Lecture 11
Datapath Design

School of Computer Science and Engineering
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4. The Processor

4.3 Building a Datapath

- **Datapath elements for instruction fetch**
  - Instruction memory: Store the instructions of a program
  - Program Counter (PC): Store the address of the instruction
  - Adder: Increment the PC to the address of the next instruction

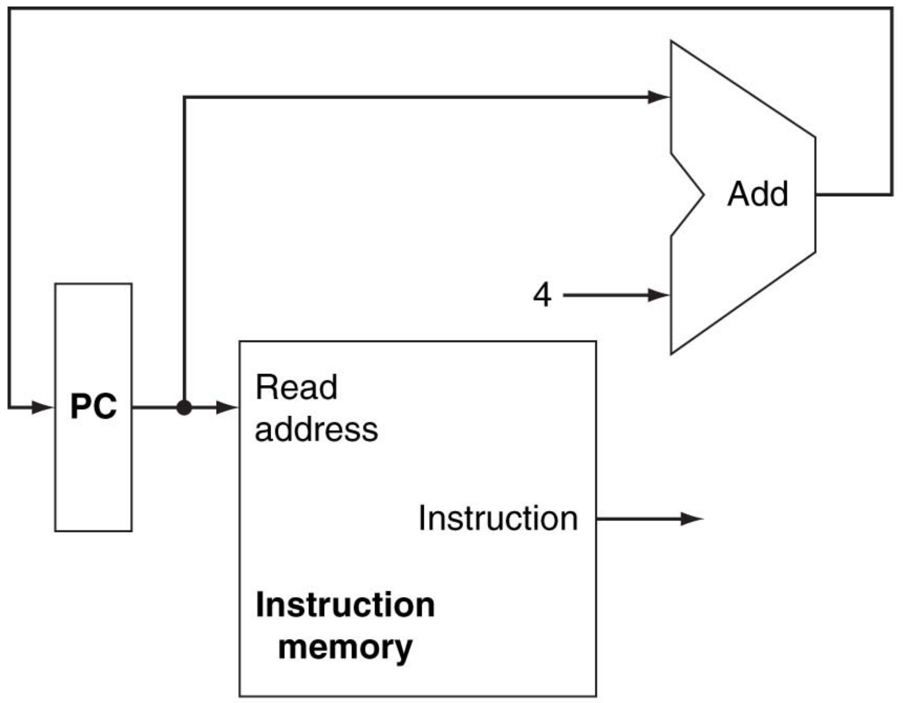


Figure 4.6

