Autotuning HLS for FPGAs using OpenTuner and LegUp

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Slides

The slides and all source code are hosted at GitHub:

- Code & Data: `github.com/phrb/legup-tuner`
- Slides: `github.com/phrb/slides-reconfig-2017-autotuning`

FPGAs

FPGAs:

- Logic Blocks and Interconnections
- Reconfigurable

Tradeoff:

- Energy Efficiency and Performance
- Programmability

Using FPGAs in Bing:

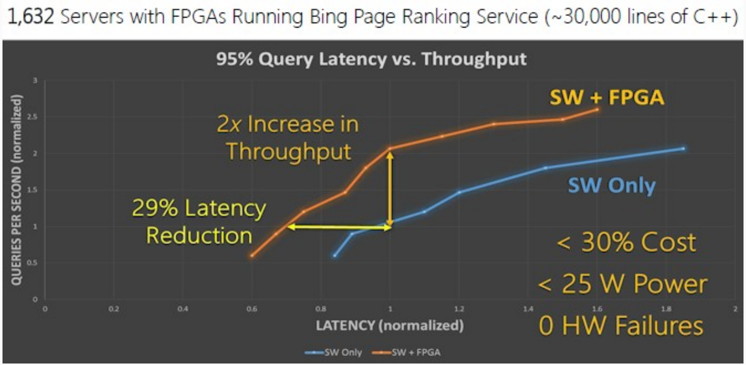


Image: `enterprisetech.com/2014/09/03/microsoft-using-fpgas-speed-bing-search/` [Accessed in 27/11/17]

LegUp HLS flow:

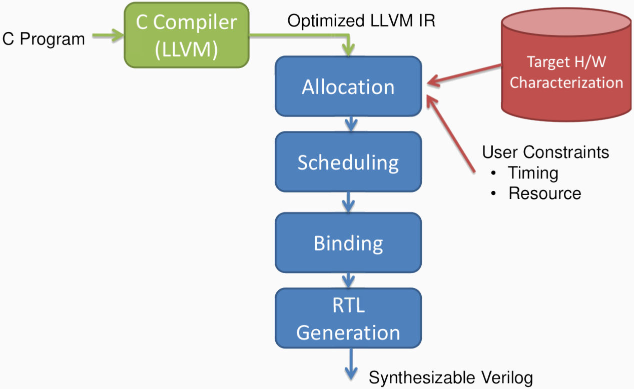
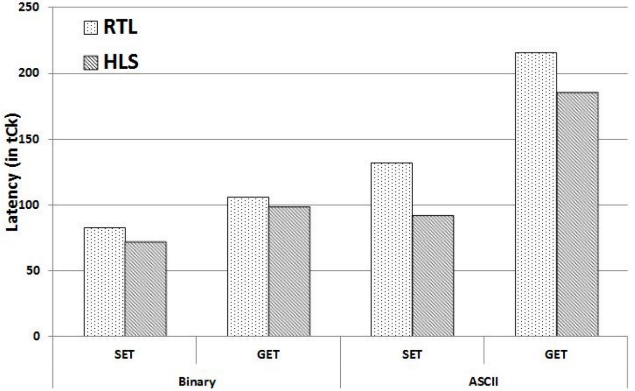


Image: Canis, Andrew Christopher. LegUp: Open-Source High-Level Synthesis Research Framework. Diss. University of Toronto, 2015.

HLS can generate lower-latency applications:



Memcached pipeline latency

Image: Karras, Kimon, Michaela Blott, and Kees Vissers. "High-Level Synthesis Case Study: Implementation of a Memcached Server." arXiv preprint arXiv:1408.5387 (2014).

