A Heuristic for Multi Objective Software Application Mappings on Heterogeneous MPSoCs

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**Introduction**

Current Platforms are Getting More Complex

- **MPSoC Platforms**
  - RISC1
  - DSP1
  - DSP2
  - RISC2
  - HW
  - DSP3

- **Graph**
  - Number of Processing Cores
  - Source: ITRS

Mobile Devices Became Part of our Daily Lives

- **Facts**
  - The market imposes strict demands in terms of performance, energy and costs
  - Complex applications require multicore processors to meet their demands

Parallel programming and optimization becomes more and more important
Motivation
Outline

Motivation

MPSoC Compilation Tool Suite

Multi Objective Heuristic *TONPET*

Case Studies

Summary
Parallelizer

- Expose multiple forms of parallelism

Mapper

- Define where and when execute tasks

Generator

- Generate code for the target platform
Mapper

Para llel code

MPSOC model

Constraints

Mapper

power

power & performance

performance

Code generator

Plain C

MPSOC toolchain

Platform binaries
Outline

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Multi Objective Heuristic \textit{TONPET}

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Summary
Multi Objective Heuristic *TONPET*

- **Objectives**
  - Performance, average power(, peak power, energy)

- **Steps**
  - Platform configuration classification
    - Classification for each combination of frequency settings
    - Mapping independent
  - Pruning of classified platform configurations
  - Pareto front calculation

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![Graph showing execution time vs. power](image-url)
Platform Configuration Classification & Pruning

- **Total Nominal Power (TNP):**
  - Maximum power consumption

- **Execution Time Indicator (ETI):**
  - Sum of running all processes on all core types

### Platform Power Configurations

<table>
<thead>
<tr>
<th>Platform</th>
<th>TNP (W)</th>
<th>ETI (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td>C2</td>
<td>1.5</td>
<td>100</td>
</tr>
<tr>
<td>C3</td>
<td>3</td>
<td>50</td>
</tr>
<tr>
<td>C4</td>
<td>2</td>
<td>220</td>
</tr>
</tbody>
</table>

### ETITNP classifier

- **Power (W) vs Execution time indicator (s)**

### Load Balancer – Pareto classified configs

- **Power (W) vs Execution time (ms)**
Pareto Front Calculation – 1/2

- Select every \( \log_2(|paretoClassConfigs|) \) for further analysis
  - \( \log_2 \): trade-off between
    - fixed number of selected Pareto classified configurations
    - constant step size

- Keep \( \text{pareto}(selectedConfigs) \)

![Graphs showing execution time vs. total nominal power and load balancer performance](image-url)
Process to Processor Mapping

- Dependency on frequency domain
  - Covering full range of power and performance

Increase number of used frequency domains
Pareto Front Calculation – 2/2

- For EvalConfig in pareto(selectedConfigs)
  - Set EvalConfig
    - Allow 1, 2, 3,… frequency domains (ordered by power consumption)
    - Load balancing
    - Calculate power and execution time
    - Keep if Pareto optimal

![Pareto Graph](image1)

![Final Pareto Graph](image2)
Outline

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Case Studies

- **ODROID-XU3 – Samsung Exynos-5422**
  - 4+4 ARM Cortex A7 + A15, 247 frequency configurations

- **Keystone II – Texas Instruments**
  - 4+8 ARM Cortex A15 + DSP TI C66x, 26 frequency configurations

- **Heterogeneous many-core virtual platform**
  - 16+16 ARM Cortex A9 + AD Blackfin 609, $3.5 \times 10^9$ frequency configurations

- **Benchmarks (written as Kahn Process Network):**
  - Audio filter (11), JPEG (24), LTE (19), Mandelbrot with 16 and 150 workers (18/152), Sobel filter (5), MIMO OFDM (36), STAP (16)

- **Evaluation**
  - Speed-up compared to R2 indicator EMOA
  - Quality of Pareto front compared to R2 indicator EMOA
Evolutionary Multi Objective Algorithm (EMOA)

- **Evolutionary Algorithms**
  - Inspired by biological evolution (black box optimization)
  - Population based
  - Genotype to phenotype mapping

- **Taxonomy**
  - Single objective
  - Multi objective
    - Dominance based
      - NSGA-2 (up to 2 objectives)
    - Indicator based
      - Hypervolume indicator (HI) (slow for more than 2 objectives)
      - R2 indicator (faster)

Minimize 2 objectives

Dominated by 2
Dominating 3
Depth 2

HI: 0.464
Comparing Pareto Solutions

- **Hypervolume Indicator (HI)**

HI: 0.846
HI: 0.877
HI difference: 3.1%

HI: 0.518
HI: 0.464
HI: 0.509
**Run time compared to constraint R2-EMOA**

- **ODROID-XU3:**
  - Speed-up 80x (worst case), 120x (average)

- **Keystone II:**
  - Speed-up 18x (worst case), 30x (average)

- **Heterogeneous many-core virtual platform**
  - Speed-up 88x (worst case), 150x (average)
Quality of Pareto front compared to R2-EMOA

- TONPET HI performance relative to R2-EMOA
  - Better than budget constrained EMOA: “+”
  - Better than budget unconstrained EMOA: “++”

<table>
<thead>
<tr>
<th></th>
<th>ODROID-XU3</th>
<th>Keystone II</th>
</tr>
</thead>
<tbody>
<tr>
<td>audio filter</td>
<td>-0.4%</td>
<td>+</td>
</tr>
<tr>
<td>JPEG</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>LTE</td>
<td>-0.3%</td>
<td>-4.6%</td>
</tr>
<tr>
<td>Man150</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Man16</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>MIMO OFDM</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>sobel filter</td>
<td>-1%</td>
<td>+</td>
</tr>
<tr>
<td>STAP</td>
<td>-0.9%</td>
<td>-6.3%</td>
</tr>
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</table>
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Summary

- Multi objective heuristic **TONPET**
  - Pareto optimum w.r.t. two objectives: power and performance
  - Classification and pruning to reduce search space
    - Applicable to many-core platforms

- Evaluation with R2-EMOA
  - Worst case speed-up
    - 18x (Keystone II), 80x (ODROID-XU3), 88x (Virtual Platform)
  - HI performance
    - 4.7% better than constraint R2-EMOA (Keystone II and ODROID-XU3)
    - 3% less than constraint R2-EMOA (Virtual Platform)

Thank you for your attention!