Executing R-format Instructions

- **Step 3**

  Use ALU for the opcode execution

- **Step 4**

  Write the data from the ALU back into a register

- **Major components**

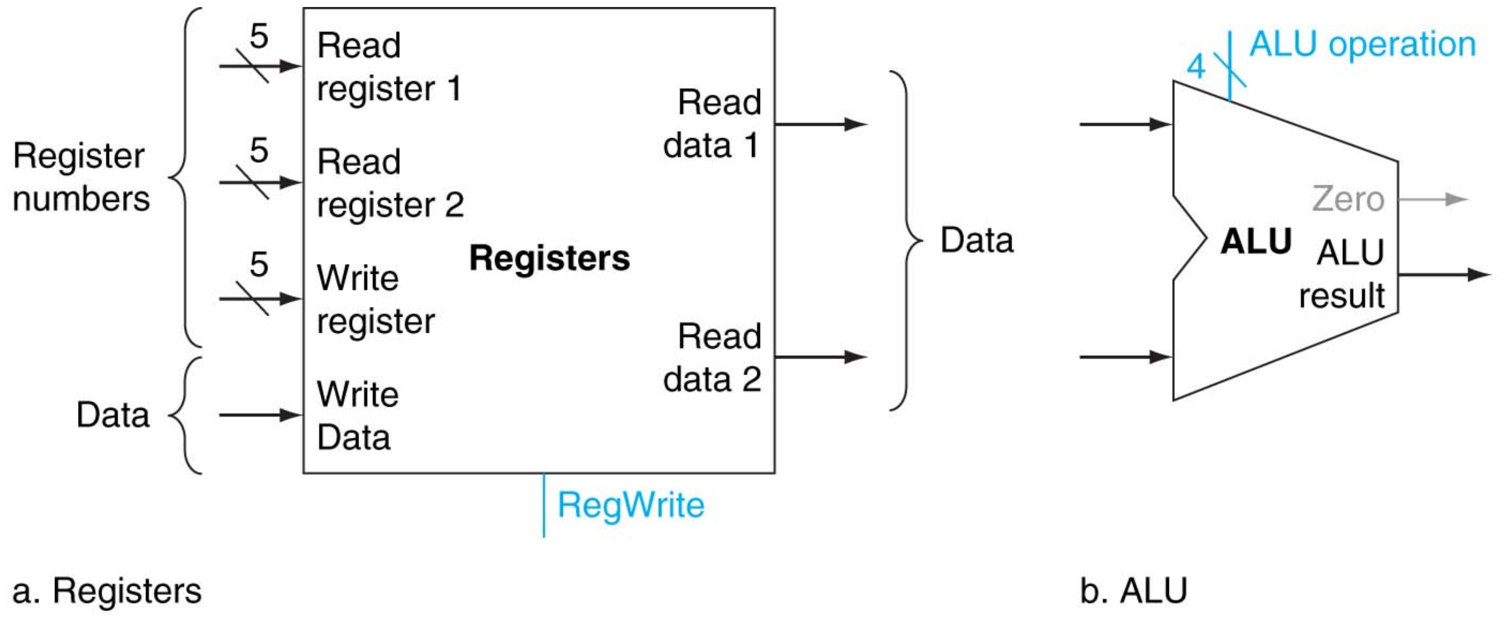
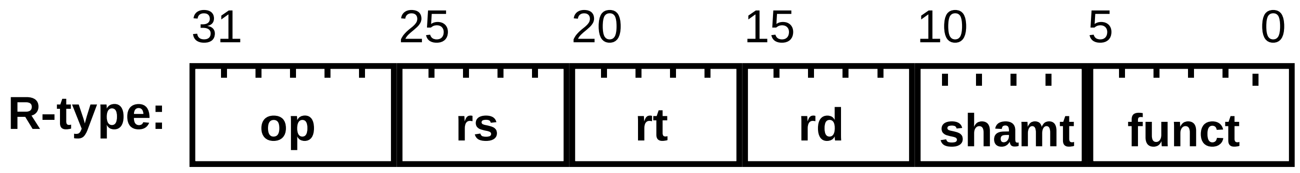
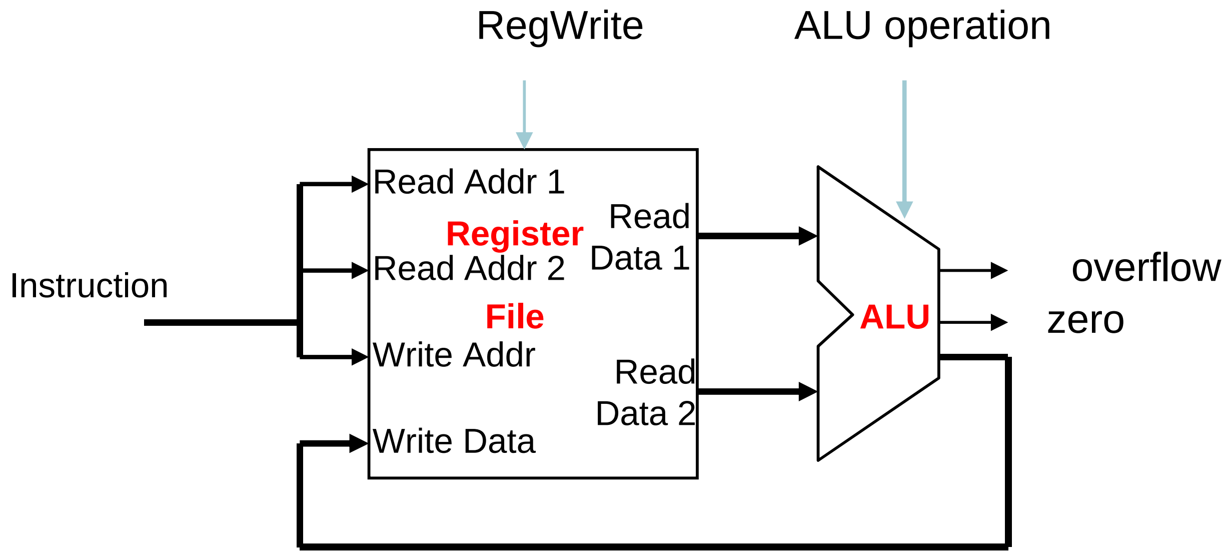


Figure 4.7

Datapath for R-format Instructions





- Note that Register File is not written every cycle (e.g. **`sw`**), so we need an explicit write control signal for the Register File

