Thermal Aware Scheduling on FPGAs

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Sep 13, 2017
Agenda

• Introduction
• Motivation
• Model
• Experiment
• Conclusion
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Ideal Case vs Actual Case

Ideally

Actually
Our Work on FPGAs

Uneven distribution

Even distribution

Cool them all!

Zzz...
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Chameleon Infrastructure

- 2U servers
- Nallatech 385A with Arria 10 chip
- Intel FPGA examples (written in OpenCL)
- Located vertically on the same rack
- Positioning numbers start at the bottom

U41_42
U43_44
U45_46
U47_48
U41_42
Thermal Variation in HPC

Peak temperature variation across FPGA boards
A Quick Example

57.81  80.82  59.84  57.14

61.87  63.23  69.32  58.49
Bird’s Eye View

App A, B, C, D …

Temperature of A, B, C, D …

Model of FPGA system

Temperature predictions when E, F, G, H runs on the system

App E, F, G, H …

Choose the placement with the lowest predicted peak temperature
Leakage Power and Temperature

Peak temperature and peak power relation

![Graph showing the relationship between peak temperature and peak power. The x-axis represents peak temperature in °C, and the y-axis represents peak power in Watt. There is a positive correlation between the two, indicated by a linear trend line with data points.]
Consistent Performance

Normalized FPGA performance across machines

![Graph showing normalized FPGA performance across different benchmarks and machines.]
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### Machine Learning Model

<table>
<thead>
<tr>
<th>Learner</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear Regression</td>
<td>Logic Utilization</td>
</tr>
<tr>
<td>Neural Network</td>
<td>RAM Blocks</td>
</tr>
<tr>
<td>Nearest Neighbor</td>
<td>Frequency</td>
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<tr>
<td>Random Forest</td>
<td>DSP Blocks</td>
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<td></td>
<td>Memory Bits</td>
</tr>
<tr>
<td></td>
<td>I/O Pins</td>
</tr>
<tr>
<td><strong>Label</strong></td>
<td><strong>Peak Temperature</strong></td>
</tr>
</tbody>
</table>
The Training Sample

- 210 combinations, select 4 tasks from 10 tasks
- 24 placements, place 4 tasks on 4 machines. One placement is one sample
- 5040 samples, in total
- 12 features, each task has 3 features
- 1 label, each placements has 1 peak temperature

12 features and 1 label, each sample
Prediction Model

Task Dependent Model

Split the samples into 2 sets, one for training (80%), the other one for testing (20%)

Task Independent Model

Build the model with 6 tasks and use the remaining 4 to test it

The result will come in Experiment section
Scheduling Methodology

• Take the task dependent model as example
• Build a prediction model with 4056 training samples (80%)
• When a task combination comes (from the remaining samples), enumerate 24 placements
• Make prediction for each placements
• Choose the lowest predicted peak temperature
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Prediction Statistics

- Correlation Coefficient
- Mean Absolute Error
- Root Mean Squared Error
- Relative Absolute Error
- Root Relative Squared Error

Graph showing predictions for different models:
- ZeroR
- Nearest Neighbor
- Linear Regression
- Random Forest
- Neural Network
Scheduler Performance

The average peak temperature of the system when we use the schedulers

The advantage we expect to get from our schedulers
Power Reduction

Peak Temperature Reduction: 4.60 °C
Peak Power Reduction: 1.77 W
Power Sum Reduction: 1.97 W

Our Schedule Decision
Scheduler Performance

Task Independent Model

- Actual Temperature
- Linear Regression
- Neural Network
- Nearest Neighbor
- Random Forest

Peak Temperature in °C vs. Placement Index
A Closer Look, Linear Regression

Task Independent Model

- Blue: Actual Temperature
- Red: Linear Regression

Peak Temperature in °C

Placement Index

Northwestern
Scheduler Performance

Task Independent Model

- Actual Temperature
- Linear Regression
- Neural Network
- Nearest Neighbor
- Random Forest

Peak Temperature in °C

Placement Index
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Conclusion

• Up to 11.50ºC peak temperature variation across machines for the same benchmark
• First study in this area to our best knowledge
• 4.36ºC peak temperature reduction on average
• Build machine learning models and develop schedule methodology to explore potential improvement