

Design a **hardwired control unit** for the following architecture. Use the structure that you have designed in **Part 4 of Project 1**.

### INSTRUCTION FORMAT

The instructions are stored in memory in **little-endian order**. Since the RAM in Project 1 has an 8-bit output, **the instruction register cannot be filled in one clock cycle**. You can load MSB and LSB in 2 clock cycles.

- In the first clock cycle ( $T=0$ ), the LSB of the instruction must be loaded from an address A of the memory to the LSB of IR [i.e., IR(7-0)].
- In the second clock cycle ( $T=1$ ), the MSB of the instruction must be loaded from an address A+1 of the memory to the MSB of IR [i.e., IR(15-8)].
- After the second clock cycle ( $T=2$ ), the instruction starts to execute.

There are 2 types of instructions as described below.

1- Instructions with address reference have the format shown in Figure 1.

- The **OPCODE** is a **6-bit field**. (Table 1 is given for opcode definition.)
- The **RSEL** is a **2-bit field**. (Table 2 is given for register selection.)
- The **ADDRESS** is an **8-bit field**.

OPCODE (6-bit)	RSEL (2-bit)	ADDRESS (8-bit)
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*Figure 1: Instructions with an address reference.*

2- Instructions without an address reference have the format shown in Figure 2.

- The **OPCODE** is a **6-bit field**. (Table 1 is given for opcode definition.)
- The **S** is a **1-bit field** that specifies whether the flags will change or not.
- The **DSTREG** is a **3-bit field** that specifies the destination register. (Table 3 is given.)
- The **SREG1** is a **3-bit field** that specifies the first source register. (Table 3 is given.)
- The **SREG2** is a **3-bit field** that specifies the second source register. (Table 3 is given.)

OPCODE (6-bit)	S (1-bit)	DSTREG(3-bit)	SREG1 (3-bit)	SREG2 (3-bit)
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*Figure 2: Instructions without an address reference.*

Table 1: OPCODE field and symbols for operations and their descriptions.

OPCODE (HEX)	SYMBOL	DESCRIPTION
0x00	BRA	$PC \leftarrow PC + \text{VALUE}$
0x01	BNE	IF Z=0 THEN $PC \leftarrow PC + \text{VALUE}$
0x02	BEQ	IF Z=1 THEN $PC \leftarrow PC + \text{VALUE}$
0x03	POP	$SP \leftarrow SP + 1, Rx \leftarrow M[SP]$
0x04	PSH	$M[SP] \leftarrow Rx, SP \leftarrow SP - 1$
0x05	INC	$DSTREG \leftarrow SREG1 + 1$
0x06	DEC	$DSTREG \leftarrow SREG1 - 1$
0x07	LSL	$DSTREG \leftarrow LSL\ SREG1$
0x08	LSR	$DSTREG \leftarrow LSR\ SREG1$
0x09	ASR	$DSTREG \leftarrow ASR\ SREG1$
0x0A	CSL	$DSTREG \leftarrow CSL\ SREG1$
0x0B	CSR	$DSTREG \leftarrow CSR\ SREG1$
0x0C	AND	$DSTREG \leftarrow SREG1\ \text{AND}\ SREG2$
0x0D	ORR	$DSTREG \leftarrow SREG1\ \text{OR}\ SREG2$
0x0E	NOT	$DSTREG \leftarrow \text{NOT}\ SREG1$
0x0F	XOR	$DSTREG \leftarrow SREG1\ \text{XOR}\ SREG2$
0x10	NAND	$DSTREG \leftarrow SREG1\ \text{NAND}\ SREG2$
0x11	MOVH	$DSTREG[15:8] \leftarrow \text{IMMEDIATE (8-bit)}$
0x12	LDR (16-bit)	$Rx \leftarrow M[AR]$ (AR is 16-bit register)
0x13	STR (16-bit)	$M[AR] \leftarrow Rx$ (AR is 16-bit register)
0x14	MOVL	$DSTREG[7:0] \leftarrow \text{IMMEDIATE (8-bit)}$
0x15	ADD	$DSTREG \leftarrow SREG1 + SREG2$
0x16	ADC	$DSTREG \leftarrow SREG1 + SREG2 + \text{CARRY}$
0x17	SUB	$DSTREG \leftarrow SREG1 - SREG2$
0x18	MOVS	$DSTREG \leftarrow SREG1$ , Flags will change
0x19	ADDS	$DSTREG \leftarrow SREG1 + SREG2$ , Flags will change
0x1A	SUBS	$DSTREG \leftarrow SREG1 - SREG2$ , Flags will change
0x1B	ANDS	$DSTREG \leftarrow SREG1\ \text{AND}\ SREG2$ , Flags will change
0x1C	ORRS	$DSTREG \leftarrow SREG1\ \text{OR}\ SREG2$ , Flags will change
0x1D	XORS	$DSTREG \leftarrow SREG1\ \text{XOR}\ SREG2$ , Flags will change
0x1E	BX	$M[SP] \leftarrow PC, PC \leftarrow Rx$
0x1F	BL	$PC \leftarrow M[SP]$
0x20	LDRIM	$Rx \leftarrow \text{VALUE}$ (VALUE defined in ADDRESS bits)
0x21	STRIM	$M[AR+\text{OFFSET}] \leftarrow Rx$ (AR is 16-bit register) (OFFSET defined in ADDRESS bits)

