L1 Cache implementation on RISC-V

# Parallel computer architecture

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### Garyfallia Anastasia Papadouli | 03533

### Iordana Gaisidou | 03570

### Dimitrios Voitsidis | 03480

### Kalliopi Nanou | 02934

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# Introduction

RISC-V, being provided under open-source licenses and being an open standard ISA in general has sparked the interest of many students in computer engineering - both undergraduate and postgraduate. The previous attendees of the Parallel computer architecture course were no exception, as they created their own implementation with a 5-stage pipeline design based on the RV32I ISA. The project was tested using official assembly tests and Verilator, a simulation based tool that converts Verilog code to C++. Our task has been to add a L1 cache memory to the provided processor.

Naturally, this has presented us with many new challenges. The initial step had to be the isolation of the memory modules out of the CPU and the creation of 2 SRAM memory modules to represent the raw cache memory, both instruction and data. As members of the team we also had to make a decision about the policies and the parameters that would determine the cache behavior.

# Project Structure

Εικόνα που περιέχει στιγμιότυπο οθόνης

Περιγραφή που δημιουργήθηκε αυτόματαThe building blocks for the project have already been provided by our predecessors. We have added a multitude of additional files including modules and testing files to materialize our ideas.

# Policies

### Parameterization

Any size relative to the architecture of the cache has been written as modifiable, using macros in a separate header file. The additional complications arise in the form of for loops. Having parameterizable size and associativity in the context of cache testing is important as the behavior of the module can be observed under different circumstances.

### Write-allocate

Whenever something has to be stored in memory, it also gets stored in cache. The benefit of such systems is apparent any time subsequent reads to the stored value are solicitated. Since what is currently examined is the cache memory functionality, we thought its use as purposeful.

### Write-back

Write-back lessens the amount of accesses in the main memory, which is something we consider desired. Write-back policy mandates that any modification of data stored in cache gets written in memory only when that cache block has to be evicted.

### 

### Bit pLRU

We decided upon pLRU (pseudo LRU) as a feausible alternative to LRU as the original LRU policy is costly to hardware.

The number of bits used by LRU:

In striking contrast with the pseudo LRU that uses only one. The way bit LRU functions is by setting a status bit for every memory reference, and reverting all but the latest status bits whenever the last zero gets flipped.

## Modules

Εικόνα που περιέχει κείμενο, διάγραμμα, στιγμιότυπο οθόνης, παράλληλα

Περιγραφή που δημιουργήθηκε αυτόματα

Starting from the highest level of the project, the toplevel module houses the 2memories that connect with the CPU module. They are replicates of the previous ones, now completely separated from the processor and with parameterizable sizing. What should be noted about these modules is the delay that they insert to fake the delay a physical memory would impose to the system whenever access got requested.

Zooming inside the CPU, the pipeline is now accompanied by the two cache memories and their respective controllers. One pair handling instructions and one data. The **cache memory** modules essentially act as arrays that hold all the data and handle all the decision making about reading/writing or evicting cache blocks. At the point of a request arriving, the cache checks asynchronously the block corresponding to the incoming address for the possibility of a cache hit. Whenever there actually is a hit, it asynchronously outputs the data as well. The **data** one makes use of a dirty bit at cache misses to facilitate the write-back policy. Writing to the cache, however is a synchronous procedure.

The cache controllers are where most of the logic is implemented. They regulate the signals and data between a cache, the CPU and the main memory. Their core is based on FSM structures.

Starting with the **instruction cache controller**, its finite state machine has 3 states, ‘idle’, ‘memRead’ and ‘memCache’. The controller starts in the idle state, and does not change as long as the cache is able to fulfill a request. In case of a read miss, it switches to the memRead case in which it inquires the memory for the data. Upon confirmation that the data solicited exist withing the memory, it switches once again to the third state,’memCache’, where the data is passed to the cache in the next cycle.

The FSM for the data cache controller is quite larger, now consisting of five different states. Those are ‘idle’, ‘write-back’, ‘memRead’, ‘memCache’ and ‘writeback-replace’. Not much changes for the idle state. However, in case of a cache miss the aforementioned dirty bit should be checked to make a choice about the next state. If the data in the cache is modified, the next stage is ‘Write-back’, instead of the typical ‘memRead’. Entering the ‘Write-back’ state, the incoming data from the cache get written to the memory and the controller once again awaits for the acknowledgement. At the point of that acknowledgement, it switches to memRead. The state of ‘memCache’ also has additional complexity in the context of a data cache. Although in the case of a read operation it behaves just like in the icache controller, in the even of a write request there is a need for a fifth state. That is because the data must be modified inside the cache module, so to change the dirty bit to one.

# Putting it all together

Using the L1 cache processor under the RISC-V ISA requires the correct

We thoroughly examined the way the RISC-V processor was put under testing, using Verilator and the official assembly tests. Nevertheless, no similar tests were available for cache testing.