Executing Memory Reference Instructions

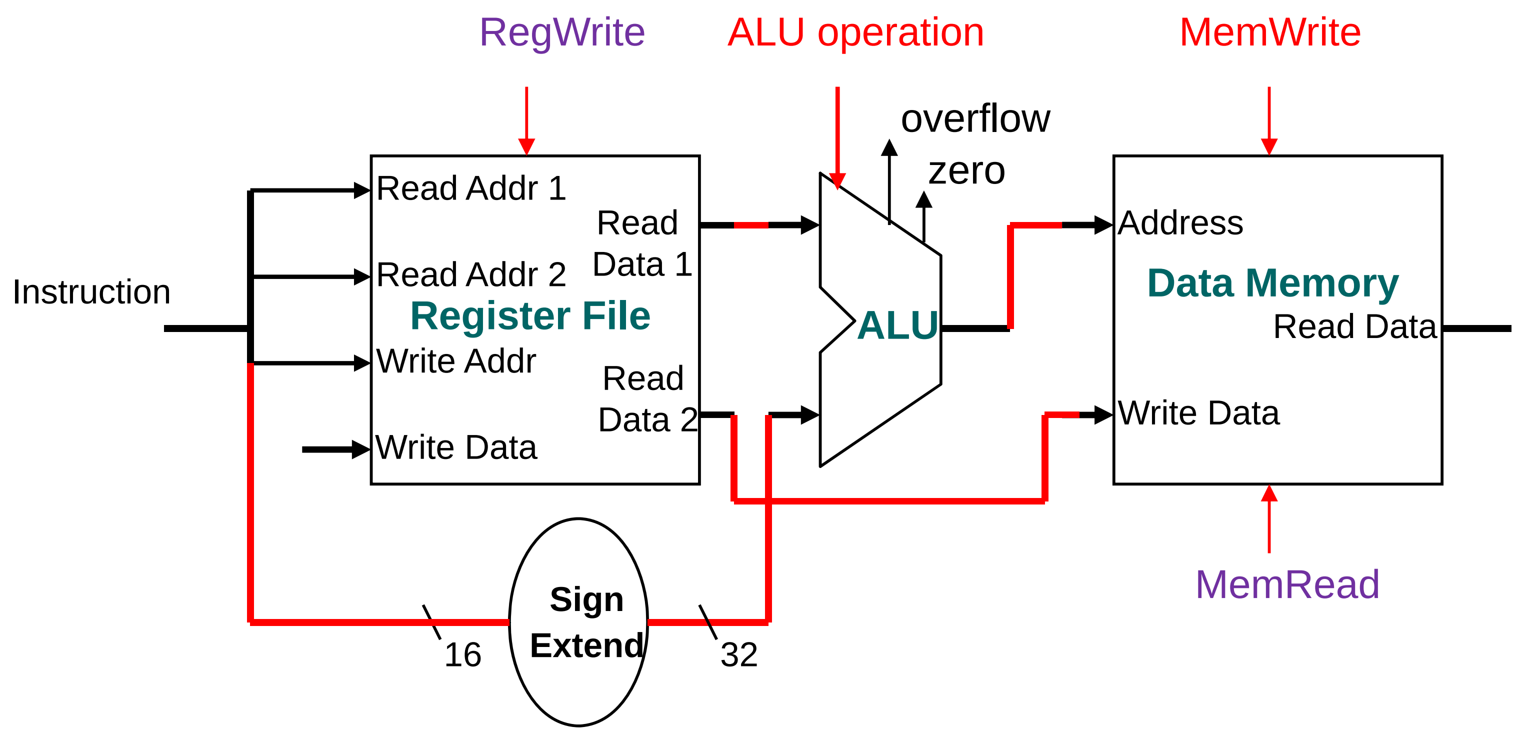
- **Step 3**

  Compute a memory address by adding the base register to the sign-extended 16-bit offset

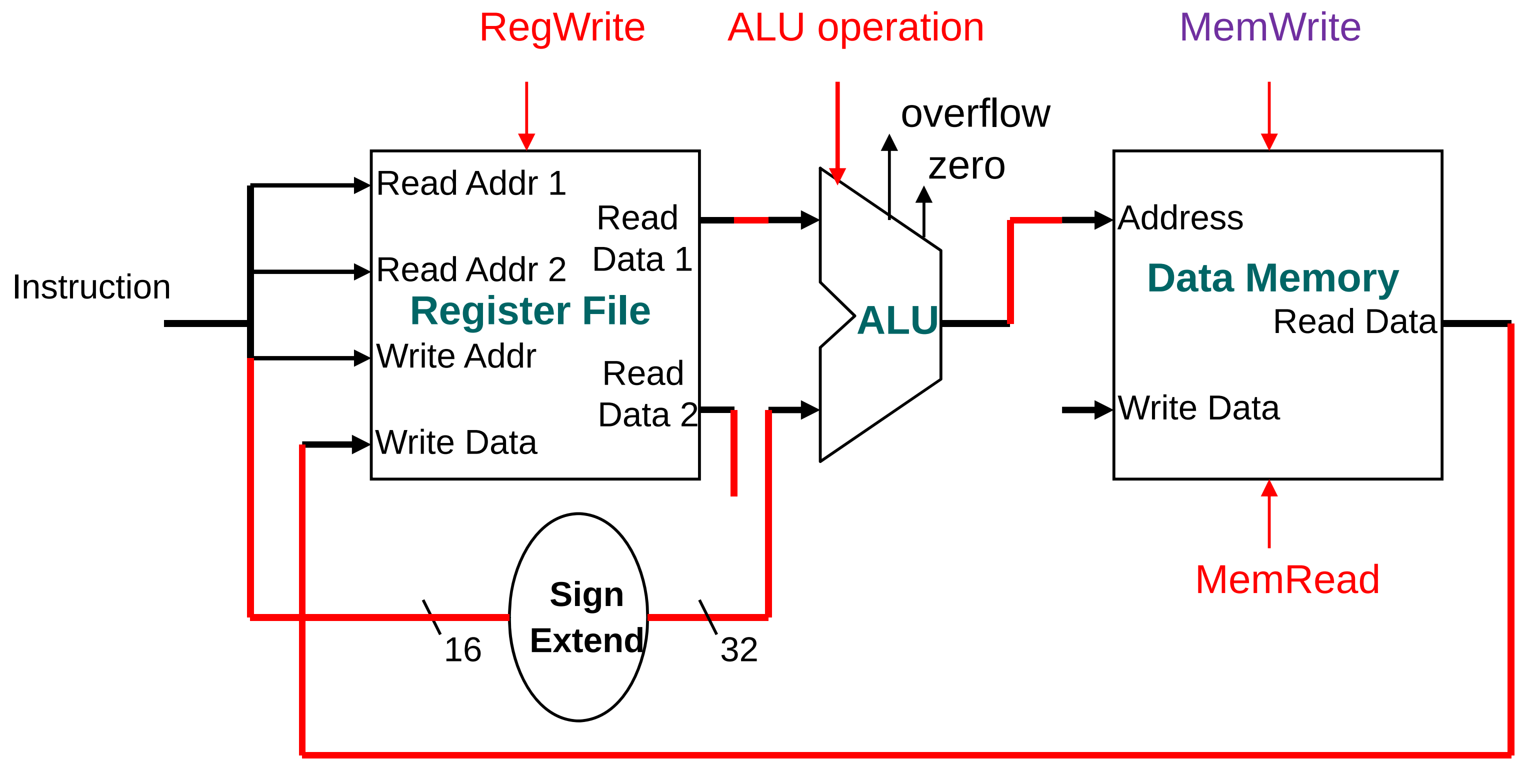
- **Step 4**
  - **`sw $9,offset_value($10)`**
    - Write **`$9`** into memory
  - **`lw $9,offset_value($10)`**
    - Read a value from memory
    - Write it into **`$9`**

