# CSE 2600
# Intro. To Digital Logic & Computer Design

Bill Siever
&
Michael Hall

# This week

- Homework 6B due tomorrow
- Homework 7A posted soon(ish)
- Thursday: Studio (bring kit?)

# Review Reading (from Mem. to Reg): Load

- Mnemonic: load word (lw)

- Format: lw t1, 8(s0)
  lw destination, offset(base)

- Address calculation: RAM index = add base address (s0) to the offset (8) = (s0 + 8)

- Result: t1 holds the data value at address (s0 + 8)
  I.e. t1 = RAM[s0+8]

- In terms of “register” array:
  REG[t1] = RAM[REG[s0]+8]]
  REG[6] = RAM[REG[8]+8]]

- Units: Memory is usually “byte addressable” and words are 4 bytes.
  So data is actually retrieved from RAM[REG[s0]+8] to RAM[REG[s0]+11]]

# Reading (from Reg to Mem.): Store

- Mnemonic: store word (sw)

- Format: sw t1, 8(s0)
  sw source, offset(base)

- Address calculation: RAM index = add base address (s0) to the offset (8) = (s0 + 8)

- Result: t1 holds the data value at address (s0 + 8)
  I.e. RAM[s0+8] = t1

- In terms of “register” array:
  RAM[REG[s0]+8]] = REG[t1]
  RAM[REG[8]+8]] = REG[6]

- ***NOTE: Stores are the one case where the “thing on the left” is not the destination!***

# Studio 6B: More Assembly (Functions & Memory)

# Chapter 6 & 7

# *Architectures*: RISC-V

- "Architecture": Programmer's view of CPU
- Fundamental data size: 32-bit "word". CPU/ALU designed for 32-bit operations (Multiple 32-bit operations can be done to do larger operations)
- Memories
  - RAM: Big array of numbers; Uses 32-bit addresses
  - Registers: Array with 32, 32-bit values. Special names correspond to intended uses (Ex: a-registers,like a0, are for "arguments" to functions)
  - Instructions: Also 32-bit values; May be stored in RAM or separate memory

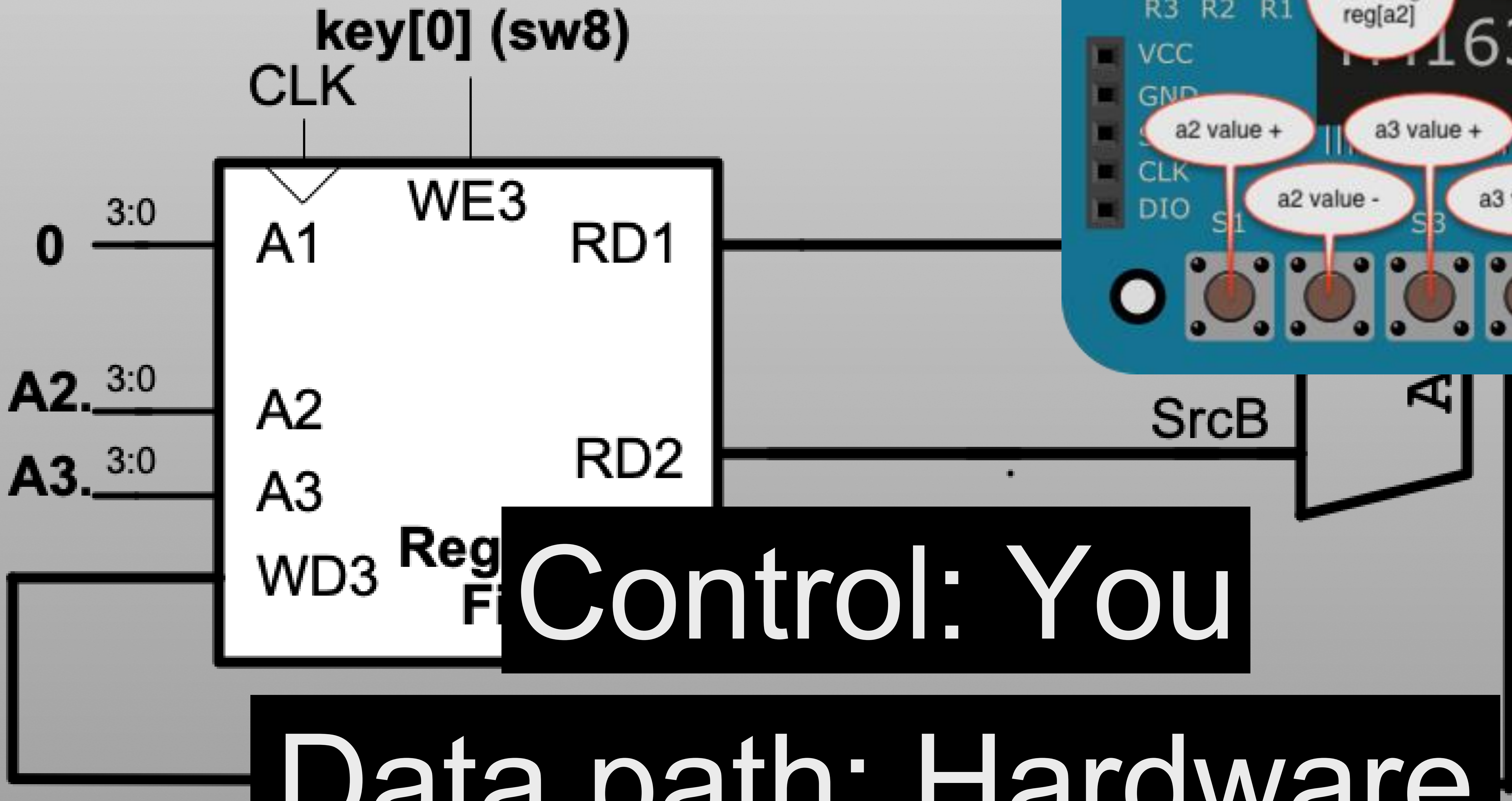
# Architectures: RISC-V

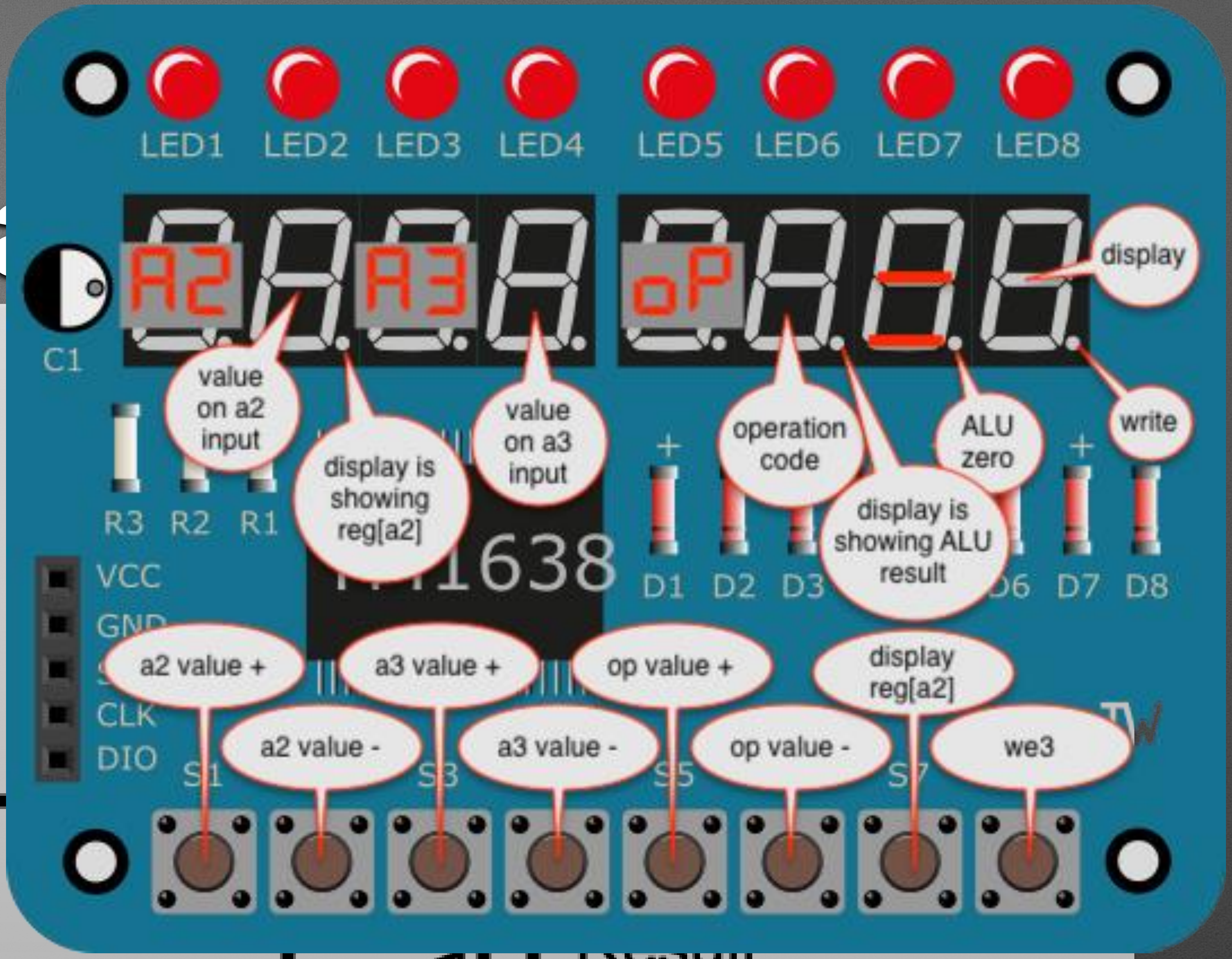
- Machine codes
  - "Substitution code": Numbers represent concepts
  - RISC-V "Instruction Set Architecture" (ISA):
    - Formats are about data locations
      ("addressing" / location of information needed)

# Architecture & MicroArchitecture

- Architecture:  Blueprint of behavior based on assembly language
- Microarchitecture: Specific implementation(s)
  - Lots of variations possible with cost/performance tradeoffs
  - Ex:  “Single Cycle” version vs. “Pipelined”
    - Single-Cycle:  Each instruction is 1 (long) cycle
    - Multi-Cycle: Instructions take more than one cycle,
      but cycles are shorter and over performance is better.