FPGAs: High-Level Synthesis

Qualitatively, with less effort:

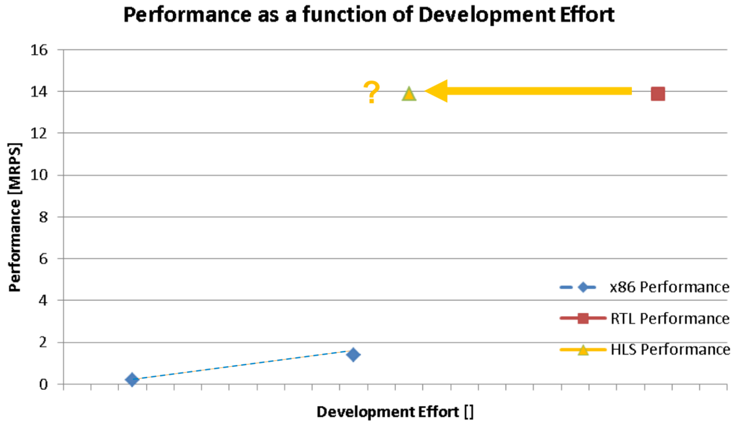


Image: Blott, Michaela, et al. "Achieving 10Gbps line-rate key-value stores with FPGAs." Presented as part of the 5th USENIX Workshop on Hot Topics in Cloud Computing. 2013.

This is an old issue:

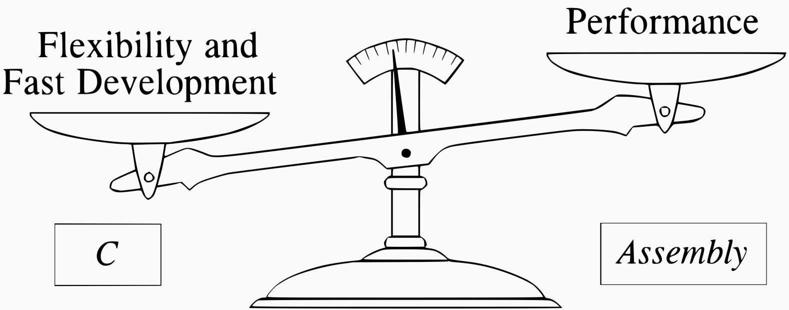


Image: Smith, Steven W. "The scientist and engineer's guide to digital signal processing." 1997

Why use autotuning for HLS?

Compare with Huang's work

Describe Xu's work with OpenTuner

Metric composition problem:

- 8 hardware metrics obtained from Quartus
- But the autotuner optimizes a single value

Benchmark and Hardware Metrics

Metric composition problem:

- 8 hardware metrics obtained from Quartus
- But the autotuner optimizes a single value

Our solution so far:

- Normalize metrics using initial values
- Optimize the normalized sum of the 8 metrics

Normalized sum of metrics:

$$f(M, W) = \frac{\displaystyle\sum_{\substack{m_i \in M \\ w_i \in W}} w_i \left(\frac{m_i}{m_i^0}\right)}{\displaystyle\sum_{w_i \in W} w_i}$$

Where M is the set of hardware metrics and W is the set of weights

Weighted Optimization Scenarios

An Optimization Scenario consists of:

- An optimization objective: performance, area, . . .
- Weights for hardware metrics

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Our scenarios:

- 3 specific scenarios & 1 balanced scenario
- Weights: powers of two from 1: irrelevant to 8: high

Weighted Optimization Scenarios

Table 1: Weights for Optimization Scenarios (High $= 8$, Medium $= 4$, Low $= 2$)

Metric	*Area*	*Perf. & Lat*	*Performance*	*Balanced*
LUT	High	Low	Low	Medium
Registers	High	High	Medium	Medium
BRAMs	High	Low	Low	Medium
DSPs	High	Low	Low	Medium
FMax	Low	High	High	Medium
Cycles	Low	High	Low	Medium

Experiments

- We performed 10 autotuning runs for each scenario
- Each run took 1.5 hours
- We kept track of how each hardware metric changed over time
- We used the Weighted Normalized Sum (WNS) as autotuning objective

Results

Presentation of results for each scenario:

- Mean of the relative changes, over 10 tuning runs
- For each hardware metric, and for WNS
- For each CHStone application
- Bluer is always better than Redder

Results: Comparing Default & Random Starts

	LUTs	Pins	BRAM	Regs	Blocks	Cycles	DSP	FMax
aes	0.79	0.91	1.00	0.56	1.00	0.47	1.00	1.12
adpcm	0.68	1.13	1.00	0.54	1.00	0.56	0.60	0.98
sha	1.00	1.03	1.00	0.82	1.00	0.55	1.00	0.89
motion	1.02	1.00	0.60	0.85	1.00	0.57	1.00	0.94
mips	1.00	0.93	1.00	0.44	1.00	0.45	0.98	1.24
gsm	0.83	1.17	1.00	0.48	1.00	0.56	0.52	0.99
dfsin	0.79	0.97	1.00	0.61	1.00	0.60	1.49	1.53
dfmul	1.00	1.06	0.90	0.47	0.90	0.47	1.31	1.10
dfdiv	0.83	1.07	0.80	0.73	0.80	0.65	1.32	1.49
dfadd	1.00	0.94	1.00	0.82	1.00	0.71	1.00	0.93
blowfish	–	–	–	–	–	–	–	–

Figure 1: Comparison of the absolute values for Random and Default starting points in the Balanced scenario

Results: the Balanced Scenario

	WNS	LUTs	Pins	BRAM	Regs	Blocks	Cycles	DSP	FMax
aes	0.94	0.90	1.00	1.00	0.97	1.00	0.98	1.00	0.76
adpcm	0.84	0.73	1.13	1.00	0.91	1.00	1.05	0.63	0.49
sha	0.98	1.00	1.03	1.00	0.96	1.00	0.86	1.00	0.97
motion	0.98	0.97	1.00	1.00	0.99	1.00	0.95	1.00	0.95
mips	0.95	1.00	1.07	1.00	0.90	1.00	1.01	0.80	0.89
gsm	0.95	0.95	1.17	1.00	0.99	1.00	0.95	0.49	1.08
dfsin	0.93	1.03	1.03	1.00	1.05	1.00	1.07	0.65	0.73
dfmul	0.85	1.00	1.13	0.90	0.88	0.90	1.06	0.31	0.76
dfdiv	0.84	1.00	1.07	0.80	1.15	0.80	1.34	0.41	0.57
dfadd	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97
blowfish	0.99	1.00	1.00	1.00	0.98	1.00	0.98	1.00	0.99

Figure 2: Relative improvement for all metrics in the *Balanced* scenario

Results: the Area Scenario

	WNS	*LUTs*	*Pins*	*BRAM*	*Regs*	*Blocks*	*Cycles*	*DSP*	*FMax*
aes	0.96	0.92	1.00	1.00	0.93	1.00	0.97	1.00	0.86
adpcm	0.83	0.78	1.11	1.00	0.96	1.00	1.04	0.63	0.52
sha	0.96	1.00	1.06	1.00	0.84	1.00	0.83	1.00	1.08
motion	0.97	0.94	1.00	1.00	0.97	1.00	0.92	1.00	0.95
mips	0.91	1.00	1.06	1.00	0.89	1.00	1.00	0.72	0.84
gsm	0.89	0.83	1.06	1.00	0.86	1.00	0.89	0.82	1.14
dfsin	0.94	1.00	1.06	1.00	1.00	1.00	1.02	0.76	0.80
dfmul	0.82	1.00	1.06	1.00	0.90	1.00	1.21	0.27	0.86
dfdiv	0.77	1.00	1.22	0.67	1.03	0.67	1.62	0.28	0.77
dfadd	0.99	1.00	1.11	1.00	0.94	1.00	1.00	1.00	1.04
blowfish	0.99	1.00	1.00	1.00	0.97	1.00	0.91	1.00	1.01