- **Major components**
  - Sign extension unit and data memory

Datapath for store Instructions



Datapath for load Instructions



Executing Branch Instructions

- **Step 3**

  Use ALU for comparison

  Compute branch target address by adding the sign-extended offset to the PC

- **Step 4**

  Change PC based on the comparison

- **Major components**
  - Shift-left-2 unit
  - Separate adder

Datapath for Branch Instruction

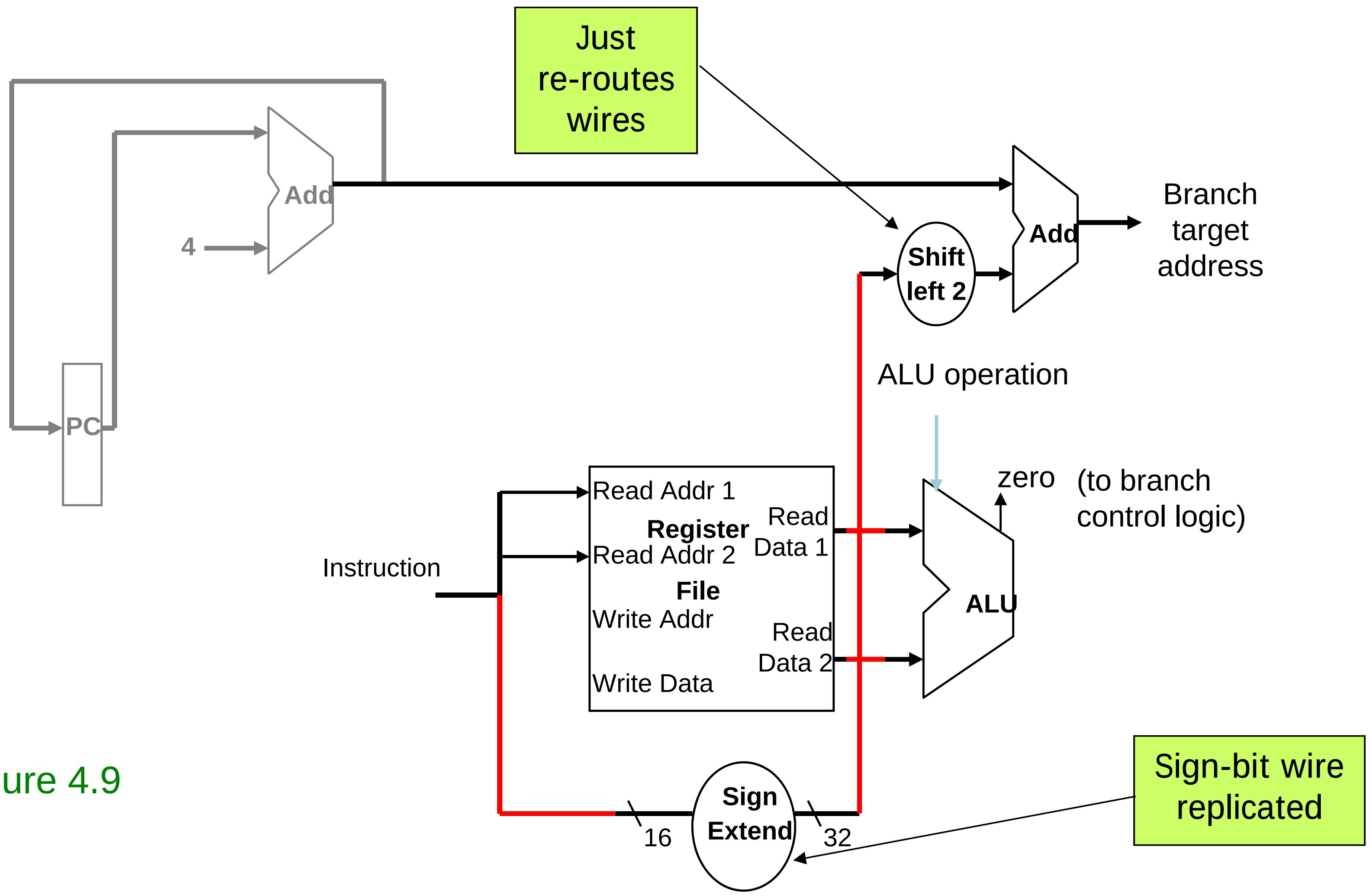
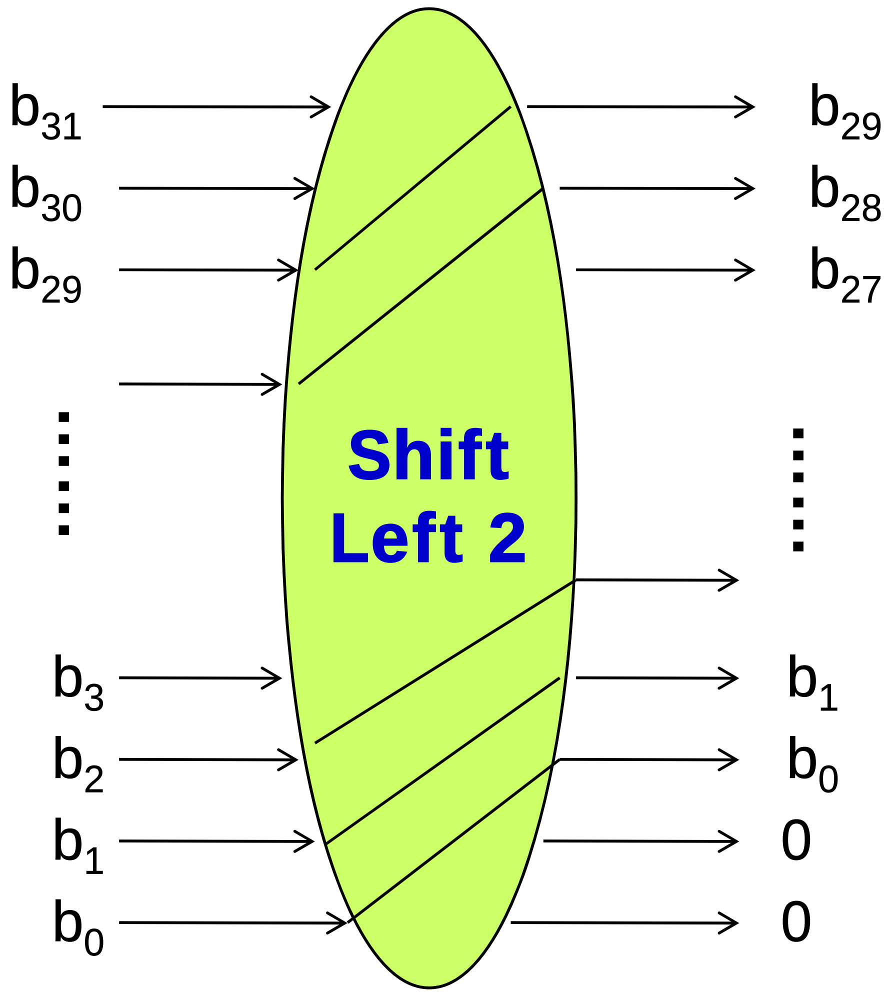
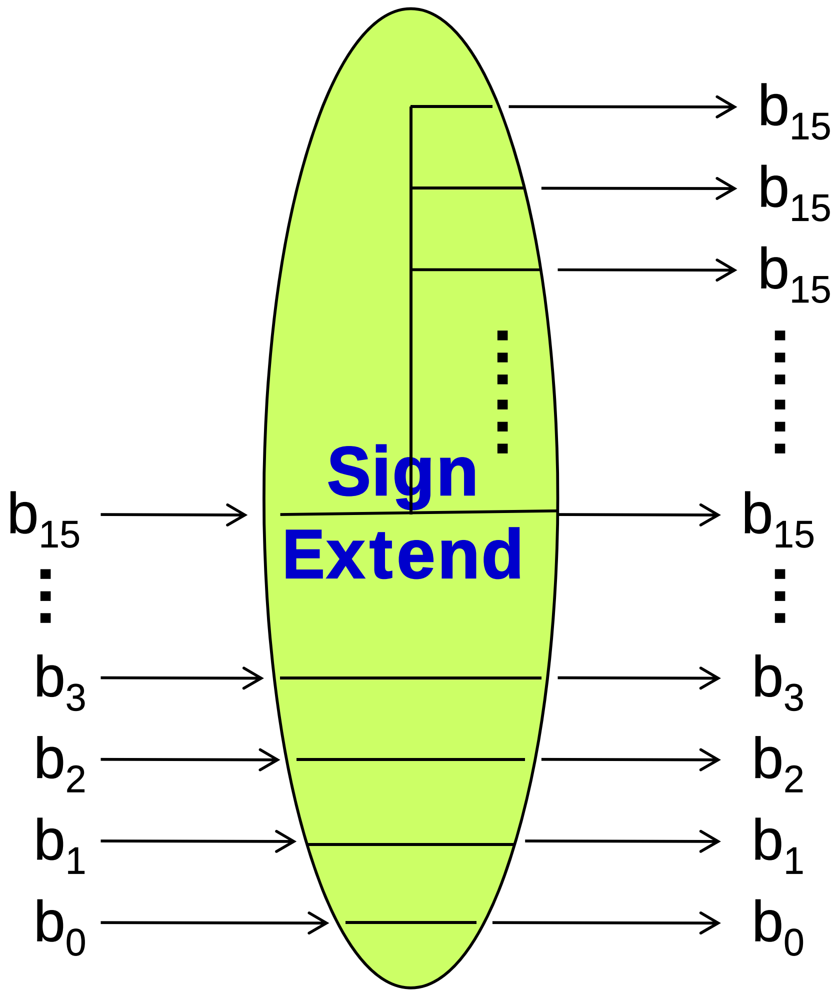