# Homework 5A: Partia

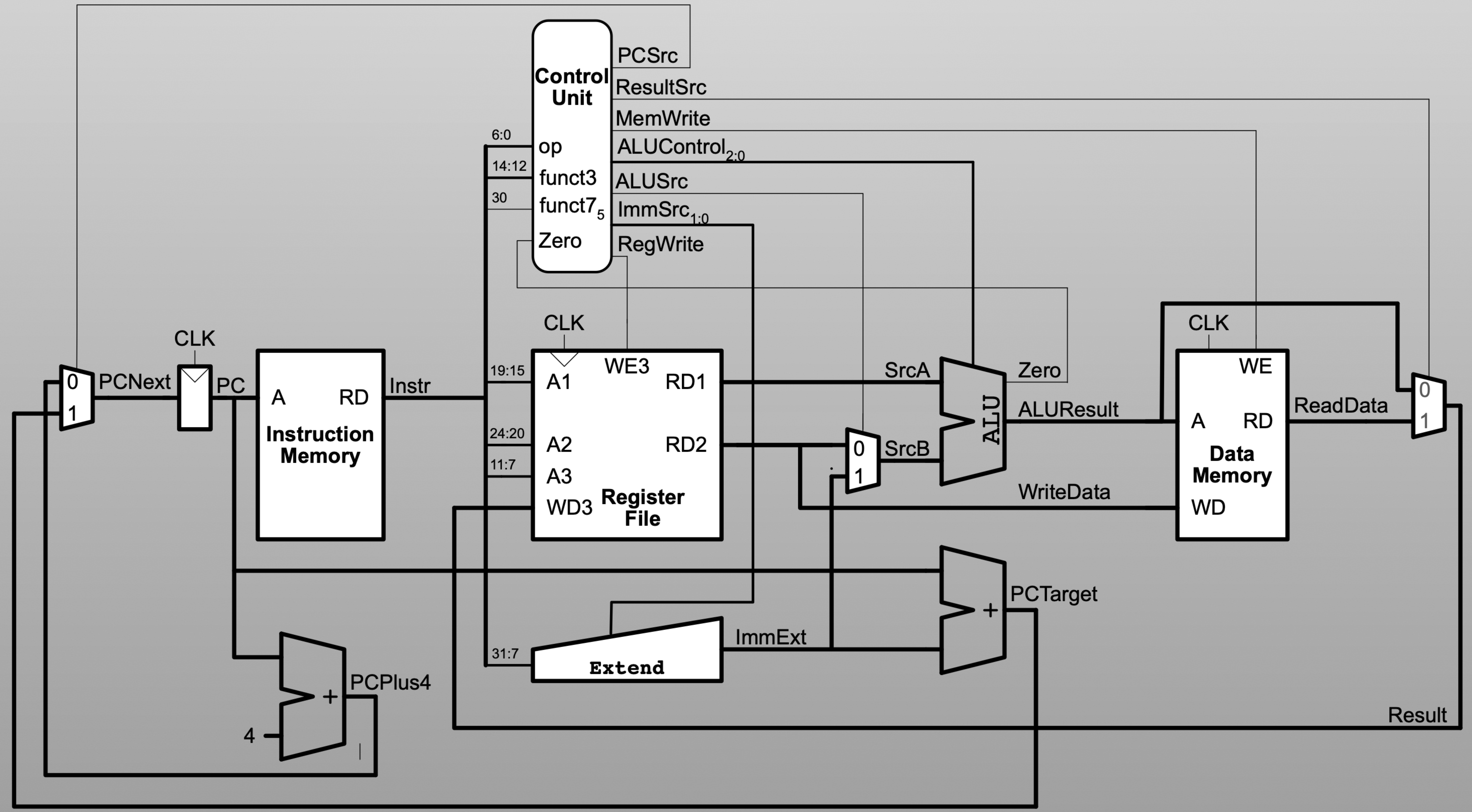


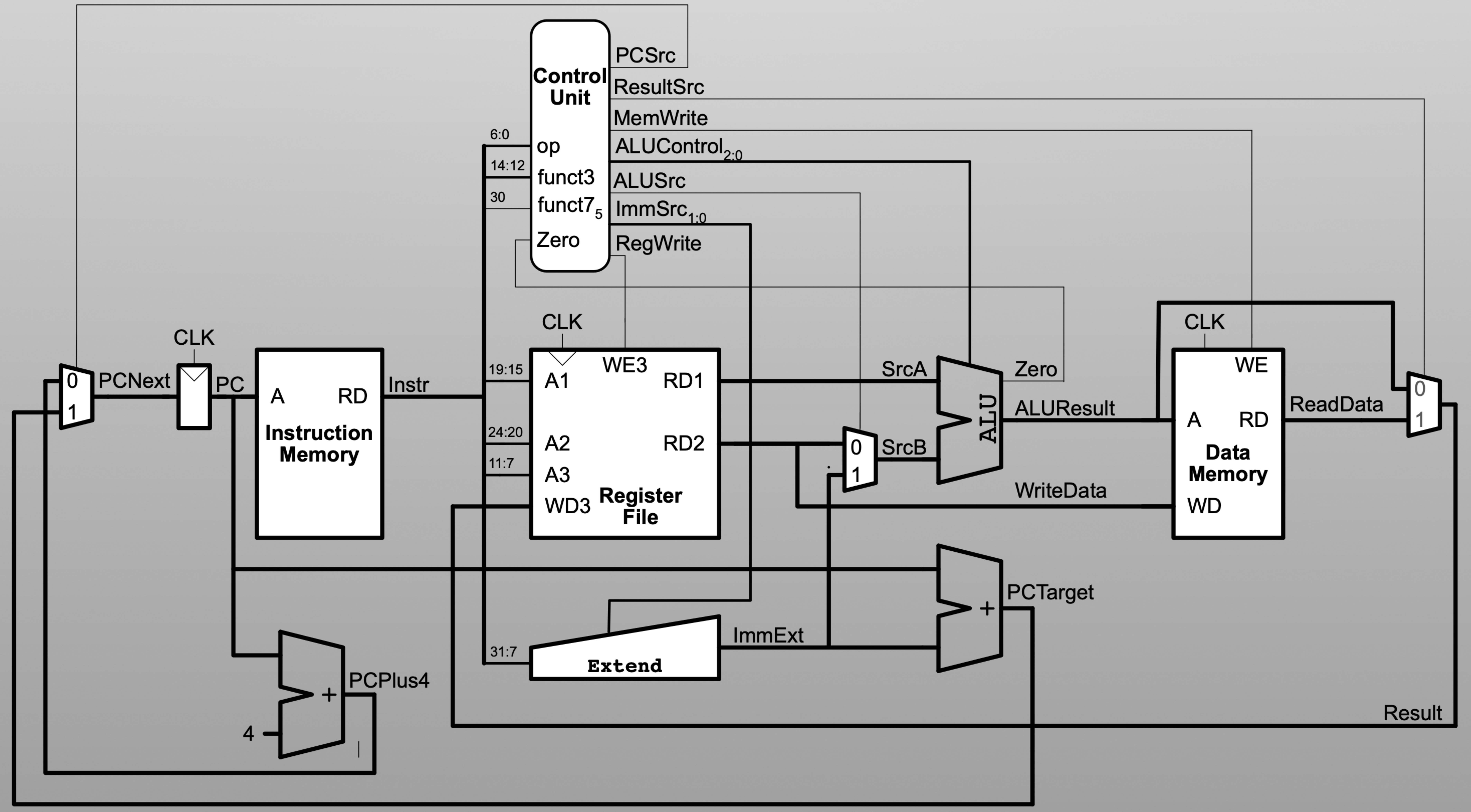

Control: You

Data path: Hardware

# Simple (Single-Cycle) RISC-V Computer



# Simple (Single-Cycle) Control vs. Datapath



# The Problem

**Find x such that** $2^x = 128$

pow in s0; x in s1

# Problem: Find x such that $2^x = 128$

```
// determines the power
// of x such that 2x = 128
int pow = 1;
int x = 0;

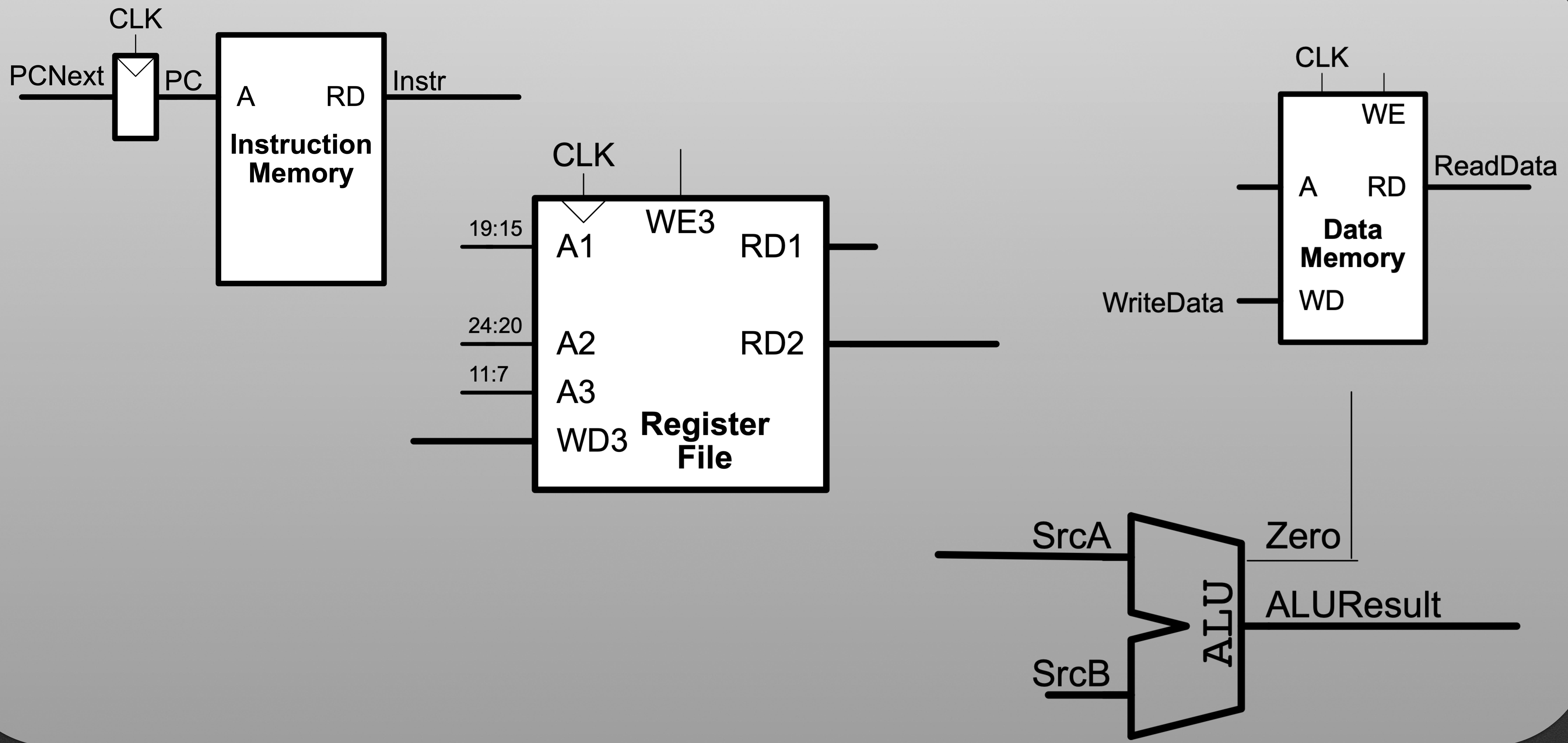

while (pow != 128) {

   pow = pow * 2;

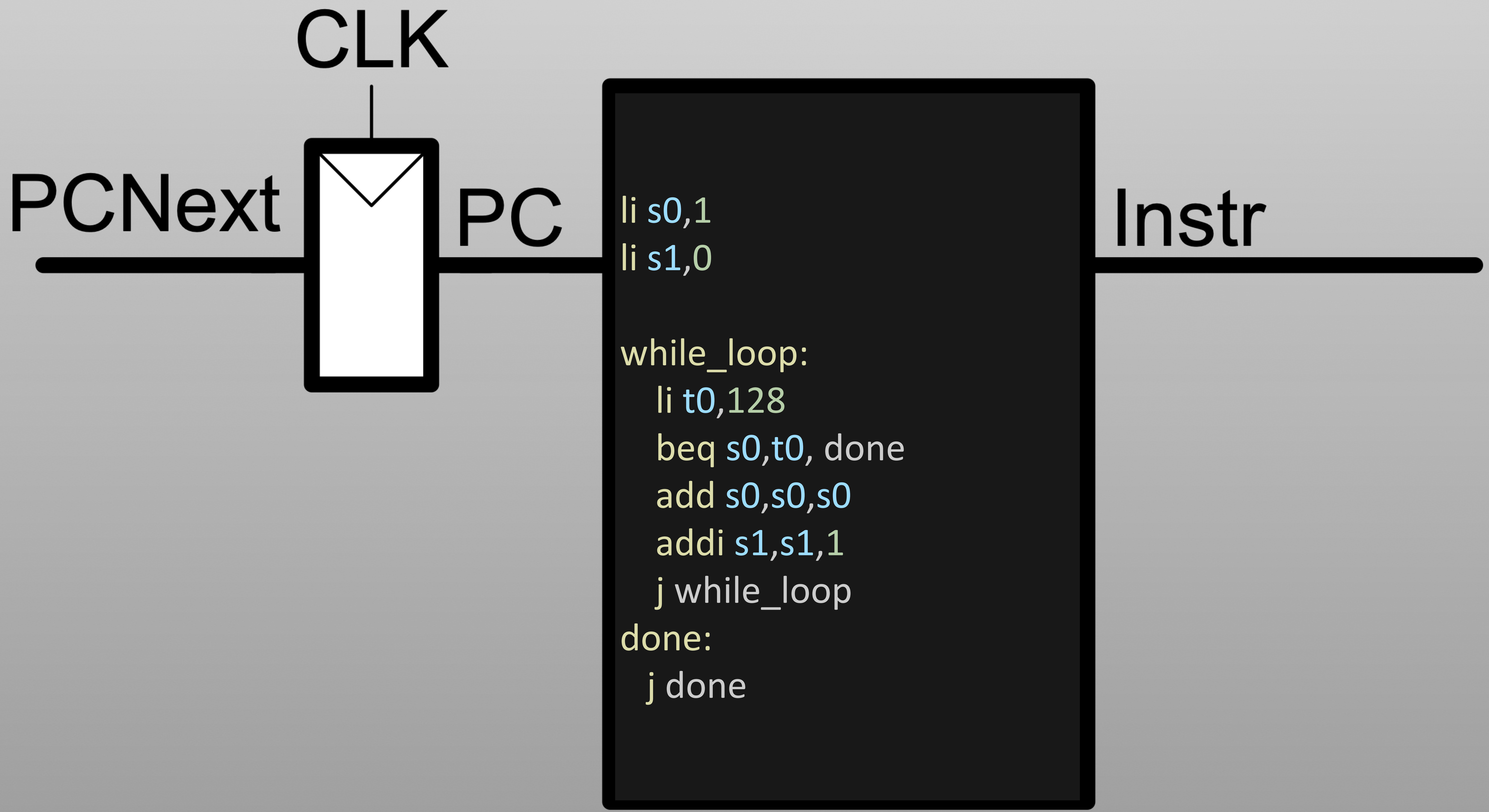
   x = x + 1;

}
```

