A Concept of a Trust Management Architecture to Increase the Robustness of Nano Age Devices

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Outline

- **Motivation**
  - Problem Statement
  - Related work
- **The SMART Approach**
  - Lack of Informational Trust
  - System Model
- **Trust Management**
  - Trust Level Determination and Processing
  - Generic Module Architecture
- **Summary & Outlook**

Motivation

Technology scaling leads to an increase in

- **Process variation**
  - **Systematic effects**
    spatial correlation between transistors
    - Primary source: lithographic irregularities
      → effects effective channel length L_{efff}
  - **Random effects**
    individual transistors
    - Primary source: varying dopant concentrations
      → effects threshold voltage V_T

- **Device degradation / aging**
  → Wear-out effects:
  - Gate oxide breakdown
  - Negative bias temperature instability
  - Electromigration
  - Hot carrier injection

Motivation

Characteristics:

- **Process variation**
  - fixed parameter fluctuations = **static**
  - can be determined after fabrication and before shipping
- **Device degradation / aging**
  Depends on operation conditions = **dynamic**
  - Temperature
  - Workload

Classical compensation technique: design for ***worst case scenario***

→ will result in an unacceptable low yield and/or performance

→ huge hardware and/or timing overhead
(usage of classical redundancy schemes for compensation of SEUs and SETs and worst case timing, resp.)

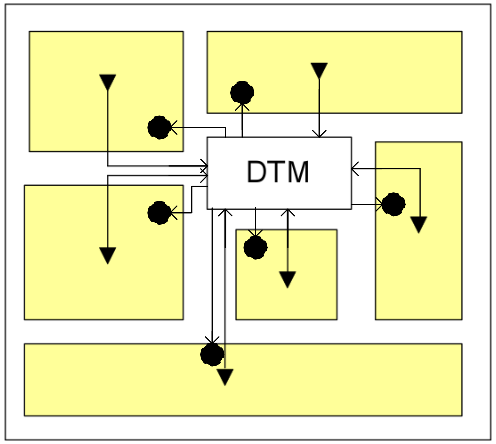
Solution: ***adjust system parameters dynamically*** to

- external requirements
- device dependent parameters

} already done for **dynamic thermal management (DTM)**

Dynamic Thermal Management

- **Temporal**
  - Dynamic Frequency Scaling (DFS)
  - Dynamic Voltage Scaling (DVS)
  - Clock gating
- **Spatial**
  - Thread migration
  - Load balancing



Problems:

- Spatial effects are not considered adequately
- Within-die variations
- Fast dynamic effects and long-term aging
- Accuracy of
  - Sensors
  - Actors setting system parameters
- Aging

Uncertainties for system management:

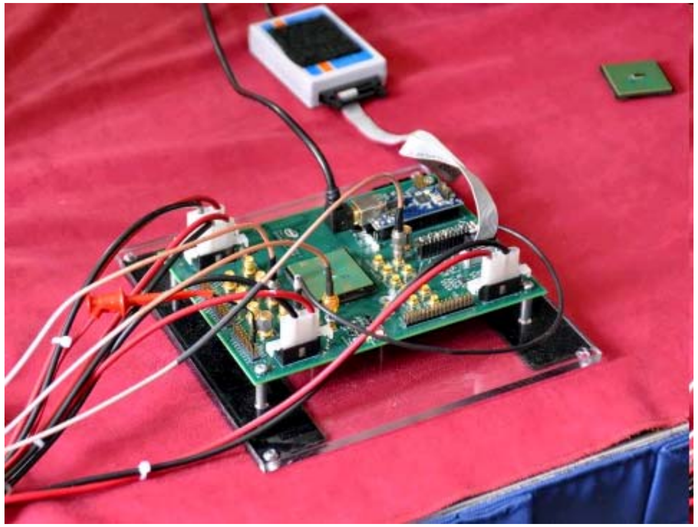
- correctness and trustworthiness of sensor information
- correct and trustworthy operation of actors

Motivation

Handling uncertainties: Intel's Palisades processor

→ Resilient Processor Design / Self-Tuning Processor

- Elimination of margins for voltage droop, temperature, and critical path activation
- **Tunable replica circuits (TRC)** can be used to detect timing errors
  digital delay sensor which can be tuned at test time to match the delay of a critical path in the circuit.
- Error correction:
  - Parameter adjustment
  - Pipeline flush
- Power reduction of 21% or performance improvement of 41%



Source: www.golem.de

Motivation

Weak point of all approaches:

Vagueness and uncertainty of data / Lack of informational trust

1. Dynamic behavior is not completely predictable
2. Trustworthiness of sensor readings
3. Uncertainty of actor operation
4. Significance of a temperature measured at a single spot
5. Environmental effects
6. Accuracy of thermal models
7. Adaptation to time-variant parameters based on fixed rule-sets

➔ **For optimal performance and trustworthy operation, dynamically changing uncertainties must explicitly taken into consideration at runtime.**

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The SMART Approach

SMART: System-on-Chip with Modular Adaptation for Robustness and Trust

System requirements:

- Guaranteed system lifetime
- Robust and trustworthy operation
- Autonomous on-chip and online operation
- Timely reaction
- Low hardware overhead, low power dissipation
- Universal applicability, independent of technology
- Scalability
- Easiness to engineer
- Complementariness to classical fault tolerance

SMART: System-on-Chip with Modular Adaptation for Robustness and Trust

General Concept: Modeling and integrating uncertainty information explicitly into device management

Trust Management

- Complementary to normal system operation
- Increases robustness
- Allows for performance optimization without sacrificing lifetime

Trust-Level:

- Uncertainty represented by specific attribute
- Normalized value between 0 and 1
- Represents the trustworthiness of information:

  1 = trusty, safe; 0 = untrusty, unsafe, no information

Trust Management

Trust-Level as additional attribute for

- **Sensors (*R-Sensors*)**

  → Trust level models e.g. ambiguity, lack of information

- **Internal variables (*R-Variables*)**

  → Trust level represents trustiness of calculations

- **Actors (*R-Actors*)**

  → Trust level models the uncertainty of actor operation caused by

  - Process variation
  - Degradation
  - Operating conditions
  - . . .

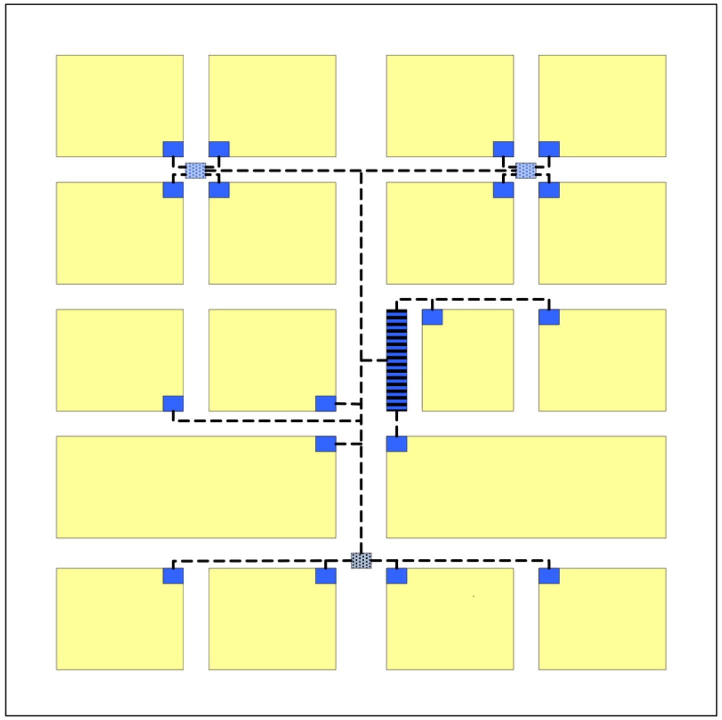
General Architecture

Functional Units (FUs) are complemented by Robustness Units (RUs)

- Additional functionality for device management
- Integrates uncertainty handling:
  - Trust-level determination (in software)
    - Plausibility check
    - Combination of sensor information
  - Reaction on uncertainties

