Autonomous Multi-Processor Systems-on-Chip Optimization with Distributed LCS

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Motivation – Challenges in SoC Design

- Increasing **fabrication defects** and sensitivity for **stochastic events** from reaching CMOS physical limits
- Increasing **thermal problems**
- Increasing **degradation effects**

**Goal:** Self-adaptive circuits addressing
- increasing process-dependent and time-dependent variabilities,
- increasing design complexity (→ scalability) and
- higher design reuse rates.

Device Variations (Threshold Voltage)  Soft Errors (Relative Failure Rate)  Aging effect on transistor performance

(Borkar 2006)
General Goals

• Autonomous optimization of multi processor systems on chip (MPSoC) by distributed highly scalable learning classifier systems
  - each core is optimized by a separate XCS
  - each XCS adapts to his core
    → solving slightly different problems
  - considering core interaction
    → capturing thermal flow between cores
  - highly reusable system

• Optimization goal
  - Optimize performance w.r.t. temperature-related timing errors as well as ambient and core temperatures
XCS overview

Performance

- Perceive environment
- Determine appropriate response (rule matching)
- Perform action

Simple model of an intelligent agent interacting with an environment

- Search space of possible rules (evolutionary alg.)
- Goal: find cooperative set of rules to solve the task

Discovery

Reinforcement

- External system rewards “good” actions.
- Propagate reward to rules which triggered the action.

- Perceive environment
- Determine appropriate response (rule matching)
- Perform action

Performance
Design-time and run-time learning

Diagram: Design-time and run-time learning.
- **Design time**
  - Design-time rule set
  - Design space exploration
  - Learning: Fitness update + Rule set update
  - Design-time LCS (XCS)
- **Run time**
  - Run-time rule set
  - Run-time monitoring
  - Fitness update
  - Rule set update
  - Run-time LCS

Rule-set translation
- empty
- random
- constructed
- Design-time rule set
- Rule set compactification
Distributed XCS – Basic Concept

Remark:
- Distributed XCS without communication
  - only local decisions
  - thermal flow are not considered
  - cores can not be properly controlled
- Global XCS
  - too complex, not scalable
  - large action set → restriction needed
  - applicable for identical core instances

Selecting classifiers to be deleted
- inverse fitness
- action set size
- prediction error
- any combination

Selecting classifiers to be copied
- randomly
- highest numerosity first
- highest fitness first

Communication Topology

Inter-XCS Communication
- uni/bi-directional ring
- complete graph
- mesh, …
Experimental Setup

- Simulation of Cell processor
- Goal: optimize performance, avoiding temperature-dependent timing errors
- Loads and ambient temperature vary

- Investigate different
  - Communication topologies
  - Migration strategies
  - Deletion strategies
- Procedure: first 5-core model, then 10-core model
Results 5-core model

Best configuration:
- Emigrate by fitness
- Communicate w. medium conn.
- Delete by prediction err.
Results 10-core model, topology with 3 neighbors

Thermal convection resistance:

- $r = 0.05$
- $r = 0.10$
- $r = 0.20$
Results 10-core model, topology with 6 neighbors

Thermal convection resistance:

\[ r = 0.05 \] \hspace{2cm} \[ r = 0.10 \] \hspace{2cm} \[ r = 0.20 \]
Results 10-core model, topology with 9 neighbors

Thermal convection resistance:

- $r = 0.05$
- $r = 0.10$
- $r = 0.20$
Conclusions

• Autonomous Optimization with Distributed Learning Classifier Systems (LCS)

• Optimize frequency and voltage to maximize performance but no timing errors

• Best configuration:
  - Emigrate by fitness
  - Communicate with medium connectivity graph
  - Delete by prediction error

• Future work:
  - More accurate model
  - Different process variabilities
Thank you.

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