# Behavior: Parts of CPU Model



# Behavior: Parts of CPU Model



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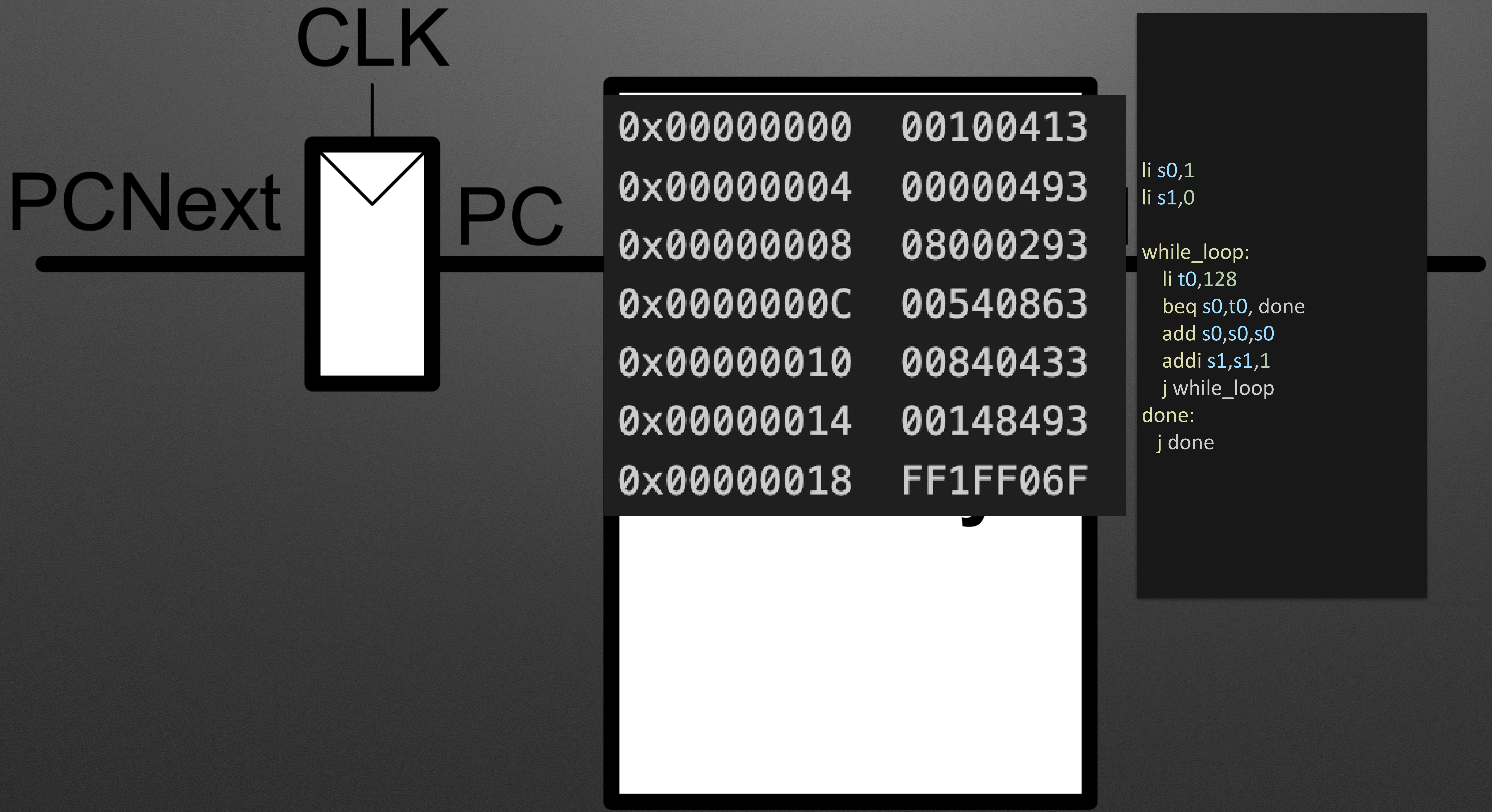


| | |
|---|---|
| 0x00000000 | 00100413 |
| 0x00000004 | 00000493 |
| 0x00000008 | 08000293 |
| 0x0000000C | 00540863 |
| 0x00000010 | 00840433 |
| 0x00000014 | 00148493 |
| 0x00000018 | FF1FF06F |

```
li s0,1
li s1,0

while_loop:
   li t0,128
   beq s0,t0, done
   add s0,s0,s0
   addi s1,s1,1
   j while_loop
done:
  j done
```

# Behavior: Parts of CPU Model

PC

| | |
|---|---|
| 0x00000000 | 00100413 |
| 0x00000004 | 00000493 |
| 0x00000008 | 08000293 |
| 0x0000000C | 00540863 |
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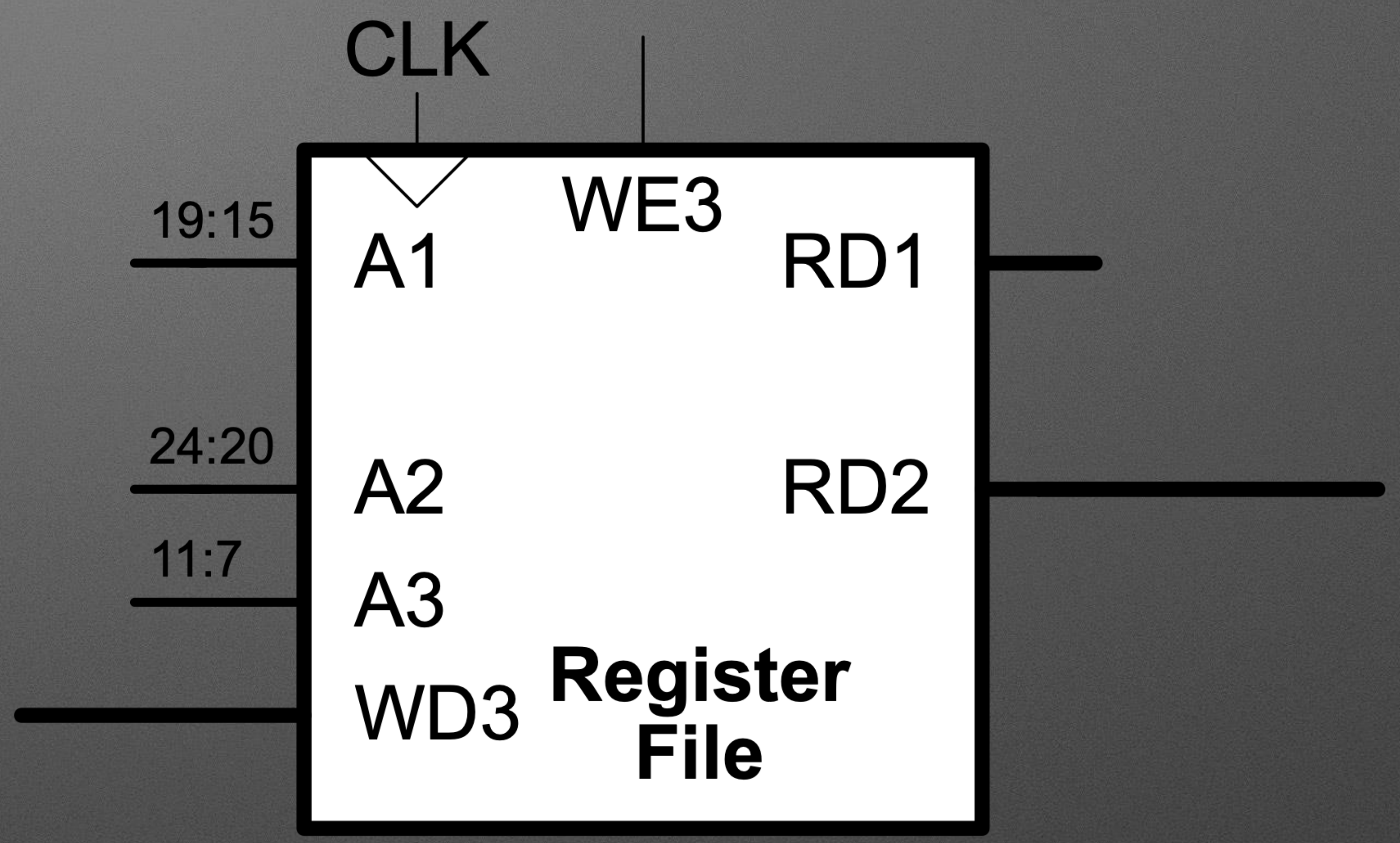
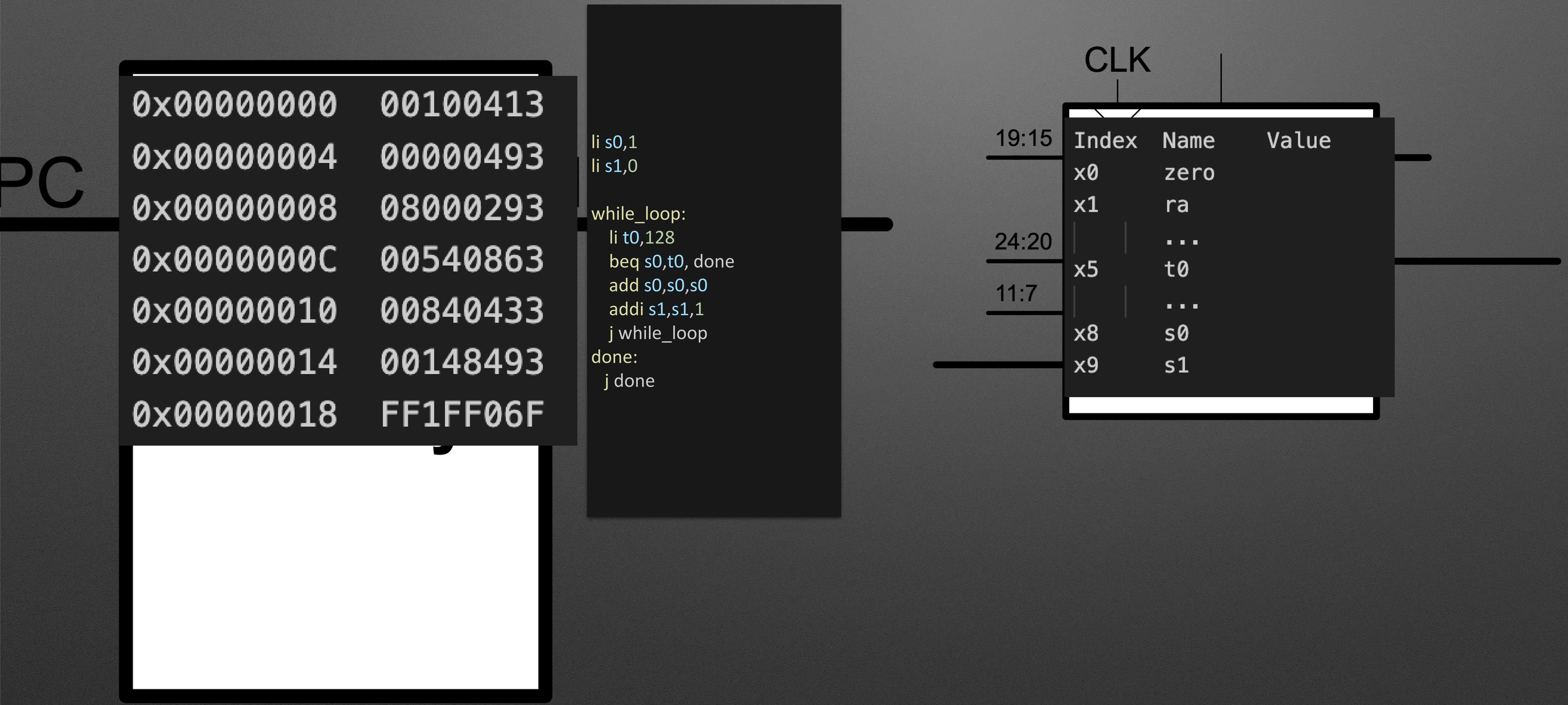
```



# Behavior: Parts of CPU Model



# Behavior: Parts of CPU Model

PC

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```
li s0,1
li s1,0

while_loop:
   li t0,128
   beq s0,t0, done
   add s0,s0,s0
   addi s1,s1,1
   j while_loop
done:
  j done
```

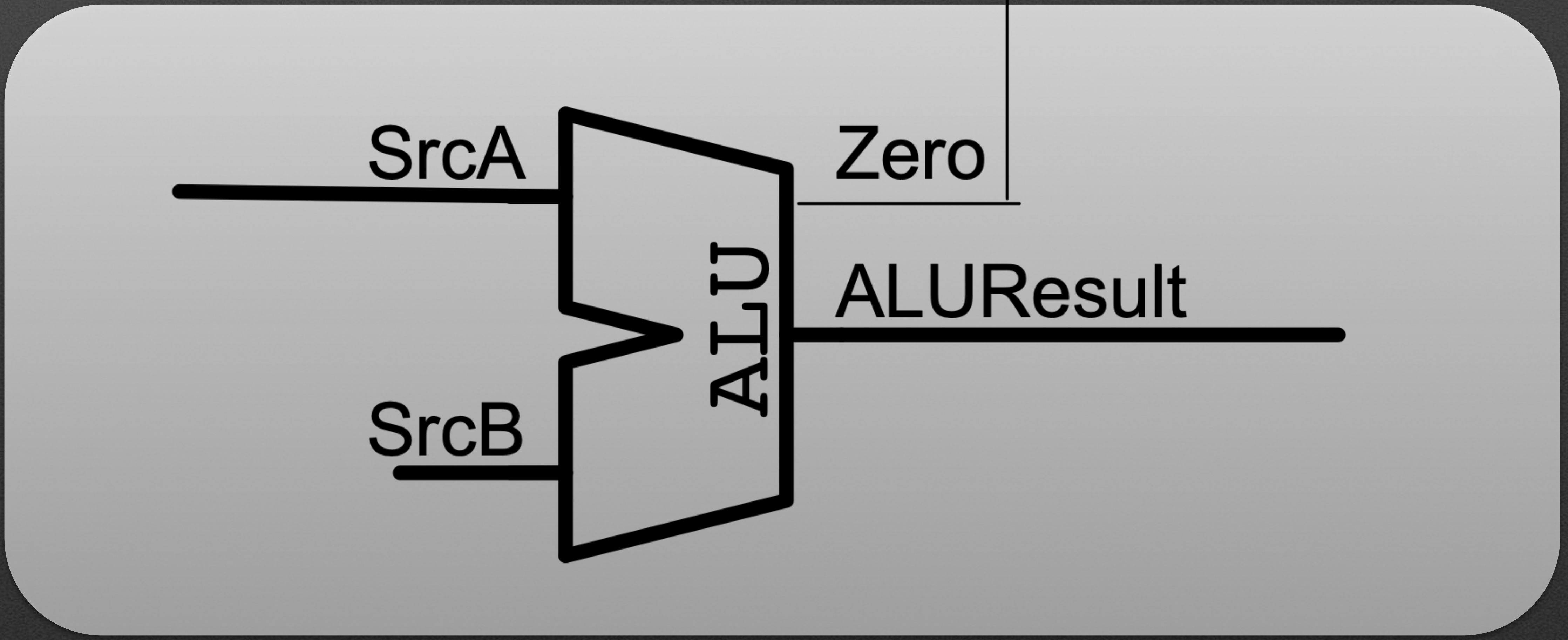
CLK

19:15

24:20

11:7

| Index | Name | Value |
|---|---|---|
| x0 | zero | |
| x1 | ra | |
| | ... | |
| x5 | t0 | |
| | ... | |
| x8 | s0 | |
| x9 | s1 | |



lodel

| | |
|---|---|
| 0x00000000 | 00100413 |
| 0x00000004 | 00000493 |
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| 0x0000000C | 00540863 |
| 0x00000010 | 00840433 |
| 0x00000014 | 00148493 |
| 0x00000018 | FF1FF06F |

```
li s0,1
li s1,0
while_loop: li t0,128
        beq s0,t0, done
        add s0,s0,s0
        addi s1,s1,1
        j while_loop
done: j done
```

CLK

WE3

19:15

24:20

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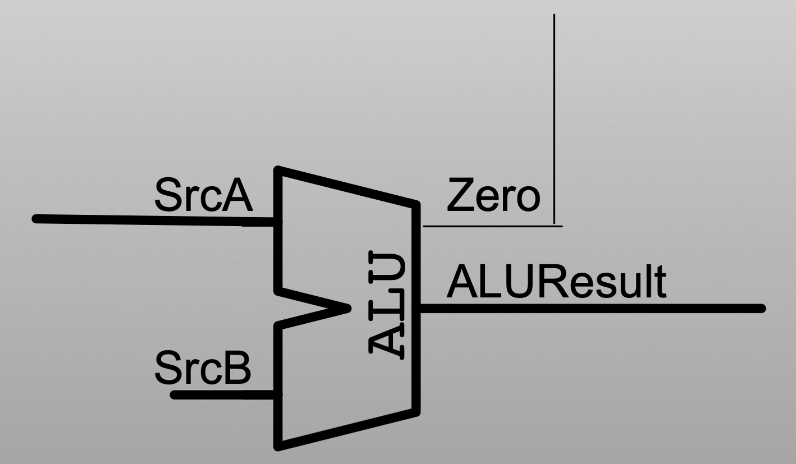
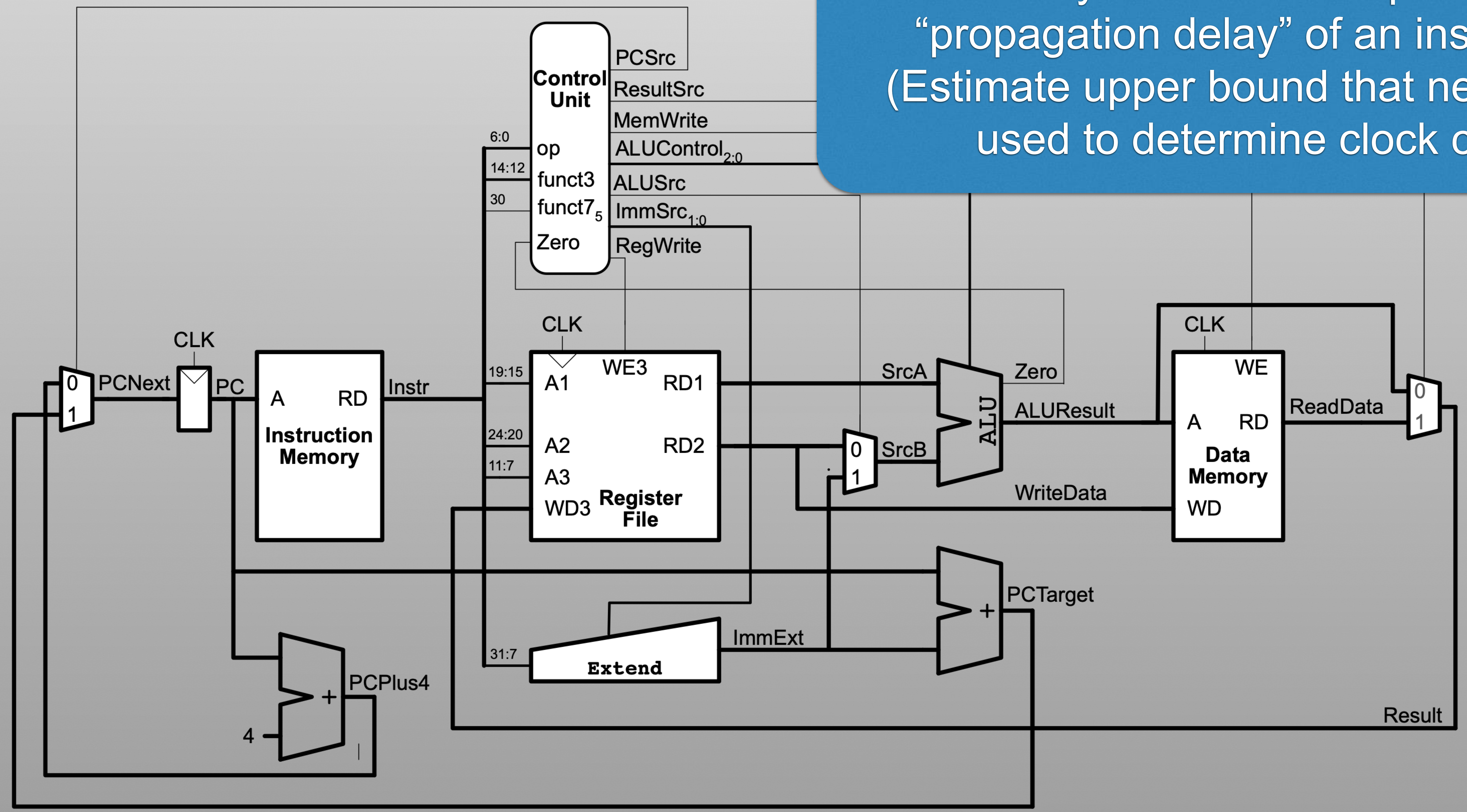
| Index | Name | Value |
|---|---|---|
| x0 | zero | |
| x1 | ra | |
| | ... | |
| x5 | t0 | |
| | ... | |
| x8 | s0 | |
| x9 | s1 | |



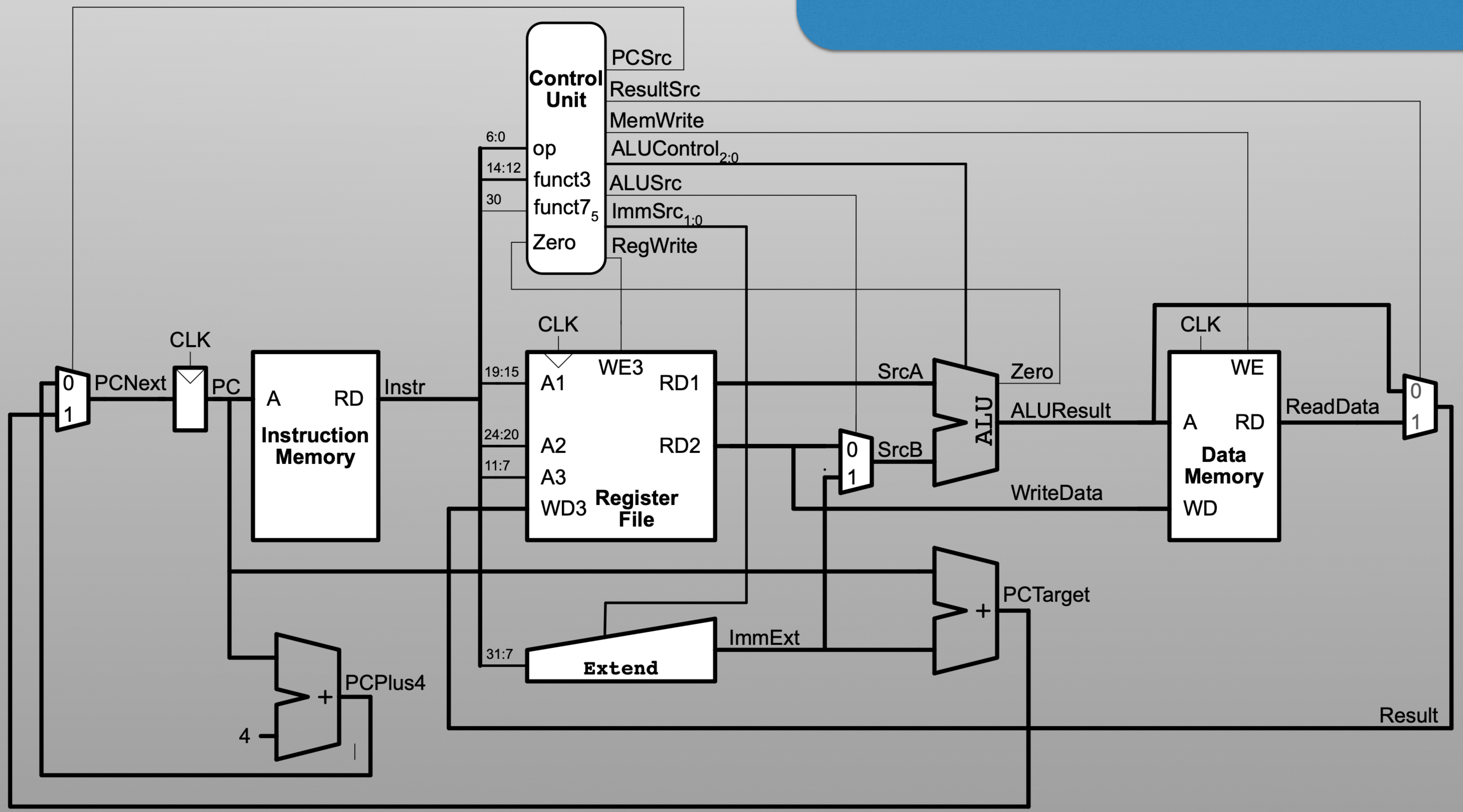
# Simple, Single-Cycle RISC-V Computer




Identify items that are part of the "propagation delay" of an instruction. (Estimate upper bound that needs to be used to determine clock cycle)

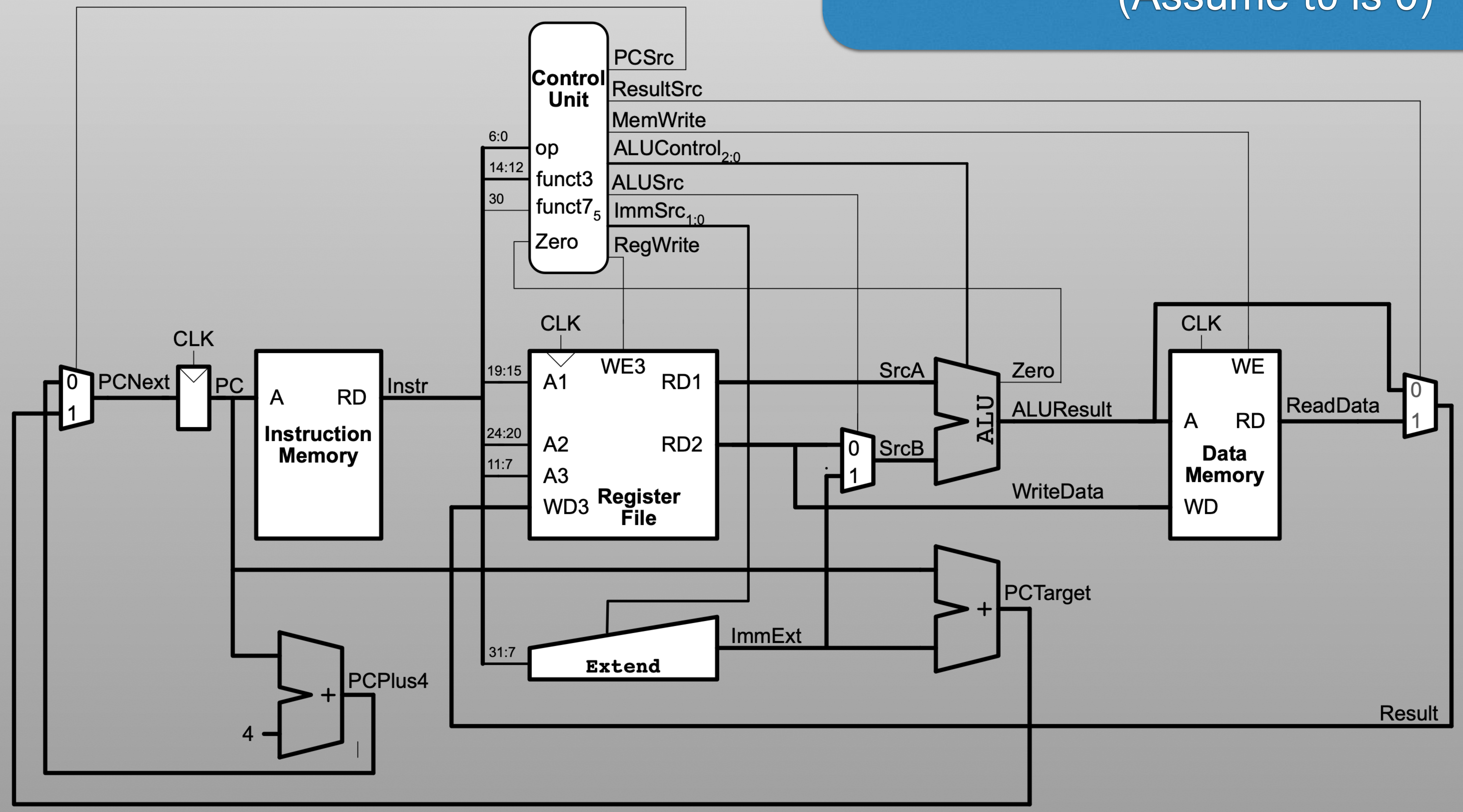
# Simple, Single-Cycle

Describe behavior of all elements and any required control signals for
add t0,t1,t1



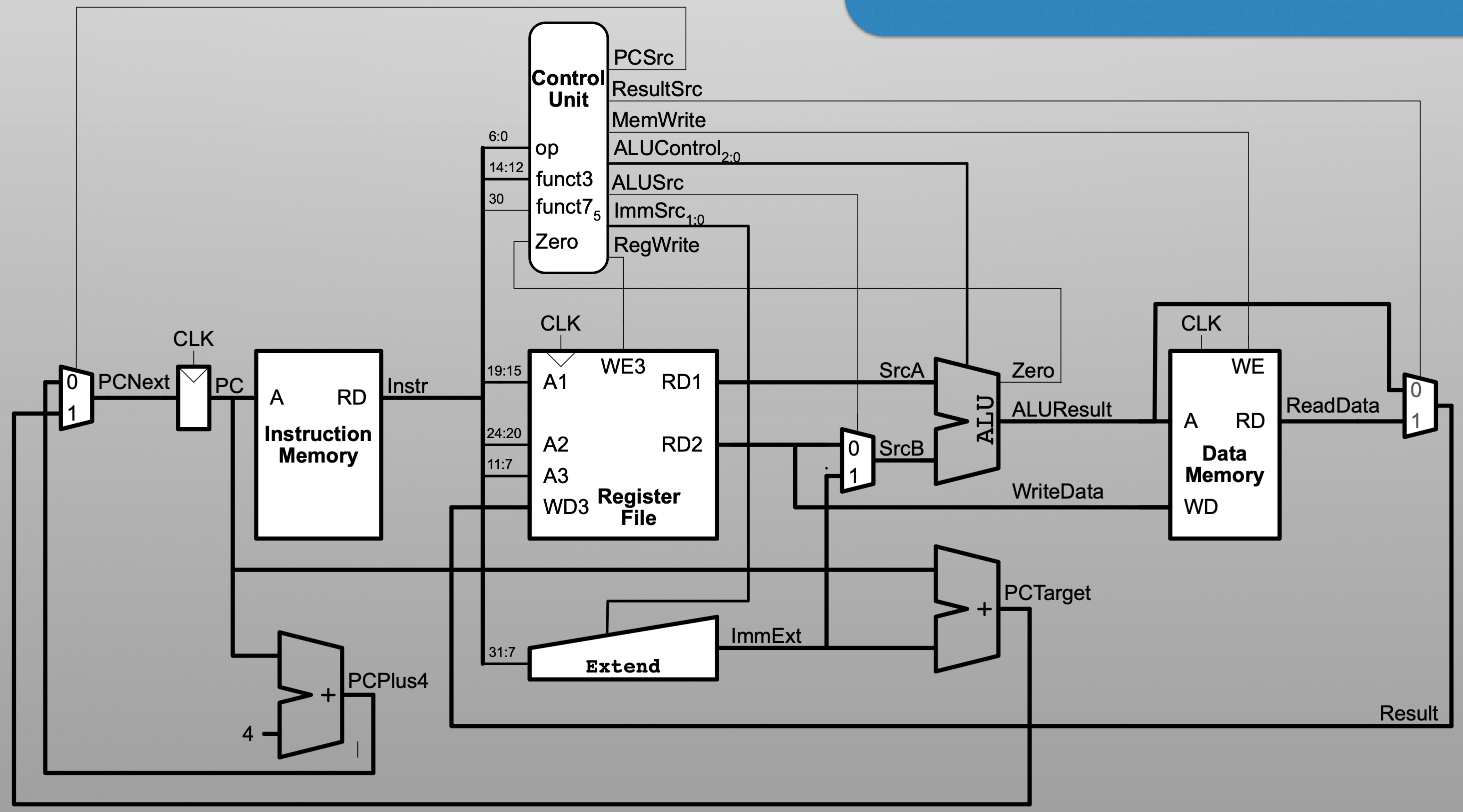
# Simple, Single-Cycle

Describe behavior of all elements and any required control signals for
beq t0,zero,loop
(Assume t0 is 0)



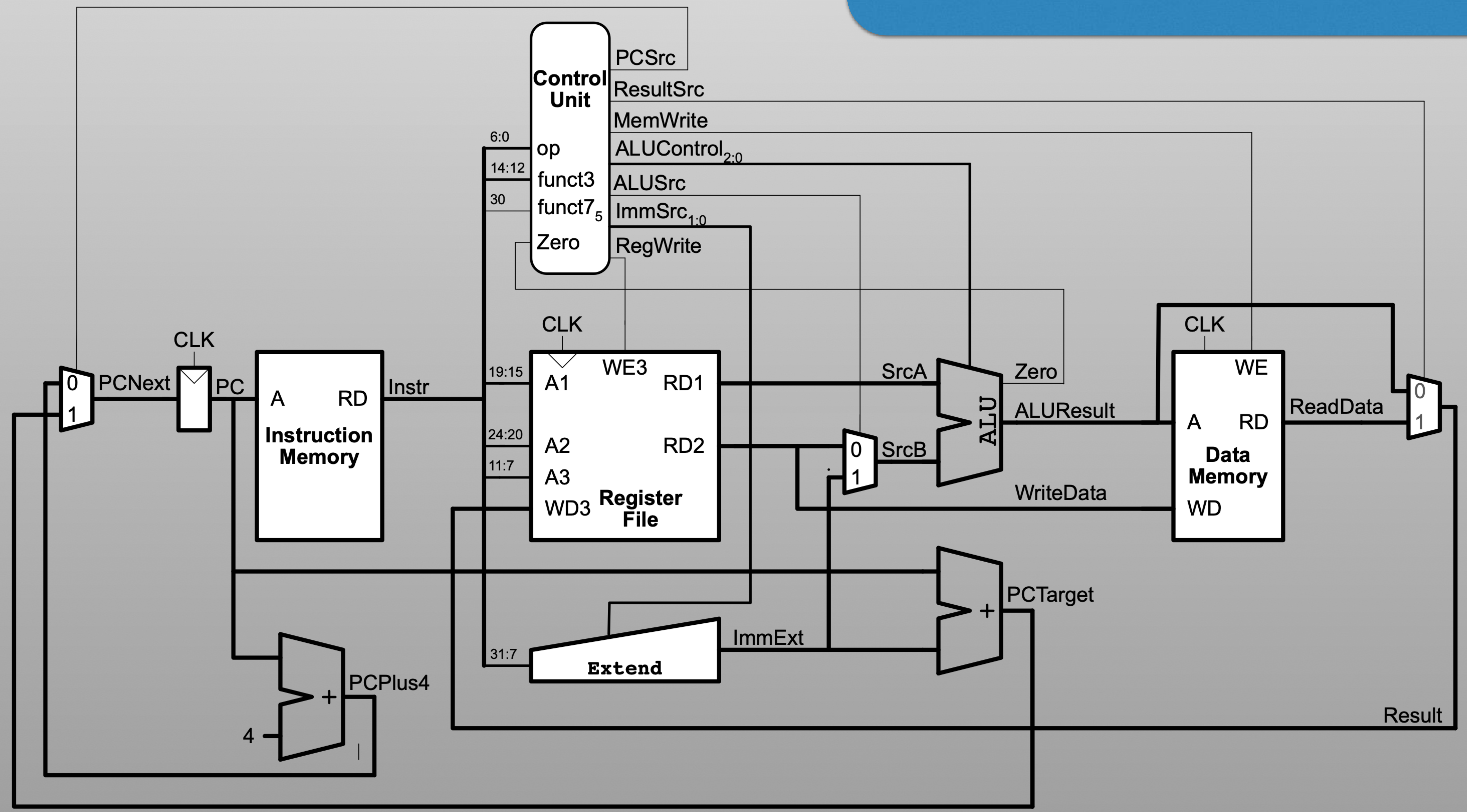
# Simple, Single-Cycle F

Describe behavior of all elements and any required control signals for
sw t0,4(a0)

