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

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  • 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
Technology scaling leads to an increase in

- **Process variation**
  - **Systematic effects**
    - spatial correlation between transistors
      - Primary source: lithographic irregularities
      - effects effective channel length $L_{eff}$
  - **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
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
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
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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Summary & Outlook
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:
  
  \[ 1 = \text{trusty, safe}; \quad 0 = \text{untrusty, unsafe, no information} \]
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:
- Yellow: Functional Unit
- Blue: Local Robustness Unit
- Dark Blue: Regional Robustness Unit
- Black: Global Robustness Unit
- Dashed lines: R-Network
RUs form a separate hierarchy for device and trust management

- Local RUs
- Regional RUs
- Global RU

Communication via a (virtual) Robustness network (*R-network*)
Layer Model

**Robustness Abstraction Layer (RAL)**
Hides uncertainty of lower layer to the application layer

<table>
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<tr>
<th>RAL – Robustness Abstraction Layer</th>
<th>Supervisor</th>
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<tbody>
<tr>
<td>Control</td>
<td>R-Sensors</td>
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<tr>
<td>Configuration</td>
<td>R-Actors</td>
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**Control**: continuous data and control actions

**Supervisor**
- **Local supervisor**: Coordinates actions of neighboring RUs
- **Global supervisor**: Reacts on outer requirements, Interface to operating system, Monitoring device lifetime

**Configuration**: Discrete actions at discrete time points, e.g. altering operation modes, task migration, …
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Summary & Outlook
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 $v_{o\_mult}$ depending on $i$ uncertain inputs $v_{in,i}$:
    $$v_{o\_mult} \leq \min_i v_{in,i} \quad \forall i$$
  - Trust level $v_{o\_red}$ when combining $j$ redundant inputs $v_{in,j}$:
    $$v_{o\_red} \geq \min_j v_{in,j} \quad \forall j$$
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
- 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

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