

1000 *Multi-Cycle CPU*

ENGR 3410 - Computer Architecture
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Fall 2008

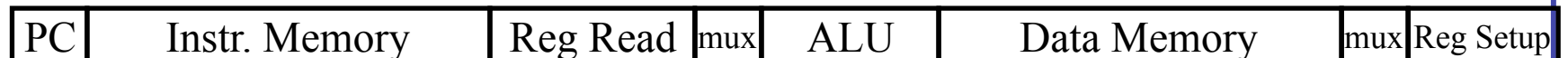
Performance of Single-Cycle Machine

CPI = 1.0, but what about cycle time? Unit reuse (l.e. adder for PC vs. ALU)

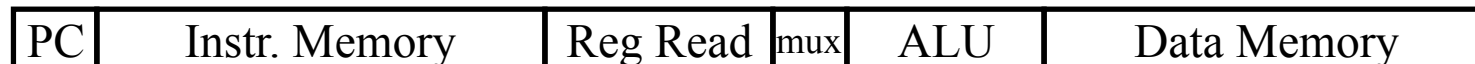
Arithmetic & Logic



Load



Store



Branch

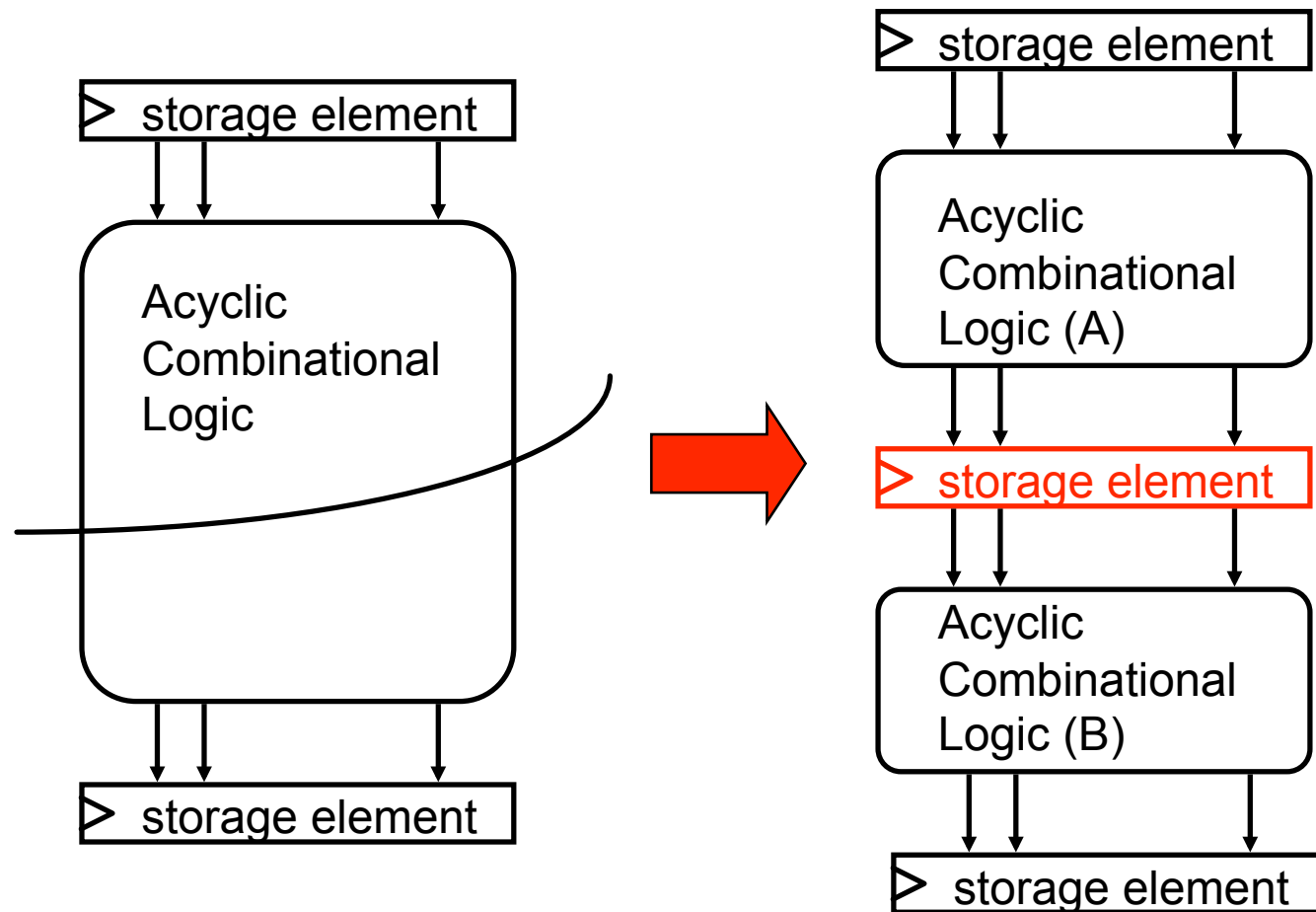


Jump



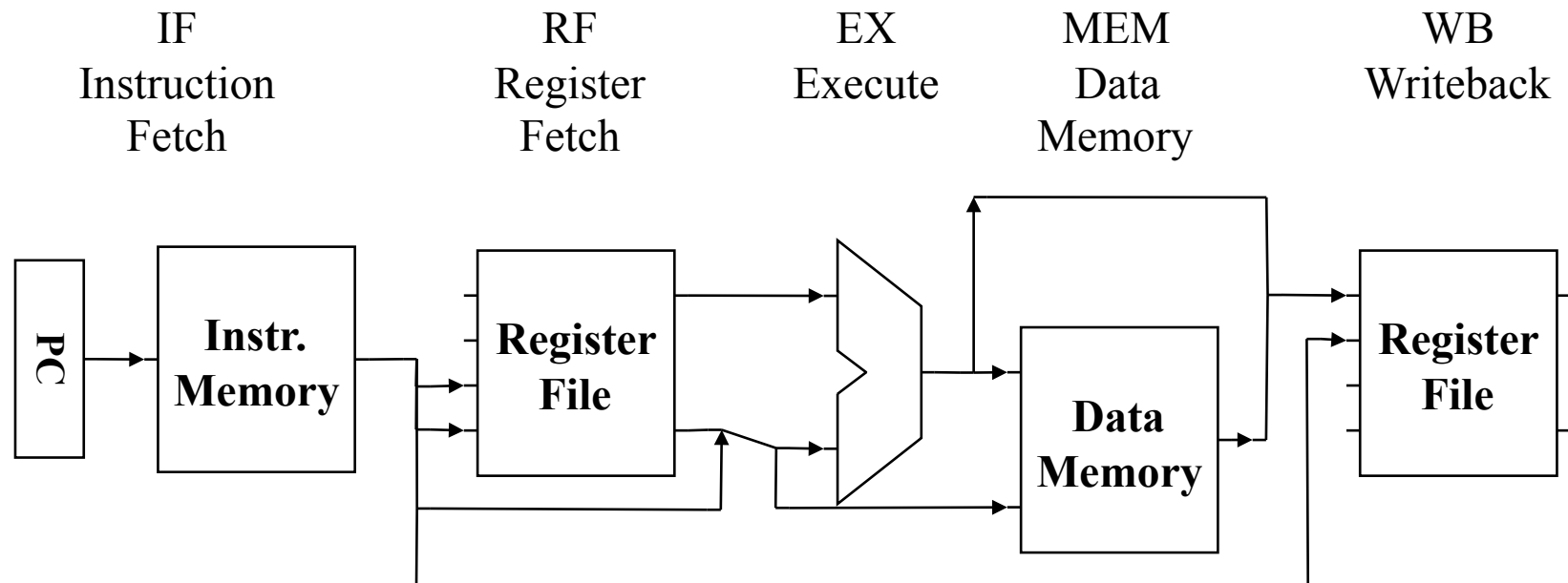
Reducing Cycle Time

- Cut combinational dependency graph and insert register / latch
- Do same work in two fast cycles, rather than one slow one



Multicycle Processor Overview

- Divide datapath into multiple cycles



Multicycle Processor Changes

- Only one memory
 - Shared between instructions and data
- Only one ALU/adder
 - Use ALU for instructions & PC computations
- Add registers to datapath
 - IR: instruction register
 - MDR: Memory Data Register
 - A & B: Values read from register file
 - ALUout: Output of ALU