Figure 4.9

Units Implementation





Creating a Single Datapath

- **The simplest datapath**
  - Single-cycle datapath (↔ Multi-cycle datapath)
    - Execute all instructions in one clock cycle
    - No datapath resource can be used more than once per instruction.
    - Any element needed more than once must be duplicated.
    - Separate instruction and data memories
  - Sharing a datapath between two different instruction types
    - Use multiplexor

Example: Building a Datapath

- **Combine the arithmetic-logical instruction datapath and the memory instruction datapath.**

[Answer]

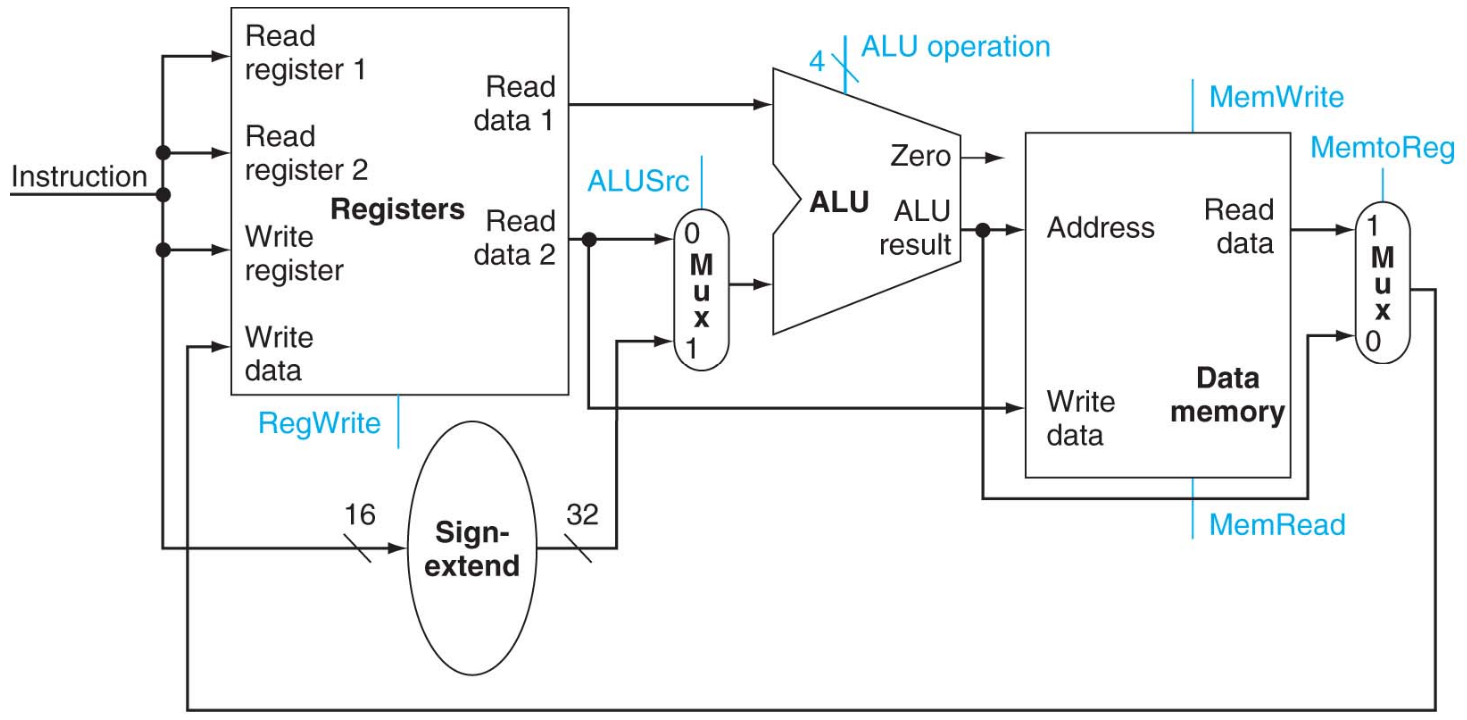


Figure 4.10