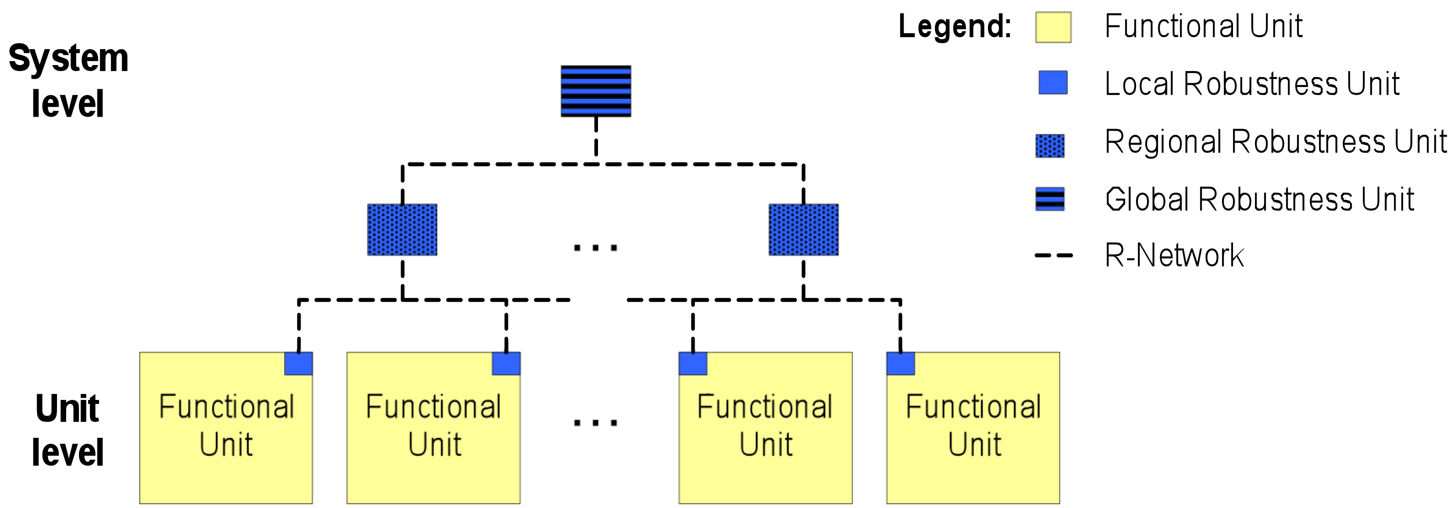
Legend:

- Functional Unit
- Local Robustness Unit
- Regional Robustness Unit
- Global Robustness Unit
- R-Network



The SMART Approach

- RUs form a separate hierarchy for device and trust management
  - Local RUs
  - Regional RUs
  - Global RU
- Communication via a (virtual) Robustness network (*R-network*)