Cycle 1: Instruction Fetch

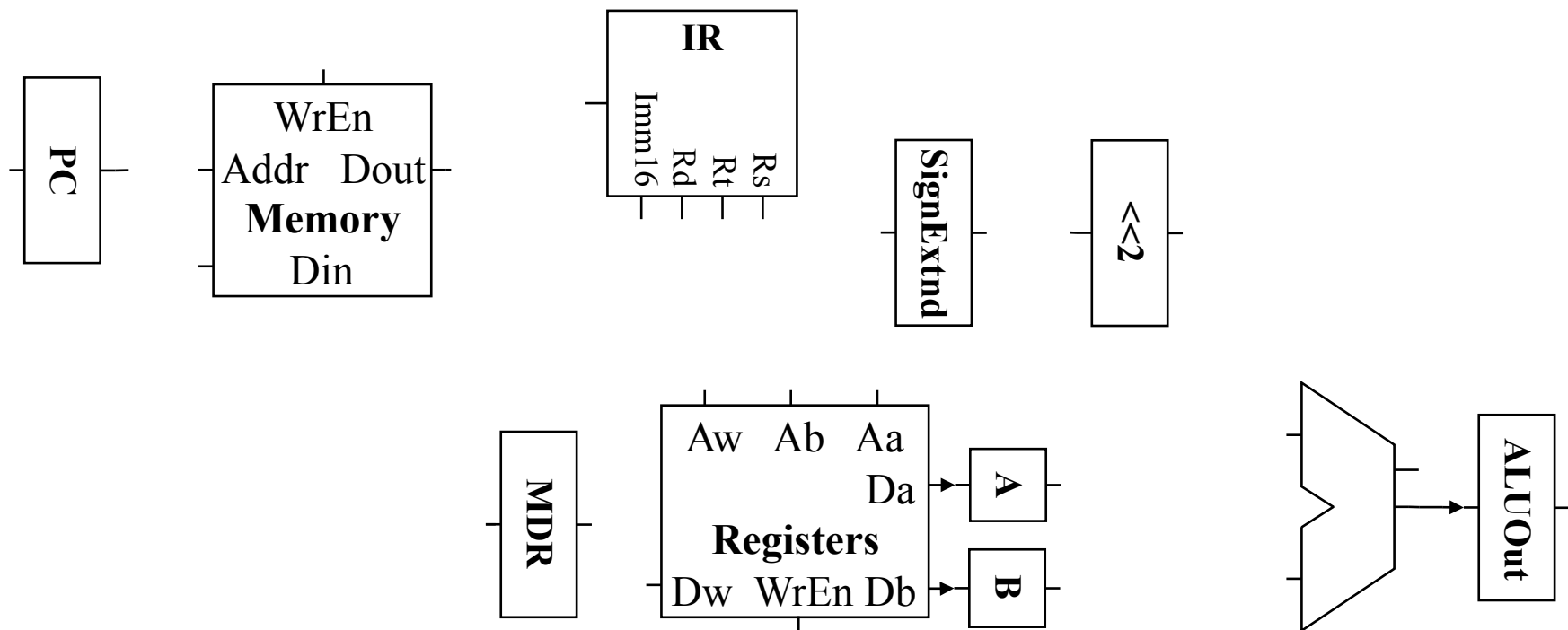
- Put the instruction to execute into the Instruction Register (IR)

RTL:

- Set the PC to the next instruction (ignore branches)

RTL:

Cycle 1 Datapath



Cycle 2: Instruction Decode, Register Fetch

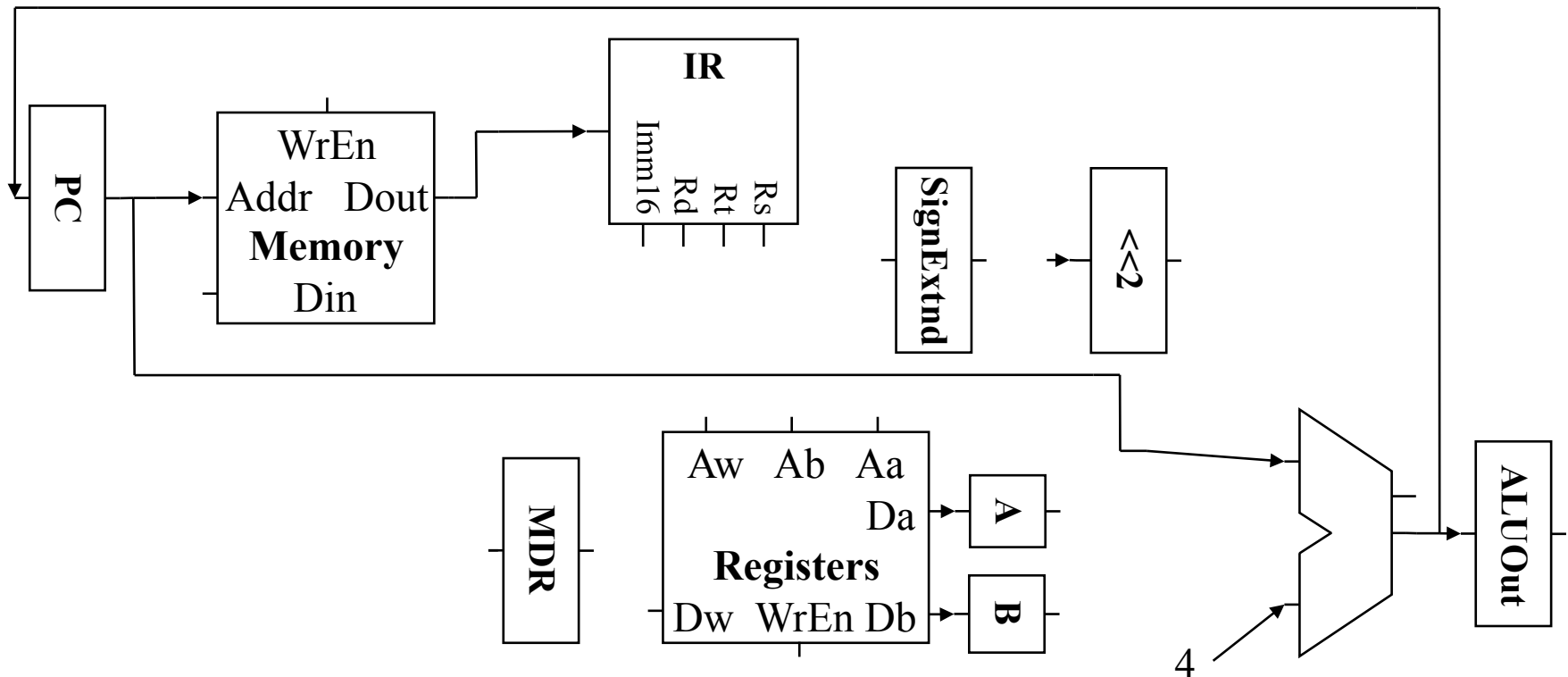
- Store the two GPR operands into registers A and B

RTL:

- Compute Branch Target (in case it's a branch operation, won't have time later)

RTL:

Cycle 1+2 Datapath

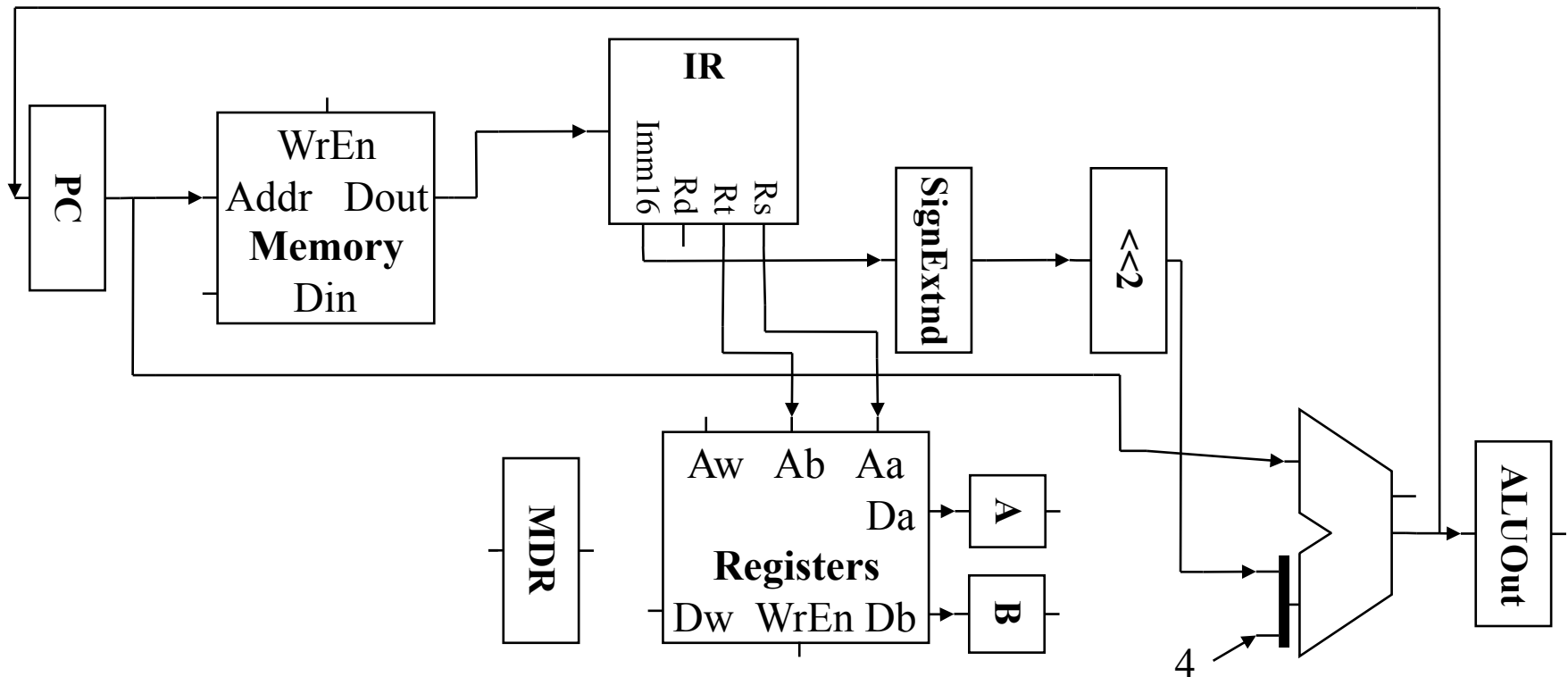


Cycle 3 (Branch)

- Branch (Beq) - Branch address in ALUout. Set PC to branch address if $A=B$

RTL:

Branch Datapath



Cycle 3-4 (Add, Subtract)

