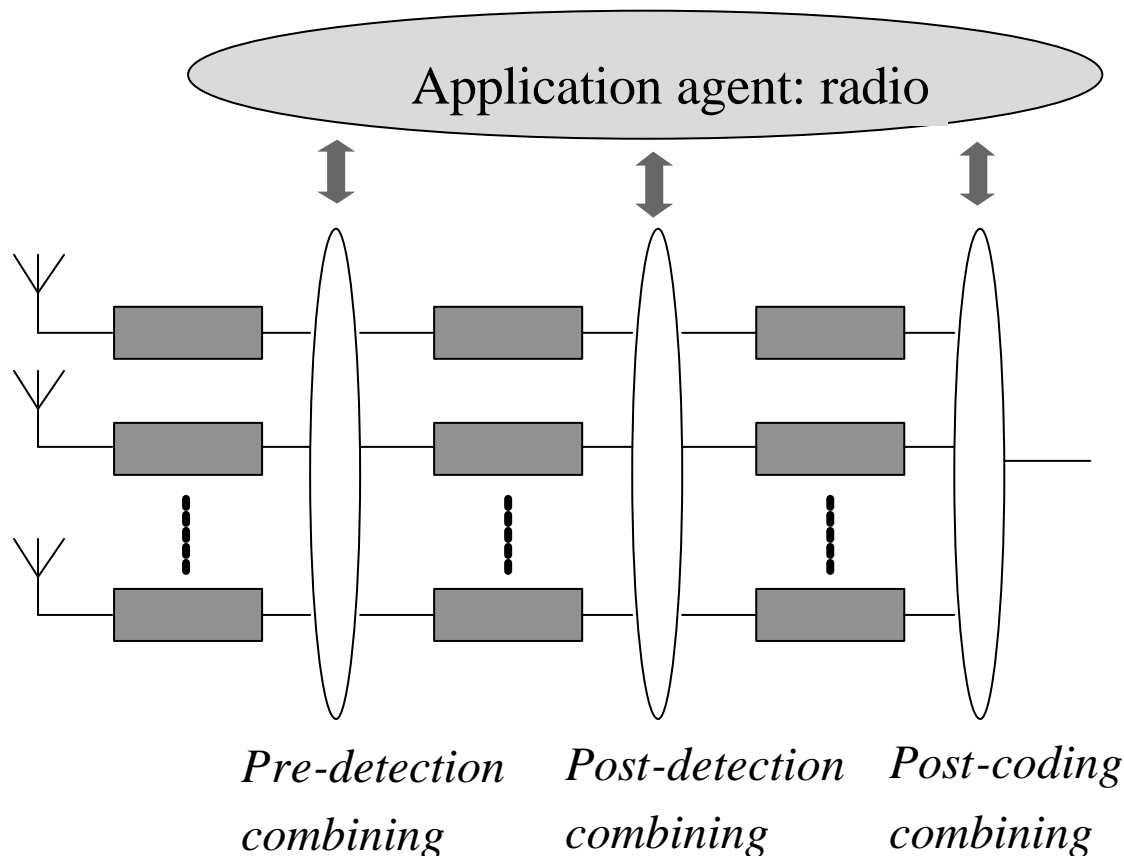
- Implement radio architectures on cell array technology platforms
 - » Infinite scalability (complexity and performance)
 - » Dynamic reconfigurability (performance optimisation and fault-tolerance)
- Incorporate fault-tolerance into radio architectures and algorithms
 - » More error-prone manufacturing due to finer scale technologies
 - » How to build robust, error-free and highly scalable systems, when basic building blocks can be defective due to static and dynamic errors or failures

◆ Tasks

- Radio component (**homogenization**) and architectures (parallelization, fault-tolerance) restructuring, and mapping (two-level)
- Agent based system encapsulation for dynamic operations e.g. autonomous reconfiguration (fault-tolerance, performance enhancement)