Table 2: RSEL table.

RSEL	REGISTER
00	R1
01	R2
10	R3
11	R4

Table 3: DSTREG/SREG1/SREG2 selection table.

DSTREG/SREG1/SREG2	REGISTER
000	PC
001	PC
010	SP
011	AR
100	R1
101	R2
110	R3
111	R4

## SIMPLE EXAMPLE

Since the PC value is initially 0, your code first executes the instruction in memory address 0x00. This instruction is BRA START\_ADDRESS where START\_ADDRESS is the starting address of your instructions.

You have to determine the binary code of the program and write it to memory. Your final Verilog implementation is expected to fetch the instructions starting from address 0x00, decode them, and execute all instructions one by one.

	BRA 0x28	# This instruction is written to the memory address 0x00, # The first instruction must be written to address 0x28
	MOVH R1, 0x00	
	MOVL R1, 0x0A	# This first instruction is written to the address 0x28, # R1 is used for the number of iterations
	MOVH R2, 0x00	
	MOVL R2, 0x00	# R2 is used to store total
	MOVH R3, 0x00	
	MOVL R3, 0xB0	
	MOVS AR, R3	# AR is used to track data address: starts from 0xA0
LABEL:	LDR R3	# $R3 \leftarrow M[AR]$ ( $AR = 0xB0$ to $0xBA$ )
	ADD R2, R2, R3	# $R2 \leftarrow R2 + R3$ (Total = Total + $M[AR]$ )
	INC AR, AR	# $AR \leftarrow AR + 1$ (Next Data)
	DEC R1, R1	# $R1 \leftarrow R1 - 1$ (Decrement Iteration Counter)
	BNE LABEL	# Go back to LABEL if Z=0 (Iteration Counter > 0)
	INC AR, AR	# $AR \leftarrow AR + 1$ (Total will be written to 0xBB)
	STR R2	# $M[AR] \leftarrow R2$ (Store Total at 0xBB)

**Submission:** Implement your design in Verilog HDL, and upload your design, simulation & Memory files to Ninova before the deadline. Only one student from each group should submit the project files (select one member of the group as the group representative for this purpose and note his/her student ID). Project files should contain your modules file (.v), simulation file (.v), memory (.mem), and a report that contains:

- the number & names of the students in the group
- information about your control unit design

If you are working as a group, all members of the group must design together. Make sure to add simulations for all modules. You must ensure that all modules work properly.