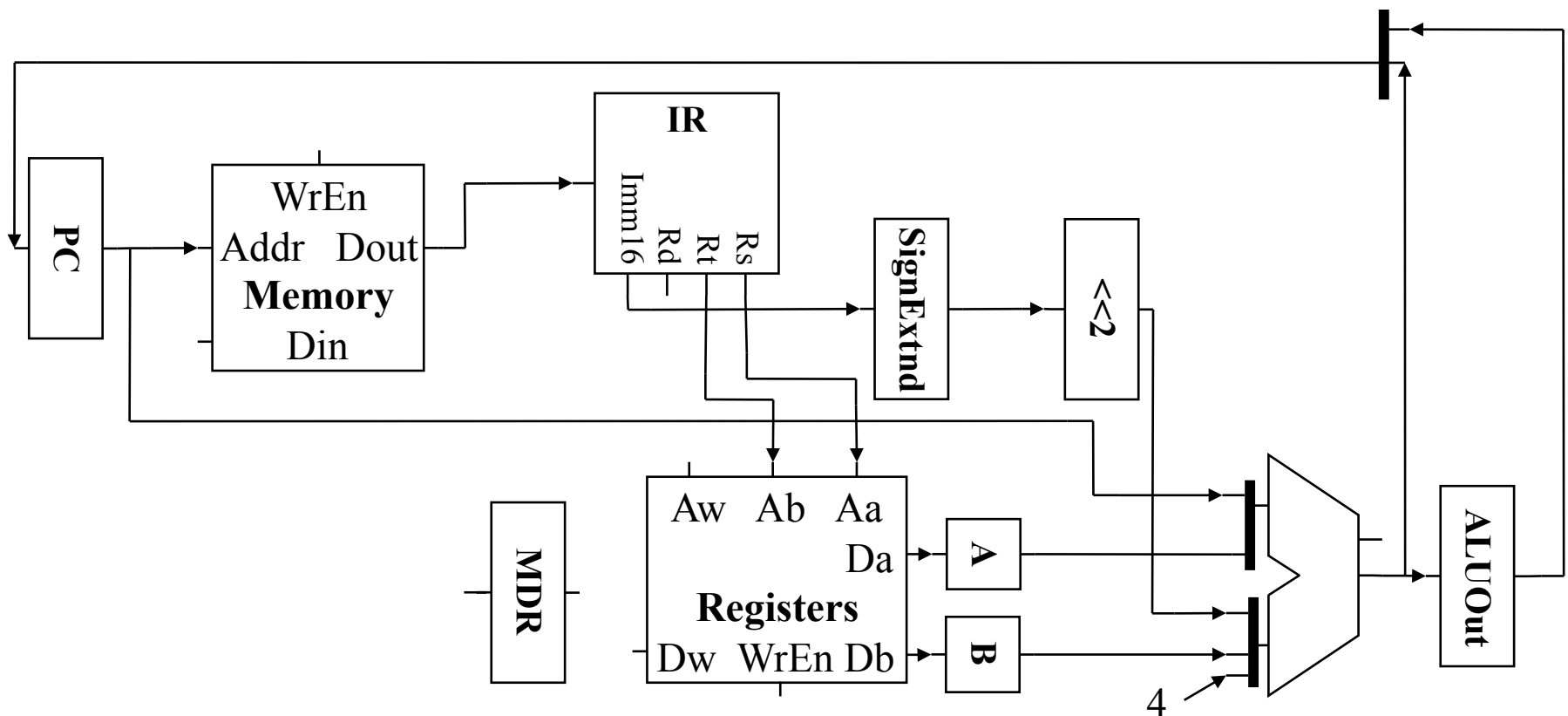
- Cycle 3: compute function in ALU, operands in A & B. Store in ALUout

RTL:

- Cycle 4: Write value from ALUout to destination register

RTL:

Branch, R-Type Datapath



Cycle 3-4 (Store)

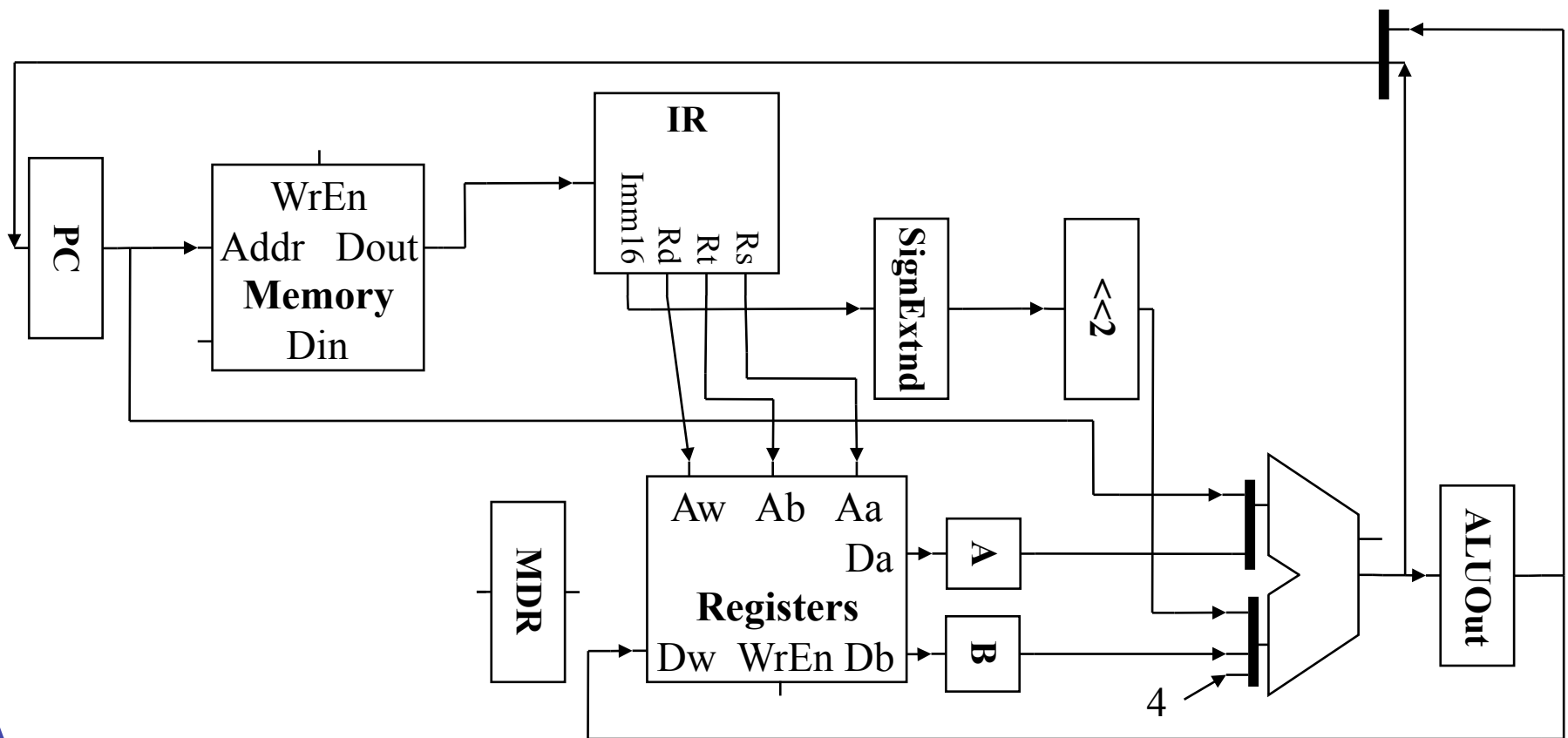
- Cycle 3: compute address from operand A and IR[15-0], put into ALUout

RTL:

- Cycle 4: Store value from operand B to address specified in ALUout

RTL:

Branch, R-Type, Store Datapath



Cycle 3-5 (Load)

- Cycle 3: compute address from operand A and IR[15-0], put into ALUout

RTL:

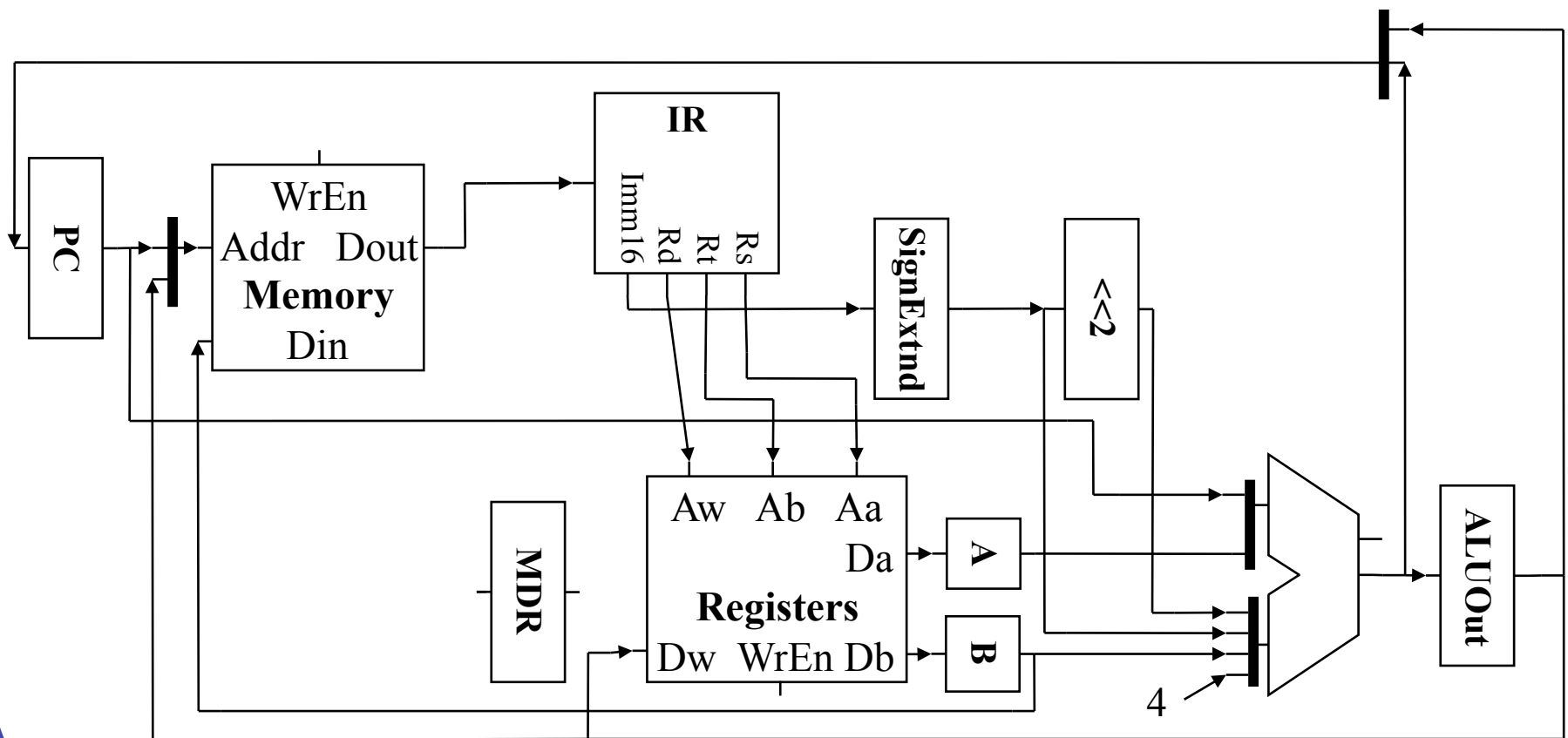
- Cycle 4: Load value from address specified in ALUout to MDR

RTL:

- Cycle 5: Write value from MDR to destination register

RTL:

Multicycle Processor Datapath



Multicycle Processor Control

- Need to control data path to perform required operations
 - Multiple cycles w/different control values each cycle, so control is an FSM.

Cycle 1: $IR = Mem[PC]; PC = PC + 4$

Cycle 2: $A = Reg[RS]; B = Reg[Rt];$
 $ALUOut = PC + (Sign-extend(Imm16) \ll 2)$

Cycle 3 Branch: $Zero = (A-B);$ If (zero) $PC = ALUOut$

Cycle 3 R-Type: $ALUOut = A \text{ op } B$

Cycle 4 R-Type: $Reg[Rd] = ALUOut$

Cycle 3 Store: $ALUOut = A + sign-extend(Imm16)$

Cycle 4 Store: $Mem[ALUOut] = B$

Cycle 3 Load: $ALUOut = A + sign-extend(Imm16)$

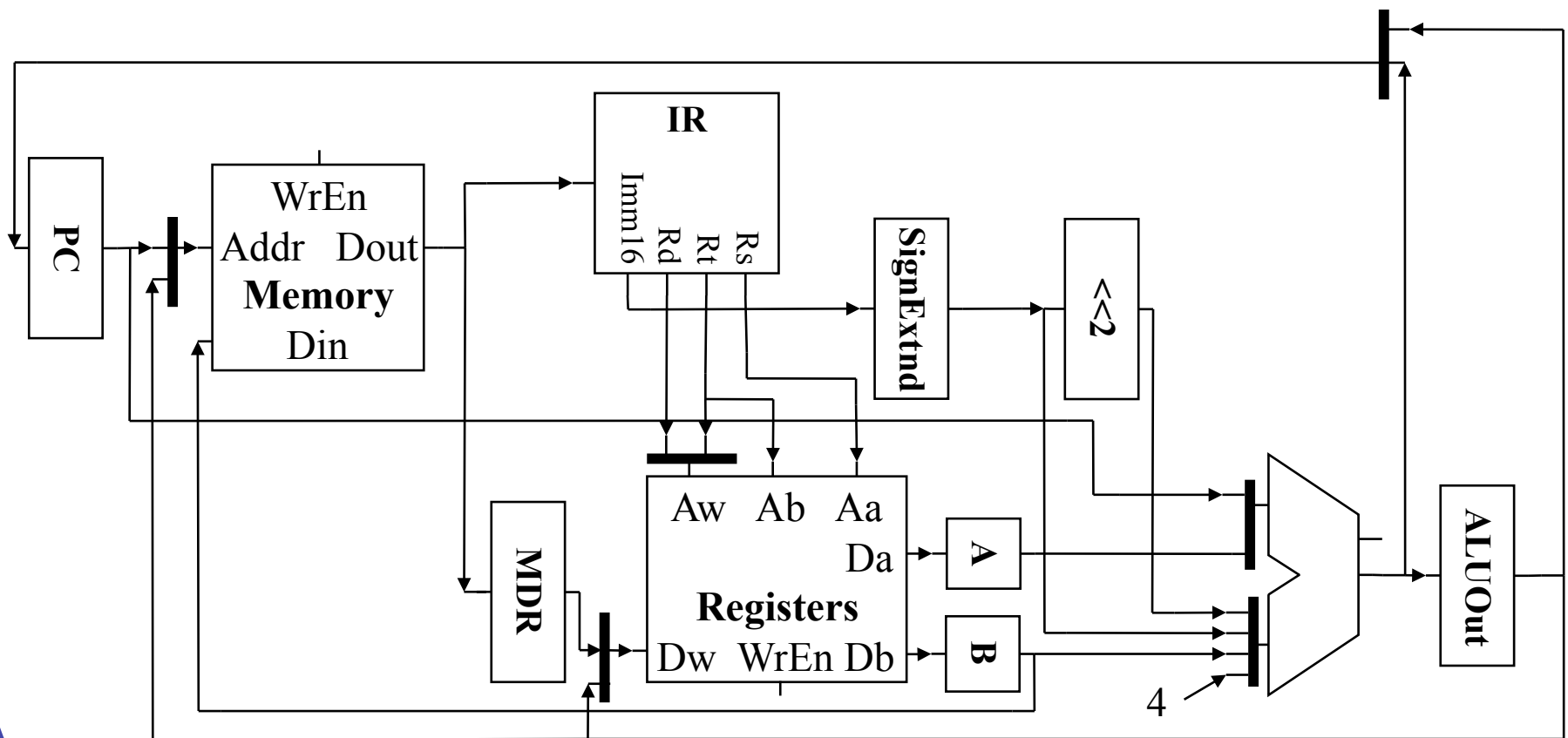
Cycle 4 Load: $MDR = Mem[ALUOut]$

Cycle 5 Load: $Reg[Rt] = MDR$

Control FSM

- **Opcodes:** LW 35, SW 43, BEQ 4, add/sub 0

Datapath Control Signals



Multicycle Datapath Control

	WE				ALU						
State	PC	Mem	Reg	IR	SrcA	SrcB	Op	Dest	MemIn	RegIn	PCSrc
1											
2											
3Br											
3Rt											
4Rt											
3St											
4St											
3Lo											
4Lo											
5Lo											
					A	<<2		Rt[20:16]	PC	MDR	ALU
					PC	SE		Rd[15:11]	ALUout	ALUout	ALUout
						B					
						4					

```

1:
IR = Mem[PC]
PC = PC + 4

2:
A = Reg[Rs]
B = Reg[Rt]
ALUOut = PC
    + (SE(imm16)<<2)

3Br:
Zero = (A-B)
If (zero) PC = ALUout

3Rt:
ALUout = A op B

4Rt:
Reg[Rd] = ALUout

3St:
ALUout = A + SE(Imm16)

4St:
Mem[ALUout] = B

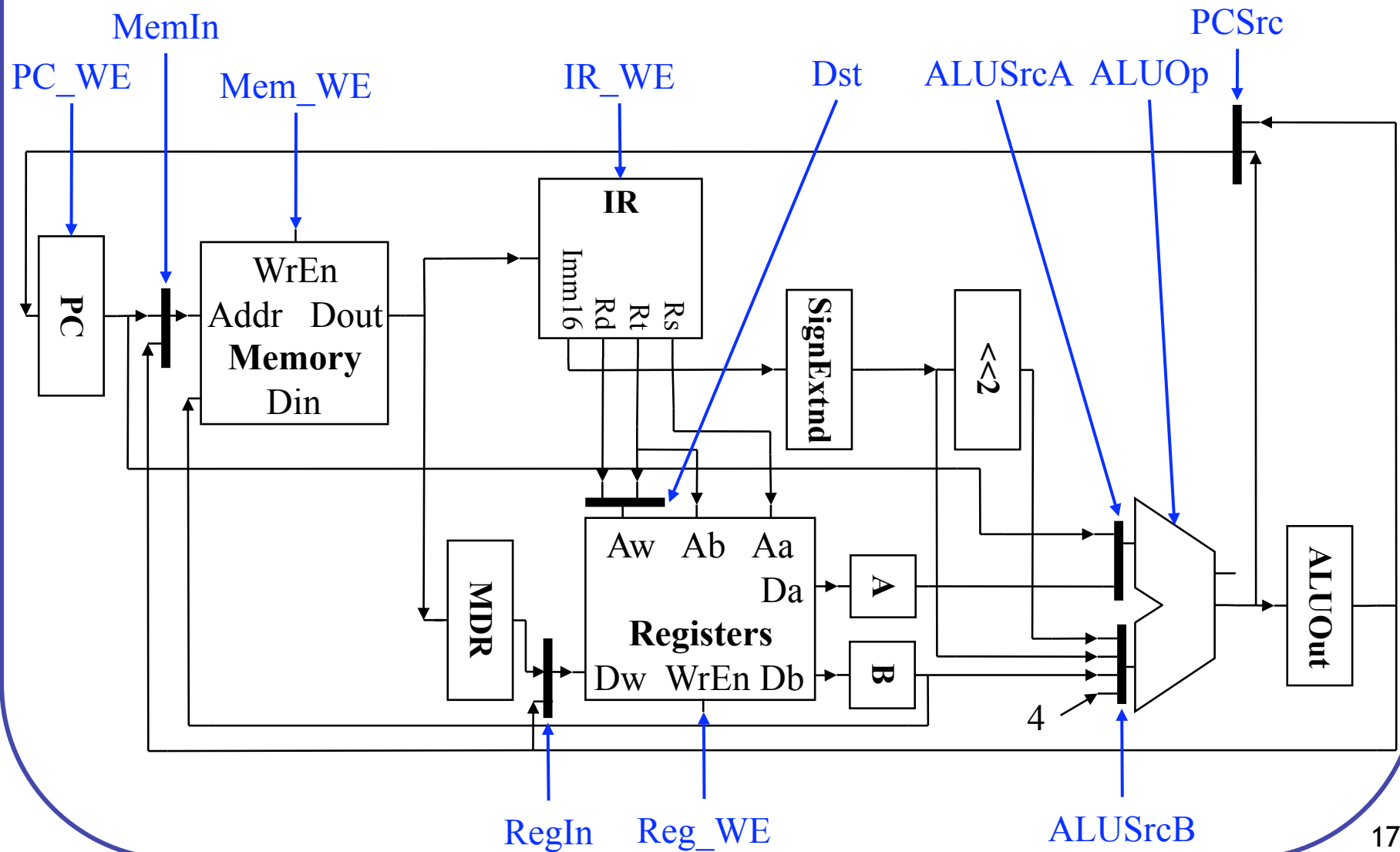
3Lo:
ALUout = A + SE(Imm16)

4Lo:
MDR = Mem[ALUout]

5Lo:
Reg[Rt] = MDR
    
```

