Computer Architecture:
MIPS Datapath Design: Single Cycle

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- Some Parts (text & figures) of this Lecture adopted from following:
  - Computer Organization & Design, The Hardware/Software Interface, 3rd Edition, by D. Patterson and J. Hennessey, MK publishing, 2005.
  - "Intro to Computer Architecture" handouts, by Prof. Hoe, CMU, Spring 2009.
  - "Computer Architecture & Engineering" handouts, by Prof. Kubiatowicz, UC Berkeley, Spring 2004.
  - "Intro to Computer Architecture" handouts, by Prof. Hoe, UWisc, Spring 2021.
  - "Computer Arch I" handouts, by Prof. Garzarán, UIUC, Spring 2009.
  - "Intro to Computer Organization" handouts, by Prof. Mahlke & Prof. Narayanasamy, Winter 2008.

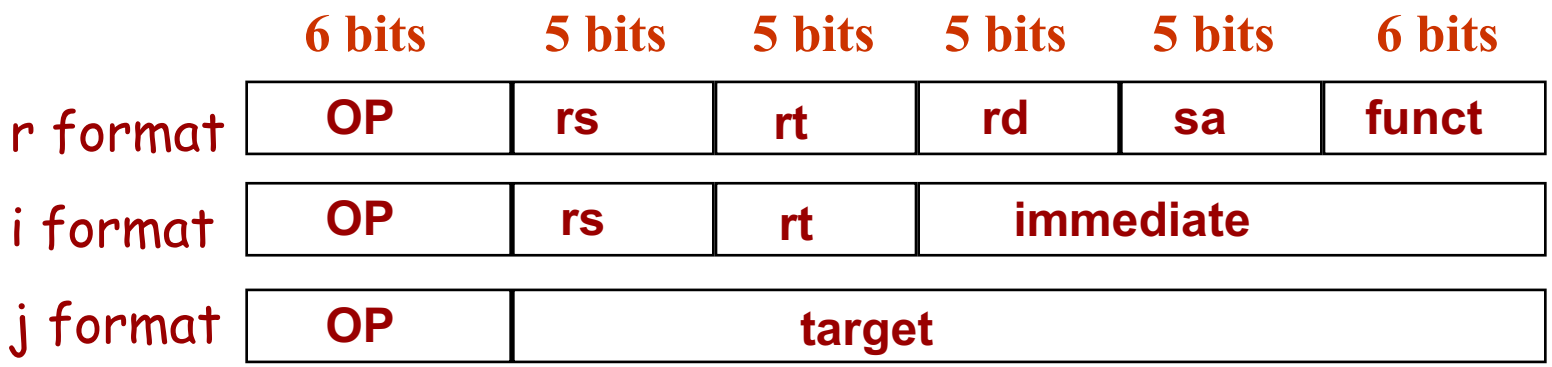
Our Lectur Today

Topics Covered Today

- MIPS ISA: Quick Review
- MIPS Single-Cycle Datapath

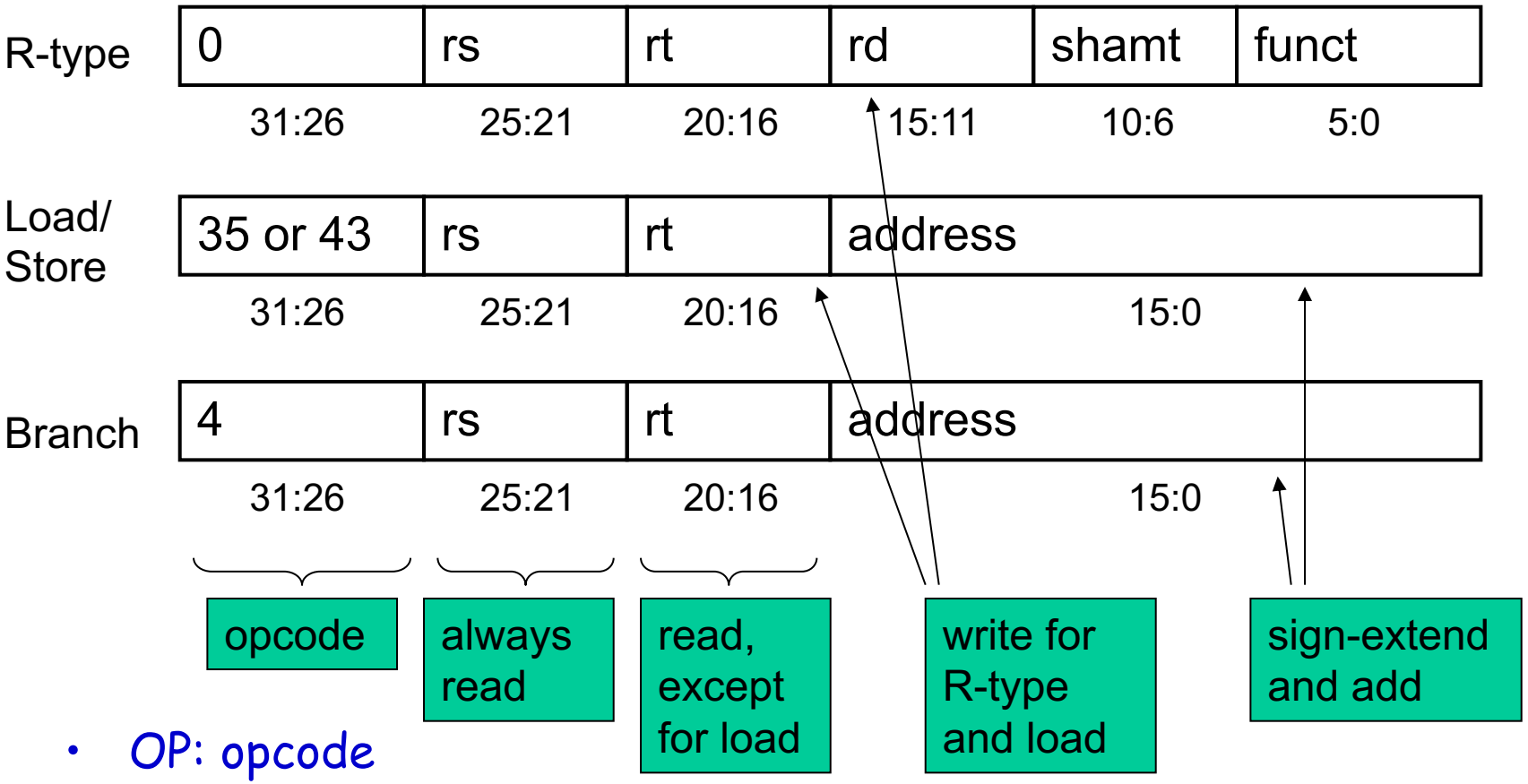
Instruction Encoding

- MIPS Instruction Format



- OP: opcode
- rs: first register source operand
- rt: second register source operand
- rd: register destination operand
- sa: shift amount
- funct: function code

MIPS ISA Format



- OP: opcode
- rs: first register source operand
- rt: second register source operand
- rd: register destination operand
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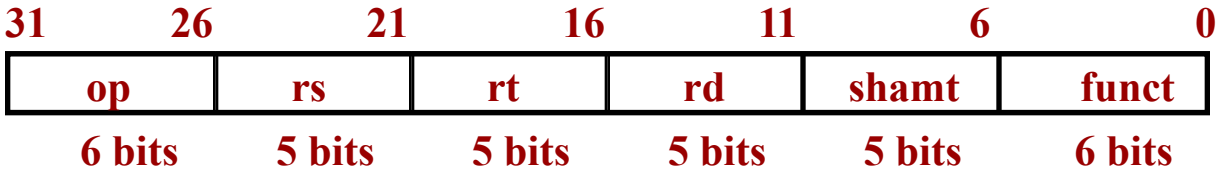
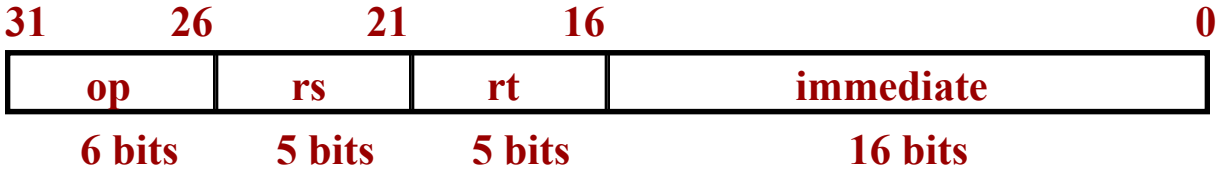
- funct: function code

MIPS Instruction Encoding

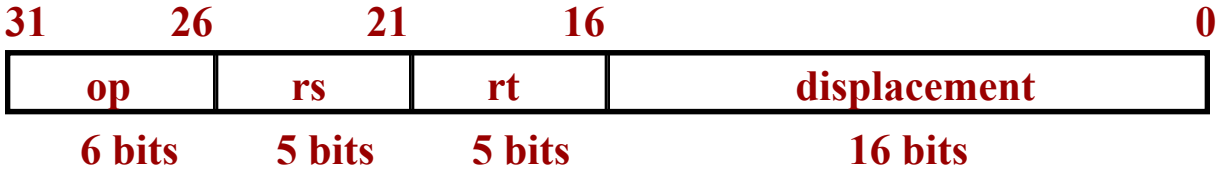
- R-TYPE
  - *add rd, rs, rt*
  - sub, and, or, slt



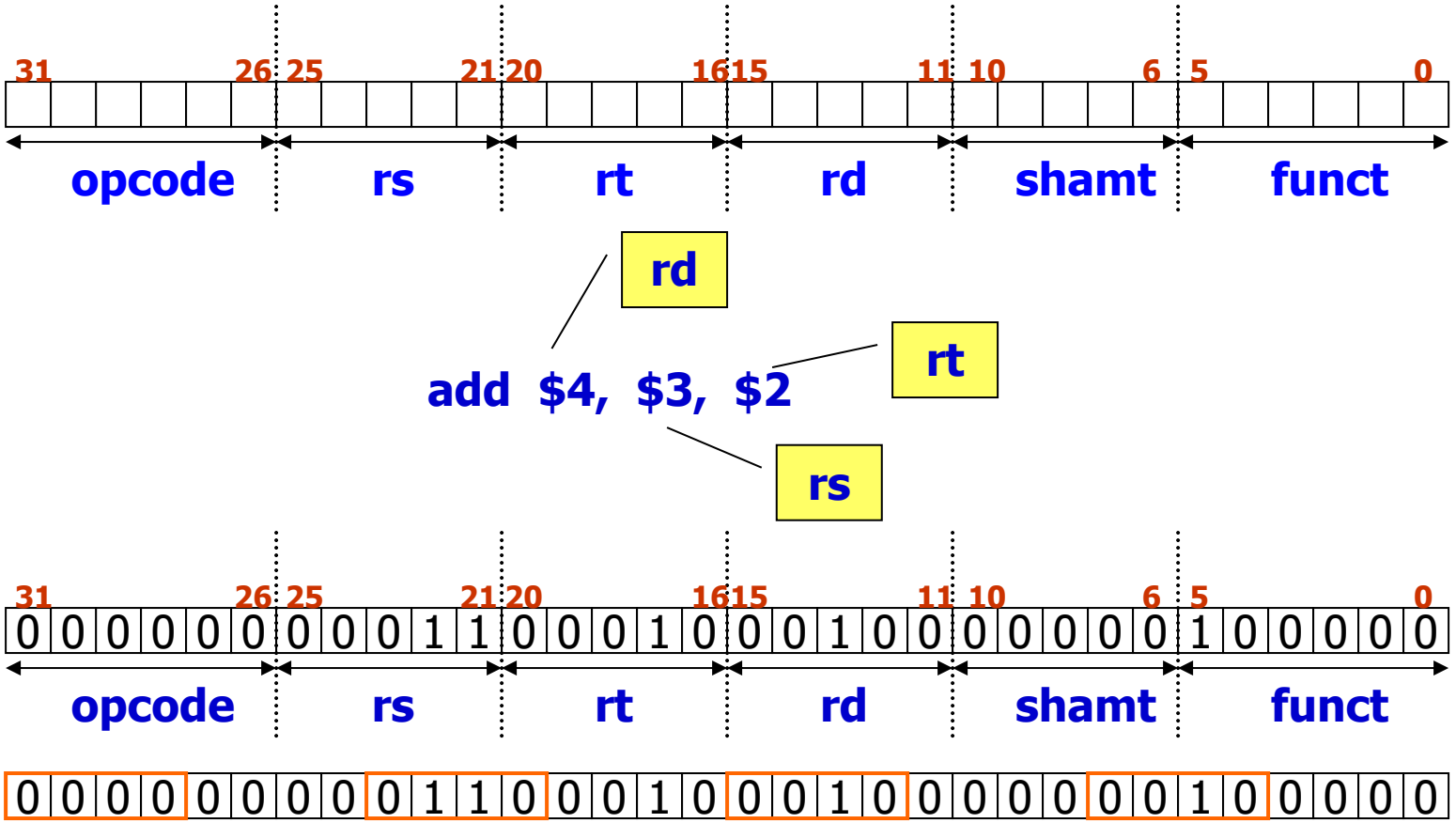
- LOAD / STORE
  - lw rt, rs, imm
  - sw rt, rs, imm



- BRANCH
  - beq rs, rt, imm



MIPS Instruction Encoding: R-Type

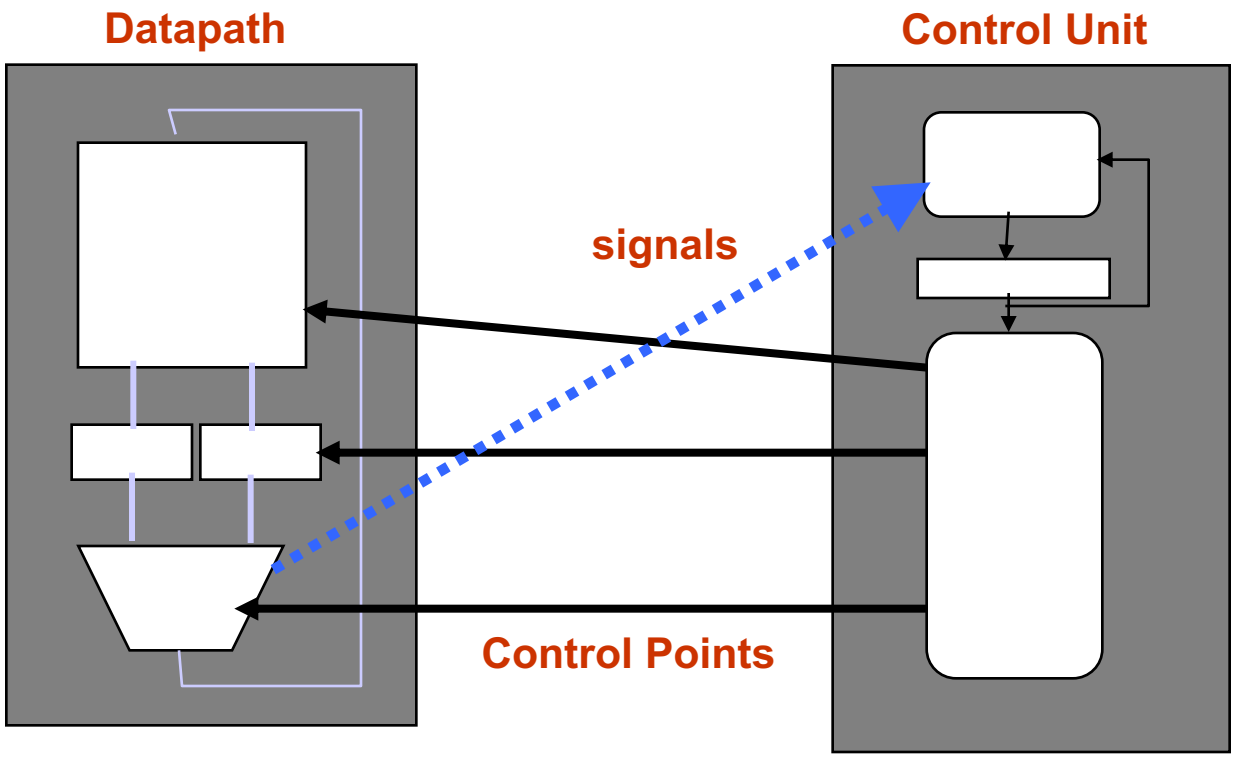


Encoding = 0x00622020

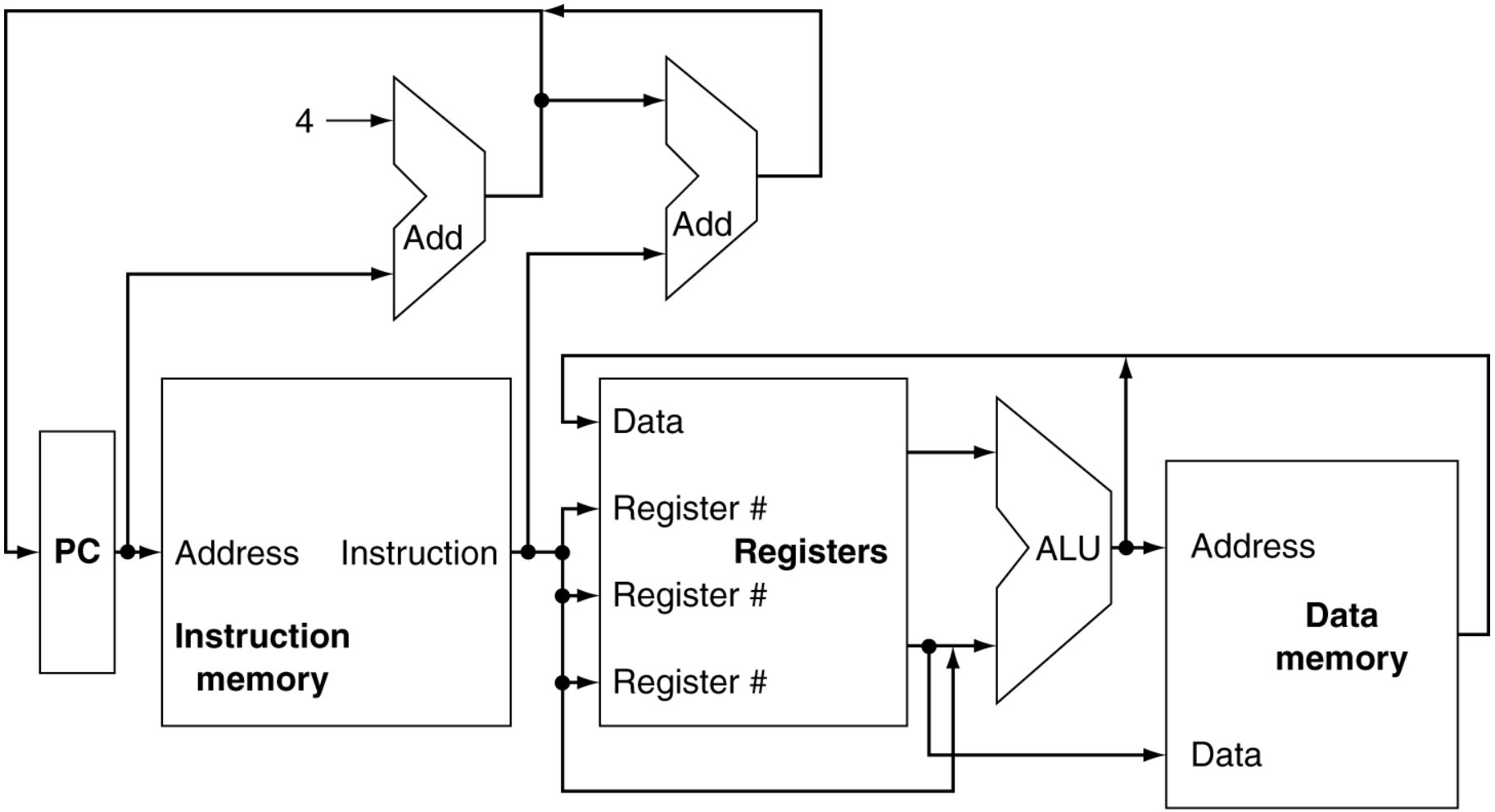
Datapath

- Datapath?
  - A functional unit used to operate on or hold data within a processors
- Datapath Elements in MIPS
  - Instruction memory
  - Data memory
  - Register file
  - ALU
  - Adders
- Control Unit
  - Schedule data movements in datapath

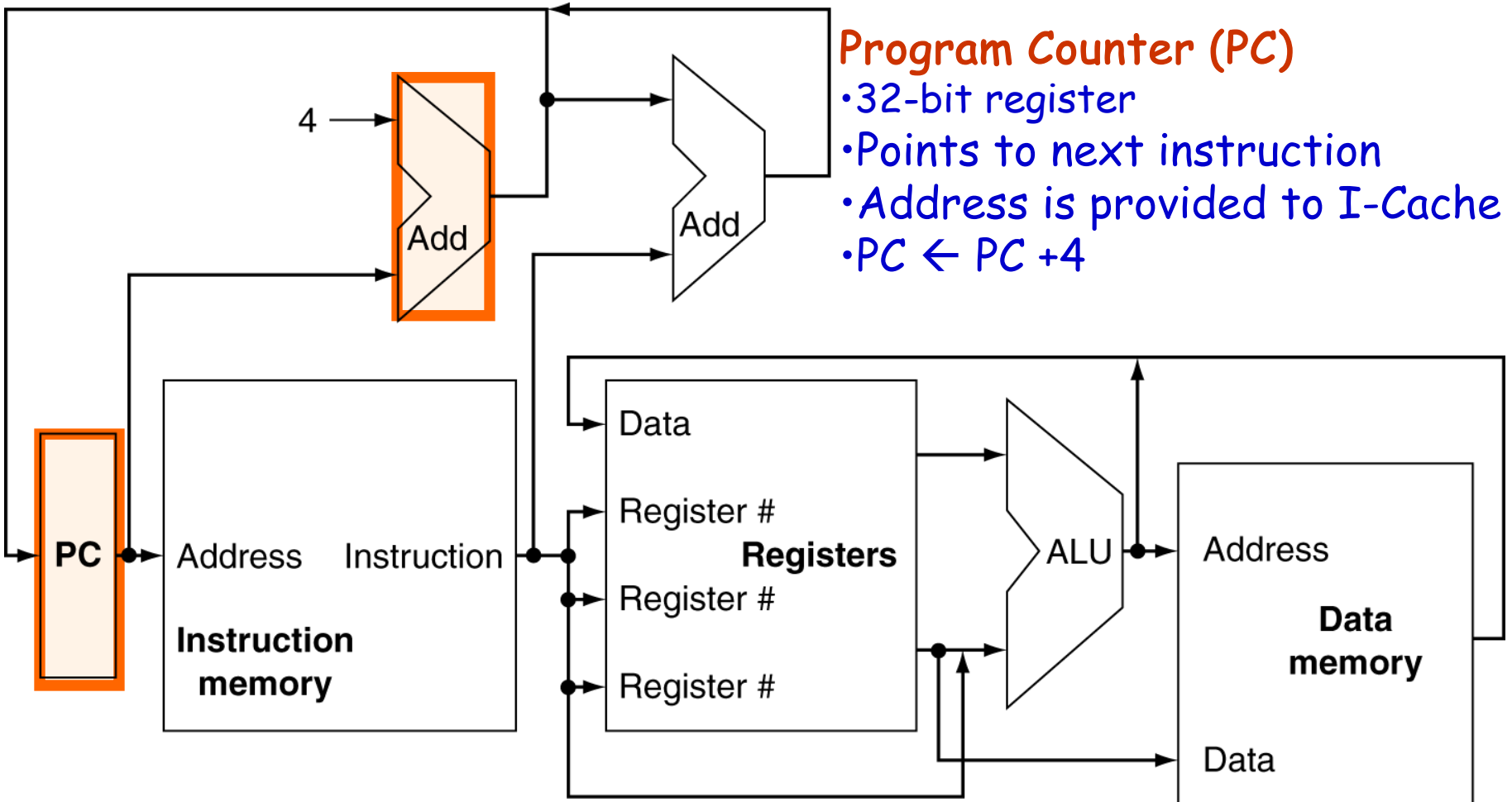
Datapath (cont.)



Single Cycle MIPS Datapath



Single Cycle MIPS Datapath: PC

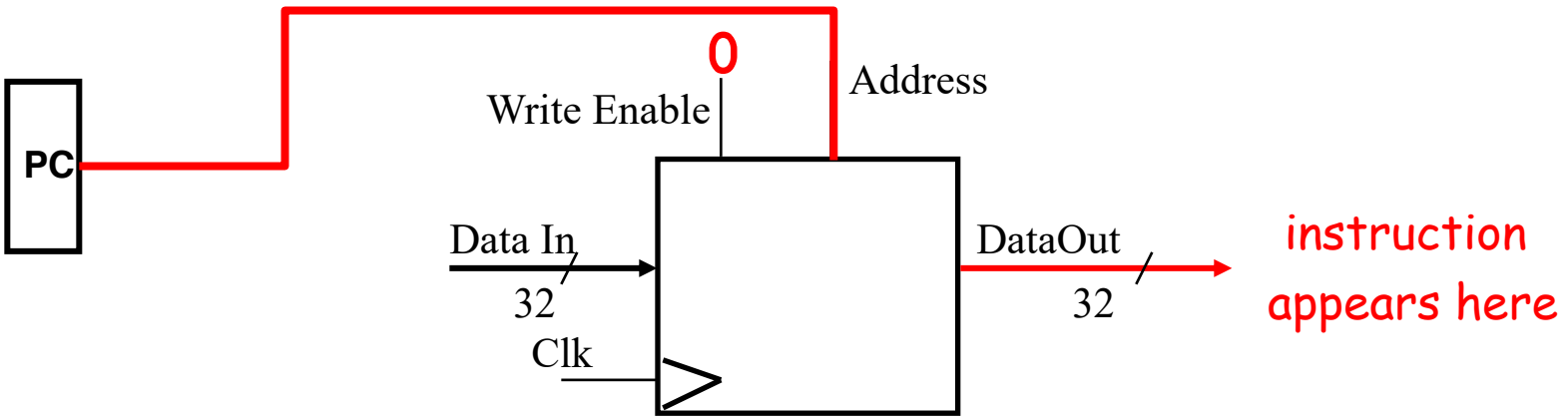


Program Counter (PC)

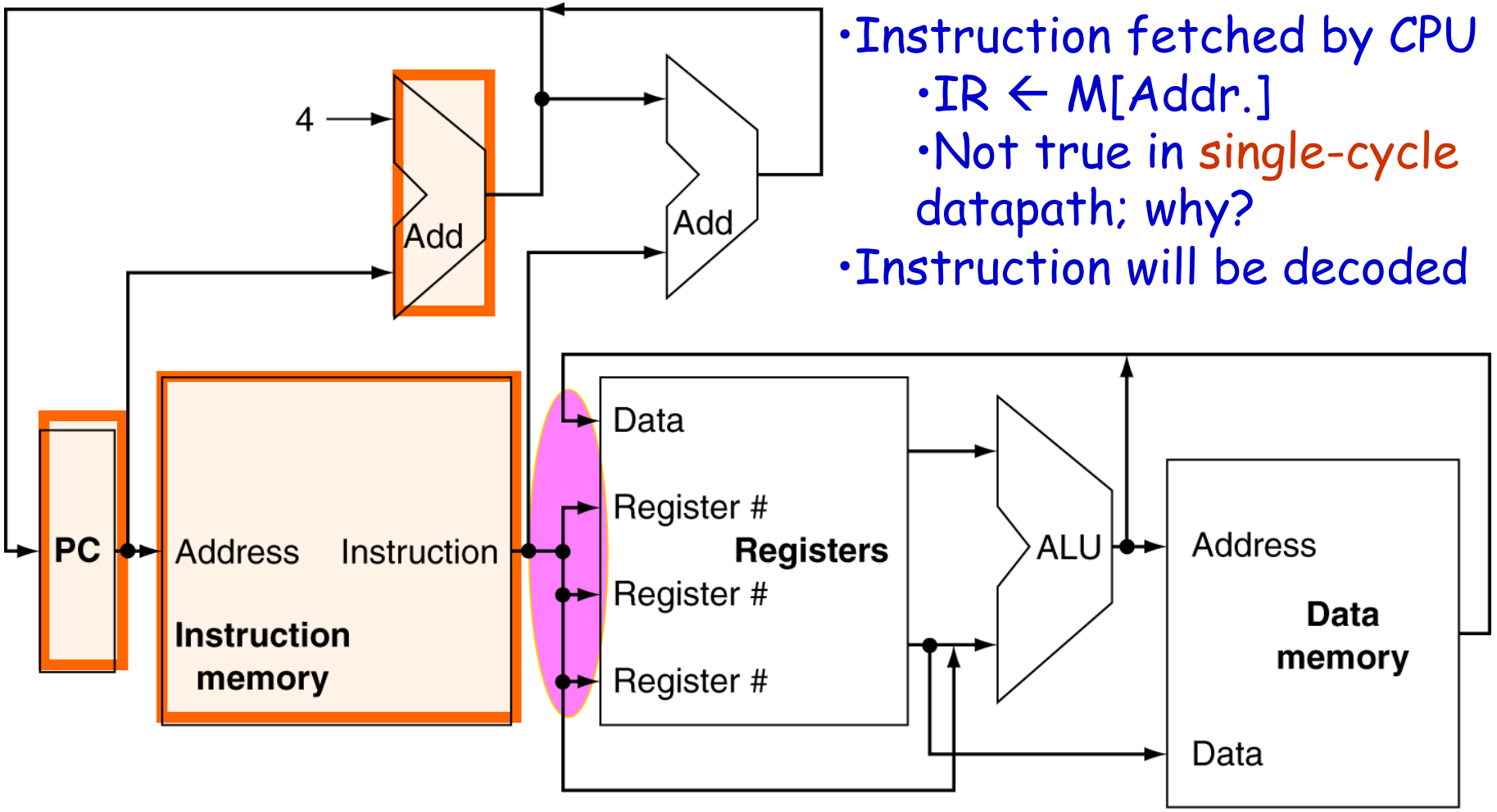
- 32-bit register
- Points to next instruction
- Address is provided to I-Cache
- PC ← PC +4

Instruction Fetch

- Program Counter (PC)
  - Supplies instruction address
  - Get instructions from memory



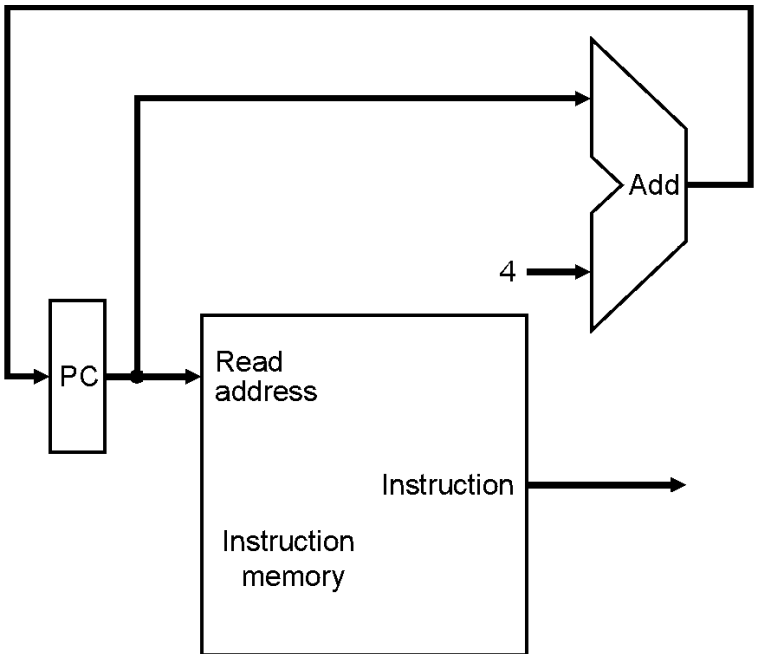
Instruction Memory (I-Cache)



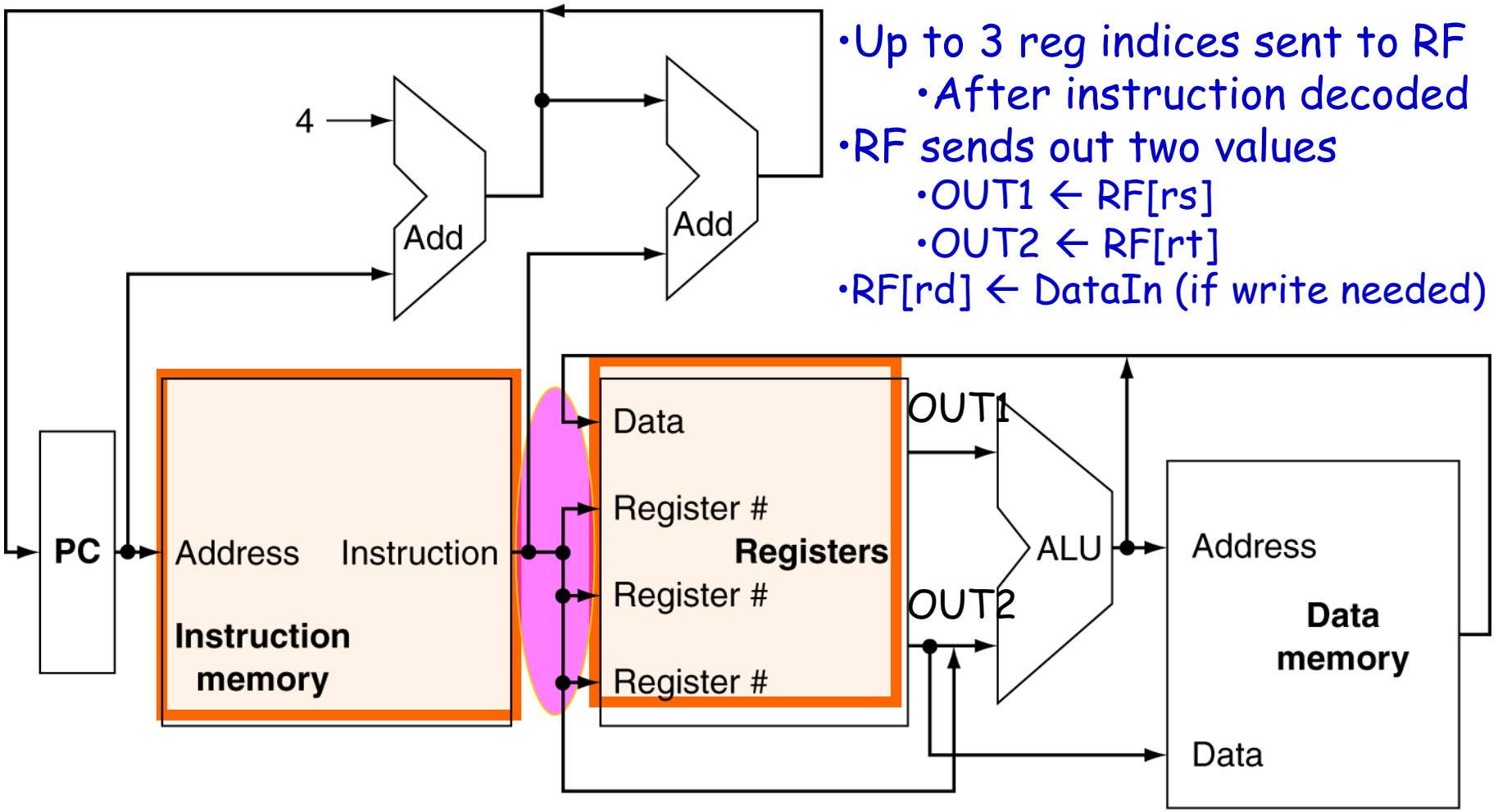
- Addr. ← PC
- Instruction fetched by CPU
  - IR ← M[Addr.]
  - Not true in single-cycle datapath; why?
- Instruction will be decoded

Instruction Fetch Unit

- Updating PC for Next Instruction
  - Sequential Code: PC ← PC + 4
  - Branch and Jump: PC ← New Address
    - we'll worry about this later



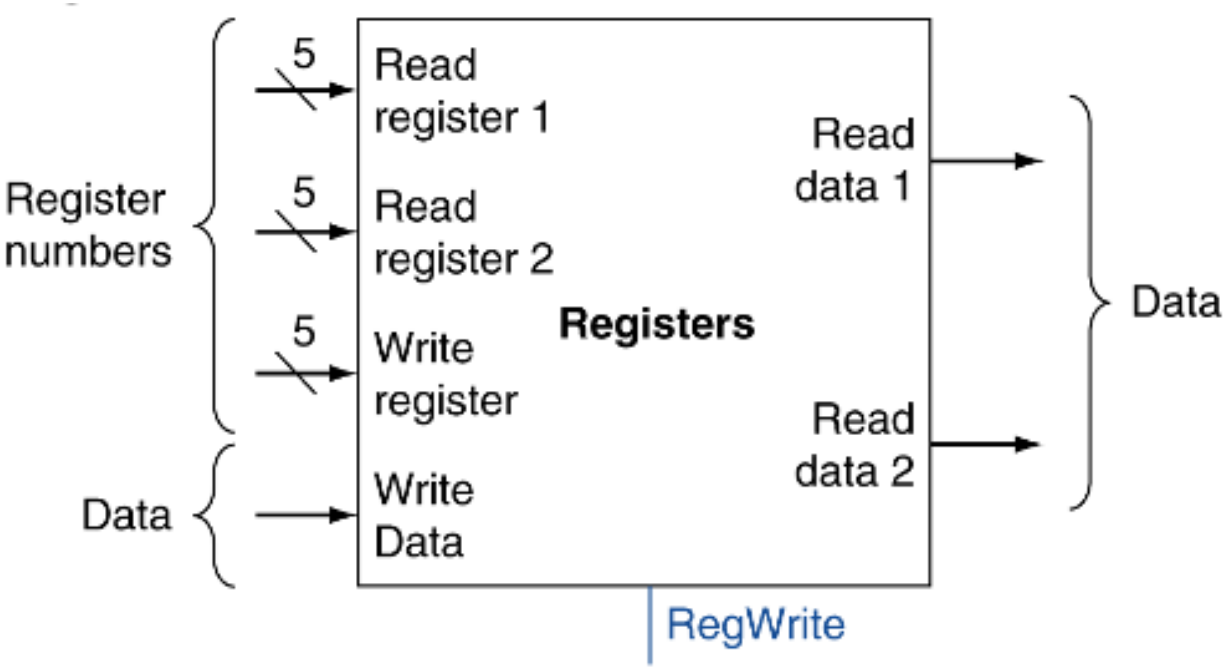
Register File



- Up to 3 reg indices sent to RF
  - After instruction decoded
- RF sends out two values
  - OUT1 ← RF[rs]
  - OUT2 ← RF[rt]
- RF[rd] ← DataIn (if write needed)

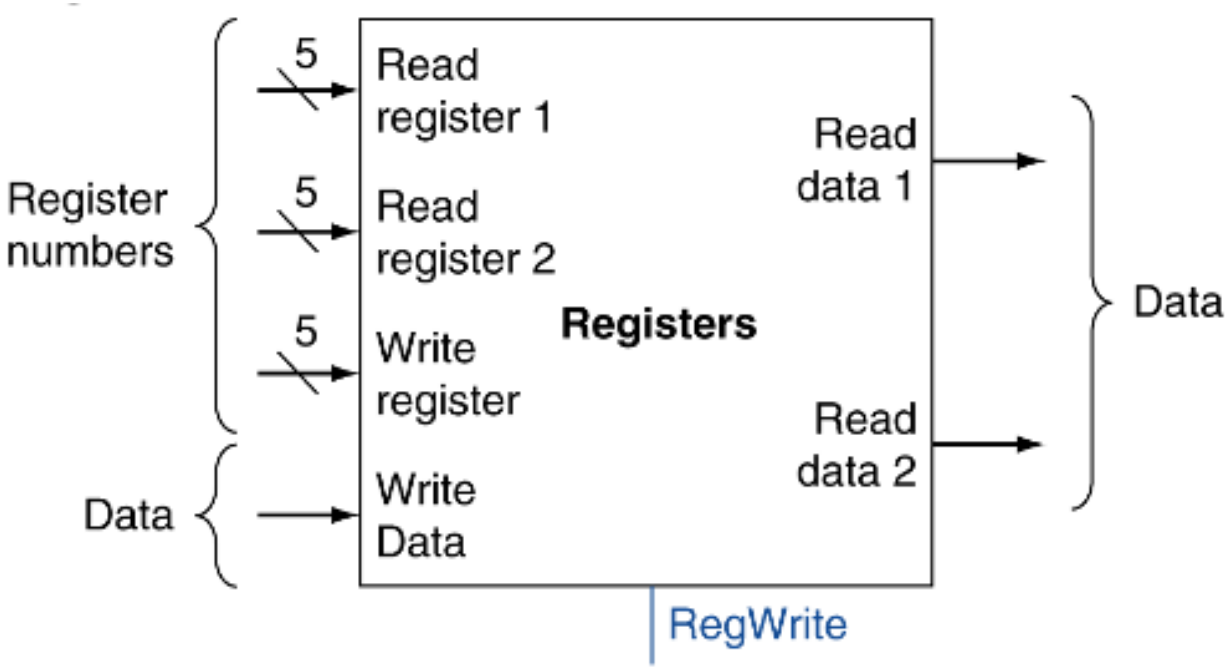
Datapath Elements

- Register File (RF)
  - Also called, General Purpose Registers (GPR)
  - Up to three indices as inputs
  - 32-bit write input data
  - Two 32-bit outputs



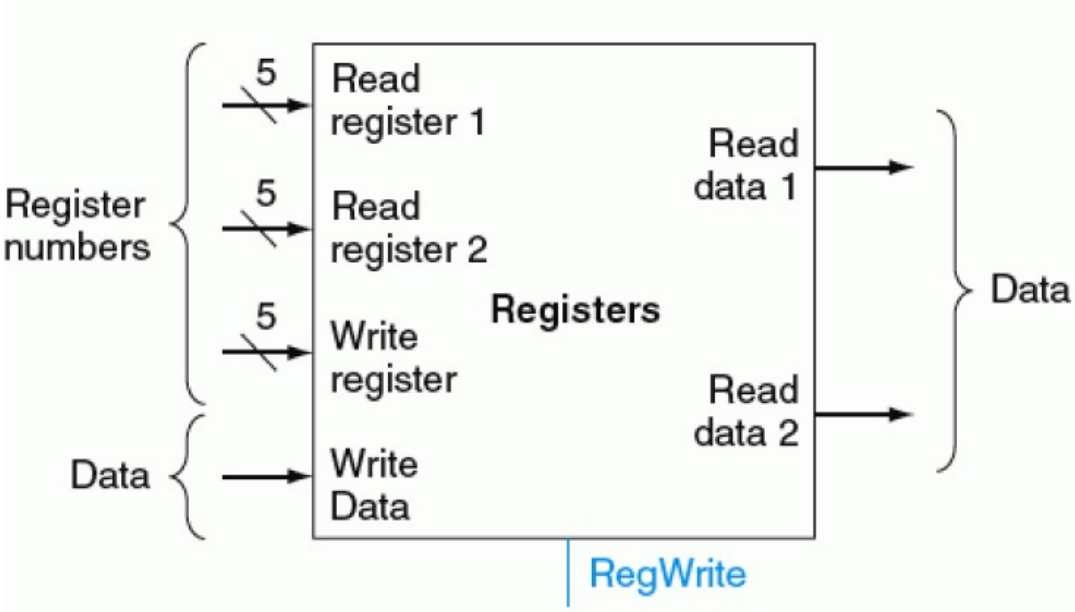
Datapath Elements (cont.)

- Question 1:
  - How read & write can be accomplished in one clock cycle without data contention?

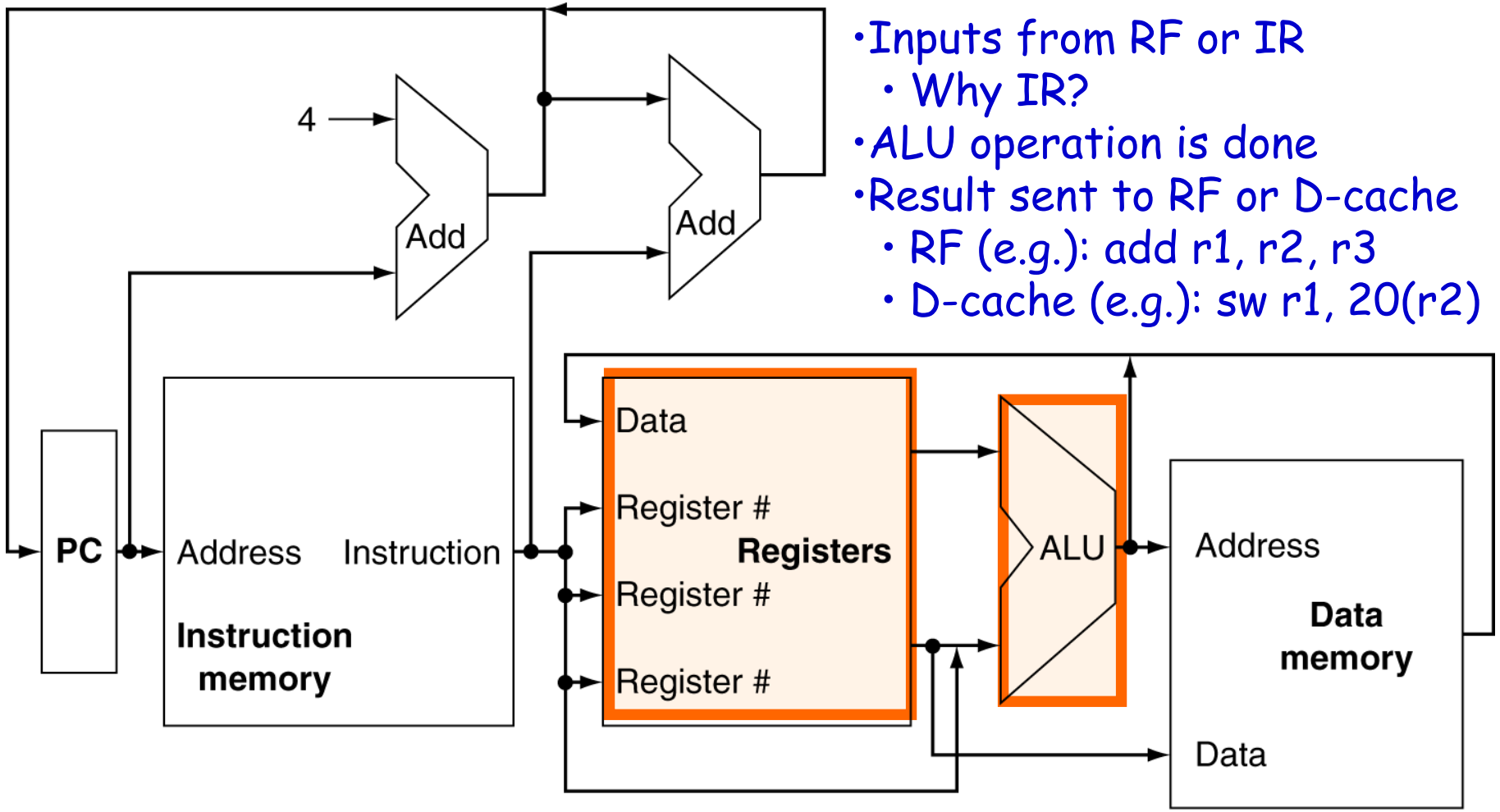


Datapath Elements (cont.)

- Question 2:
  - How two simultaneous read operations possible?



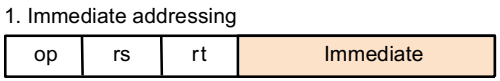
Arithmetic Logical Unit (ALU)



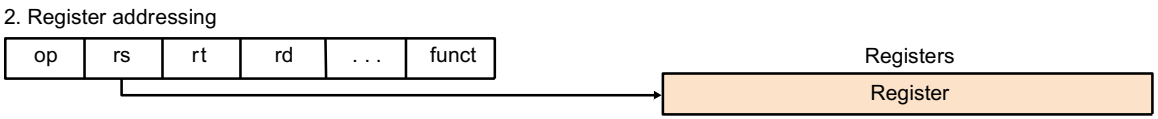
- Inputs from RF or IR
  - Why IR?
- ALU operation is done
- Result sent to RF or D-cache
  - RF (e.g.): add r1, r2, r3
  - D-cache (e.g.): sw r1, 20(r2)

MIPS Addressing Modes

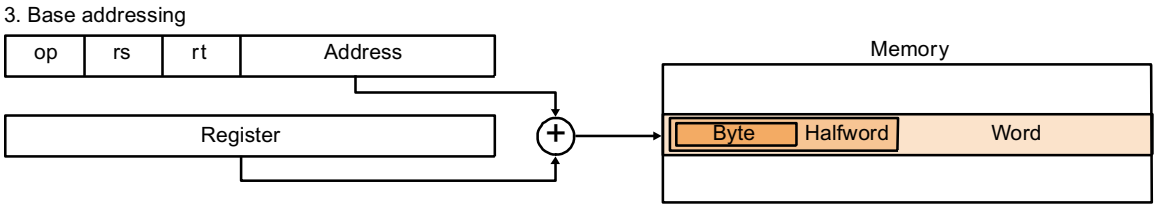
Operand is constant



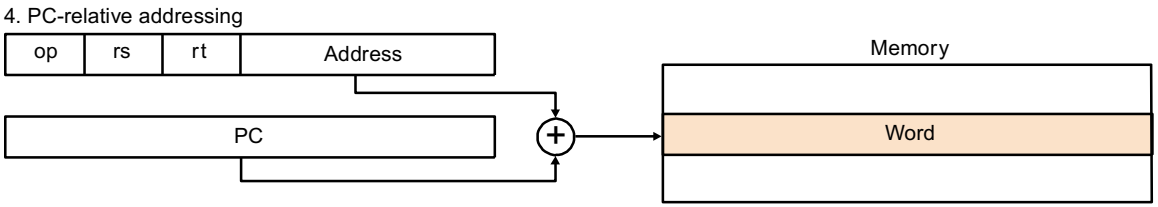
Operand is in register



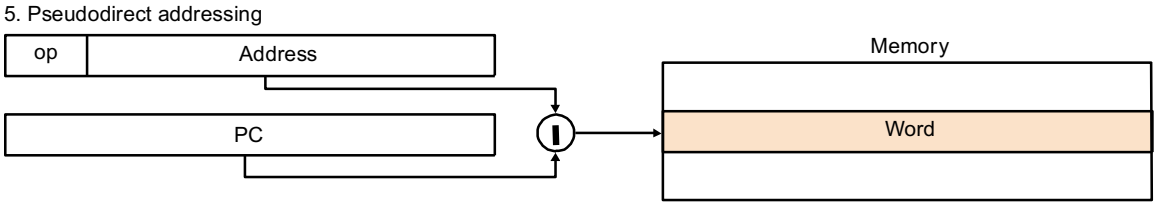
lb $t0, 48($s0)



bne $4, $5, Label
(label will be assembled into a distance)

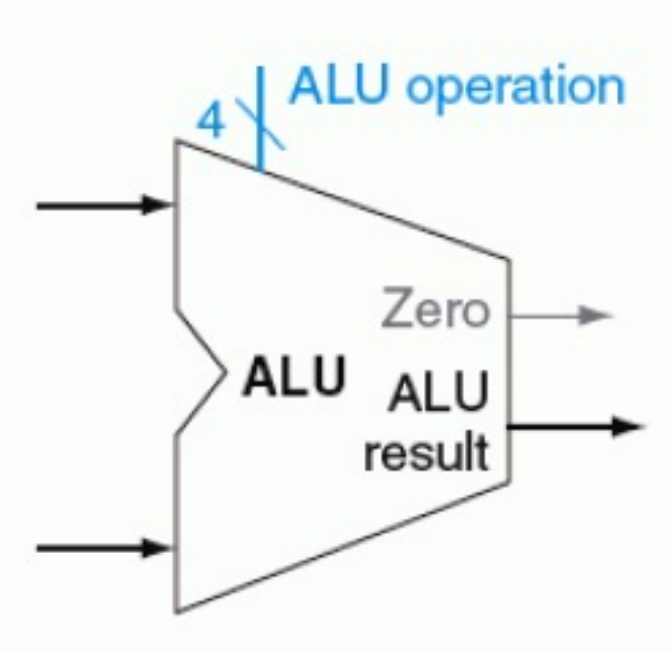


j Label

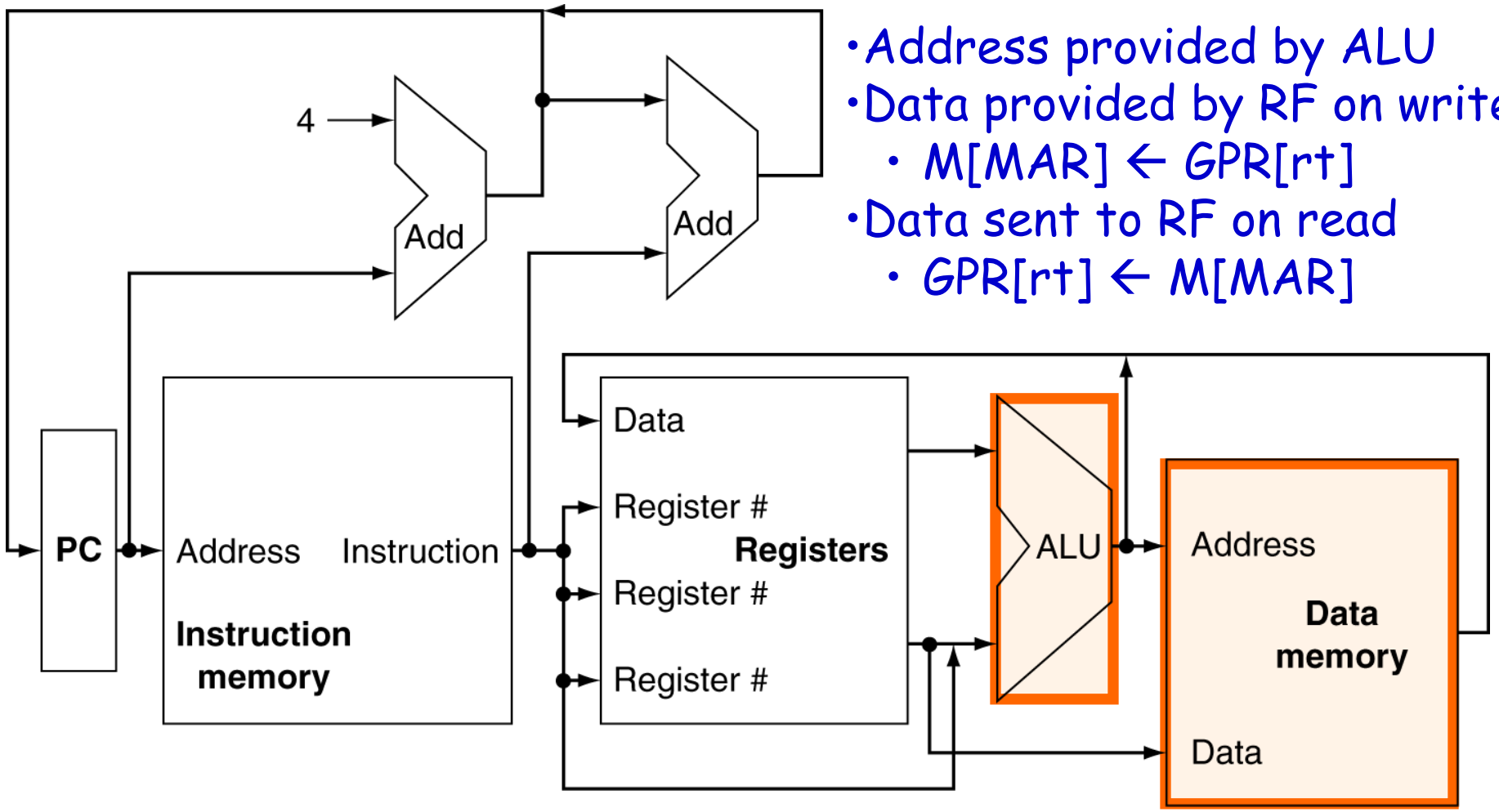


Datapath Elements (cont.)

- ALU
  - Two 32-bit inputs
  - One 32-bit output
  - 4-bit operation selector
  - Zero?



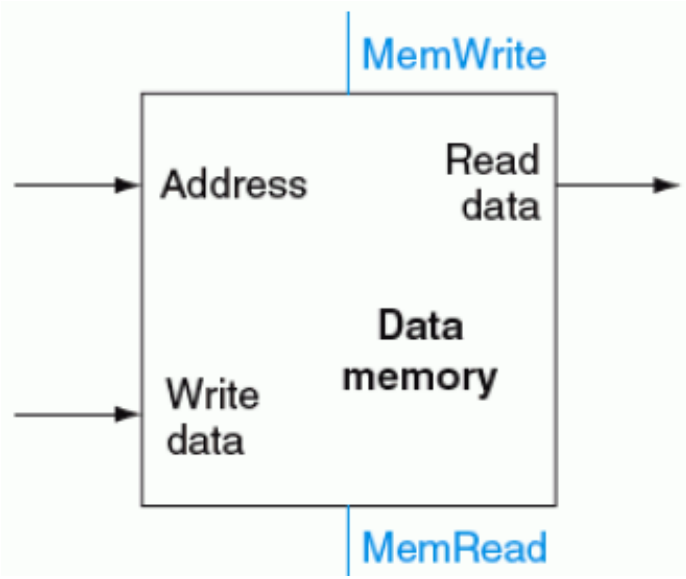
Data Memory (D-Cache)



- Address provided by ALU
- Data provided by RF on write
  - M[MAR] ← GPR[rt]
- Data sent to RF on read
  - GPR[rt] ← M[MAR]

Datapath Elements (cont.)

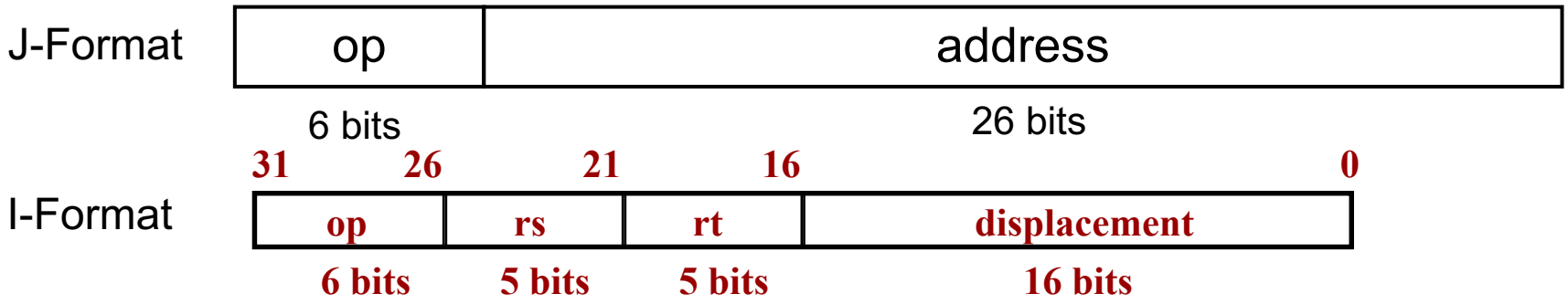
- Data Memory Unit
  - Address
    - Loads/store: MAR = GPR[rs] + imm16
  - 32-bit write data
    - Write data ← GPR[rt]
  - 32-bit read data
    - GPR[rt] ← Read data
  - MemRead signal
  - MemWrite signal

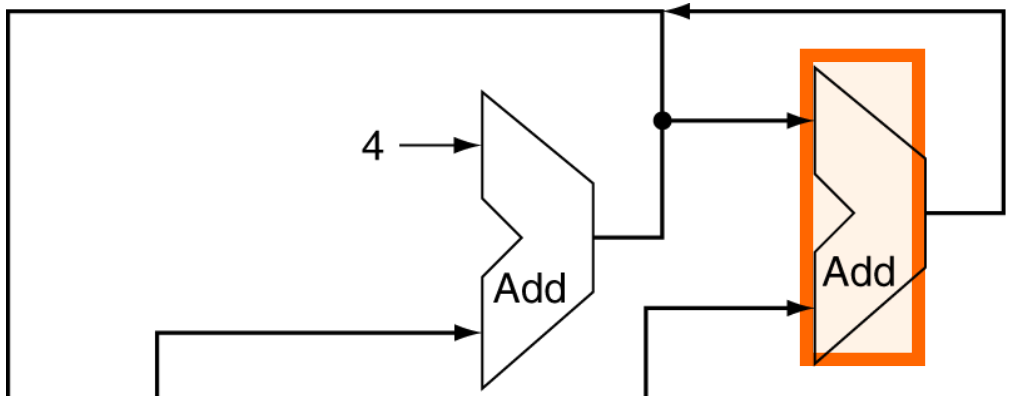


Datapath Elements: Discussion

- Compare MemRead and MemWrite Activation Process in Following Cases
  - Case A: separate I-cache & D-cache with separate data bus
  - Case B: separate I-cache & D-cache with common data bus
  - Case C: unified I-cache & D-cache

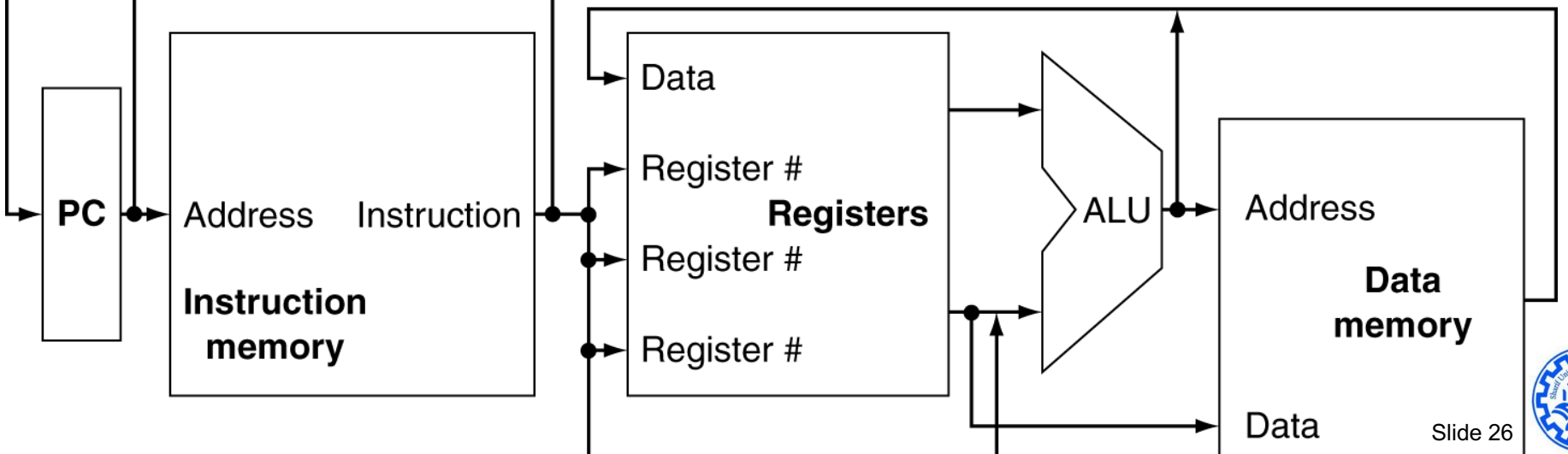
Abstract View of MIPS Implementation





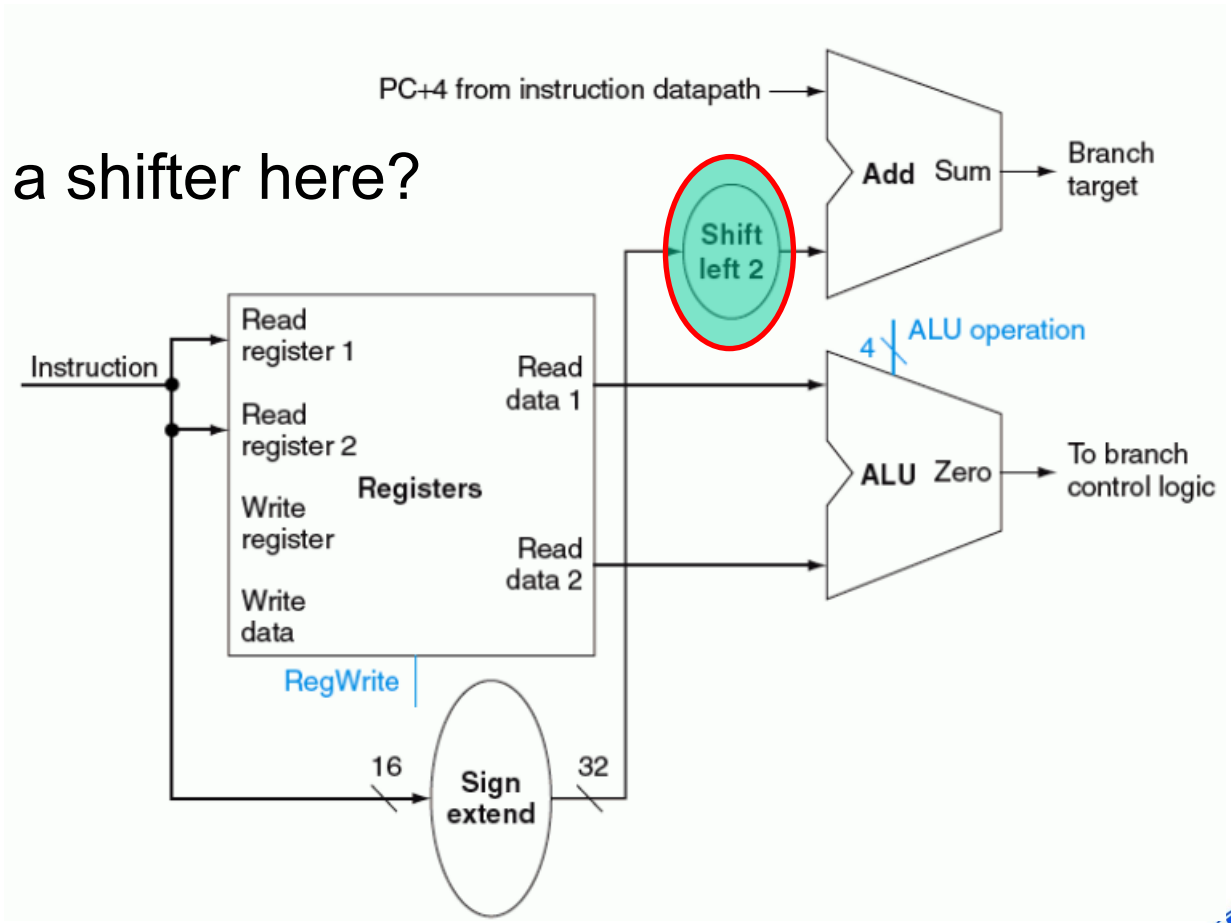
How about this adder?

- Used on Jump instructions
- Sequential instructions
  - PC ← PC + 4
- Jump instructions
  - PC ← PC + 4 + (address<<2)



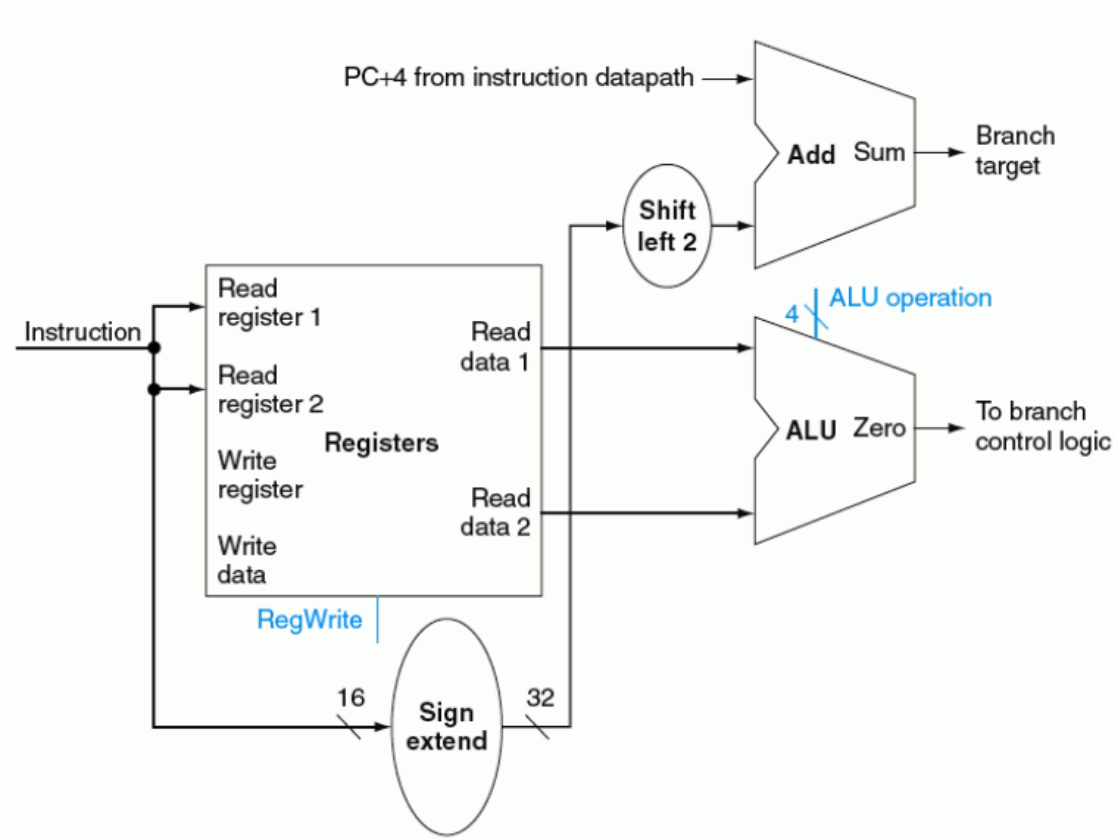
Datapath Elements (cont.)

- Branch Unit
  - Sign extend unit
  - Adder
  - Shifter
  - Do we need a shifter here?

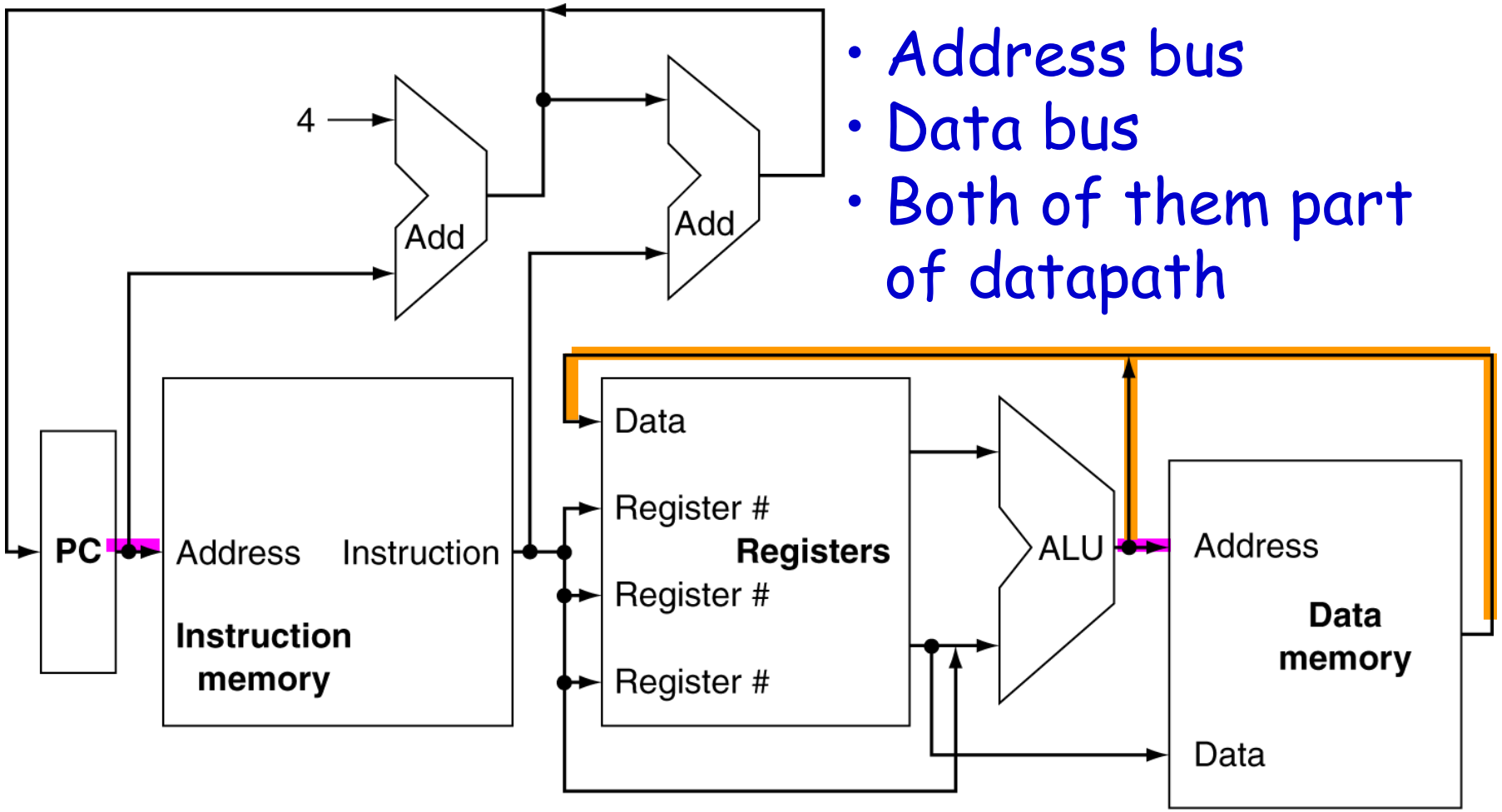


Practice

- In Following Circuit:
  - Draw sign-extend & shift logic

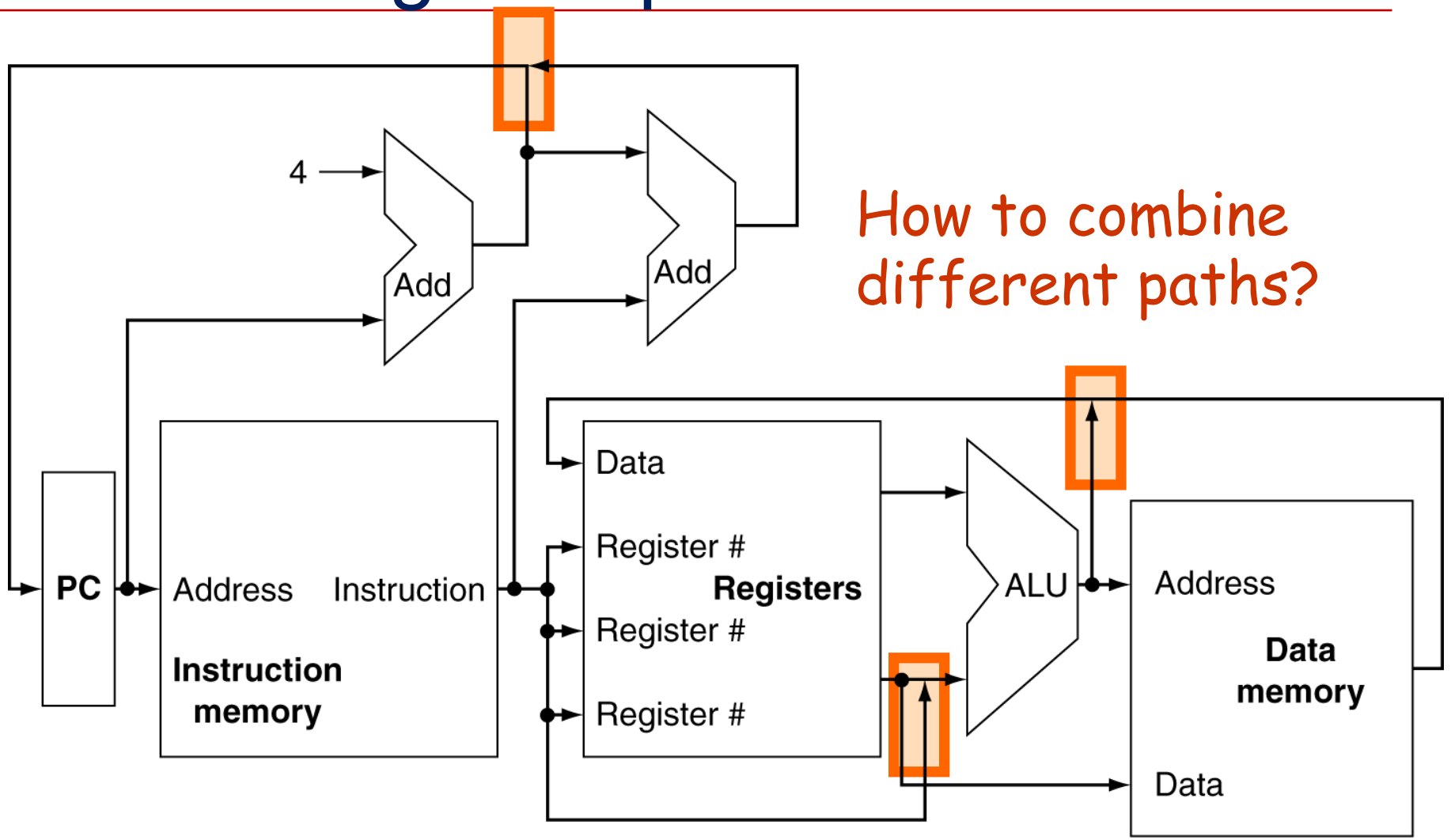


Address Bus & Data Bus



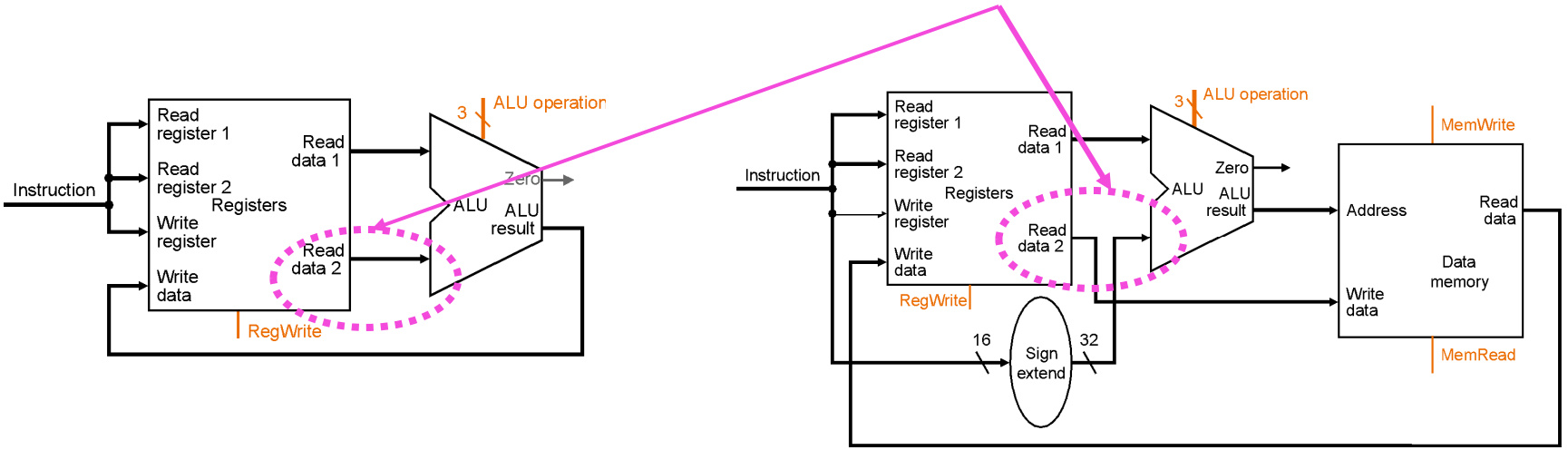
- Address bus
- Data bus
- Both of them part of datapath

Combining Datapaths



Combining Datapaths (cont.)

- Question:
  - How to have different datapaths for different instructions?

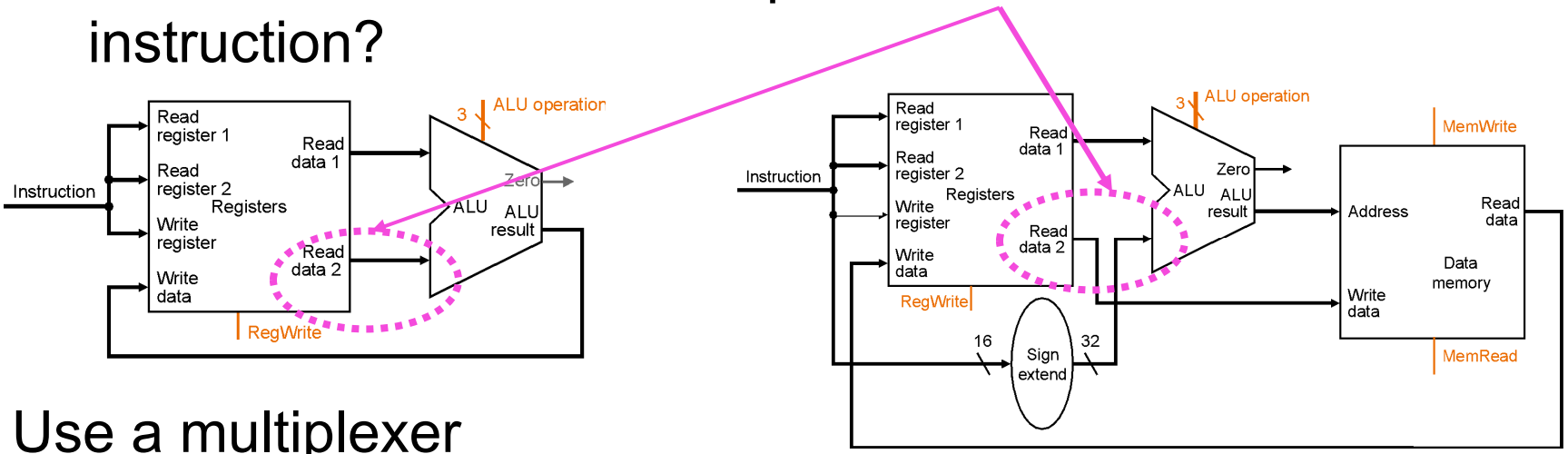


R-type

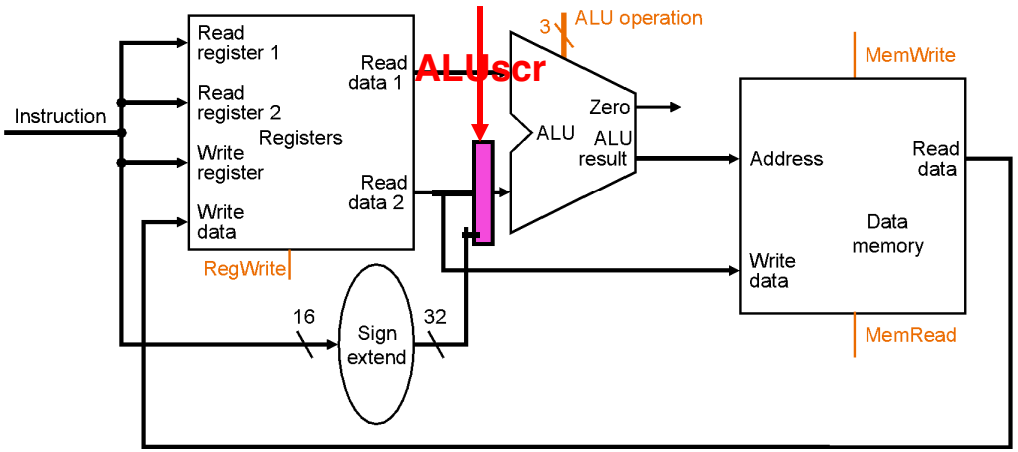
Store

Combining Datapaths (cont.)

- Question:
  - How to have different datapaths for different instruction?

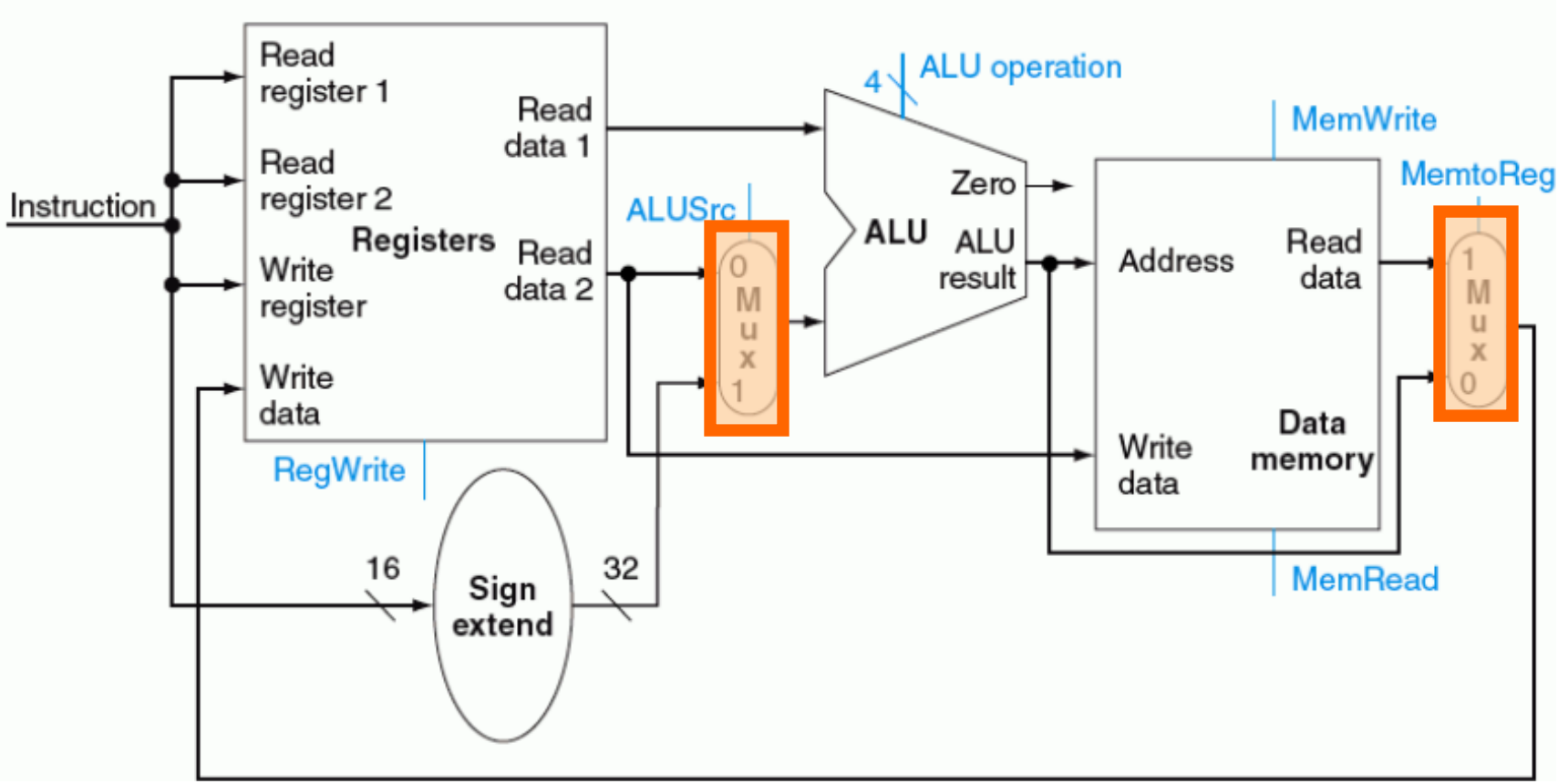


- Use a multiplexer

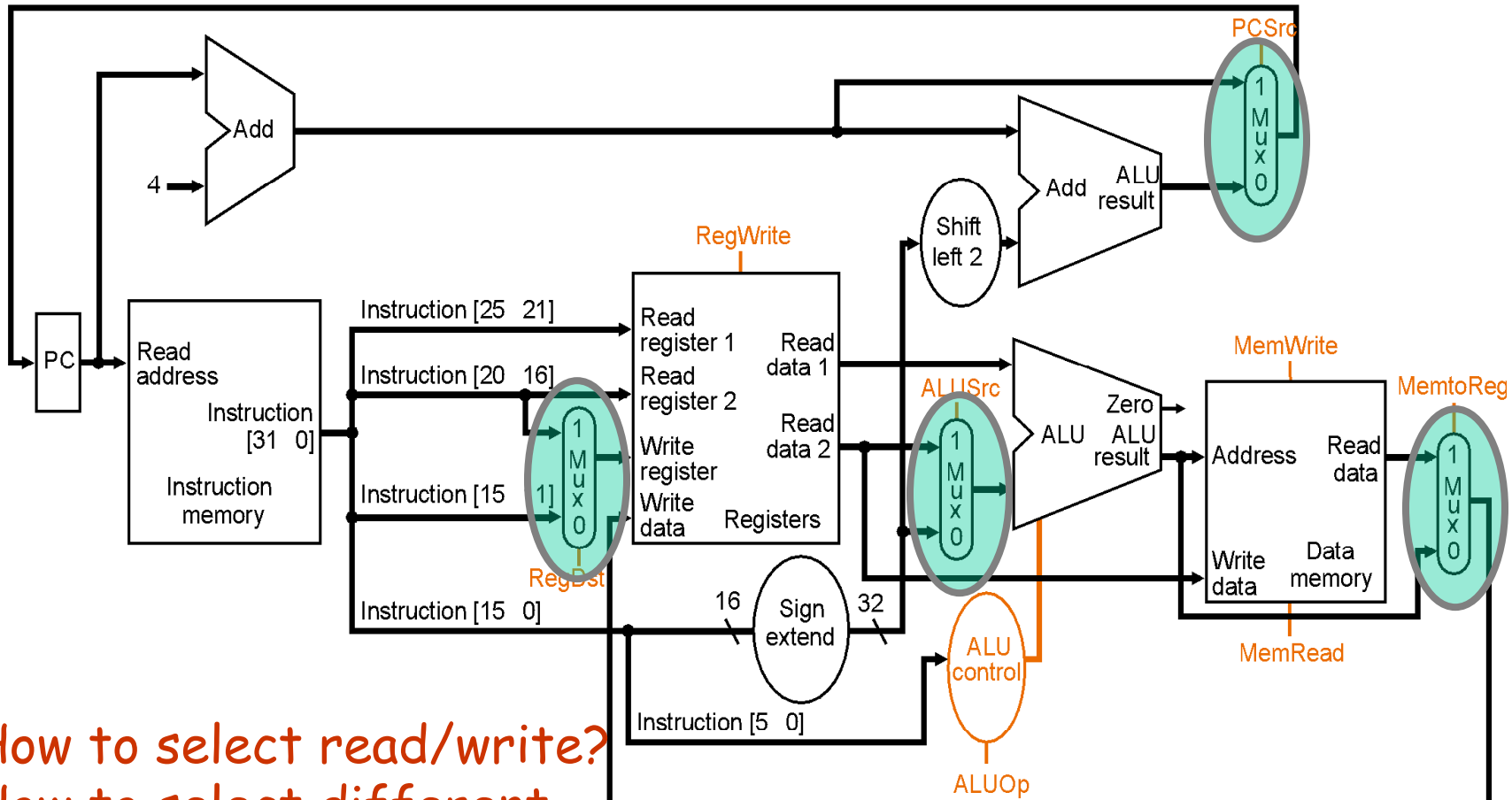


Combining Datapaths (cont.)

- Merging R-type datapath with load/store datapath using multiplexer



All Together: Single Cycle Datapath



How to select read/write?
How to select different datapaths?

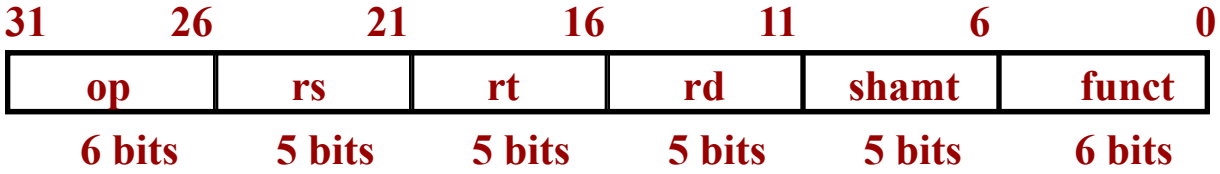
Practice

- Question:
  - Could we swap rs, rt, & rd bits to have easier datapath design?
  - In other words, can we remove RegDst MUX?

Practice: Hint

- R-type
  - rs & rt: read index bits
  - rd: write index bits
- lw:
  - rs: read index bits
  - rt: write index bits
- sw:
  - rs & rt: read index bits

- R-TYPE
  - *add rd, rs, rt*
  - sub, and, or, slt



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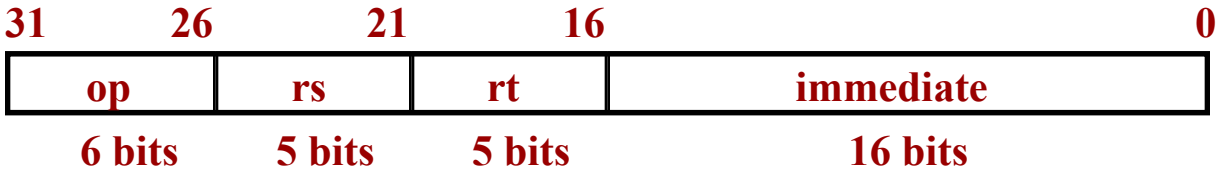
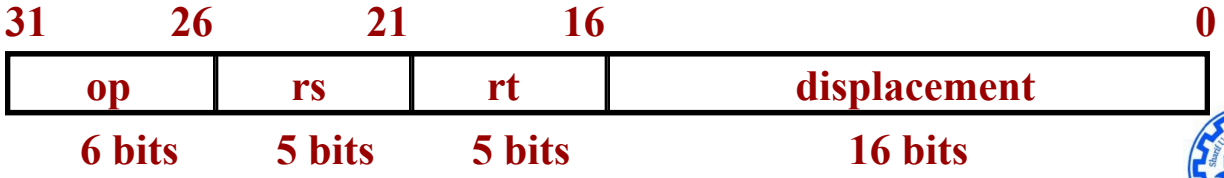
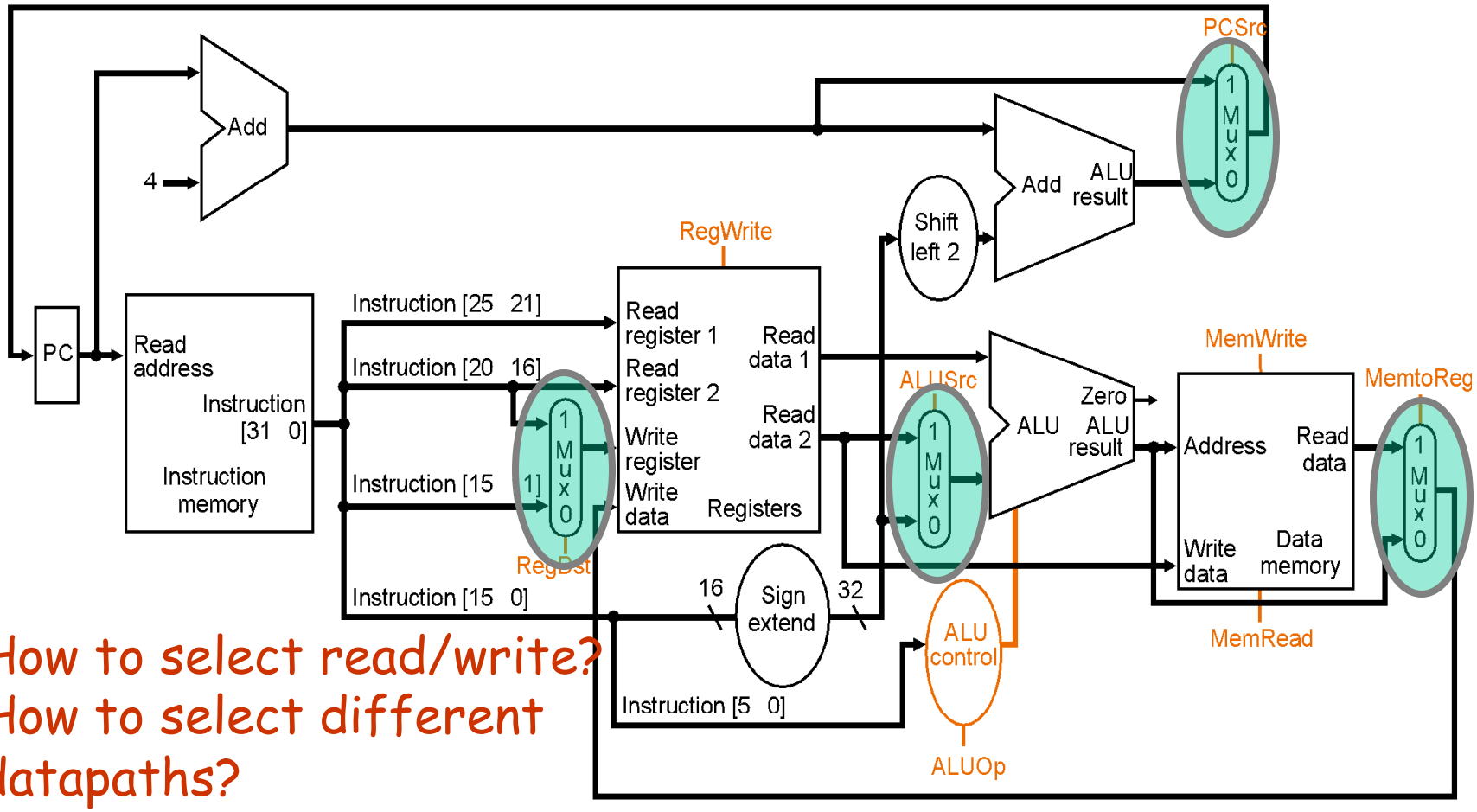
  - sw rt, rs, imm



- BRANCH
  - beq rs, rt, imm

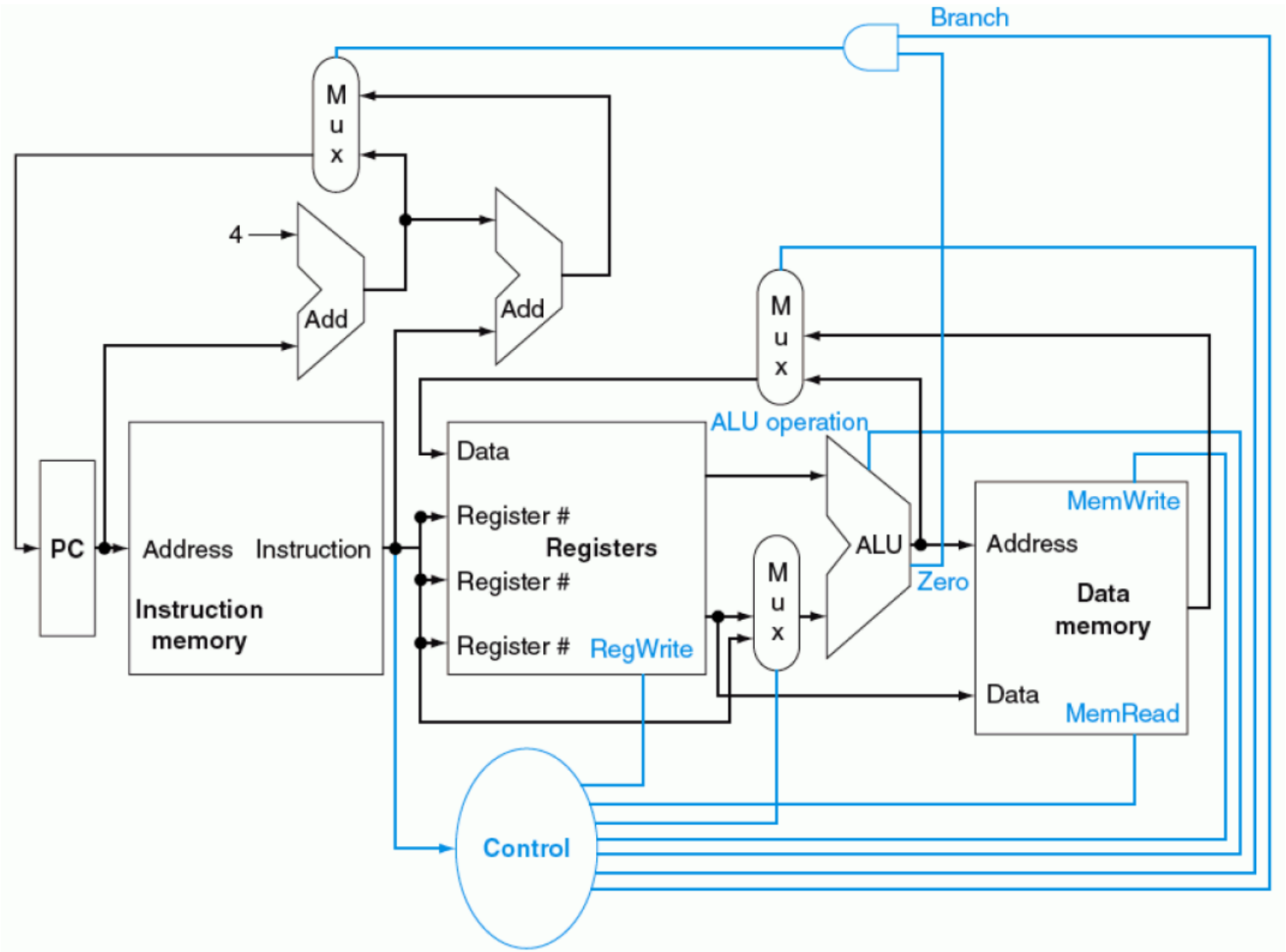


All Together: Single Cycle Datapath



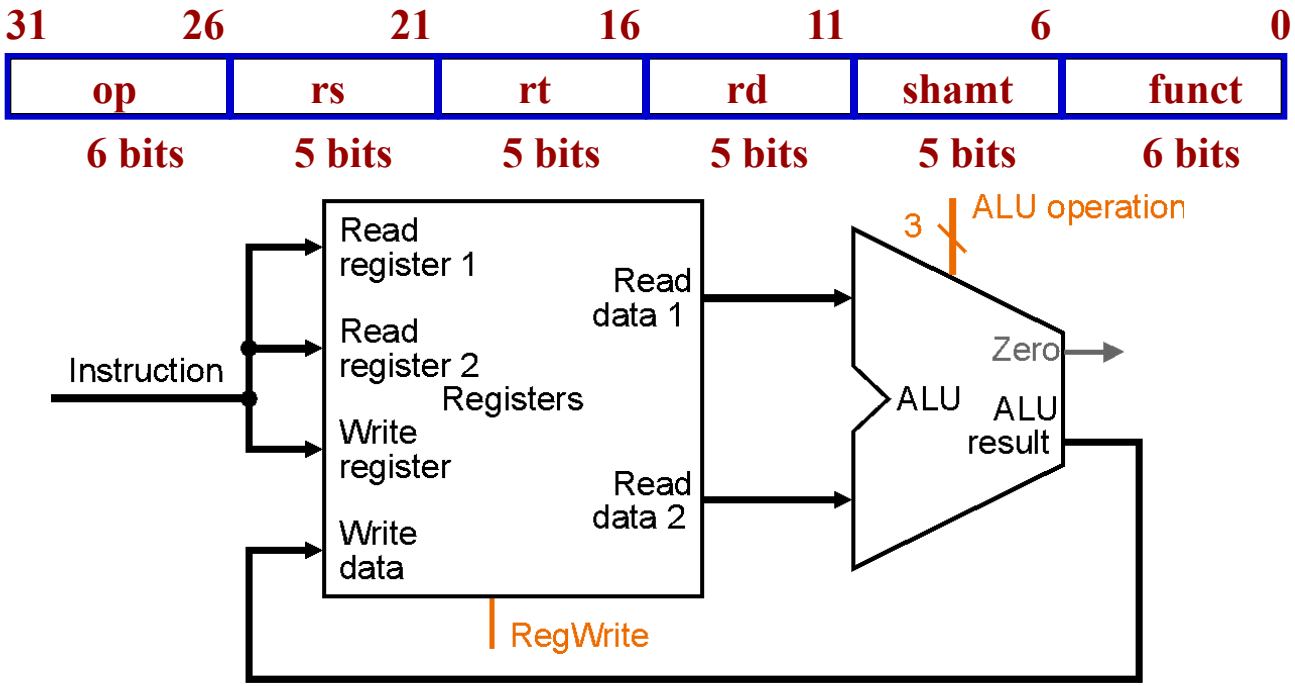
How to select read/write?
How to select different datapaths?

Abstract View of MIPS Implementation: Control



Datapath for Reg-Reg Operations

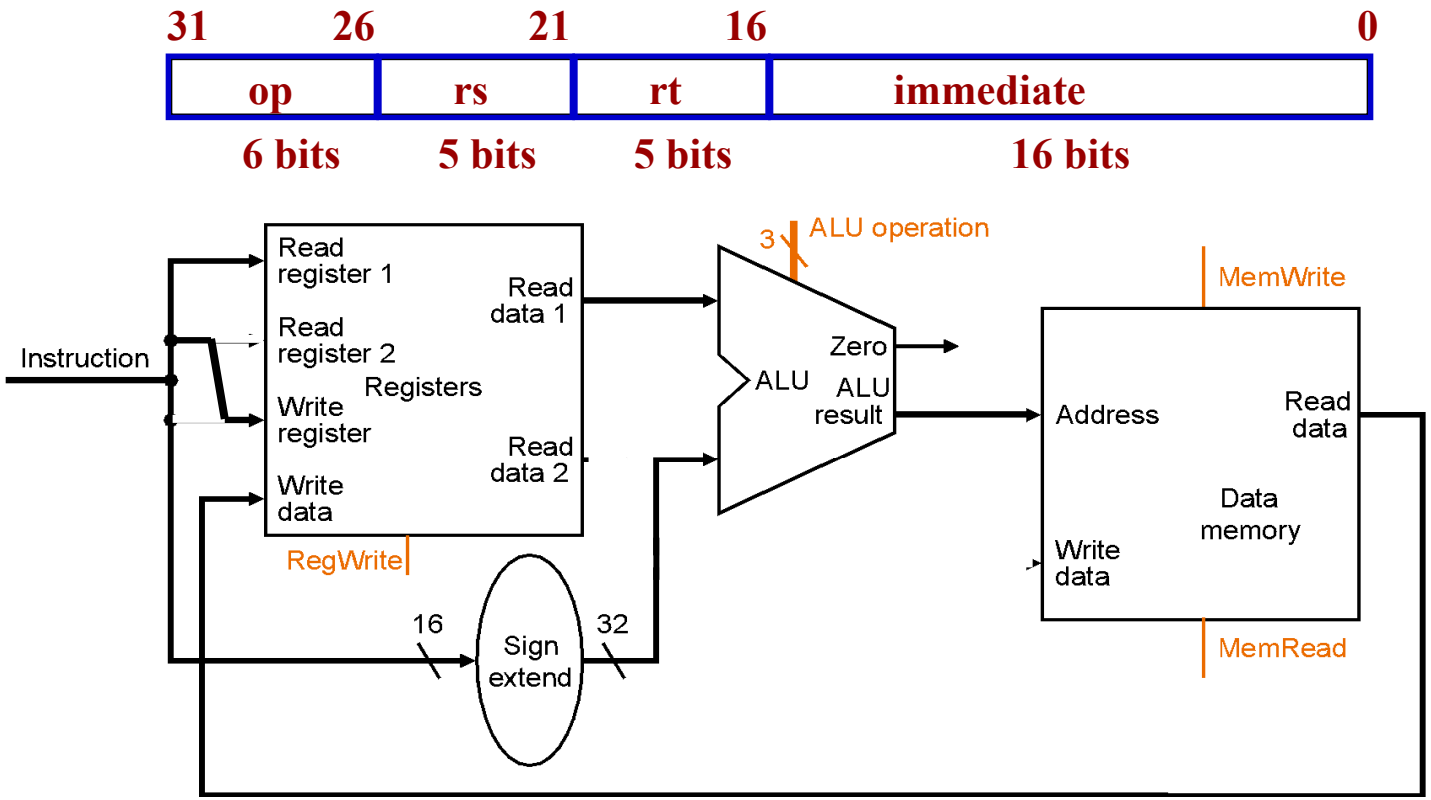
- GPR[rd] ← GPR[rs] op GPR[rt]
  - Example: *add rd, rs, rt*
  - ALUoperation signal depends on op and funct



***ALU operation* and *RegWrite*: control logic after decoding instruction**

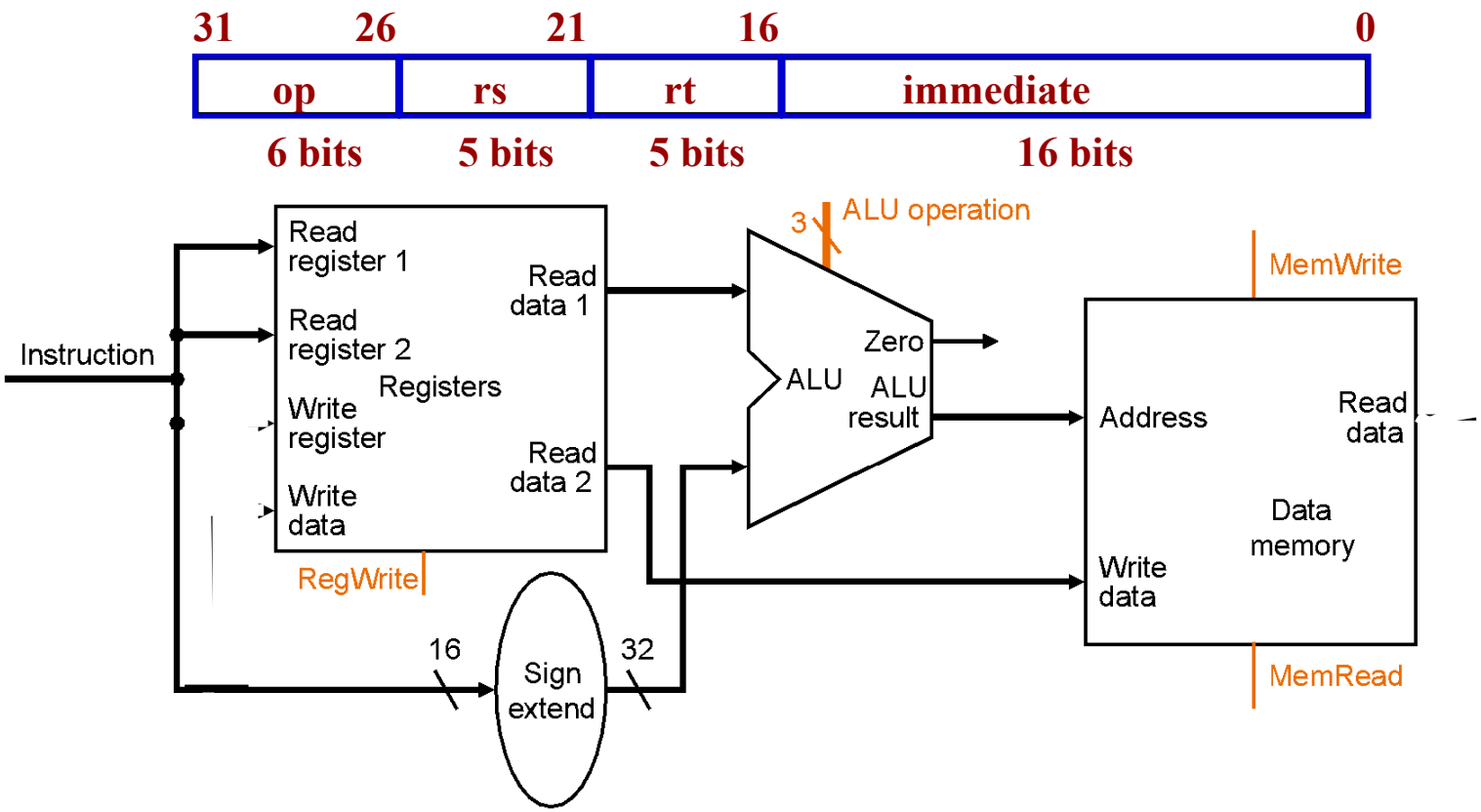
Datapath for Load Operations

- GPR[rt] ← Mem[GPR[rs] + SignExt[imm16]]
  - Example: *lw rt, rs, imm16*



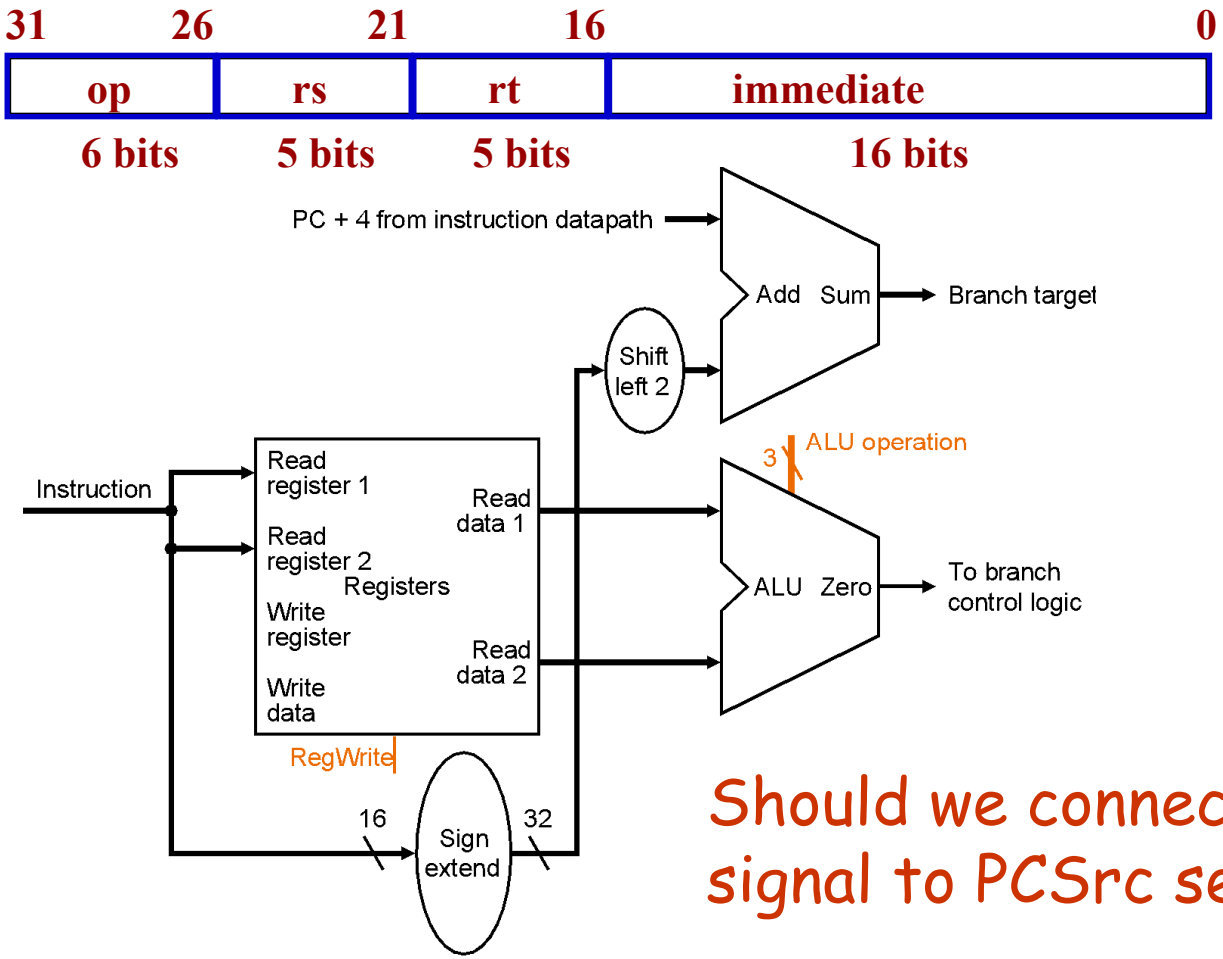
Datapath for Store Operations

- Mem[GPR[rs] + SignExt[imm16]] ← GPR[rt]
  - Example: *sw rt, rs, imm16*



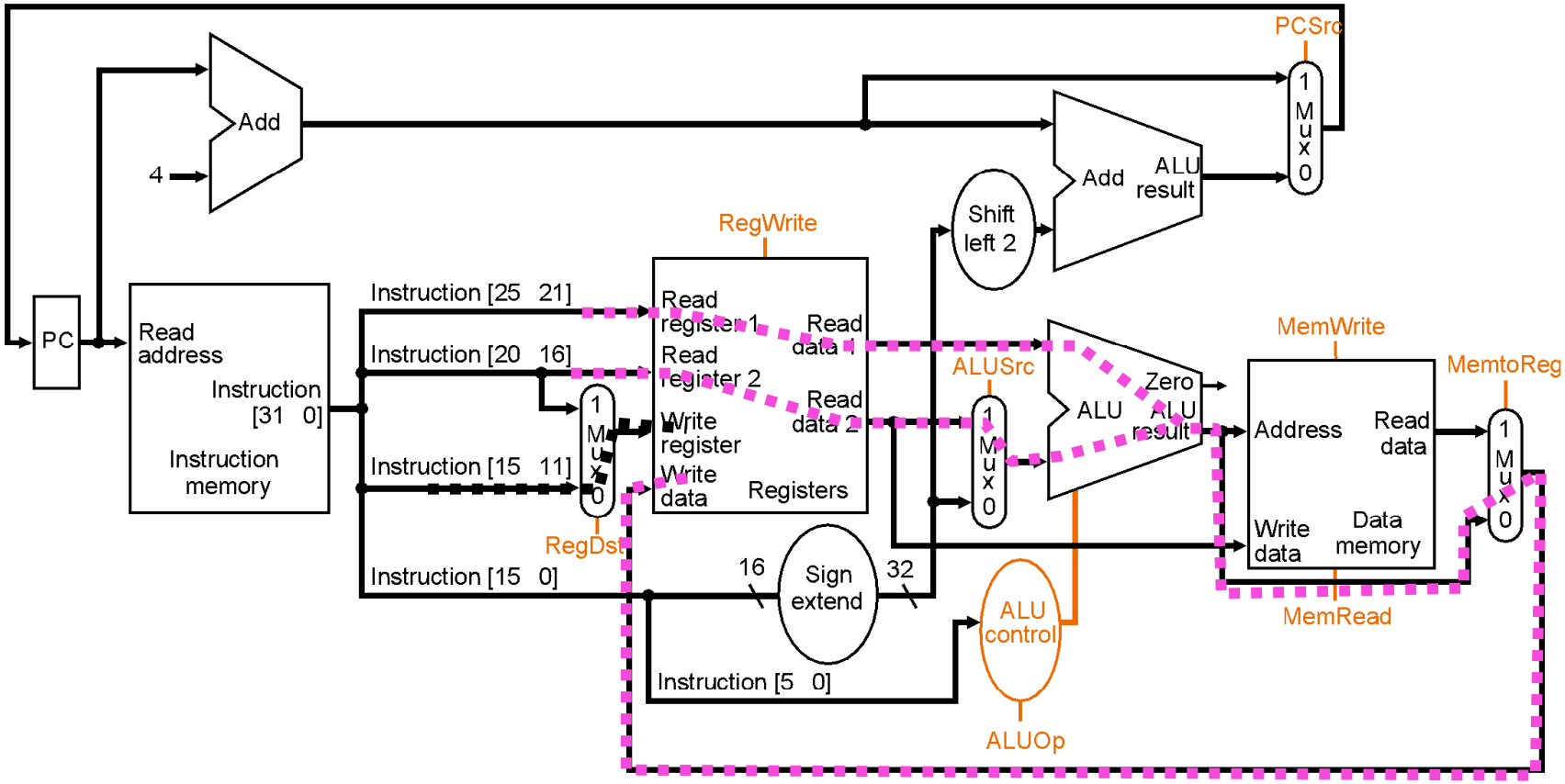
Datapath for Branch Operations

- *beq rs, rt, imm16*



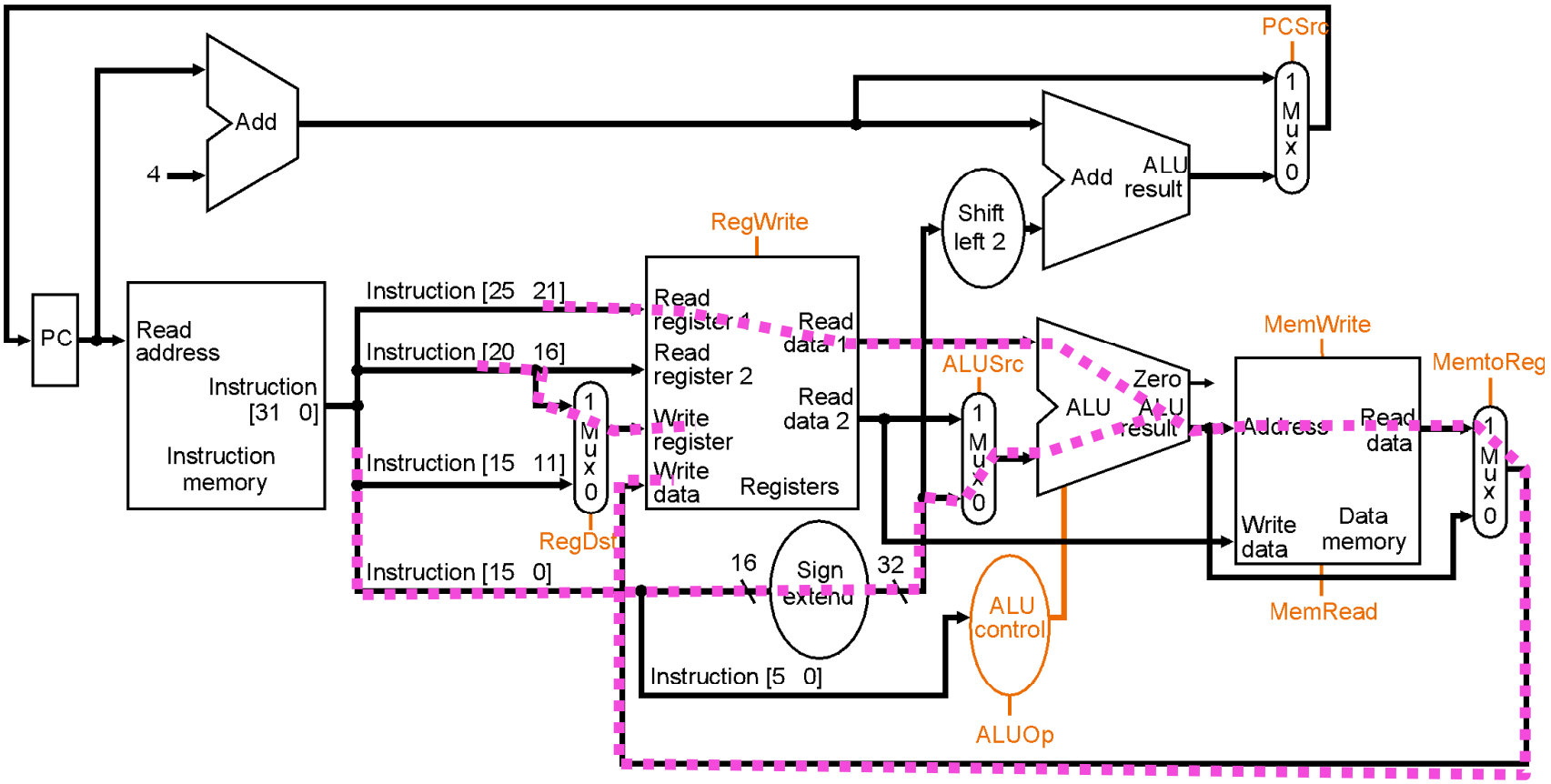
Should we connect "Zero" signal to PCSrc selector?

R-Format Datapath (e.g. *add*)



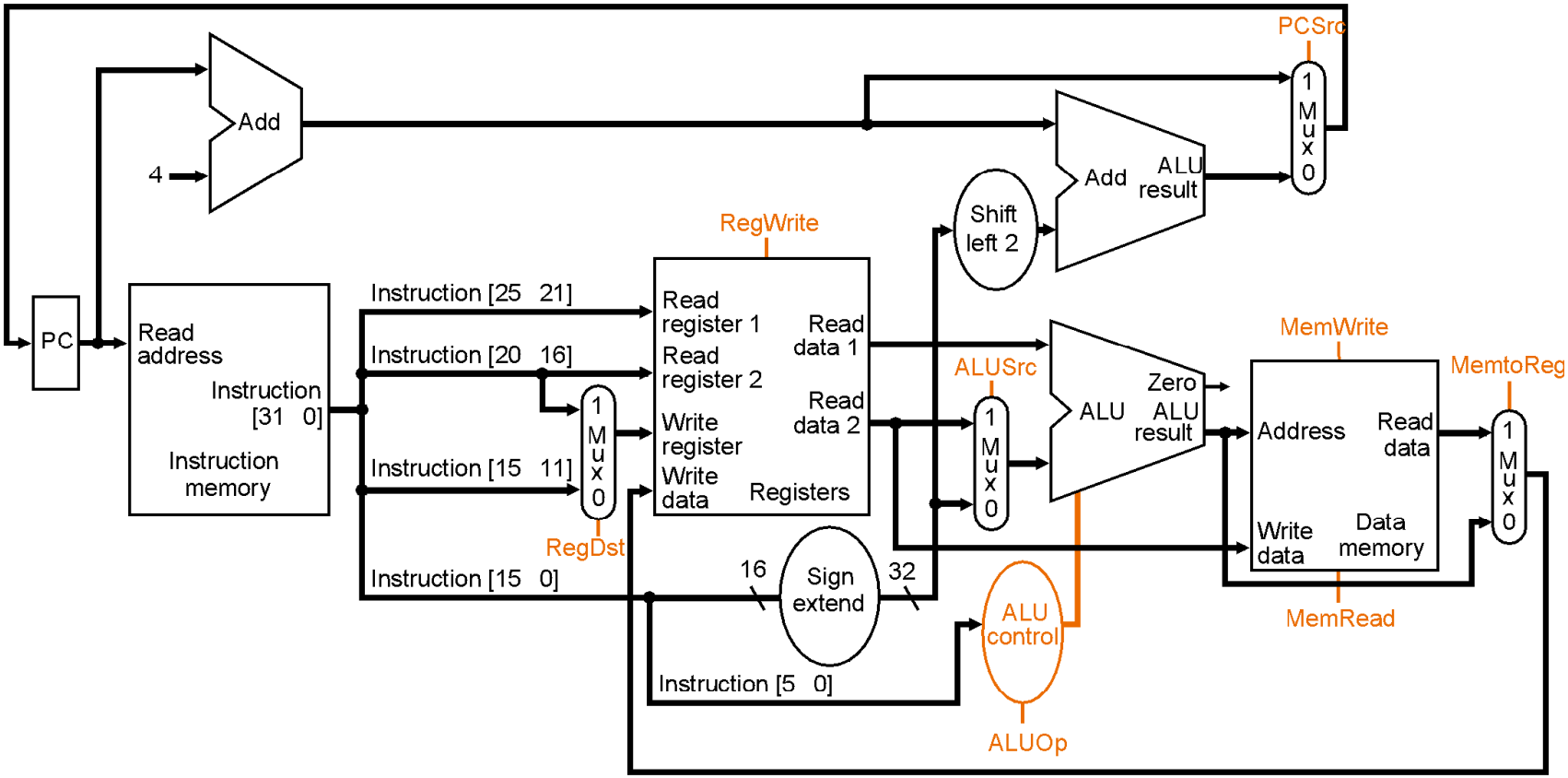
Need ALUsrc=1, ALUop="add", MemWrite=0, MemToReg=0, RegDst = 0, RegWrite=1 and PCsrc=1.

Load Datapath

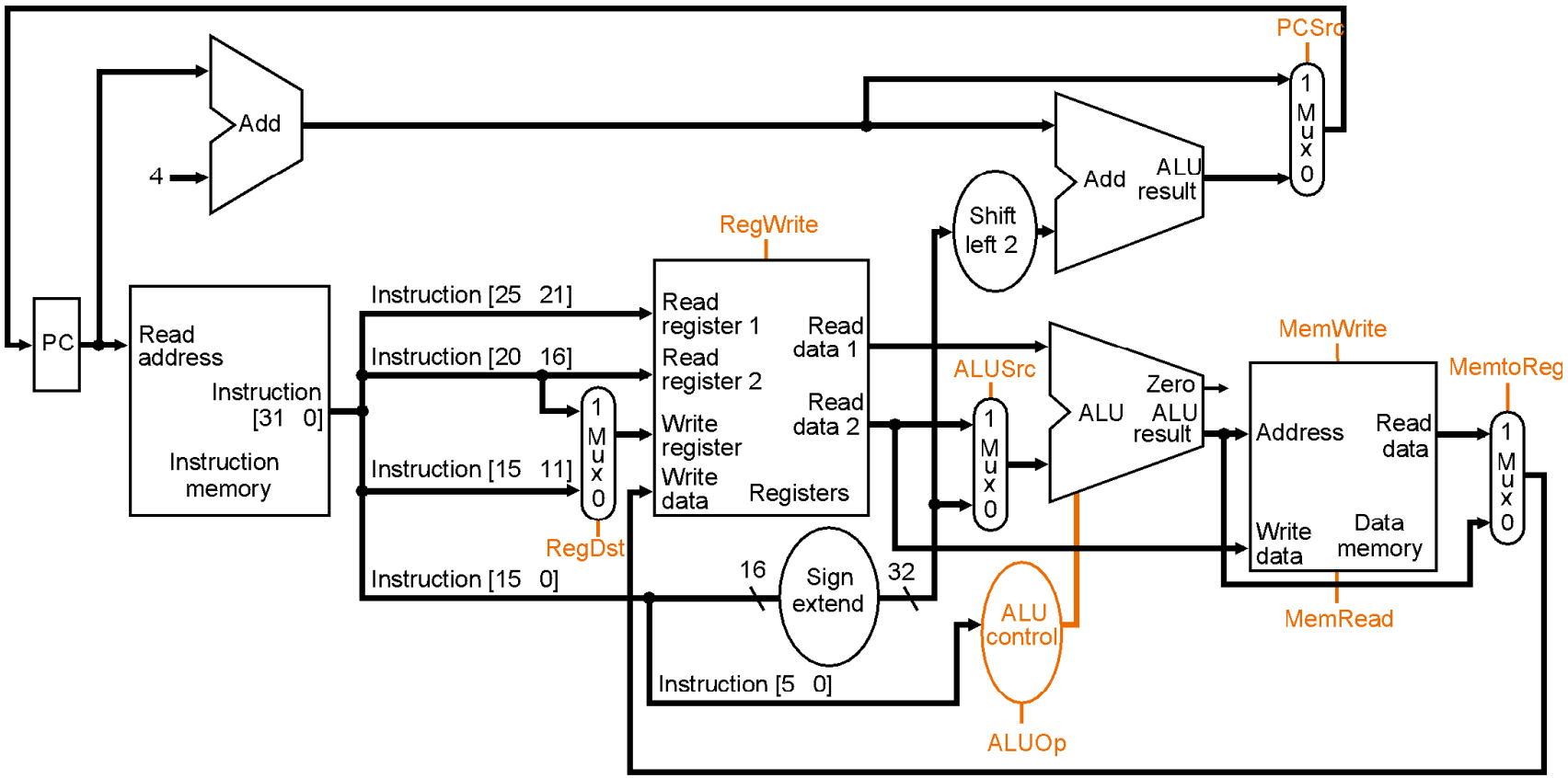


What control signals do we need for load??

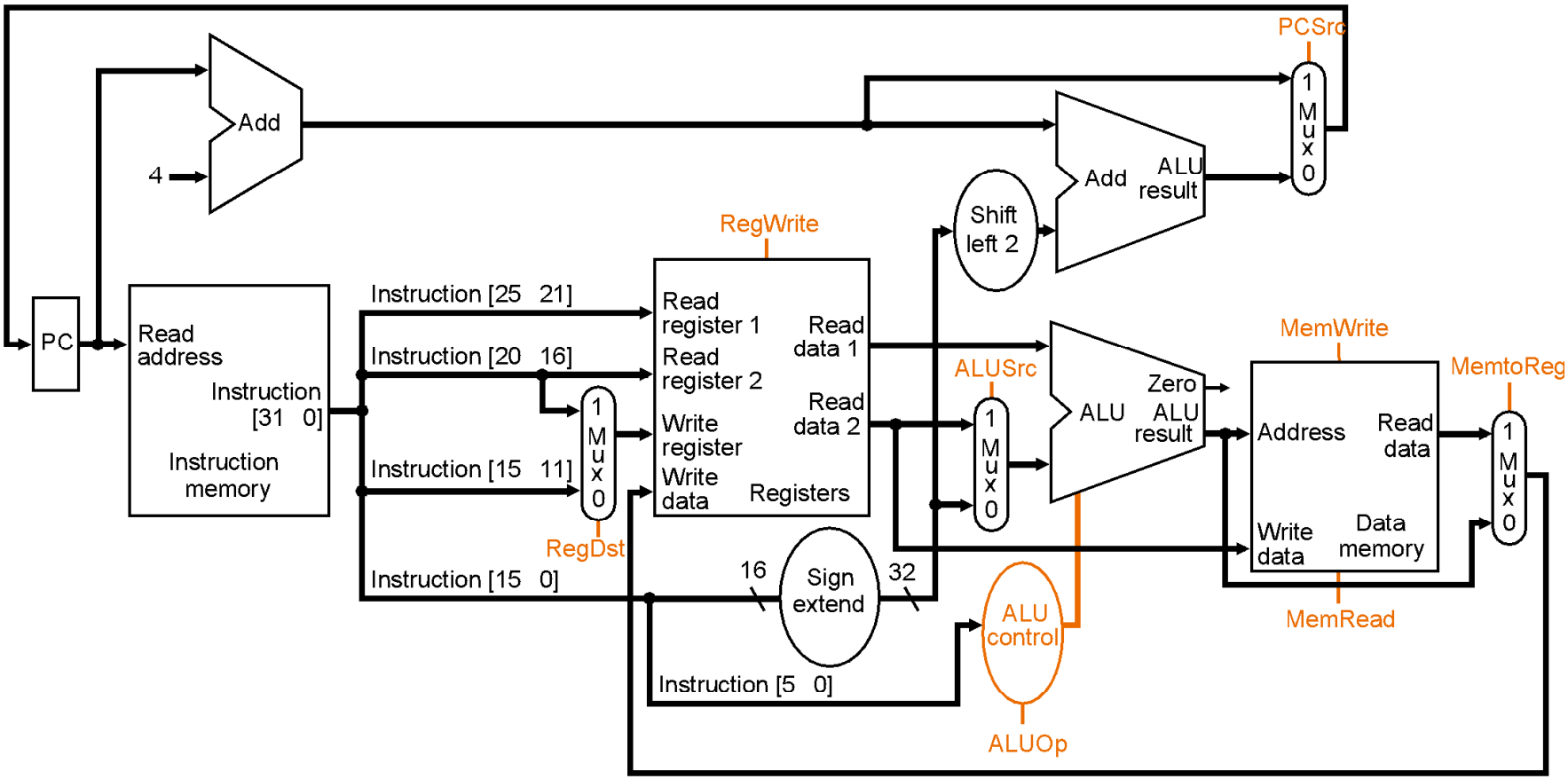
Store Datapath



beq Datapath

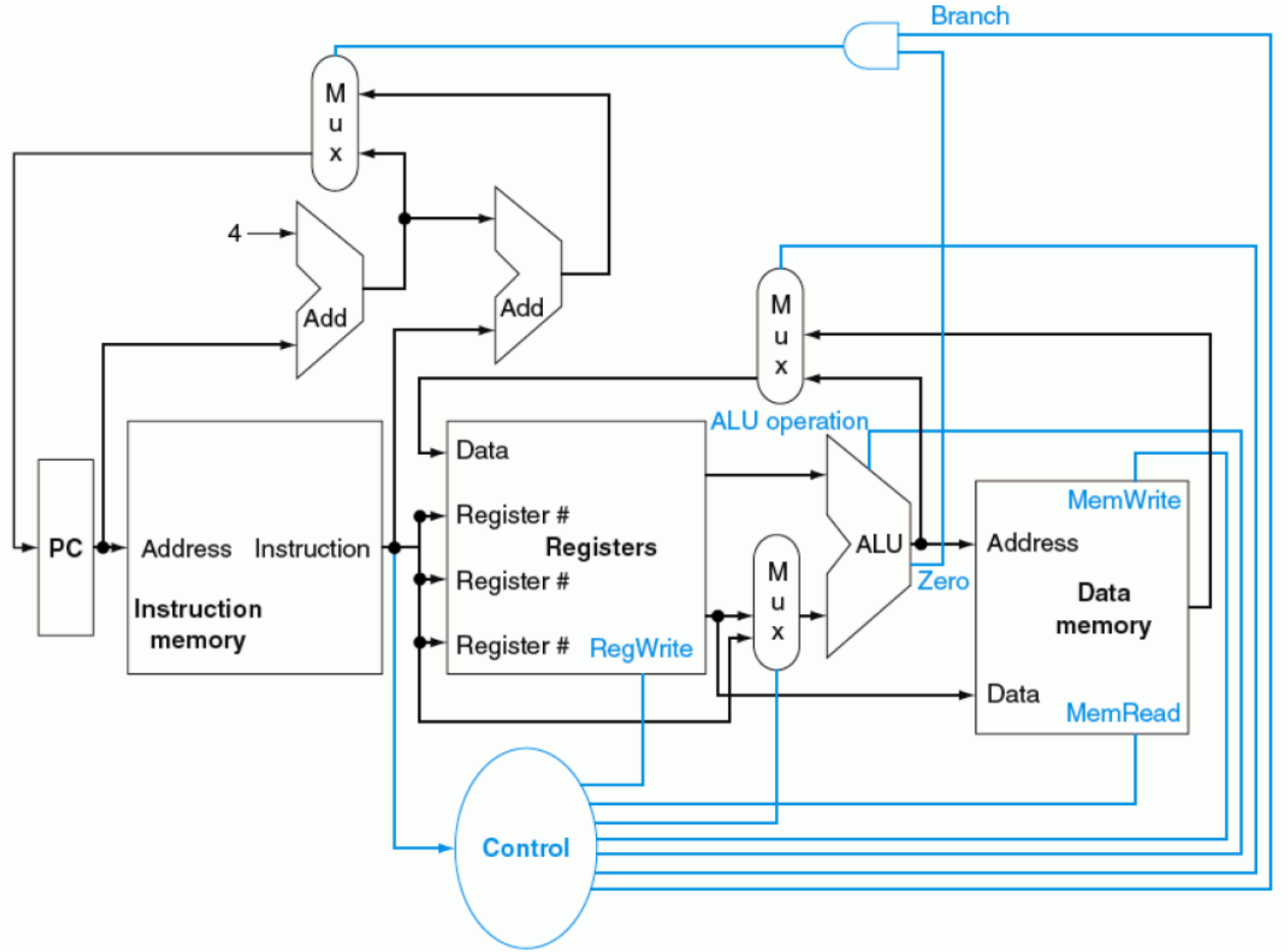


Putting it All Together: Datapath



We have everything except details for generating **control signals**

Next Step: MIPS Control Unit




Thanks for Your Attention!