CLI PPER: Counter-based Low Impact Processor Power Estimation at Run-time

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Outline

- Motivation
- Methodology
- Results
- Example Application
- Summary
Motivation

103.3 mJ 116.9 mJ 134.9 mJ
↑ 50% Compression ↑

90.4 mJ 95.1 mJ 106.9 mJ
↑ 90% Compression ↑
Motivation

• Conserving power and energy has become a major design problem for portable devices
• Knowledge of run-time power/energy data allows clever decisions to be made
• Any optimization system requires overheads. These must not outweigh the benefits.
• Problem
  – Run-time feedback of power/energy required
  – Power measurement is either not frequent enough or costs too much energy

• Solution
  – Estimate power consumption in parallel to execution
  – Use small counters to minimize impact
CLIPPER Methodology

• Model power of system
• Detect events that contribute to power consumption
• Add event counters to tally event occurrence
• Produce macro-model of system via regression analysis
• Modify software to read counters
CLIPPER Methodology

- **RTL Processor Model**
- **Synthesis (I)**
- **Gate Level Model**
  - **Simulation (II)**
  - **Power Calculation (III)**
  - **Power Waveform**
  - **Analysis (IV)**
  - **Switching Activity**
- **Power Estimation System**
- **RTL Processor with Counters**
  - **Synthesis (V)**
  - **Gate Level Model**
  - **Simulation (VI)**
  - **Switching Activity**
  - **Events**
  - **Events**
  - **Events**
- **Power Macro Modeling (VIII)**
- **Power Table**
- **CLIPPER Methodology**

The diagram illustrates the CLIPPER Methodology, focusing on the integration of various stages including synthesis, power calculation, simulation, and estimation system.
### Power Simulation

<table>
<thead>
<tr>
<th>Component</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.../op/processor/Pc</td>
<td>0.01044</td>
</tr>
<tr>
<td>.../UF_DIV1/Pc</td>
<td>0.0002853</td>
</tr>
<tr>
<td>.../UF_MUL1/Pc</td>
<td>0.0002193</td>
</tr>
<tr>
<td>.../oriD_MEMC/Pc</td>
<td>0.003736</td>
</tr>
<tr>
<td>.../MEMC/Pc</td>
<td>0.005223</td>
</tr>
</tbody>
</table>

**Time Scale:**

- 120 ns to 150 ns

**Cursor Position:**

- Cursor 1: 136100 ns

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CLIPPER Methodology

RTL Processor Model

Synthesis (I)

Gate Level Model

Simulation (II)

Power Waveform

Switching Activity

Analysis (IV)

Events

RTL Processor with Counters

Synthesis (V)

Gate Level Model

Simulation (VI)

Switching Activity

Power Waveform

Power Macro Modeling (VIII)

Power Table

Estimation System
Event Analysis

Processor Modules ➔ Event Selection ➔ Selected Modules ➔ Event Selection ➔ Events

Power Waveform ➔ Event Analysis ➔ Events
Finding Events

• Events are detected by states of one or more control signals
• Most events are easily determined. E.g:
  – Cache misses
  – Major operations (divide, flops, etc.)
  – Peripheral access
Finding Events

• For each significant power change in trace
  – Find signals that change at the same time
  – If signals correlate with power throughout trace, add it to an event

• For each event
  – Remove covered signals in the set

• For each pair of events
  – Remove duplicates
CLIPPER Counters

Processor

ALU  Divider  GPR  Other Modules

Events

Data Cache

Counters

Multiplexor

Data Cache Bus
CLIPPER Methodology

RTL Processor Model

Synthesis (I)

Gate Level Model

Simulation (II)

Power Waveform

Power Calculation (III)

Switching Activity

Analysis (IV)

Events

Power Calculation (V)

Gate Level Model

Simulation (VI)

Switching Activity

Power Waveform

Power Macro Modeling (VIII)

Power Table

CLIPPER Methodology

Estimation System
CLIPPER Methodology

- **RTL Processor Model**
  - Synthesis (I)
  - Gate Level Model Simulation (II)
  - Switching Activity

- **Power Waveform**
  - Power Calculation (III)
  - Analysis (IV)

- **RTL Processor with Counters**
  - Synthesis (V)
  - Gate Level Model Simulation (VI)
  - Switching Activity

- **Power Macro Modeling (VIII)**
  - Power Waveform
  - Power Table

- **Estimation System**
## Power Table

<table>
<thead>
<tr>
<th>Event</th>
<th>Power Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base (Static + Constant Dynamic Power)</td>
<td>57</td>
</tr>
<tr>
<td>Divide</td>
<td>460</td>
</tr>
<tr>
<td>Multiply</td>
<td>9</td>
</tr>
<tr>
<td>Register File Write</td>
<td>17</td>
</tr>
<tr>
<td>Dcache Miss</td>
<td>198</td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>
Implementation

