

ISA for the CS 3220 Project

Opcodes are 4 bits.

Functions (secondary opcodes) are 4 bits.

Immediate operands are 16 bits.

Register indices are 4 bits (RS1, RS2, RD).

Rough Verilog example:

```
wire[31:0] iword;
wire[3:0] rd, rs1, rs2
wire[15:0] imm;
wire[3:0] fn;
wire[3:0] opcode;

assign opcode = iword[3:0];
assign fn = iword[7:4];
assign imm = iword[23:8];
assign rs2 = iword[23:20];
assign rs1 = iword[27:24];
assign rd1 = iword[31:28];
```

ALU-R

```
ADD    : {fmt: "RD,RS1,RS2",iword: "RD RS1 RS2 000000000000 0000 0000"}
SUB    : {fmt: "RD,RS1,RS2",iword: "RD RS1 RS2 000000000000 0001 0000"}
AND    : {fmt: "RD,RS1,RS2",iword: "RD RS1 RS2 000000000000 0100 0000"}
OR     : {fmt: "RD,RS1,RS2",iword: "RD RS1 RS2 000000000000 0101 0000"}
XOR    : {fmt: "RD,RS1,RS2",iword: "RD RS1 RS2 000000000000 0110 0000"}
NAND   : {fmt: "RD,RS1,RS2",iword: "RD RS1 RS2 000000000000 1100 0000"}
NOR    : {fmt: "RD,RS1,RS2",iword: "RD RS1 RS2 000000000000 1101 0000"}
XNOR   : {fmt: "RD,RS1,RS2",iword: "RD RS1 RS2 000000000000 1110 0000"}
```

ALU-I

```
ADDI   : {fmt: "RD,RS1,imm",iword: "RD RS1 imm[15:0] 0000 1000"}
SUBI   : {fmt: "RD,RS1,imm",iword: "RD RS1 imm[15:0] 0001 1000"}
ANDI   : {fmt: "RD,RS1,imm",iword: "RD RS1 imm[15:0] 0100 1000"}
ORI    : {fmt: "RD,RS1,imm",iword: "RD RS1 imm[15:0] 0101 1000"}
XORI   : {fmt: "RD,RS1,imm",iword: "RD RS1 imm[15:0] 0110 1000"}
NANDI  : {fmt: "RD,RS1,imm",iword: "RD RS1 imm[15:0] 1100 1000"}
NORI   : {fmt: "RD,RS1,imm",iword: "RD RS1 imm[15:0] 1101 1000"}
XNORI  : {fmt: "RD,RS1,imm",iword: "RD RS1 imm[15:0] 1110 1000"}
MVHI   : {fmt: "RD,imm", iword: "RD 0000 imm[15:0] 1011 1000"}
```

Load/Store

```
LW     : {fmt: "RD,imm(RS1)", iword: "RD RS1 imm[15:0] 0000 1001"}
SW     : {fmt: "RS2,imm(RS1)",iword: "RS1 RS2 imm[15:0] 0000 0101"}
```

CMP-R

```
F      : {fmt: "RD,RS1,RS2", iword: "RD RS1 RS2 000000000000 0000 0010"}
EQ      : {fmt: "RD,RS1,RS2", iword: "RD RS1 RS2 000000000000 0001 0010"}
LT      : {fmt: "RD,RS1,RS2", iword: "RD RS1 RS2 000000000000 0010 0010"}
LTE     : {fmt: "RD,RS1,RS2", iword: "RD RS1 RS2 000000000000 0011 0010"}
T       : {fmt: "RD,RS1,RS2", iword: "RD RS1 RS2 000000000000 1000 0010"}
NE      : {fmt: "RD,RS1,RS2", iword: "RD RS1 RS2 000000000000 1001 0010"}
GTE     : {fmt: "RD,RS1,RS2", iword: "RD RS1 RS2 000000000000 1010 0010"}
GT      : {fmt: "RD,RS1,RS2", iword: "RD RS1 RS2 000000000000 1011 0010"}
```