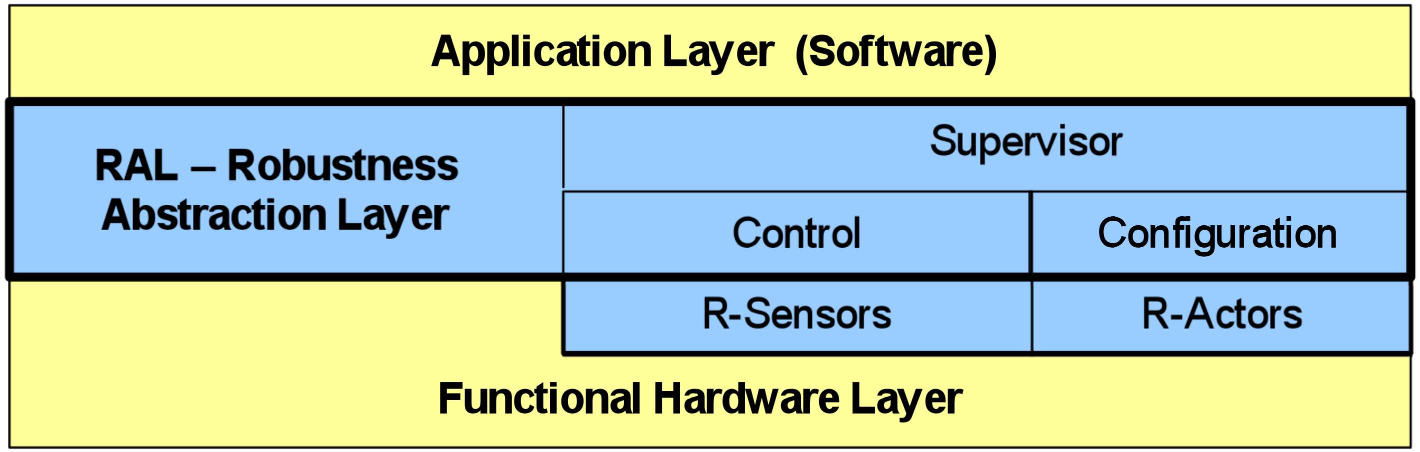


The SMART Approach

Layer Model

Robustness Abstraction Layer (RAL)

Hides uncertainty of lower layer to the application layer



Control: continuous data and control actions

Configuration: Discrete actions at discrete time points, e.g. altering operation modes, task migration, …

Supervisor

Local supervisor
- Coordinates actions of neighboring RUs

Global supervisor
- Reacts on outer requirements
- Interface to operating system
- Monitoring device lifetime

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Trust Level Determination (Examples)

Approaches for sensors:

- Noise amplitude
- Noise signal traces for comparison with known shape trends
- Noise + additional sensory information
- Noise amplitude of power and ground lines
- Consideration of dynamic changes (e.g. temperature) for assumption of system parameters between measuring points

Approaches for actors:

- Physical models
- Observation of past behavior to predict how a given value will cause the intended effect

Trust Level Processing

Based on fuzzy logic operators and techniques

- Easy to engineer
- Robust / do not require a precise formal model
- Different qualities of input variables can be combined harmonically
- Allows blending between different optimized controllers for trusty and untrusty system states

Example: internally generated signals (***R-variables***) based on *R-sensors*

- Trust level υ_{o_mult} depending on i uncertain inputs $\upsilon_{in,I}$:

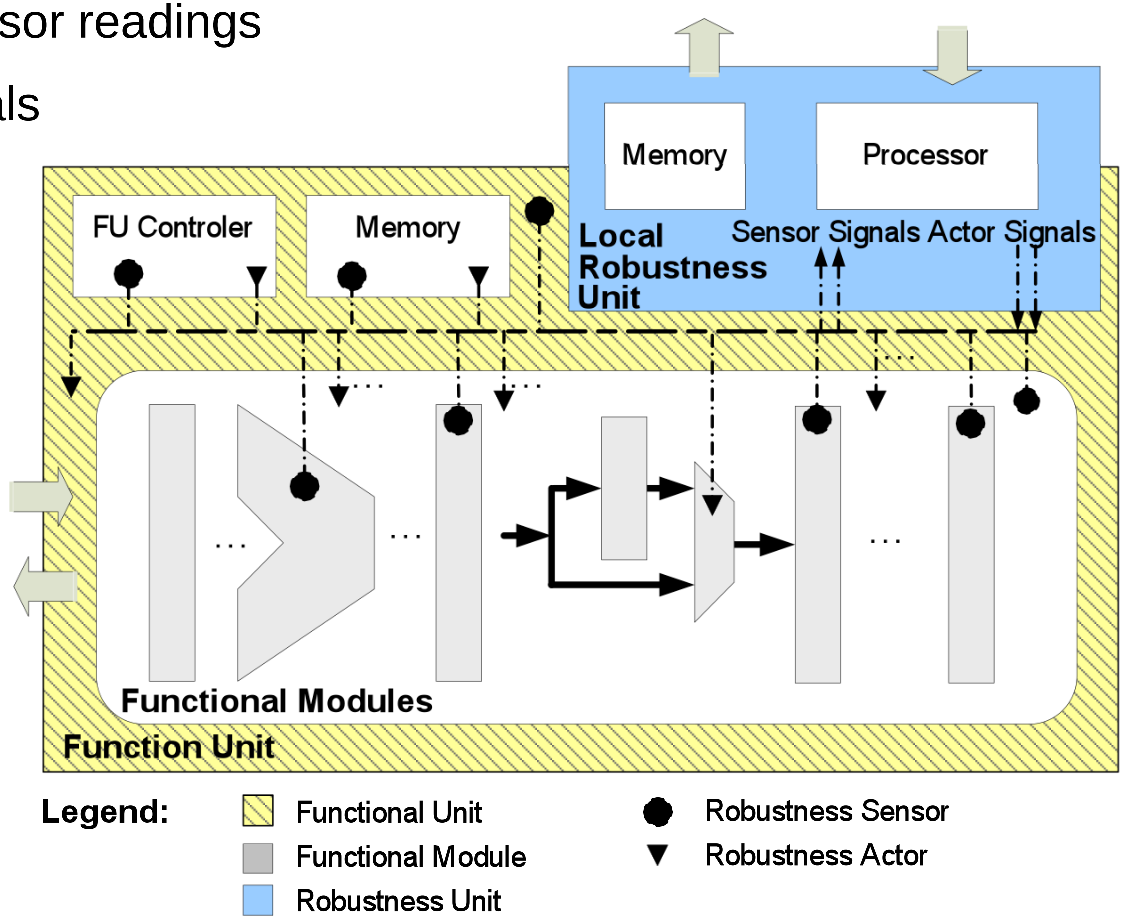
$$\upsilon_{o\_mult} \leq \min_i \upsilon_{in,i} \quad \forall i$$