Simple Datapath for MIPS Architecture

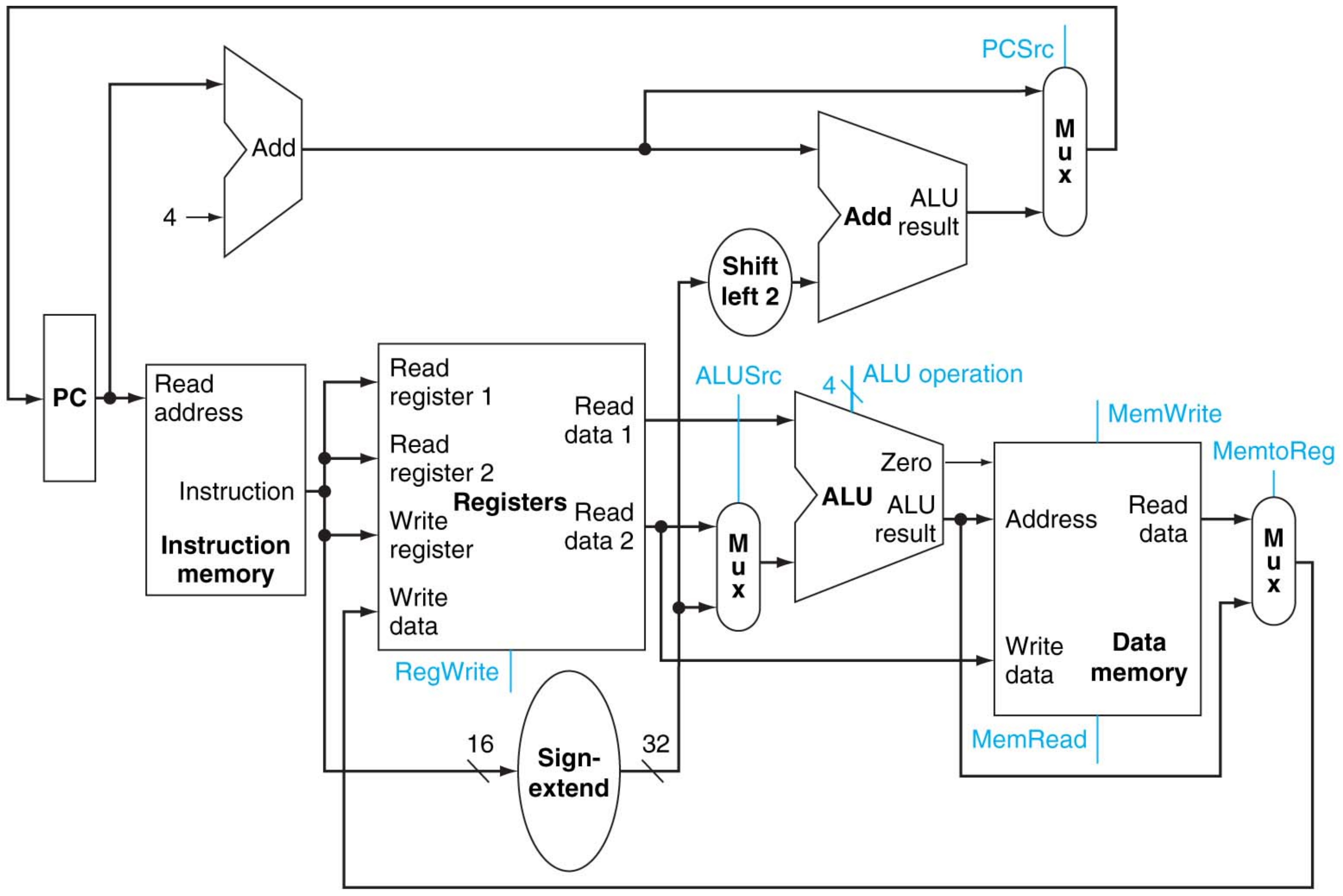


Figure 4.11

4.4 A Simple Implementation Scheme

The ALU Control

ALU operation	Function
0000	AND
0001	OR
0010	add
0110	subtract
0111	set on less than
1100	NOR

Instruction opcode	ALU Op	Instruction operation	Function field	Desired ALU action	ALU operation
lw	**00**	load word	xxxxxx	add	0010
sw	**00**	store word	xxxxxx	add	0010
beq	**01**	branch on equal	xxxxxx	subtract	0110
R-type	**10**	add	100000	add	0010
R-type	**10**	subtract	100010	subtract	0110
R-type	**10**	AND	100100	and	0000
R-type	**10**	OR	100101	or	0001
R-type	**10**	set on less than	101010	set on less than	0111