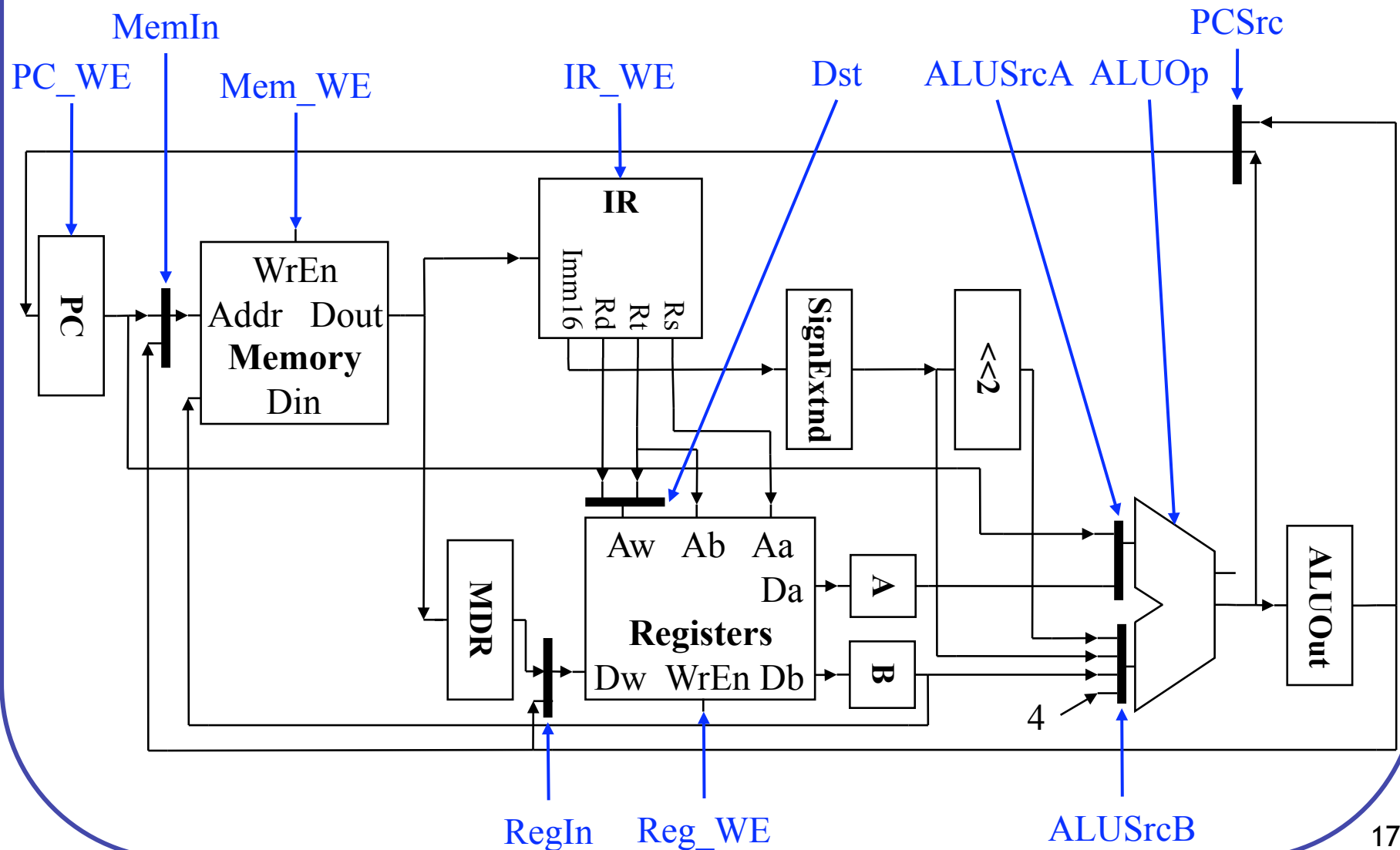
Cycle 1 Control

- $IR = Mem[PC]; PC = PC + 4$



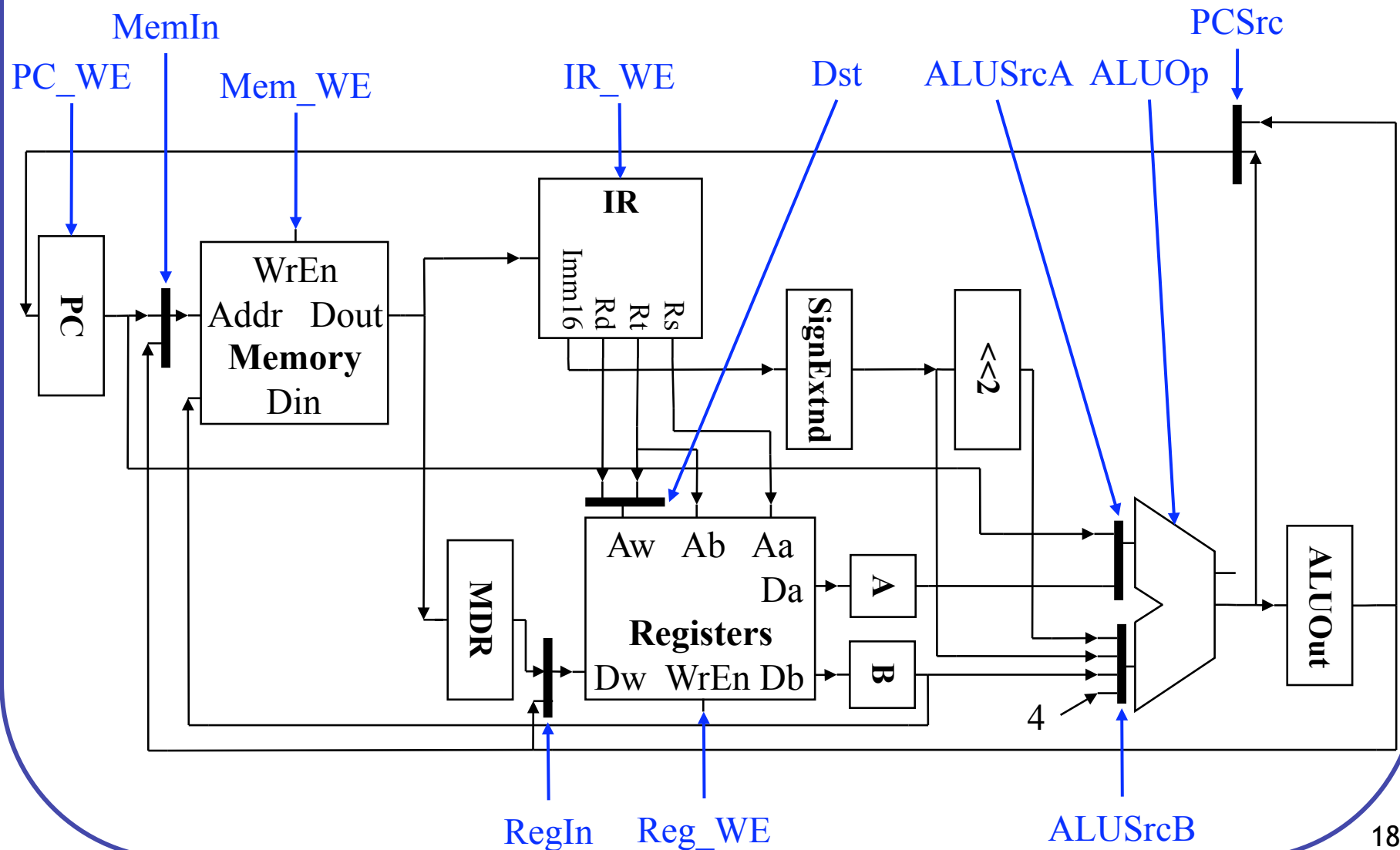
Cycle 2 Control

- $A = \text{Reg}[Rs]; B = \text{Reg}[Rt]; \text{ALUOut} = \text{PC} + (\text{Sign-extend}(\text{Imm16}) \ll 2)$