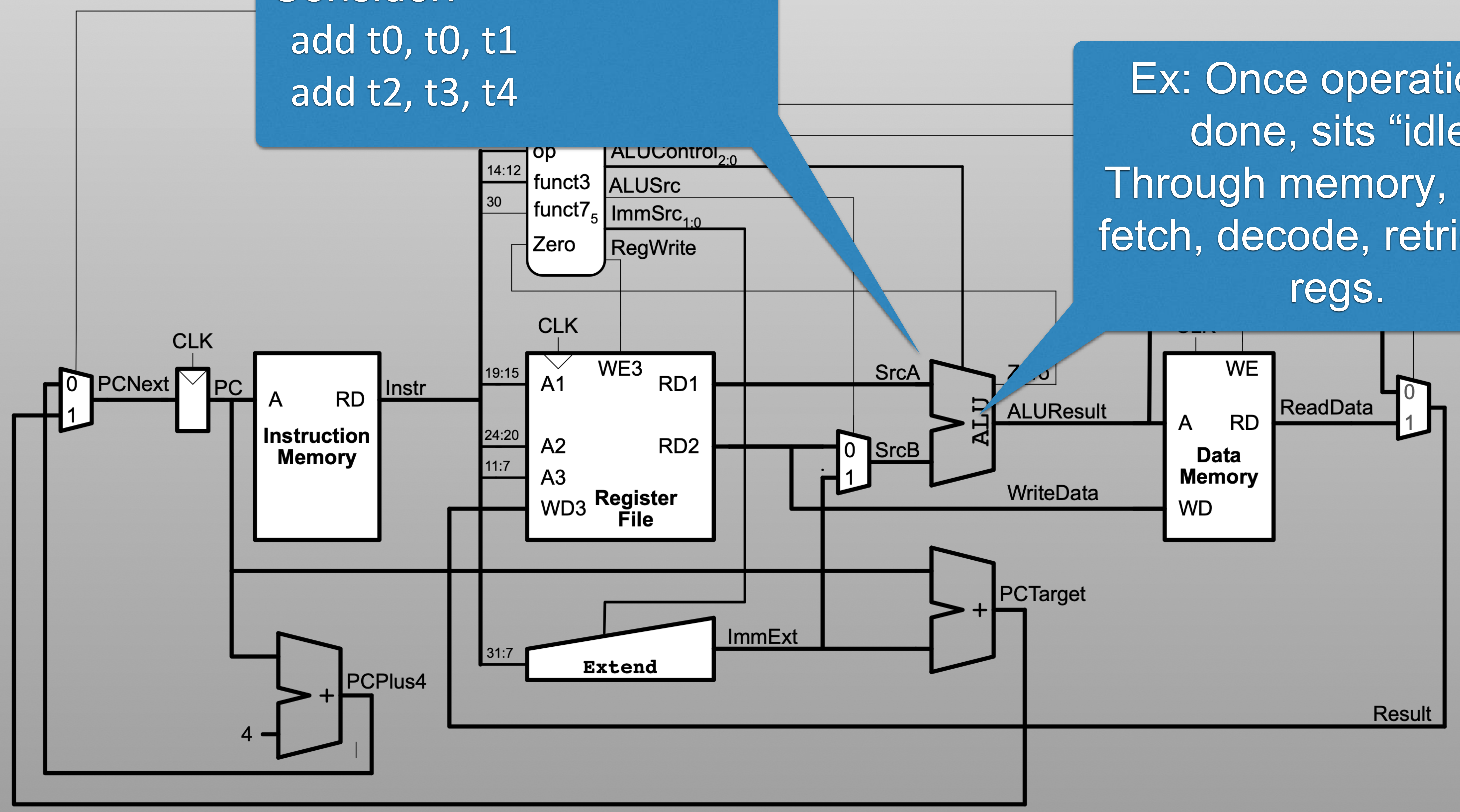


# Simple, Single-Cycle F

Describe behavior of all elements and any required control signals for
lw t0,4(a0)



# Simple, Single-Cycle: Inefficient!




Consider:

add t0, t0, t1

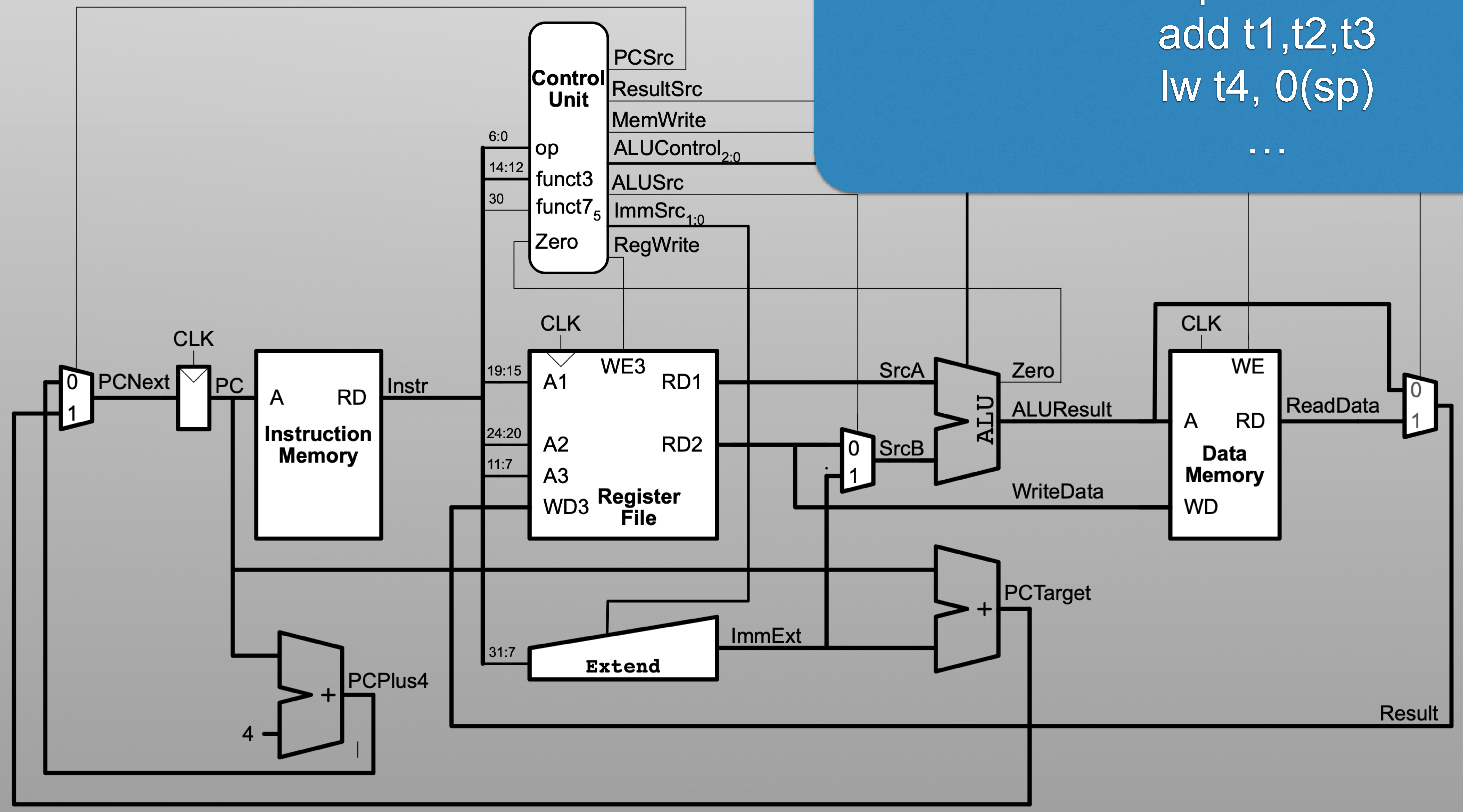
add t2, t3, t4

Ex: Once operation is done, sits "idle"

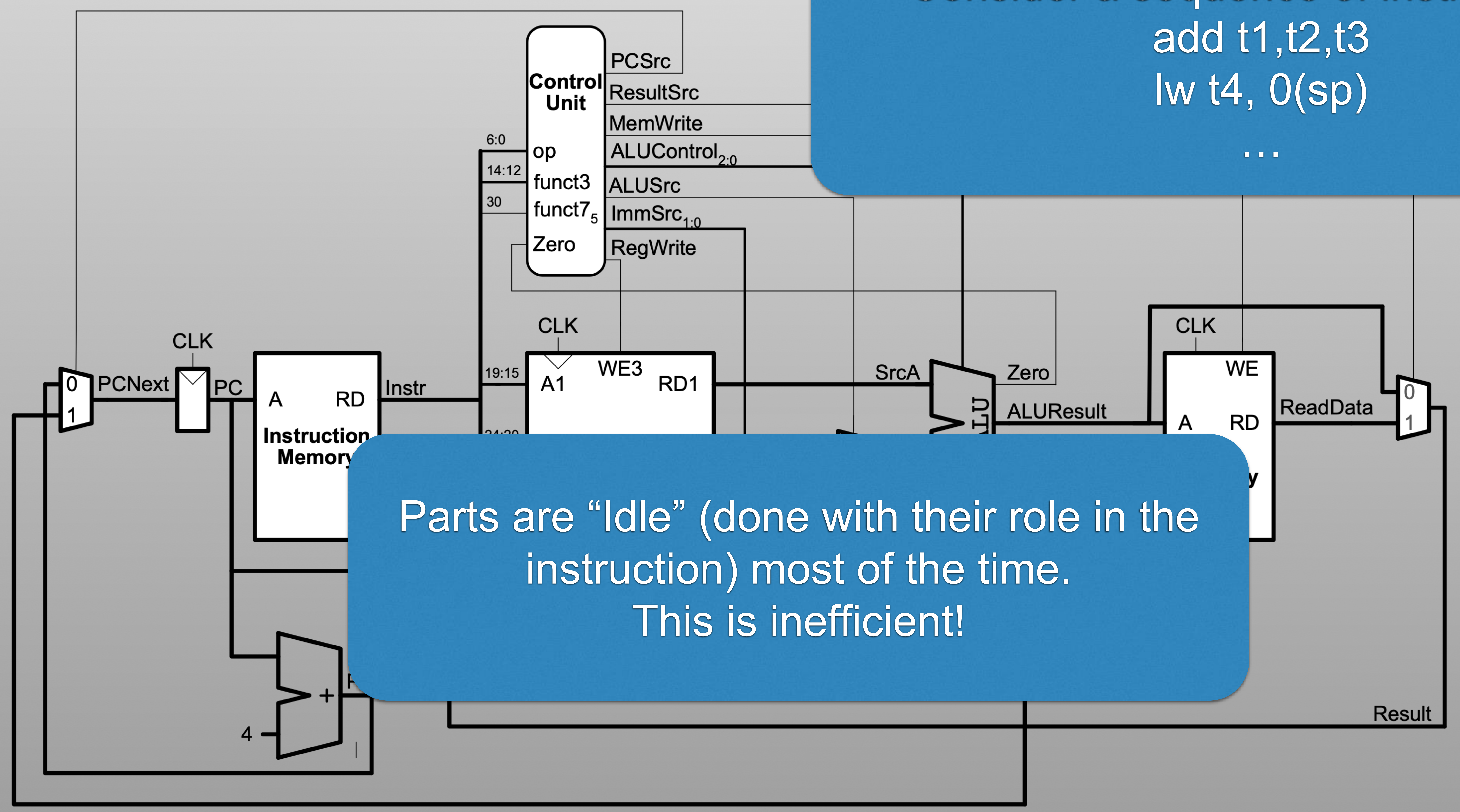
Through memory, clock, fetch, decode, retrieve of regs.

