Coarse-Grained Reconfiguration: Run-time Adaptivity in Cyber Physical Systems

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21-23 June 2017 – Palermo (IT)
Outline

• Introduction
  • CERBERO and Cyber Physical Systems
  • HEVC Codec and Software Approximate Computing
• Approximate HEVC interpolators
  • Coarse-Grained Reconfiguration
  • From CG HEVC Interpolators to CGR HEVC Interpolators
• Results
  • Achieved Adaptivity
  • Comparison with the State of the Art
• Conclusions
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CERBERO project

Cross-layer modEl-based framework for multi-objective design of reconfigurable systems in uncertain hybrid environments

→ continuous design environment for Cyber-Physical Systems (CPS) including modelling, deployment and verification

Self-healing system for planetary exploration
Smart Travelling for Electric Vehicle
Oceans Monitoring

http://www.cerbero-h2020.eu/
Cyber Physical Systems (CPS)

Complex systems with different interacting and deeply intertwined components, providing multiple and distinct behavioral modalities potentially changing over time, that contribute concurrently to determine the behavior of the system as a whole.

Layers (dominant aspects):

- functional
- physical
- communication

Subjected to Functional (F) and Non-Functional (NF) requirements variation in time.
High Efficiency Video Coding (HEVC)

Recent video codec developed by the Joint Collaboration Team on Video Coding (VCEG and MPEG). It provides up to 50% bit rate reduction at the same subjective video quality with respect to previous standards (H.264).
Approximate HEVC Interpolation in Software

With high frame rates the motion vector could be composed of fractional pixel values. In these cases an interpolation (FIR filtering) of the matching block is necessary.

![Table Image]

→ up to 28% energy saving with a small degradation of decoding quality on an ARM big.LITTLE SoC

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Run-time Adaptivity in CPS

At the CPS physical level application specific efficient accelerators capable of providing flexibility and dynamic adaptation to changeable F/NF requirements.

NF requirements: energy budget

F requirements: video quality demand

locally remotely

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Coarse-Grained Reconfiguration: Run-time Adaptivity in Cyber Physical Systems
Reconfigurable computing provides a trade-off between execution efficiency typical of ASICs and flexibility mainly exhibited by GP devices.

<table>
<thead>
<tr>
<th></th>
<th>Fine-Grained (FG)</th>
<th>Coarse-Grained (CG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>bit-level</td>
<td>☺️</td>
<td>☹️</td>
</tr>
<tr>
<td>word-level</td>
<td>☹️</td>
<td>☻️</td>
</tr>
<tr>
<td>flexibility</td>
<td>☹️</td>
<td>☹️</td>
</tr>
<tr>
<td>speed</td>
<td>☹️</td>
<td>☻️</td>
</tr>
<tr>
<td>memory</td>
<td>☹️</td>
<td>☹️</td>
</tr>
</tbody>
</table>

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CG HEVC interpolators

Example N=4

\[ y_1 = c_0x_0 + c_1x_1 + c_2x_2 + c_3x_3 \]
\[ y_2 = c_0x_1 + c_1x_2 + c_2x_3 + c_3x_4 \]
\[ y_3 = c_0x_2 + c_1x_3 + c_2x_4 + c_3x_5 \]

\[ z_9 = c_0y_1 + c_1y_9 + c_2y_17 + c_3y_25 \]
\[ z_{10} = c_0y_2 + c_1y_{10} + c_2y_{18} + c_3y_{26} \]
\[ z_{11} = c_0y_1 + c_1y_9 + c_2y_17 + c_3y_{25} \]

- serial horizontal 8-taps FIR
- horizontally filtered rows
- parallel horizontal 8-taps FIR
- final normalization step

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CGR HEVC interpolators

Profile | HIGH | MEDIUM | LOW
---|---|---|---
Quality | # Taps | Energy | Quality | # Taps | Energy | Quality | # Taps | Energy
Luma | 8/7 | | | 5 | | | 3 | |
Chroma | 4 | | | 3 | | | 2 | |

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Achieved Adaptivity

<table>
<thead>
<tr>
<th>design @200 MHz Xilinx XC7Z020</th>
<th>LUT</th>
<th>FF</th>
<th>BRAM</th>
<th>DSP</th>
<th>Fmax [MHz]</th>
<th>tap</th>
<th>dP (Vivado) [mW]</th>
<th>dE [μJ]</th>
<th>time per block [cycles]</th>
<th># interpolated pixels in a fixed time</th>
</tr>
</thead>
<tbody>
<tr>
<td>legacy_luma</td>
<td>212</td>
<td>37</td>
<td>4</td>
<td>16</td>
<td>213</td>
<td>8</td>
<td>11</td>
<td>0.248</td>
<td>460</td>
<td>57957</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td>12 (+9%)</td>
<td>0.270</td>
<td>460 (+0%)</td>
<td>57957 (+0%)</td>
</tr>
<tr>
<td>reconf_luma (vs legacy %)</td>
<td>582</td>
<td>85</td>
<td>4</td>
<td>16</td>
<td>200 (-6%)</td>
<td>7</td>
<td>11 (+0%)</td>
<td>0.245</td>
<td>395 (-14%)</td>
<td>59033 (+2%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>10 (-9%)</td>
<td>0.217</td>
<td>265 (-42%)</td>
<td>61191 (+6%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>10 (-9%)</td>
<td>0.211</td>
<td>135 (-71%)</td>
<td>63357 (+9%)</td>
</tr>
<tr>
<td>legacy_chroma</td>
<td>163</td>
<td>33</td>
<td>2</td>
<td>8</td>
<td>217</td>
<td>4</td>
<td>9</td>
<td>0.053</td>
<td>107</td>
<td>14753</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>9 (+0%)</td>
<td>0.053</td>
<td>107 (+0%)</td>
<td>14753 (+0%)</td>
</tr>
<tr>
<td>reconf_chroma (vs legacy %)</td>
<td>383</td>
<td>65</td>
<td>2</td>
<td>8</td>
<td>200 (-12%)</td>
<td>3</td>
<td>8 (-11%)</td>
<td>0.045</td>
<td>73 (-32%)</td>
<td>15293 (+4%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>6 (-33%)</td>
<td>0.033</td>
<td>39 (-64%)</td>
<td>15835 (+7%)</td>
</tr>
</tbody>
</table>

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Comparison with the State of the Art

**this work:** 4 luma and 3 chroma parallel filters running at 150 MHz → UHD@60 fps

- High (8/7 tap luma, 4 tap chroma)
- Medium (5 tap luma, 3 tap chroma)
- Low (3 tap luma, 2 tap chroma)

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Conclusions

- **CERBERO**: continuous design environment for Cyber-Physical Systems (CPS)
  - run-time F/NF requirements driven adaptivity
- **HEVC** power/energy hungry, latest video coding standard
  - Approximate computing on HEVC interpolators demonstrated to provide energy versus quality trade-off
- **Coarse-Grained Reconfiguration** (CGR) allows approximation of HEVC interpolators in hardware
  - our solution challenges outperforms state of the art solutions

- Future directions on:
  - adopt a **multiplier-less** solution to further reduce consumption
  - embedding the **whole HEVC codec on FPGA** (software/hardware)
CPS Summer School 2017

Porto Conte Ricerche, Alghero (Italy) – September 25-30, 2017
Designing Cyber-Physical Systems – From concepts to implementation
Multi-objective Methodologies and Tools for Self-healing and Adaptive Systems
Distinguished lecturers: Alberto Sangiovanni-Vincentelli, Hironori Kasahara, Muhammad Shafique

Application deadline: July 7th, 2017
http://www.cpsschool.eu/
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