

Computer Systems and -architecture

Project 6: Full Datapath

1 Ba INF 2021-2022

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Don't hesitate to contact the teaching assistant of this course. You can reach him in room M.G.305 or by e-mail.

Time Schedule

Projects are solved in pairs of two students. Projects build on each other, to converge into a unified whole at the end of the semester. During the semester, you will be evaluated three times. At these evaluation moments, you will present your solution of the past projects by giving a demo and answering some questions. You will immediately receive feedback, which you can use to improve your solution for the following evaluations.

For every project, you submit a small report of the project you made by filling in `verslag.html` completely. A report typically consists of 500 words and a number of drawings/screenshots. Put all your files in one `tgz` archive, as explained on the course's website, and submit your report to the exercises on Blackboard.

- Report deadline: **December 12, 2021, 23u55**
- Evaluation and feedback: **December 17, 2021**

Project

Read sections 4.1, 4.2, 4.3 and 4.4 of Chapter 4. You can use all Logisim libraries for this assignment.

1. In the previous assignment, we used the ALU operations as instructions and added two additional instructions (`lw` and `sw`). Next to these instructions, in this assignment we also support immediate instructions as well as branch and jump instructions.

We introduce a number of new instructions, including instructions for `jump` and `branch`. Because you should be able to branch, you will have to connect your **program counter** to your datapath so that it can jump to a given address instead of just the next instruction.

Implement the instructions described in the table below (“imm” stands for “immediate”, “uns” stands for “unsigned” and “sig” stands for “signed, two's complement”). You already have implemented the R-type instructions and the `lw/sw` instructions in the previous assignment.

12	11	10	9	8	7	6	5	4	3	2	1	0	name	instruction	description
0000					rd			000		000			zero ¹	zero rd	\$rd := 0
0000					rd			rs		001			not ¹	not rd rs	\$rd := !\$rs
0000					rd			rs		010			inv ¹	inv rd rs	\$rd := -\$rs
0000					rd			rs		011			sll ¹	sll rd rs	\$rd := \$rs << 2
0000					rd			rs		100			srl ¹	srl rd rs	\$rd := \$rs >> 2
0000					rd			rs		101			sla ¹	sla rd rs	\$rd := \$rs * 2
0000					rd			rs		110			sra ^{1,2}	sra rd rs	\$rd := \$rs / 2
0000					rd			rs		111			cp ¹	cp rd rs	\$rd := \$rs
0001					rd			rs		rt			or ¹	or rd rs rt	\$rd := \$rs \$rt
0010					rd			rs		rt			and ¹	and rd rs rt	\$rd := \$rs & \$rt
0011					rd			rs		rt			add ¹	add rd rs rt	\$rd := \$rs + \$rt
0100					rd			rs		rt			sub ¹	sub rd rs rt	\$rd := \$rs - \$rt
0101					rd			rs		rt			lt ¹	lt rd rs rt	\$rd := \$rs < \$rt ? 1 : 0
0110					rd			rs		rt			gt ¹	gt rd rs rt	\$rd := \$rs > \$rt ? 1 : 0
0111					rd			rs		rt			eq ¹	eq rd rs rt	\$rd := \$rs = \$rt ? 1 : 0
1000					rd			rs		rt			neq ¹	neq rd rs rt	\$rd := \$rs != \$rt ? 1 : 0
1001					rd			rs		u. imm			lw	lw rd rs imm	\$rd := MEM[\$rs+imm]
1010					rd			rs		u. imm			sw	sw rd rs imm	MEM[\$rs+imm] := \$rd
1011					rd		unsigned immediate						ori	ori rd imm	\$rd := \$rd imm
1100					rd		unsigned immediate						lui	lui rd imm	\$rd := imm << 6
1101					rd		immediate (signed)						brnz	brnz rd imm	\$rd != 0 ? \$pc := \$pc + 1 + imm
1110					rd		immediate (signed)						jr	jr rd imm	\$pc := \$rd + imm
1111					target address						0		j	j imm	\$pc := addr
1111					target address						1		jal ³	jal imm	\$r7 := \$pc + 1; \$pc := addr

¹ R-type instruction.

² Integer division.

³ Register r7 will be reserved for the return address of the jal instruction.

- In order to get all control lines right, you will have to add a **Control Unit** circuit to your datapath.
 - Input is the instruction (13 bits).
 - Outputs are the ALU OP-code as well as all control lines for i.e. the program counter, instruction and data memory, multiplexers and the register file. Choose your control lines wisely: this can make the implementation a lot easier!

More information on the implementation of a control unit can be found in Section 4.4 of *Computer organization and design*.

- Similarly you can create an **Immediate** circuit (this is different from the book's datapath):
 - Input is the instruction (13 bits).
 - Output is the immediate value (12 bits), depending on the instruction this will be a 3, 6, or 8-bit value that is unsigned/sign extended/shifted to 12 bits.

- Once done, your datapath can correctly execute a program written in machine language, as the behaviour of arithmetic, branching and memory operations is now fully implemented! You can use the script `Test.py` as follows (note the `-f` flag to denote the simulation of a full datapath:

```
python Test.py -f -t <test-file> -c <circ-file>
```

You can use labels for branching and jumping in your tests. When testing the full datapath, you can only perform checks at the end of the program. (This is because of branching: it would not make sense to check a register value in the middle of a loop, as it can have a different value in a different iteration of the loop.)

- To prepare for the next lab session, read section 4.9 of Chapter 4.