# Simple, Single-Cycle RISC-V Computer

Consider a sequence of instructions:
add t1,t2,t3
lw t4, 0(sp)
…



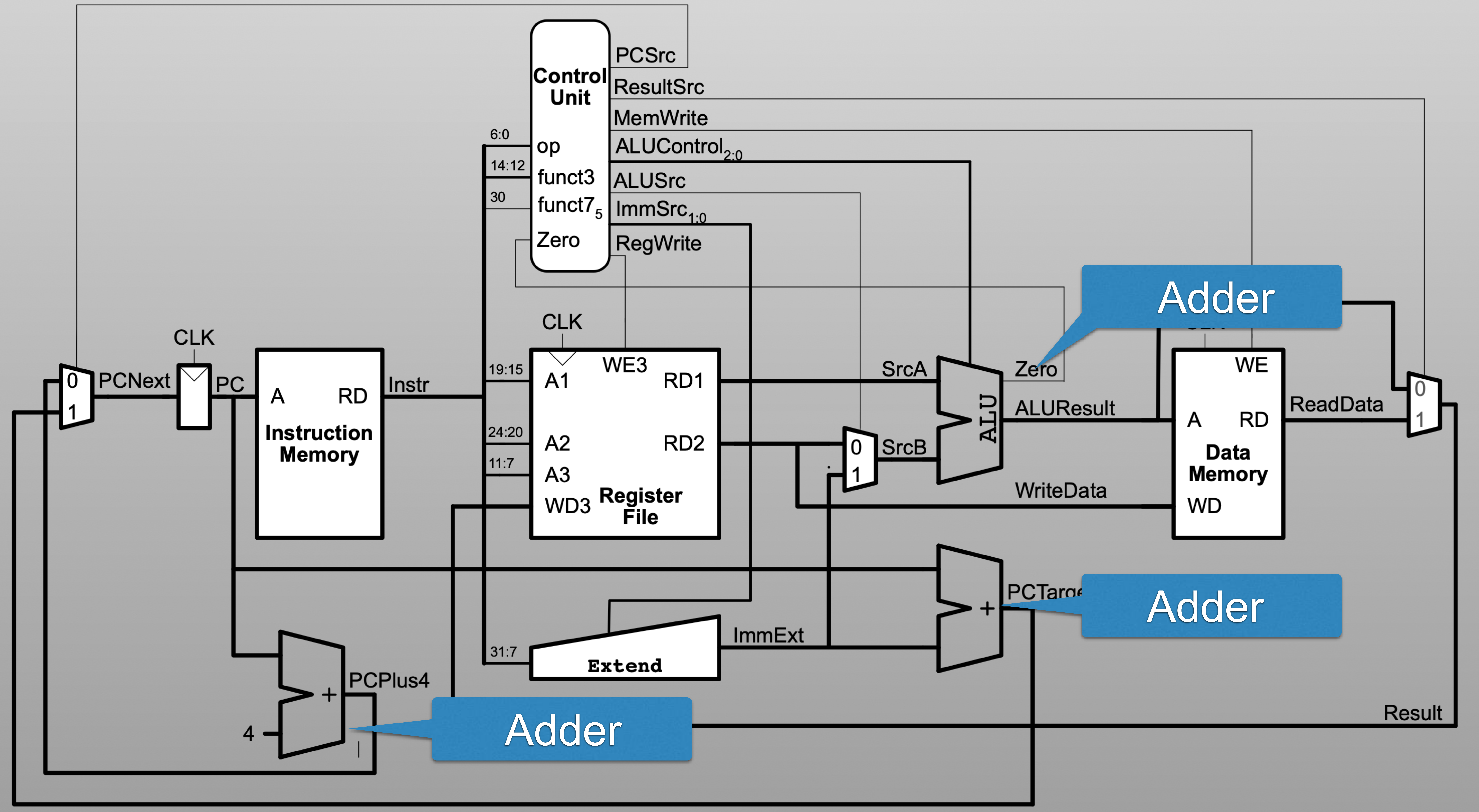
# Simple, Single-Cycle RISC-V Computer



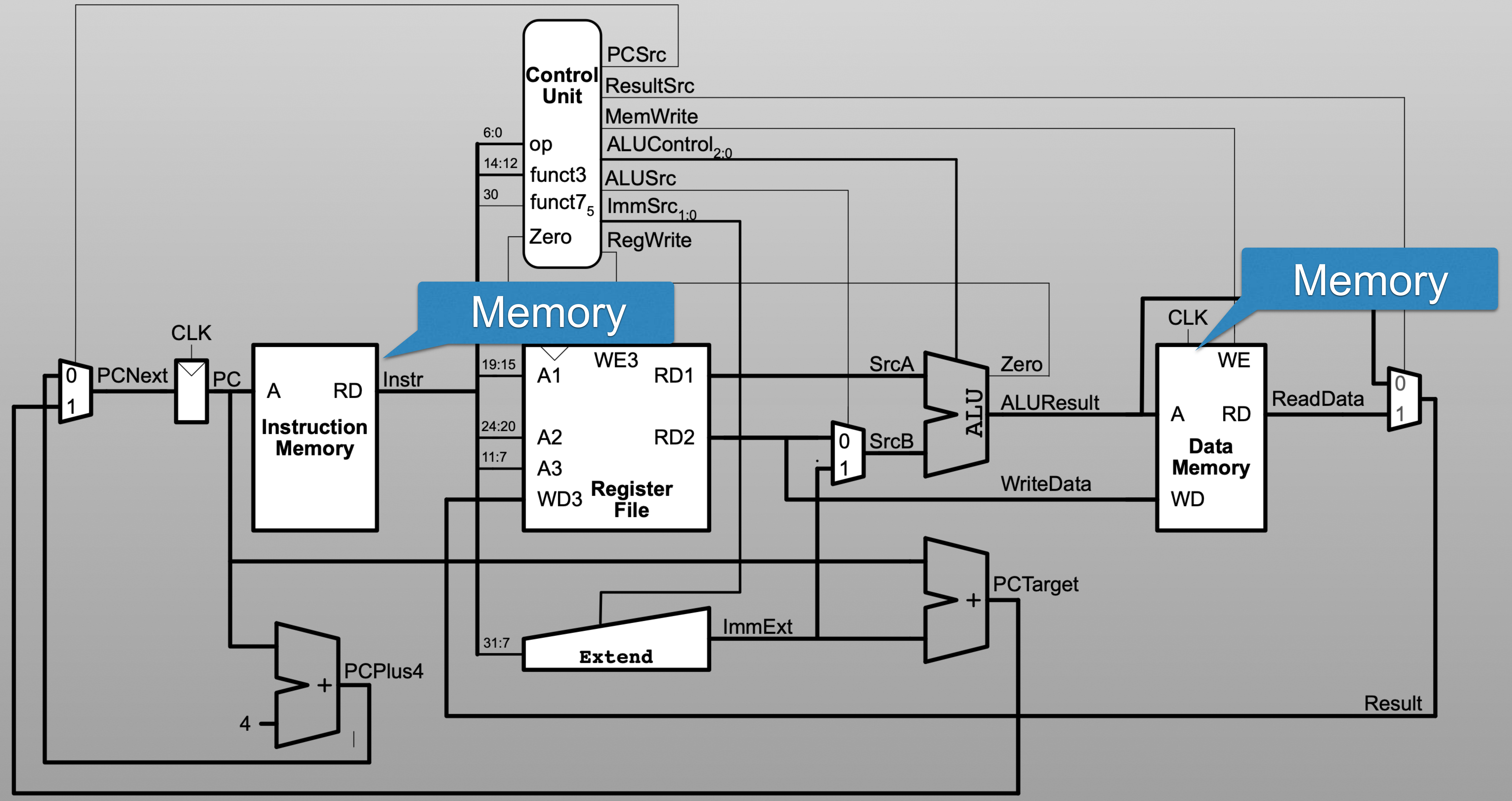

Consider a sequence of instructions:
add t1,t2,t3
lw t4, 0(sp)
…

Parts are “Idle” (done with their role in the instruction) most of the time.
This is inefficient!

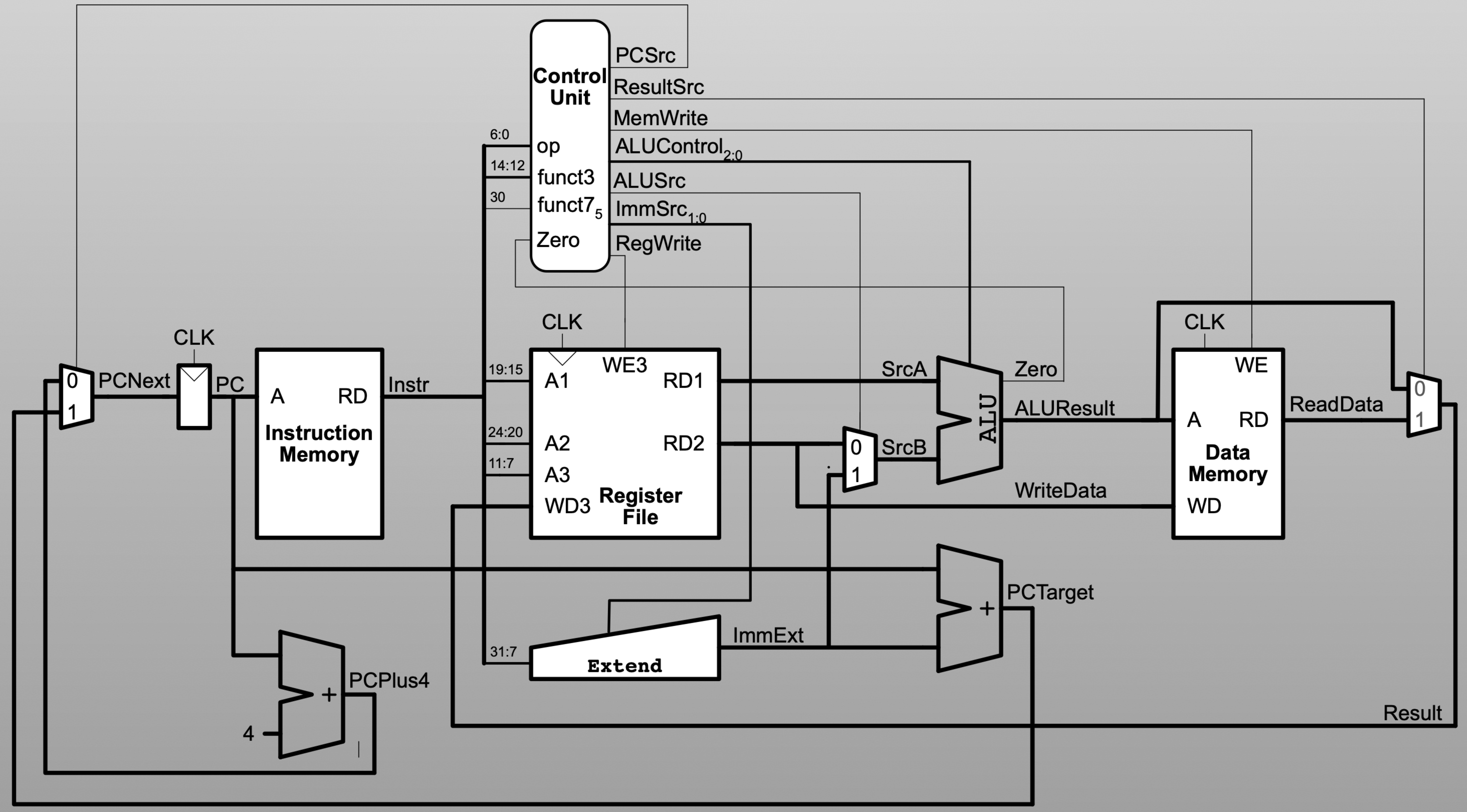
# Simple, Single-Cycle: Inefficient!



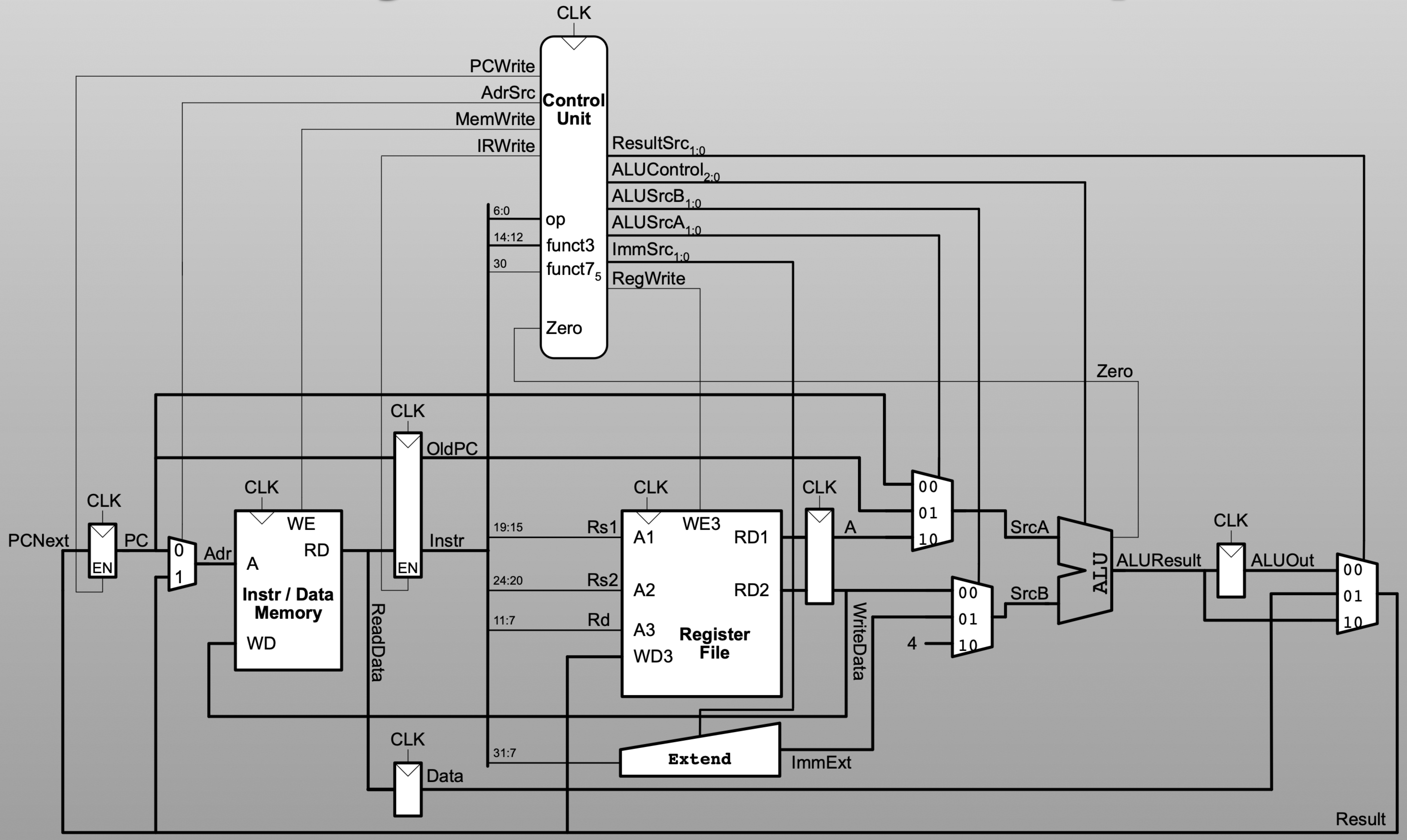
# Simple, Single-Cycle: Inefficient!