- Trust level υ_{o_red} when combining j redundant inputs $\upsilon_{in,j}$:

$$\upsilon_{o\_red} \geq \min_j \upsilon_{in,j} \quad \forall j$$

Generic Module Architecture

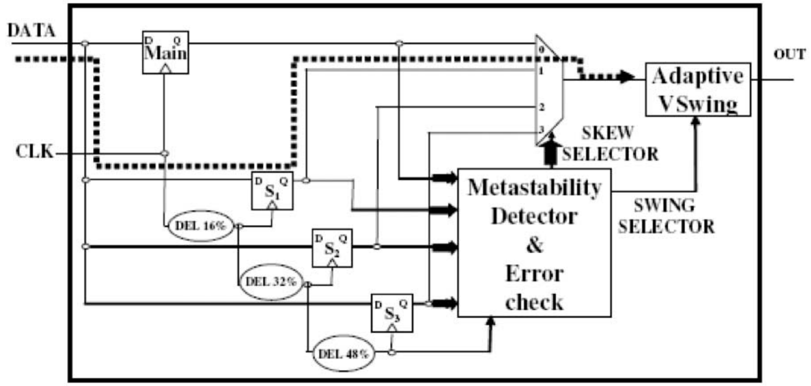
- FU contains sensors and actors
- Short term history of sensor readings
- RU generates trust signals
- RU communicates with
  - higher levels
  - operating system
- RU performs
  - trust management
  - device management



Exemplary scenario

System reaction on timing violations in pipelined FUs

- Detection: extended versions of the Razor flip-flop
- Uncertainties:
  - quantization errors (static factor)
  - significance of the path under test for the whole FU (dynamic factor)
    - Information has to be used to generate trust level



Taken from: M. Simone, M. Lajolo, D. Bertozzi „Variation tolerant NoC design by means of selfcalibrating links“

- System reaction
  Effect of each reaction has to be estimated by the RU (e.g. test mode)
  - Frequency adaption → *continuous*
  - Adding of pipeline stages → *discrete*
  - Time borrowing between pipeline stages → *continuous/discrete*

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Summary & Outlook

Summary

SMART approach (System-on-Chip with Modular Adaptation for Robustness and Trust)

- Concept for integrating uncertainty information explicitly into device management.

  Addressing: - within-die variation
  - dynamic operating conditions
  - device degradation

- Trust Management
  - Trust level attribute for representing uncertainty
  - Explicit modeling of uncertainties
  - Explicit consideration of uncertainties for discrete and continuous control actions

Outlook

- Concrete sensor and actor modeling
- Setting up a framework for the SMART architecture
- Use of safe online learning techniques for adaptation
- Formal modeling of trust management
- Long-term device management, e.g. dynamic life-time management, rejuvenation

Thank you for your attention