Figure 4.12

Main Control and ALU Control

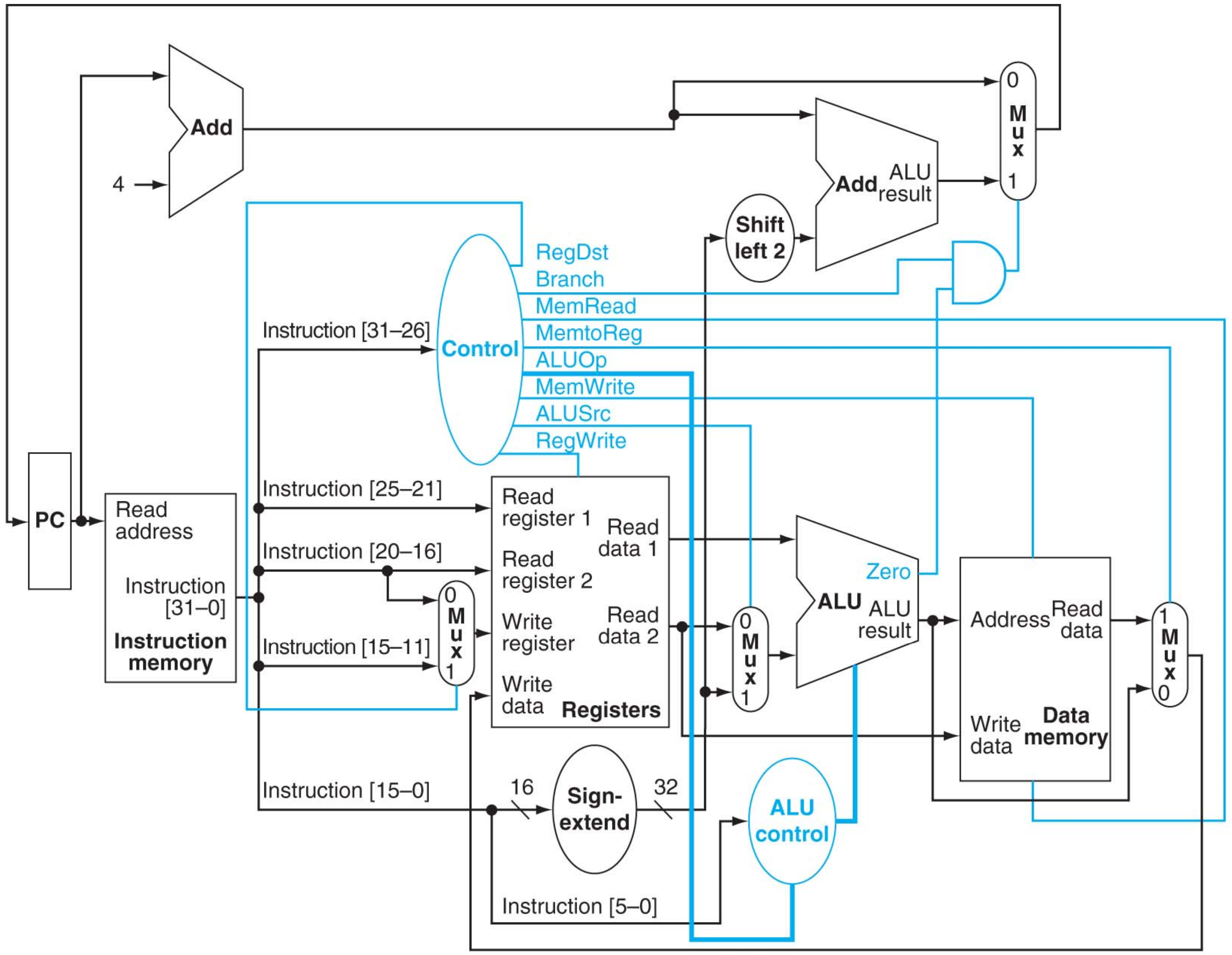


Figure 4.17

Truth Table for the ALU Control Bits

ALUOp		Function field						ALU Operation
ALUOp1	ALUOp0	F5	F4	F3	F2	F1	F0	
0	0	x	x	x	x	x	x	0010
x	1	x	x	x	x	x	x	0110
1	x	x	x	0	0	0	0	0010
1	x	x	x	0	0	1	0	0110
1	x	x	x	0	1	0	0	0000
1	x	x	x	0	1	0	1	0001
1	x	x	x	1	0	1	0	0111

Figure 4.13

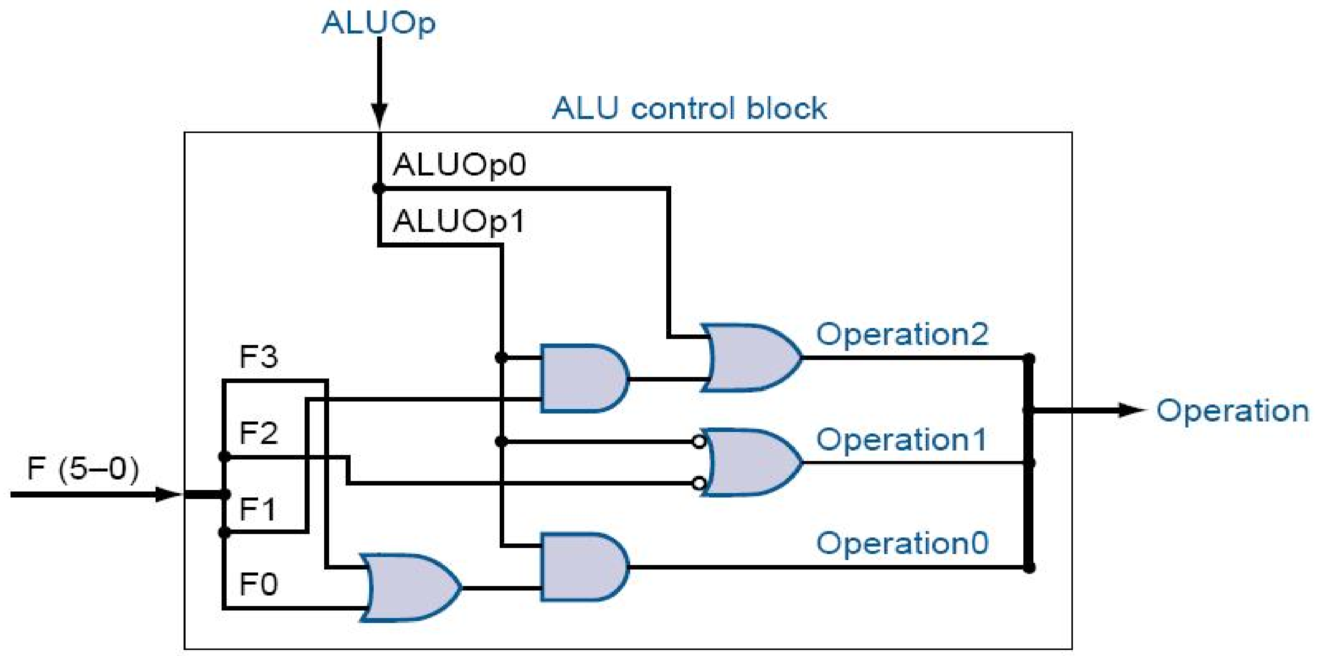
Implementation of ALU Control

Operation3 = 0

Operation2 = ALUOp0 + ALUOp1 · F1

Operation1 = ALUOp1' + F2'

Operation0 = ALUOp1 · (F0 + F3)


ALUOp
ALU control block
ALUOp0
ALUOp1
F3
F2
F (5–0)
F1
F0
Operation2
Operation1
Operation0
Operation