Figure 3: Relative improvement for all metrics in the *Area* scenario

Results: the Performance Scenario

	WNS	LUTs	Pins	BRAM	Regs	Blocks	Cycles	DSP	FMax
aes	0.82	0.75	1.00	1.00	0.92	1.00	1.05	1.00	0.63
adpcm	0.84	0.94	1.17	1.00	0.96	1.00	0.94	0.69	0.74
sha	0.92	1.00	1.06	1.00	0.92	1.00	0.88	1.00	0.96
motion	0.99	1.00	1.00	1.00	1.01	1.00	1.00	1.00	0.98
mips	0.90	1.00	1.06	1.00	0.93	1.00	1.03	0.83	0.80
gsm	0.95	0.92	1.00	1.00	0.95	1.00	0.90	1.00	1.02
dfsin	0.87	1.11	1.06	1.00	1.27	1.00	1.25	0.53	0.56
dfmul	0.77	1.00	1.17	0.83	0.85	0.83	1.04	0.21	0.70
dfdiv	0.81	1.00	1.06	1.00	1.03	1.00	1.25	0.50	0.59
dfadd	0.97	1.00	1.00	1.00	0.97	1.00	1.00	1.00	0.94
blowfish	0.94	1.00	1.00	1.00	0.98	1.00	0.91	1.00	0.95

Figure 4: Relative improvement for all metrics in the *Performance* scenario

Results: the Performance & Latency Scenario

	WNS	LUTs	Pins	BRAM	Regs	Blocks	Cycles	DSP	FMax
aes	0.83	0.83	1.00	1.00	0.88	1.00	0.89	1.00	0.73
adpcm	0.76	0.78	1.11	1.00	0.95	1.00	0.98	0.62	0.47
sha	0.88	1.00	1.06	1.00	0.85	1.00	0.77	1.00	1.00
motion	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95
mips	0.95	1.00	1.11	1.00	0.91	1.00	0.99	0.89	0.96
gsm	0.92	0.92	1.11	1.00	0.87	1.00	0.90	0.67	1.11
dfsin	0.97	1.00	1.17	1.00	0.99	1.00	0.99	0.61	1.00
dfmul	0.86	1.00	1.22	1.00	0.89	1.00	1.01	0.33	0.84
dfdiv	0.82	1.00	1.11	1.00	0.84	1.00	0.96	0.34	0.83
dfadd	0.98	1.00	1.17	1.00	0.94	1.00	0.98	1.00	1.01
blowfish	0.96	1.00	1.00	1.00	0.97	1.00	0.93	1.00	0.97

Figure 5: Relative improvement for all metrics in the *Performance & Latency* scenario

Results: Comparing the Weighted Normalized Sum (WNS)

	Balanced	*Area*	*Performance*	*Perf. & Lat.*
aes	0.94	0.96	0.82	0.83
adpcm	0.84	0.83	0.84	0.76
sha	0.98	0.96	0.92	0.88
motion	0.98	0.97	0.99	0.98
mips	0.95	0.91	0.90	0.95
gsm	0.95	0.89	0.95	0.92
dfsin	0.93	0.94	0.87	0.97
dfmul	0.85	0.82	0.77	0.86
dfdiv	0.84	0.77	0.81	0.82
dfadd	1.00	0.99	0.97	0.98
blowfish	0.99	0.99	0.94	0.96
Average	0.93	0.91	0.89	0.90

Figure 6: Relative improvement for **WNS** in all scenarios

In all scenarios:

- Heavily weighted metrics improved the most
- Lightly weighted or irrelevant metrics did not worsen greatly

Results: Conclusion

In all scenarios:

- Heavily weighted metrics improved the most
- Lightly weighted or irrelevant metrics did not worsen greatly

Autotuning starting point:

- A random start might achieve more relative improvement
- But a sensible start achieves better absolute values

Limitations of this Work

Discuss the issues with the weighted cost function

Future Work

Discuss all future work topics

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