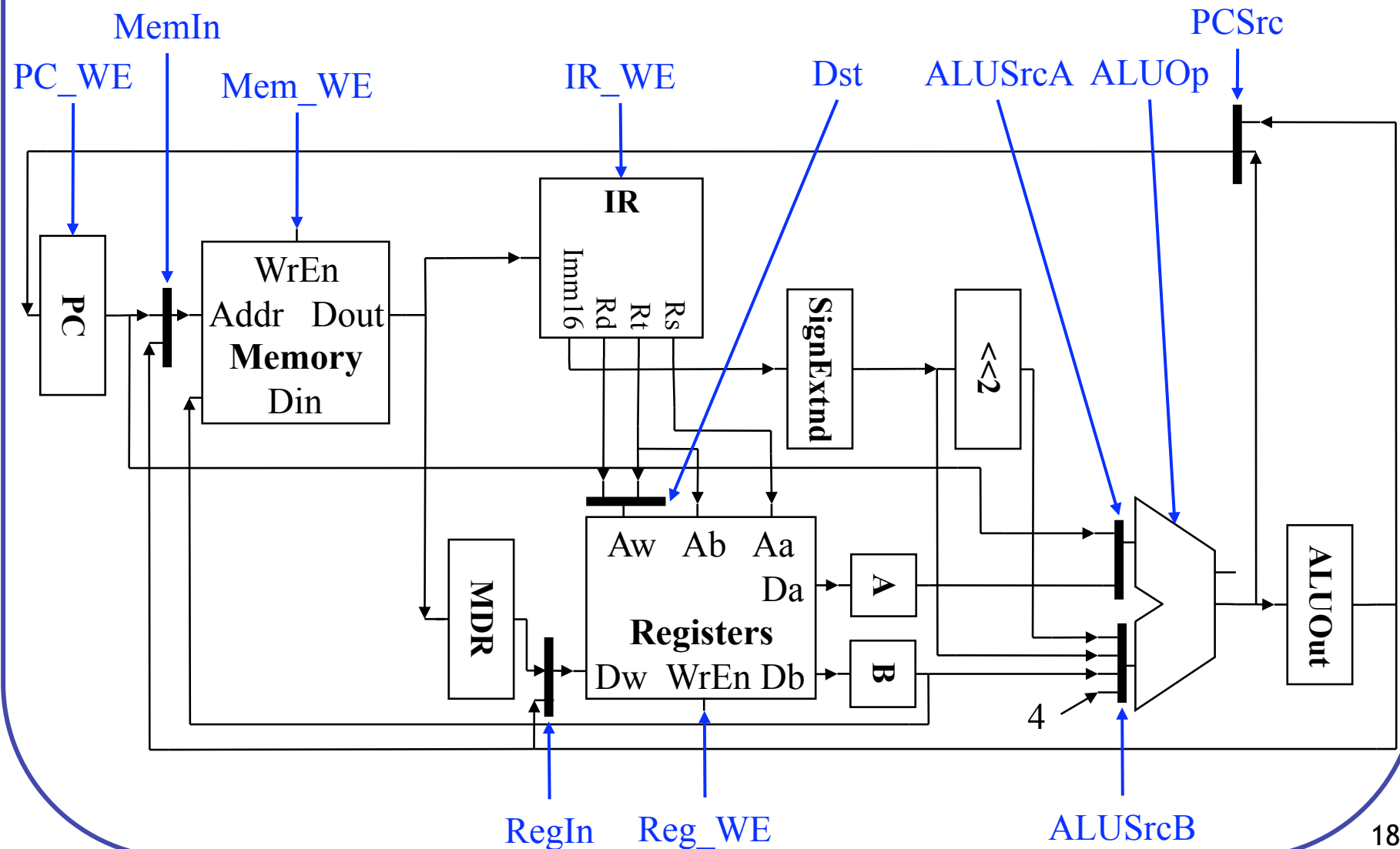
Cycle 3 (Branch) Control

- Zero = (A-B); If (zero) PC = ALUOut



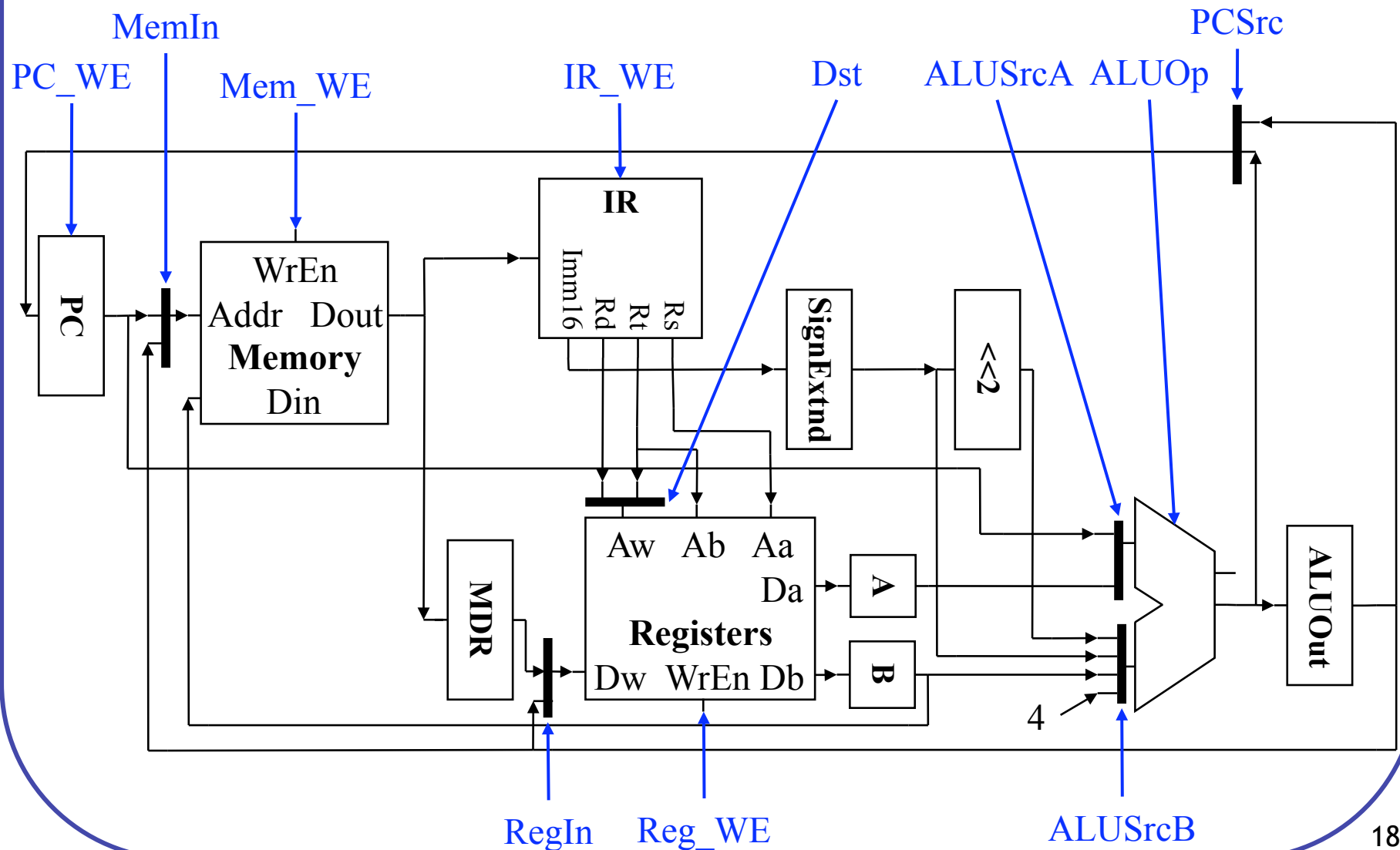
Cycle 3 (R-Type) Control

- $ALU_{out} = A \text{ op } B$



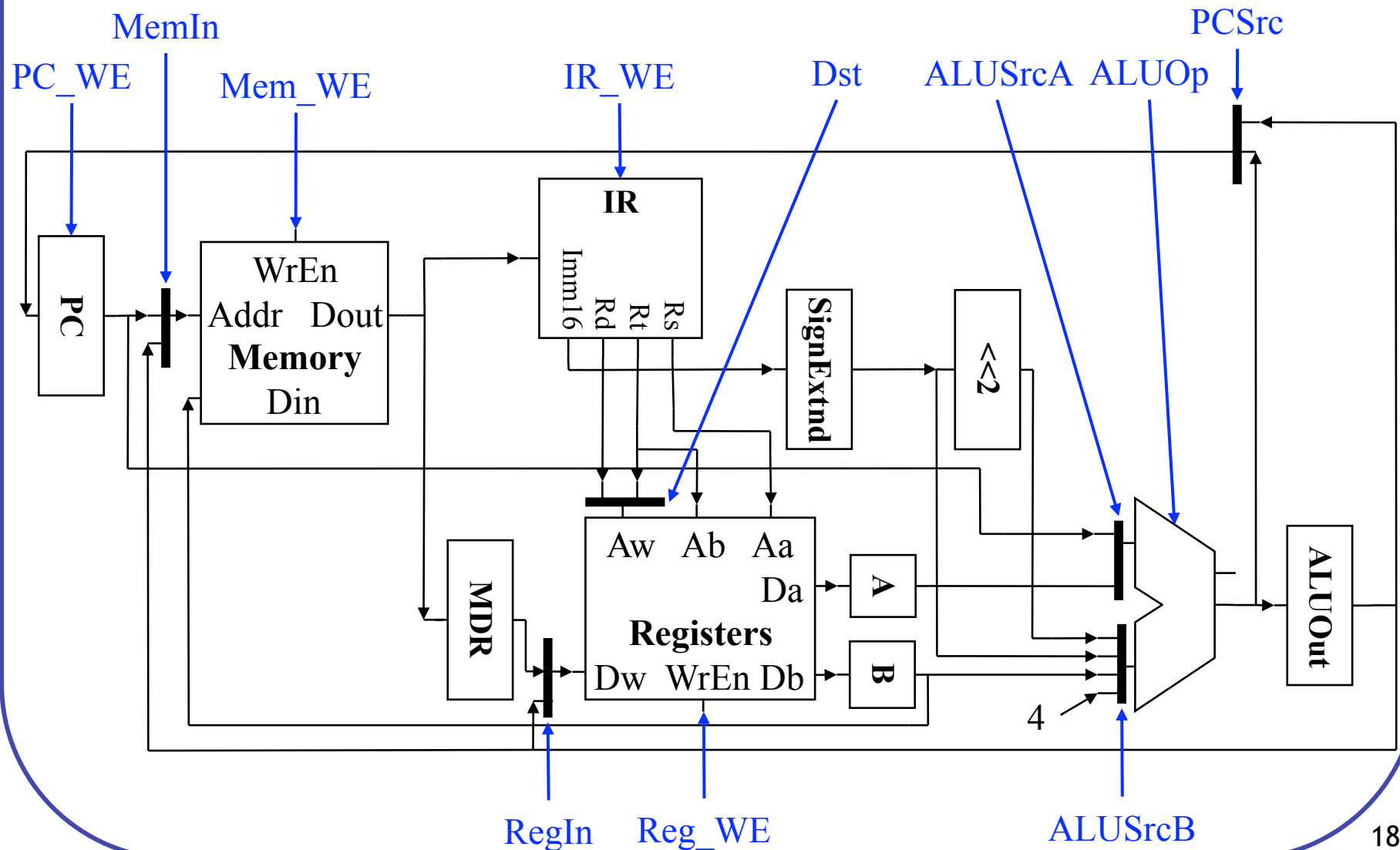
Cycle 4 (R-Type) Control

- $\text{Reg}[\text{Rd}] = \text{ALUout}$



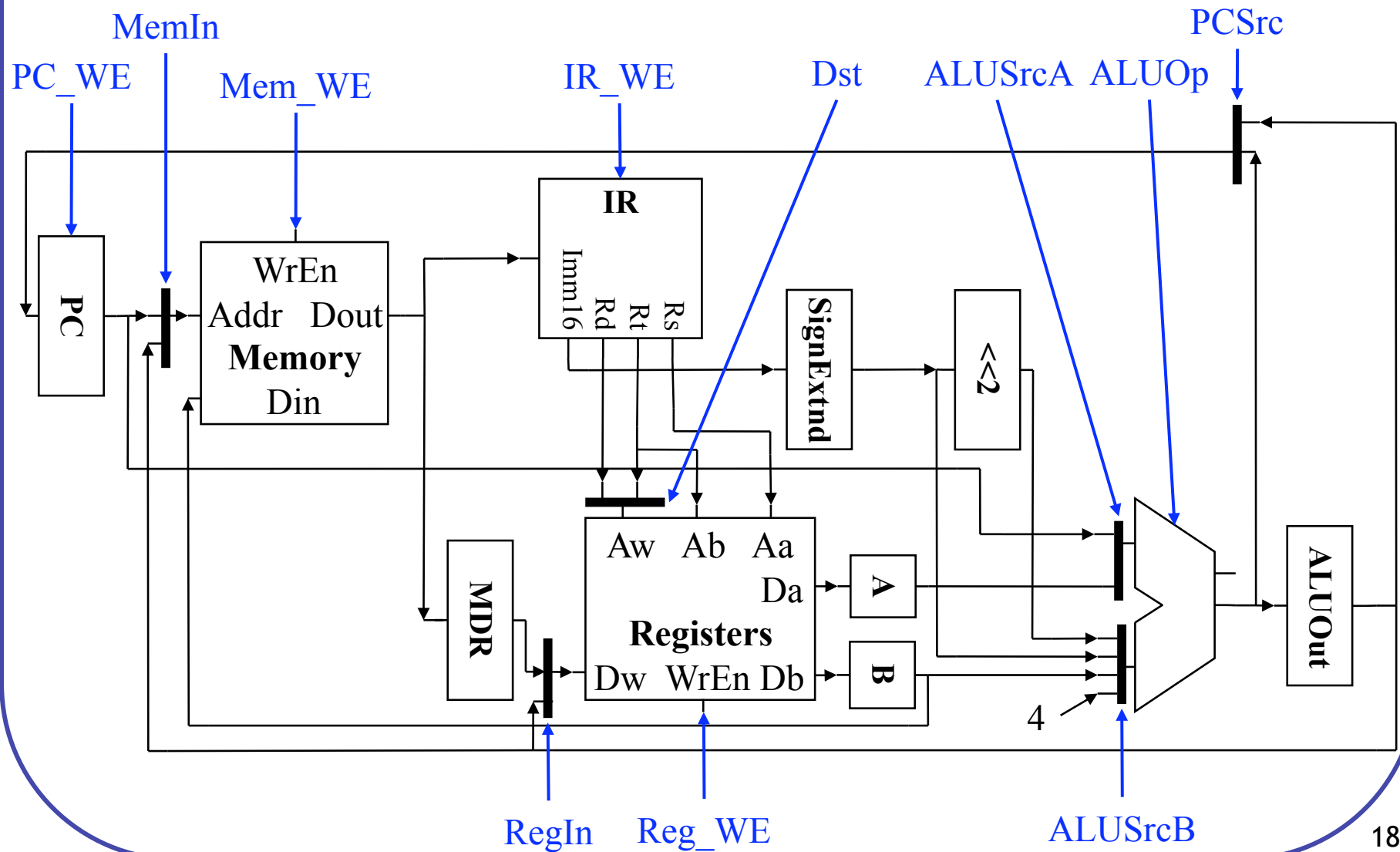
Cycle 3 (Store) Control