Fault-Tolerant Radio Approach

General SDR Framework



- ◆ Study of different parallel radio structures
 - MIMO
 - Diversity techniques
- ◆ General components
 - Modulation, filtering
 - Coding
 - » Source, channel, fault-tolerance (integration)
 - » Use of single coding for multiple standards
- ◆ Combining approaches to optimise system performance under channel and hardware failures
- ◆ Agent based SDR operations
 - Analysis of failures (channel, HW)
 - Reconfiguration management
 - » Selection and optimisation of components
 - » # of parallel threads

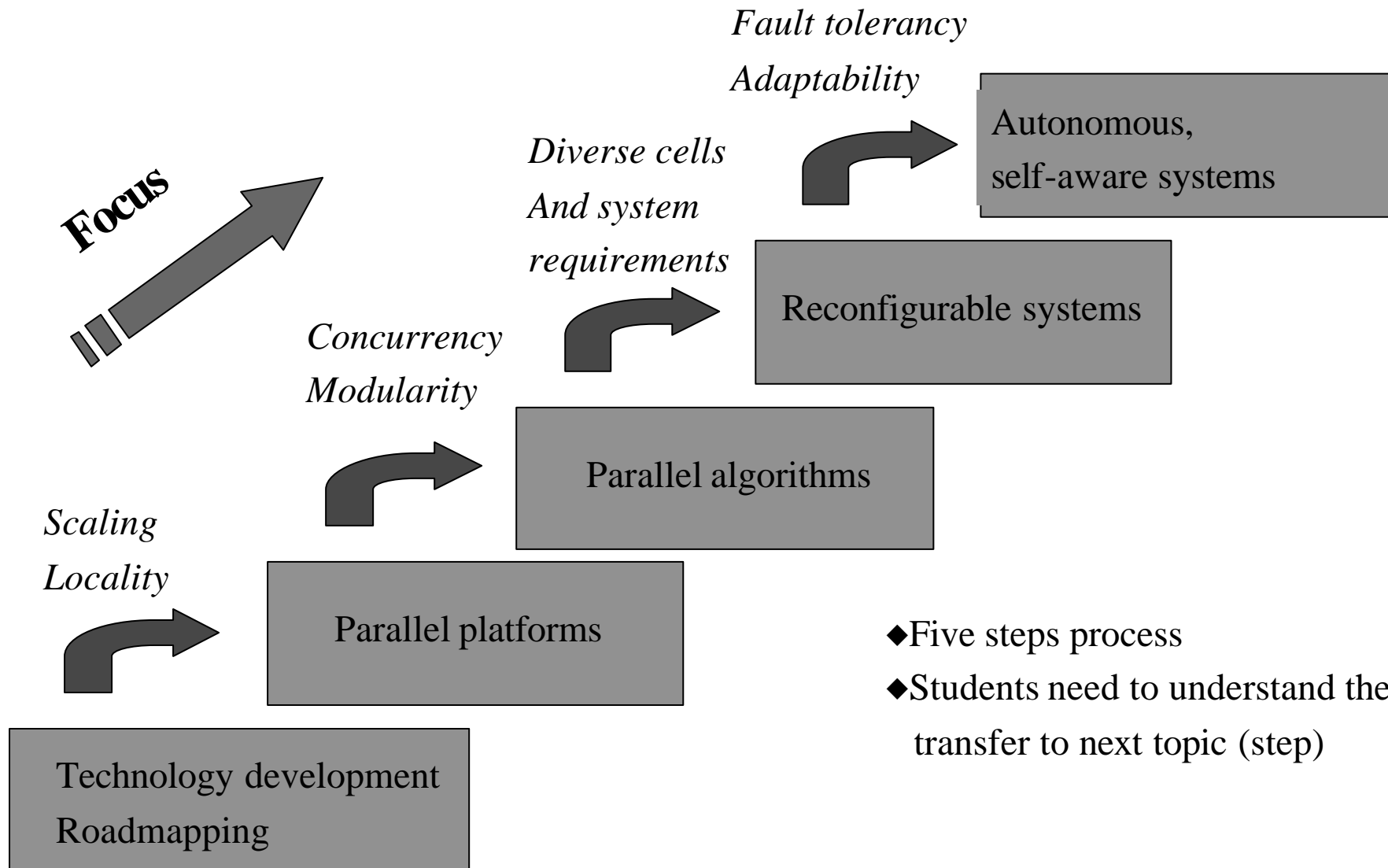
University of Turku Trip towards Nanoelectronics

- ◆ Electronics activities at University of Turku concentrated on technology development and clean-room techniques 1985-1998
- ◆ Phase 1: 1999-2003 creation of system curriculum
 - Start-up to build polytechnique curriculum
 - 3 new areas with coherent planning and goals
 - » System circuits
 - » Digital and computer systems
 - » Communication systems
- ◆ Phase 2: 2004-2006 towards nanoelectronics curriculum
 - An introduction course in nanosystems design
 - » Give focus to M.Sc and Ph.D students, educate assistants
 - » New focus into research
 - » Establishing new research topics
 - New research areas and projects
 - Active international partner search
- ◆ Phase 3: Nordic Master Programme 2008: Integrated technology and innovation view
 - At the beginning very strongly focusing current design concepts towards nanoscale problematics (key focus in CMOS based solutions)
 - Gradually moving towards new computational models and concepts, and nonCMOS silicon and also organic technologies (2007-2010)
 - -Nordic co-operation with DTU, KTH and UiO

New Computation Platforms towards Nano Systems

- ◆ Introduction /Jouni Isoaho
 - Course organisation and objectives
 - Introduction to system design
- ◆ Technology / Hannu Tenhunen
 - Technology road-mapping
 - New design principles on nanoscale technologies
 - Emerging circuit technologies
- ◆ Parallel Platforms / Jouni Isoaho, Ari Paasio
 - Intro to parallel computing and platforms
 - Architectures and concepts of parallel platforms
 - » Bus and array based platforms
 - » Communication solutions
 - Example: Cellular Neural Network
- ◆ Algorithm design towards parallel systems / Jouni Isoaho
 - Principles of parallel algorithm design
 - Locally connected and regular algorithms and architectures
 - Complexity analysis with technology mapping
 - Examples
- ◆ Reconfigurable systems / Jouni Isoaho
 - FPGA and processor technology
 - Reconfigurable system implementations
- ◆ System management / Jouni Isoaho
 - Functionality and principles
 - Fault tolerancy
 - Agent technology
 - Control for dynamic systems
- ◆ Summary / Jouni Isoaho

Teaching Approach



Summary (1)

- ◆ Key aspects for successful nano-regime NoC designs are **build-in fault-tolerancy, flexible use of resources, and easy scalability.**
- ◆ Key innovation to be solved
 - **Self-design.** Extending design methodologies from actual design phase to self-design.
 - **Unlimited** scalability. Solving yield and design methodology limitations to exploit highly parallel and highly homogenous platforms. This needs work with algorithms, system concepts and architectures (towards homogenous processing units)
 - **Design layers and abstractions.** A new meta-design layer to provide system level intelligence to ensure dynamic use of resources and reliable implementations in non-robust technology basis.
- ◆ More error-prone manufacturing due to finer scale technologies
 - How to build robust, error-free and highly scalable systems, when basic building blocks can be defective due to static and dynamic errors or failures.
 - Fault-tolerance issues in all levels of abstraction
- ◆ Noise, clocking and performance problems due to current system approaches towards higher performance demand.
 - This means avoiding of global interconnections
 - It can mostly be eliminated by heavily increasing concurrency in the system and algorithm levels

Summary (2)

- ◆ Design and implementation perspectives should change from overall systems to modular functionally fully verified dynamic components component
- ◆ Key issues is not how to build a single functional element, it is how make system from them.
- ◆ In curriculum this means
 - Research and education topics need a overall, coherent focusing
- ◆ International masters programmes are necessary to perform this demanding technology shift with reasonable resources and time
 - Two type of curricula: topics (vertical) and overall system (horizontal) oriented
 - Collection of different expertises is necessity
- ◆ Horizontal co-operation is often necessary to achieve critical mass in order to solve individual problems, but to have correct problems and perspectives there is an urgent need for vertical insight overall issues

We should try to do everything simple and easy, not complicate them more!