CMP-I

```
FI      : {fmt: "RD,RS1,imm", iword: "RD RS1 imm[15:0] 0000 1010"}
EQI     : {fmt: "RD,RS1,imm", iword: "RD RS1 imm[15:0] 0001 1010"}
LTI     : {fmt: "RD,RS1,imm", iword: "RD RS1 imm[15:0] 0010 1010"}
LTEI    : {fmt: "RD,RS1,imm", iword: "RD RS1 imm[15:0] 0011 1010"}
TI      : {fmt: "RD,RS1,imm", iword: "RD RS1 imm[15:0] 1000 1010"}
NEI     : {fmt: "RD,RS1,imm", iword: "RD RS1 imm[15:0] 1001 1010"}
GTEI    : {fmt: "RD,RS1,imm", iword: "RD RS1 imm[15:0] 1010 1010"}
GTI     : {fmt: "RD,RS1,imm", iword: "RD RS1 imm[15:0] 1011 1010"}
```

BRANCH

```
BF      : {fmt: "RS1,RS2,imm", iword: "RS1 RS2 imm[15:0] 0000 0110"}
BEQ     : {fmt: "RS1,RS2,imm", iword: "RS1 RS2 imm[15:0] 0001 0110"}
BLT     : {fmt: "RS1,RS2,imm", iword: "RS1 RS2 imm[15:0] 0010 0110"}
BLTE    : {fmt: "RS1,RS2,imm", iword: "RS1 RS2 imm[15:0] 0011 0110"}
BEQZ    : {fmt: "RS1,imm", iword: "RS1 0000 imm[15:0] 0101 0110"}
BLTZ    : {fmt: "RS1,imm", iword: "RS1 0000 imm[15:0] 0110 0110"}
BLTEZ   : {fmt: "RS1,imm", iword: "RS1 0000 imm[15:0] 0111 0110"}

BT      : {fmt: "RS1,RS2,imm", iword: "RS1 RS2 imm[15:0] 1000 0110"}
BNE     : {fmt: "RS1,RS2,imm", iword: "RS1 RS2 imm[15:0] 1001 0110"}
BGTE    : {fmt: "RS1,RS2,imm", iword: "RS1 RS2 imm[15:0] 1010 0110"}
BGT     : {fmt: "RS1,RS2,imm", iword: "RS1 RS2 imm[15:0] 1011 0110"}
BNEZ    : {fmt: "RS1,imm", iword: "RS1 0000 imm[15:0] 1101 0110"}
BGTEZ   : {fmt: "RS1,imm", iword: "RS1 0000 imm[15:0] 1110 0110"}
BGTZ    : {fmt: "RS1,imm", iword: "RS1 0000 imm[15:0] 1111 0110"}

JAL     : {fmt: "RD,imm(RS1)", iword: "RD RS1 imm[15:0] 0000 1011"}
```

PSEUDO INSTRS

B is implemented using BEQ

```
BR      : {fmt: "imm", itext: ["BEQ R6,R6,imm"]}
```

NOT is implemented using NAND

```
NOT     : {fmt: "RD,RS", itext: ["NAND RD,RS,RS"]}
```

BLE, BGE are implemented using LTE/GTE and BNEZ

```
BLE     : {fmt: "RS1,RS2,imm", itext: ["LTE R6,RS1,RS2","BNEZ R6,imm"]}
```

```
BGE     : {fmt: "RS1,RS2,imm", itext: ["GTE R6,RS1,RS2","BNEZ R6,imm"]}
```

CALL/RET/JMP are implemented using JAL

```
CALL    : {fmt: "imm(RS1)", itext: ["JAL RA,imm(RS1)"]}
```

```
RET     : {fmt: "", itext: ["JAL R9,0(RA)"]}
```

```
JMP     : {fmt: "imm(RS1)", itext: ["JAL R9,imm(RS1)"]}
```

Single cycle processor specification

Requirements for the processor:

- It must implement the documented ISA.
- PC must start at (byte address) 0x40.
- SW to address 0xF0000000 must display bits 15 to 0 as hexadecimal digits on the HEX display.
- SW to address 0xF0000004 must display bits 9 to 0 on LEDR.
- SW to address 0xF0000008 must display bits 7 to 0 on LEDG.
- LW from address 0xF0000010 must read the current KEY state. The result should be 0 when no KEY pressed, and 0xF when all are pressed.
- LW from address 0xF0000014 reads SW state.
- The 32-bit value we read should really be {22'b0,SWd) where SWd is a debounced value of SW.