• Implementation of SimpleScalar processor with the integer PISA instruction set created with ASIPMeister
• On-chip instruction and data cache
• Synthesized in Synopsys Design Compiler in 180nm process with 125Mhz clock speed
• 9 events detected (divide, multiply, icache miss, dcache miss, dcache w/b, register change etc.)
<table>
<thead>
<tr>
<th></th>
<th>Original</th>
<th>Modified</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gate Area (NANDs)</td>
<td>127,994</td>
<td>134,238</td>
<td>4.9%</td>
</tr>
<tr>
<td>Total Power (mW)</td>
<td>77.19</td>
<td>79.48</td>
<td>3.0%</td>
</tr>
</tbody>
</table>
qsort

The graph shows the power consumption (in mW) over time (in ms) for a qsort operation. The graph compares measured and estimated power levels, with the measured data represented by a blue line and the estimated data by a pink line. The power consumption fluctuates significantly over the duration of the operation, with a noticeable decrease in the last few milliseconds.
## Accuracy

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>Cycles (mils.)</th>
<th>Power Error</th>
<th>Energy (mJ)</th>
<th>Energy Error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Avg</td>
<td>Max</td>
<td>Measured</td>
</tr>
<tr>
<td>g721e</td>
<td>2.9</td>
<td>0.77%</td>
<td>4.97%</td>
<td>1.566</td>
</tr>
<tr>
<td>g721d</td>
<td>2.6</td>
<td>0.48%</td>
<td>5.05%</td>
<td>1.441</td>
</tr>
<tr>
<td>jpeg</td>
<td>4.2</td>
<td>1.27%</td>
<td>6.86%</td>
<td>2.559</td>
</tr>
<tr>
<td>qsort</td>
<td>3.7</td>
<td>0.85%</td>
<td>4.80%</td>
<td>2.124</td>
</tr>
<tr>
<td>rawcaudio</td>
<td>3.2</td>
<td>1.45%</td>
<td>8.04%</td>
<td>1.988</td>
</tr>
<tr>
<td>rawdaudio</td>
<td>2.9</td>
<td>0.58%</td>
<td>2.30%</td>
<td>1.793</td>
</tr>
<tr>
<td>tiff2bw</td>
<td>3.1</td>
<td>0.89%</td>
<td>6.00%</td>
<td>1.924</td>
</tr>
<tr>
<td>tiff2rgba</td>
<td>2.8</td>
<td>1.58%</td>
<td>6.24%</td>
<td>1.685</td>
</tr>
</tbody>
</table>
Example Application

Available Energy per image: 79.7 mJ

Energy used for this image: 120.3 mJ

Level 12 → Level 4
Example Application

Available Energy per image:

79.4 mJ

Energy used for this image:

83.9 mJ

Level 4 → Level 2
Example Application

Available Energy per image: 79.9 mJ

Energy used for this image: 71.7 mJ
Example Application

Available Energy per image: 79.9 mJ

Energy used for this image: 80.2 mJ

Level 3 → Level 2
Example Application

Available Energy per image: 80.5 mJ
Energy used for this image: 71.8 mJ

Level 2 → Level 3
Example Application

Available Energy per image:
80.5 mJ

Energy used for this image:
80.2 mJ

Level 3  →  Level 3
Example Application

Available Energy per image: 81.2 mJ

Energy used for this image: 73.3 mJ

Level 3 → Level 4

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Example Application

Available Energy per image: 81.6 mJ

Energy used for this image: 77.0 mJ

Level 4  →  Level 4
Example Application

Available Energy per image: 82.1 mJ

Energy used for this image: 76.8 mJ

Level 4  →  Level 4
Example Application

Available Energy per image: 82.8 mJ

Energy used for this image: 76.8 mJ

Level 4 → Level 4
Example Application

Available Energy per image: 83.7 mJ

Energy used for this image: 76.8 mJ

Level 4 → Level 4
Example Application

Available Energy per image: 84.8 mJ
Energy used for this image: 76.9 mJ

Level 4 → Level 5
Example Application

Available Energy per image: 86.8 mJ

Energy used for this image: 84.7 mJ

Level 5 → Level 5
Example Application

Available Energy per image: 84.8 mJ

Energy used for this image: 92.8 mJ

Level 5 → Level 4

UNSW
Example Application

Available Energy per image: 84.9 mJ

Energy used for this image: 84.4 mJ

Level 4  →  Level 4

UNSW
Available Energy per image:  85.4 mJ

Energy used for this image:  84.5 mJ

Level 4  →  Level 4
Example Application

Available Energy per image: 1 mJ

Energy used for this image: 84.5 mJ

Level 4 → Level 4
Summary

• Power feedback is highly desired
• Estimation provides feasible approach to provide this data
• CLIPPER methodology provides high accuracy with low impact
• Examples demonstrate usefulness of power feedback for dynamic approaches
Questions?