- $ALU_{out} = A + \text{sign-extend}(Imm16)$



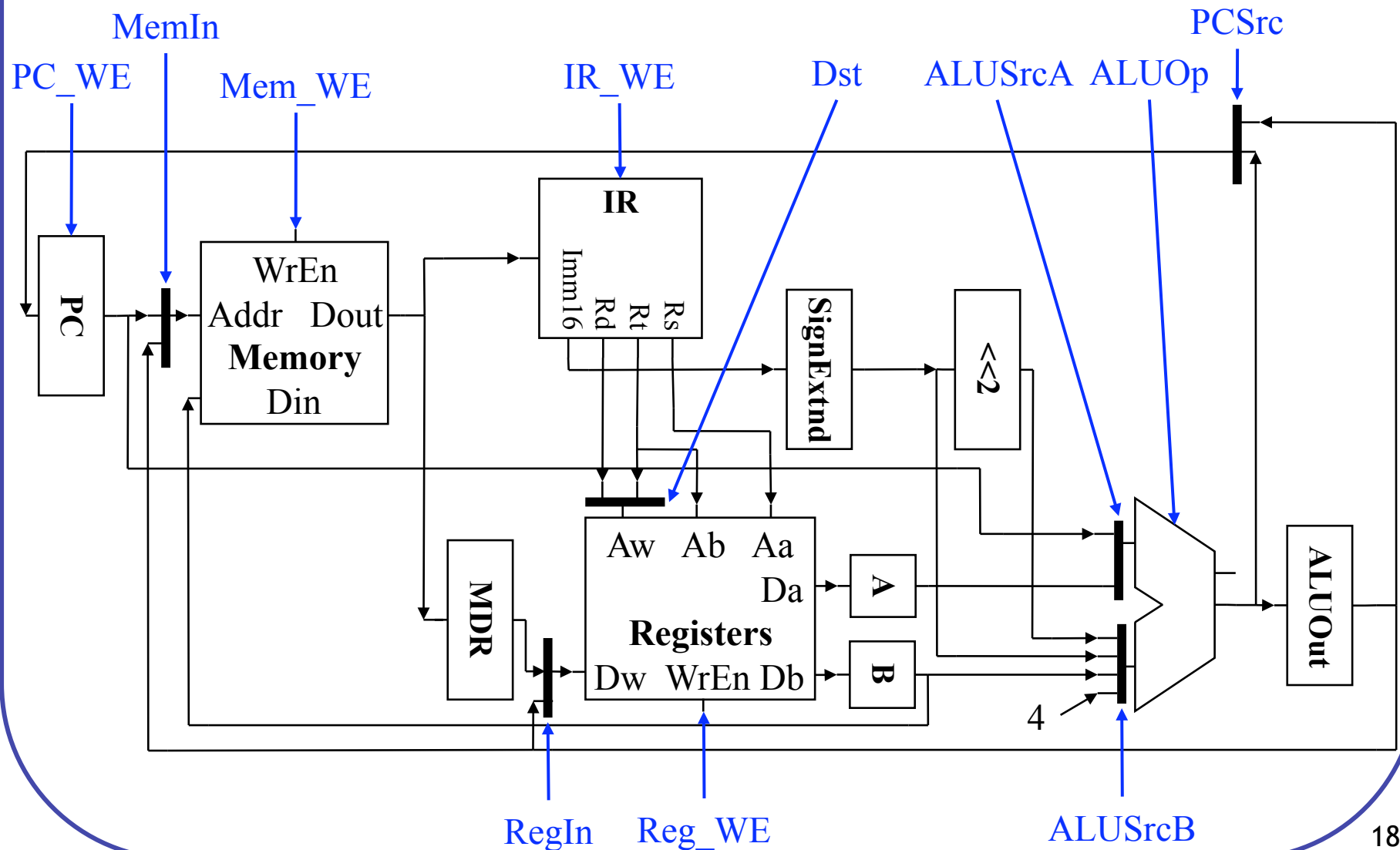
Cycle 4 (Store) Control

- $\text{Mem}[\text{ALUOut}] = B$



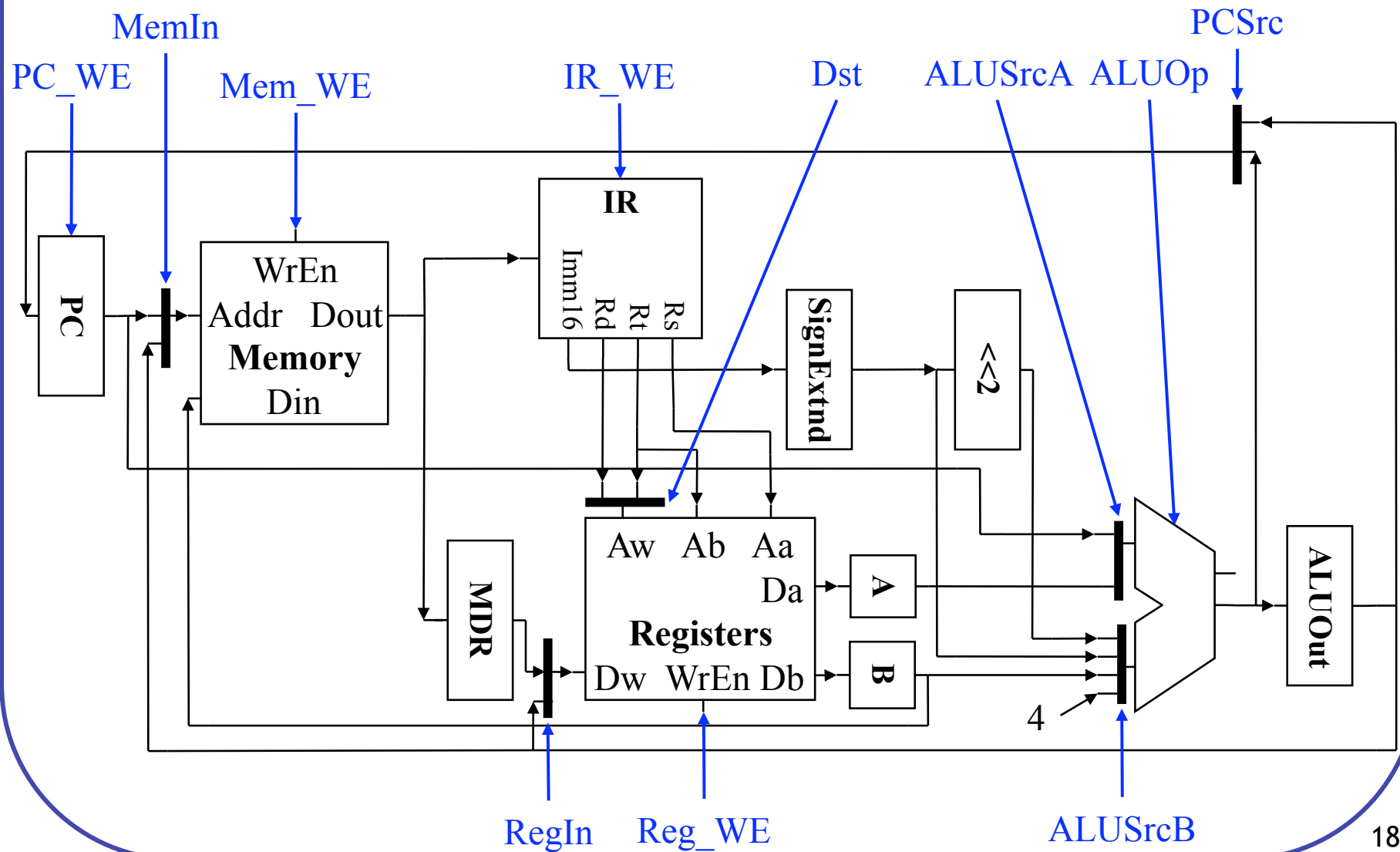
Cycle 3 (Load) Control

- $ALU_{out} = A + \text{sign-extend}(Imm16)$



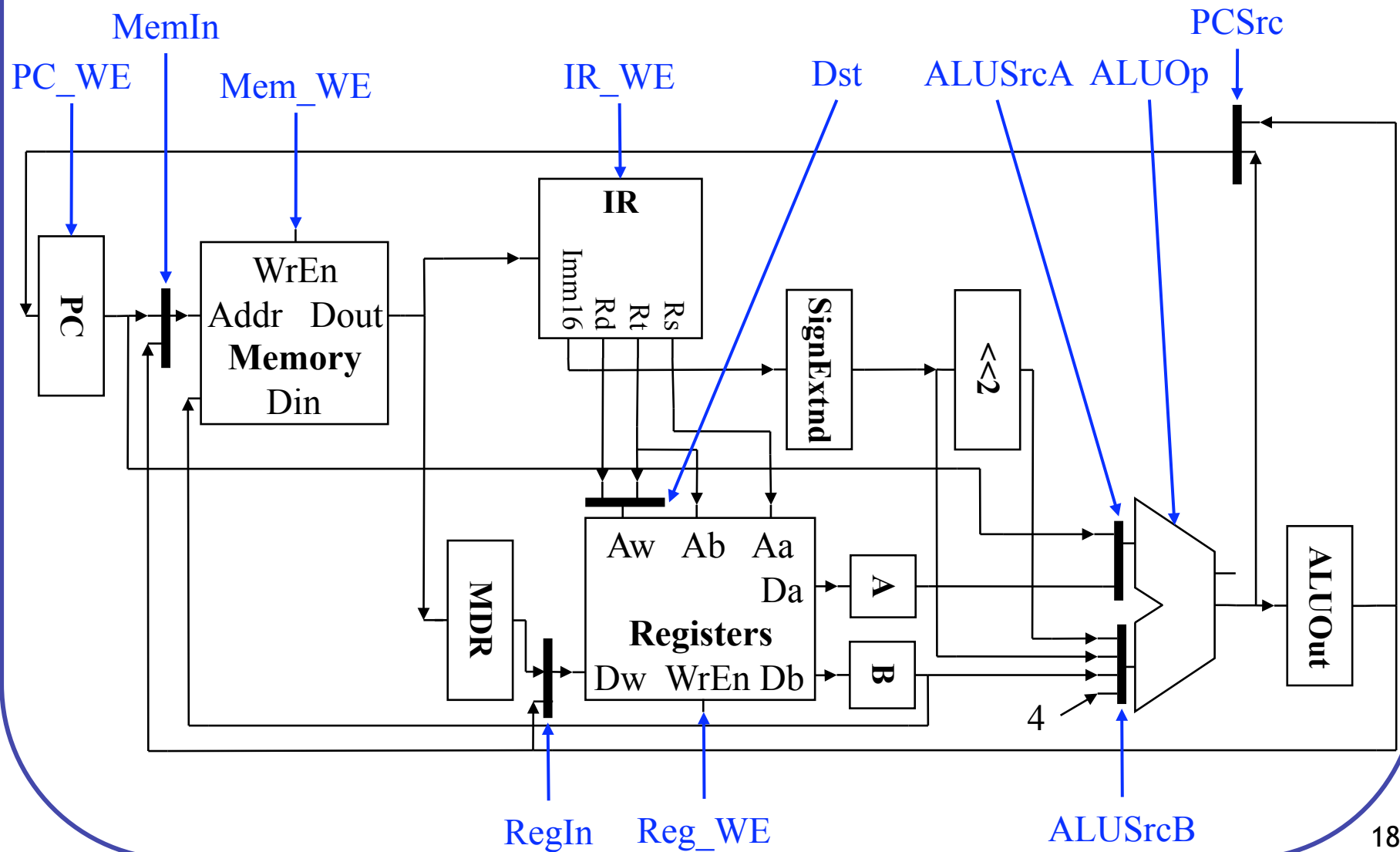
Cycle 4 (Load) Control

- MDR = Mem[ALUout]



Cycle 5 (Load) Control

- $\text{Reg}[\text{Rt}] = \text{MDR}$



Multicycle CPI

- Compute the CPI of the machine, given the frequencies specified

$$CPI = \sum_{types} (Cycles_{type} * Frequency_{type})$$

Instruction Type	Type Cycles	Type Frequency	Cycles * Freq
ALU		50%	
Load		20%	
Store		10%	
Branch		20%	
CPI:			

Multicycle Summary

- By splitting the single-cycle datapath up we achieve: