Best Practice for Caching of Single-Path Code

Martin Schoeberl, Bekim Cilku, Daniel Prokesch, and Peter Puschner

Technical University of Denmark
Vienna University of Technology
Context

- Real-time systems
  - Worst-case execution time (WCET) counts

- Different from average-case performance
  - Standard processors are optimized for average-case performance

- Design a processor and a compiler for real-time systems
  - The T-CREST approach
T-CREST

- Time-predictable multicore
  - Processor
  - Network-on-chip
  - Memory hierarchy
  - Compiler
  - WCET analysis (AbsInt aiT and platin)

- Most parts open-source

- https://github.com/t-crest
Patmos Processor

- Time-predictable processor
- Called Patmos
- Flexibility to define the instruction set
  - LLVM compiler adapted for Patmos
- Co-design for low WCET of
  - Patmos
  - Compiler
  - WCET analysis
Patmos Processor

- RISC pipeline
- Dual issue
- Special caches
- No time dependency between instructions
Hardware Description

- Chisel
  - Scala embedded Language
  - Higher level than VHDL/Verilog

- Generates two versions
  - C++ based emulator
  - Verilog based hardware description

- Cycle accurate emulation in C++ faster than VHDL/Verilog simulation
  - Based on the hardware description
Single-path Programming

- Remove input data dependent control flow decisions
  - Gives constant execution time
  - Uses (heavily) predicates

- If-conversion
  - Execute both branches
  - Use if condition for result write back

- Constant loop iterations
  - Use loop bounds
  - Exit condition for result write back
Single-path Programming

- Loops need to be bounded
  - In WCET analyzable programs anyway
- T-CREST compiler can generate single path code from C programs
  - For non-recursive programs
- Simply measure execution time
Single-Path Support in Patmos

- Constant execution time of all instructions
- Predicated instructions
  - 8 predicates
  - One is constant true
  - Write result when predicate is true
  - Otherwise do nothing (NOP instruction)
- All instructions are predicated
  - Execution time independent from predicate
Caches in Patmos

- Configurable: type and size

- For data: normal data cache, stack cache, and scratchpad memory

- For instructions:
  - Standard instruction cache
  - Prefetching instruction cache (SP)
  - Method cache
  - Scratchpad memory
    - Currently only single core (Loader issue)
Method Cache

■ Originally developed for the Java processor JOP
  ♦ Therefore called method cache

■ Now also used in
  ♦ SHAP
  ♦ Merasa processor (CarCore)
  ♦ Metzlaff PhD thesis

■ Also in Patmos
Method Cache

- Caches whole method/functions
  - May load unused instructions
- Misses only on call or return
  - Other instructions guaranteed hits
- Cache is divided in blocks
- Method can span several blocks
- Continuous blocks for a method
- Replacement FIFO
- Tag memory: One entry per block
Evaluation

- TACLeBench benchmarks V 1.9
  - Self-contained benchmarks

- Patmos configured for DE2-115 FPGA board

- 8 KB instruction cache
  - 16 methods when method cache

- Cycle accurate emulator to collect the data
Method vs. Standard Cache

Relative performance

- adpcm_dec
- dpcm_enc
- binary_search
- bsort
- cjpeg
- wrbmp
- complex_updates
- count_negative
- cover
- duff
- fac
- g723_enc
- gsm_dec
- huffman_dec
- iir
- insert_sort
- jfdctint
- lift
- lms
- matrix
- md5
- petrinet
- powerwindow
- prime
- sha
- state

Martin Schoeberl
Caching of Single-Path Code
2-way vs Direct Mapped

Relative performance

- 2-way
- 0.5
- 1.0

Caching of Single-Path Code
Method vs Standard Cache 2 KB

Relative performance

Caching of Single-Path Code
Best Practice for Caching of Single-Path Code

This folder contains information and scripts to run the evaluation experiments for the paper "Best Practice for Caching of Single-Path Code", Martin Schoeberl, Bekim Cilku, Daniel Prokesch, and Peter Puschner, accepted for WCET 2017.

Prerequisites: T-CREST

We use the open-source platform T-CREST for our experiments. Therefore, you need all T-CREST tools installed. A brief installation instruction can be found at the Patmos repository.

We also provide a VM with Ubuntu where all needed packages are installed. However, that VM is used in teaching and does not contain the latest version of T-CREST. Therefore, you need to reinstall T-CREST there with:

```
rm -rf t-crest
mkdir ~/t-crest
cd ~/t-crest
git clone https://github.com/t-crest/patmos-misc.git misc
./misc/build.sh
```

The Benchmarks
Conclusion

- Single-path code gives constant execution time
- Compared different caching organizations
- No single winner
- In FPGA we can use application specific caching