Assembler specification

The assembler must read an assembly file containing a program that follows the ISA spec, and it must output a MIF file with 2048 32-bit words of memory (8192 bytes in total).

Opcode and function mappings

For the following tables, the rows indices represent the most significant bits (MSB) and the column indices are the LSB.

General opcode mapping

LSB MSB	00	01	10	11
00	ALU-R		CMP-R	
01		SW	BRANCH	
10	ALU-I	LW	CMP-I	JAL
11				

ALU-R/ALU-I function mapping

LSB MSB	00	01	10	11
00	ADD/ADDI	SUB/SUBI		
01	AND/ANDI	OR/ORI	XOR/XORI	
10				
11	NAND/NANDI	NOR/NORI	NXOR/NXORI	

CMP-R/CMP-I function mapping

MSB \ LSB	00	01	10	11
00	F/FI	EQ/EQI	LT/LTI	LTE/LTEI
01				
10	T/TI	NE/NEI	GTE/GTEI	GT/GTI
11				

BRANCH function mapping

MSB \ LSB	00	01	10	11
00	BF	BEQ	BLT	BLTE
01		BEQZ	BLTZ	BLTEZ
10	BT	BNE	BGTE	BGT
11		BNEZ	BGTEZ	BGTZ

Instruction format

- ALU-R
 - $rd = rs1 \text{ op } rs2$
- CMP-R
 - $rd = (rs1 \text{ op } rs2) ? 1 : 0$
- Store
 - $Mem[rs1 + \text{signextension}(imm)] = rs2$
- Load
 - $rd = Mem[rs1 + \text{signextension}(imm)]$
- ALU-I
 - $rd = rs1 \text{ op } \text{signextension}(imm)$
- CMP-I
 - $rd = (rs1 \text{ op } \text{signextension}(imm)) ? 1 : 0$
- BRANCH
 - if $(rs1 \text{ op } rs2)$ $PC = PC + 4 + (\text{signextension}(imm) * 4)$
- JAL
 - $rd = PC + 4$
 - $PC = rs1 + 4 * \text{signextension}(imm)$

Assembler syntax

- Instruction opcodes and register names:

- Are **reserved words (can't be used as labels).**
 - Appear in **either lowercase or uppercase.**
 - If there is a destination register, it is listed first.
- Labels:
 - Are created using a name and then ":" at the start of a line
 - **Corresponds to the address where label created**
- Immediate operands – number or label
 - If number, hex (C format, e.g. 0xffff) or decimal (can have - sign)
 - If label, just use the name of the label (without ":")
 - For PC-relative, the **immediate field is label_addr-PC-4**
 - For other insts, the **immediate field is 16 least-significant bits of label_addr**
- Each register has multiple names:
 - R0..R3 are also A0..A3 (function arguments, caller saved)
 - R3 is also RV (return value, caller saved)
 - R4..R5 are also T0..T1 (temporaries, caller saved)
 - R6..R8 are also S0..S2 (callee-saved values)
 - R9 reserved for assembler use
 - R10..R11 reserved for system use (we'll see later for what)
 - R12 is GP (global pointer)
 - R13 is FP (frame pointer)
 - R14 is SP (stack pointer)
 - Stack grows down, SP points to lowest in-use address
 - R15 is RA (return address)

Special assembler instructions

- .ORIG <number>
 - Changes "current" address to <number>
- .WORD <value>
 - Places 32-bit word <value> at the current address
 - <value> can be a number or a label name
 - If label name, value is the full 32-bit label_addr
- .NAME <name>=<value>
 - Defines a name (label) with a given value (number)