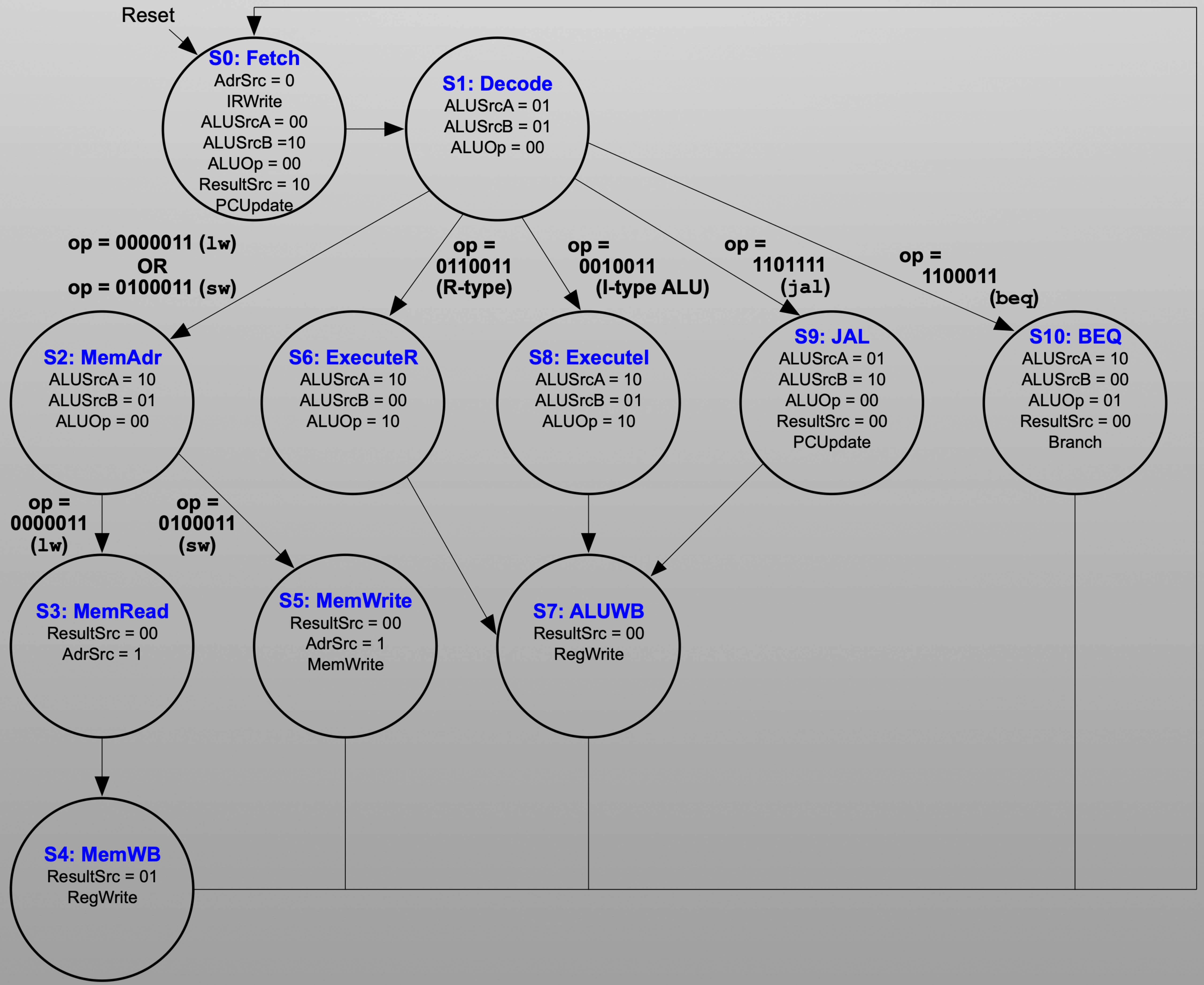
# Simple, Single-Cycle RISC-V Computer



# Multi-Cycle RISC-V Computer



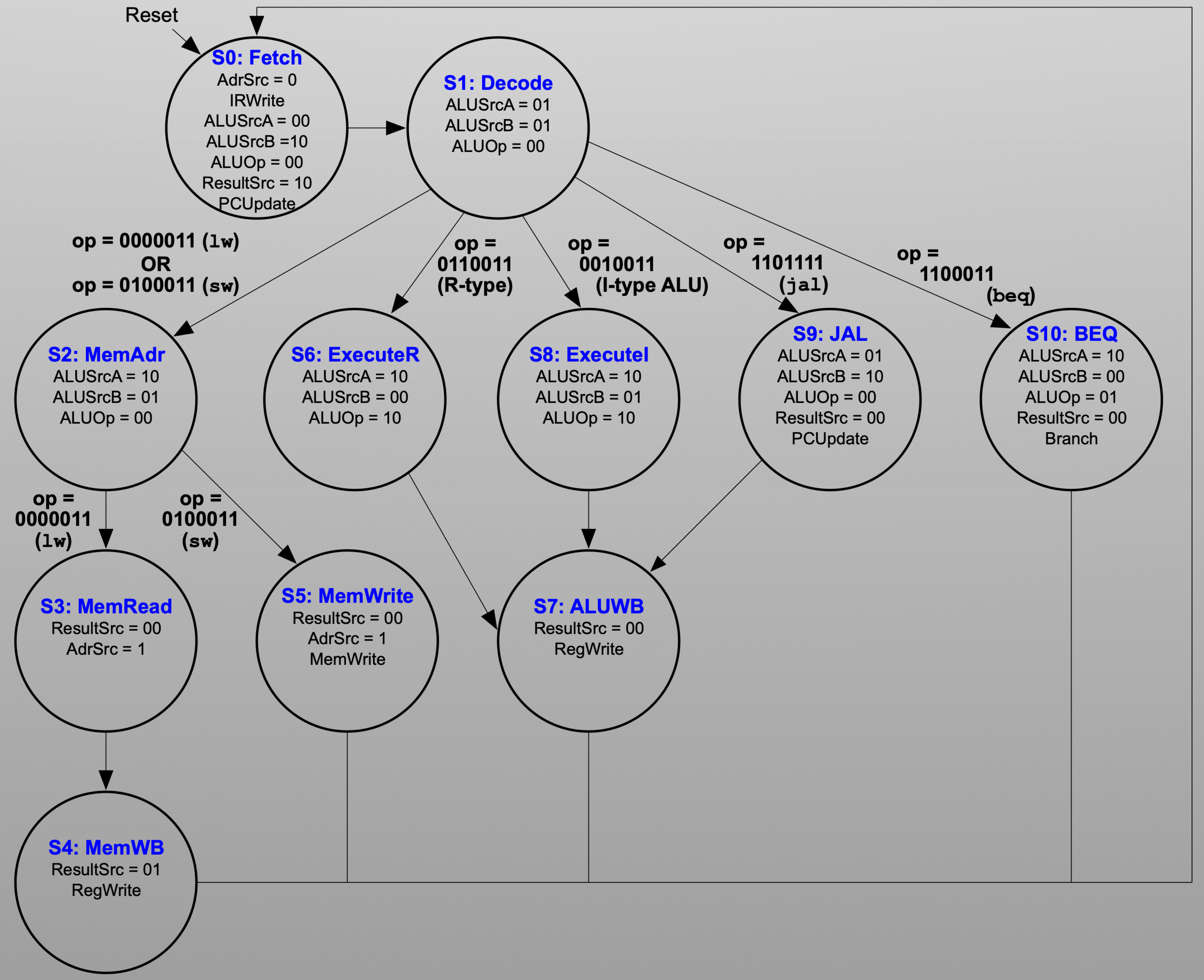
# Process


Reset
S0: Fetch
AdrSrc = 0
IRWrite
ALUSrcA = 00
ALUSrcB =10
ALUOp = 00
ResultSrc = 10
PCUpdate
S1: Decode
ALUSrcA = 01
ALUSrcB = 01
ALUOp = 00
op = 0000011 (lw)
OR
op = 0100011 (sw)
op =
0110011
(R-type)
op =
0010011
(I-type ALU)
op =
1101111
(jal)
op =
1100011
(beq)
S2: MemAdr
ALUSrcA = 10
ALUSrcB = 01
ALUOp = 00
S6: ExecuteR
ALUSrcA = 10
ALUSrcB = 00
ALUOp = 10
S8: ExecuteI
ALUSrcA = 10
ALUSrcB = 01
ALUOp = 10
S9: JAL
ALUSrcA = 01
ALUSrcB = 10
ALUOp = 00
ResultSrc = 00
PCUpdate
S10: BEQ
ALUSrcA = 10
ALUSrcB = 00
ALUOp = 01
ResultSrc = 00
Branch
op =
0000011
(lw)
op =
0100011
(sw)
S3: MemRead
ResultSrc = 00
AdrSrc = 1
S5: MemWrite
ResultSrc = 00
AdrSrc = 1
MemWrite
S7: ALUWB
ResultSrc = 00
RegWrite
S4: MemWB
ResultSrc = 01
RegWrite

# Pros/Cons of Multi-Cycle

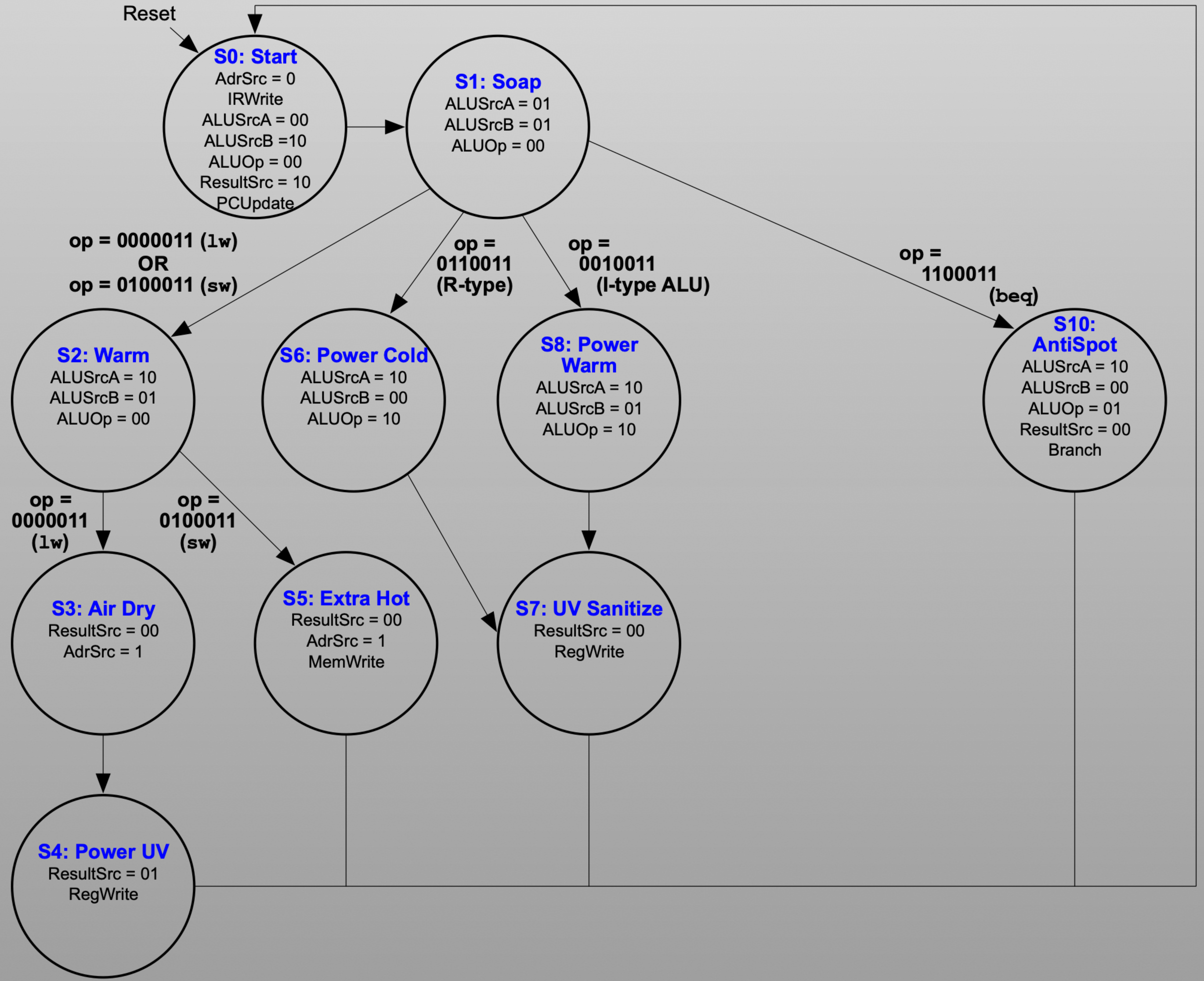
- Instructions take only required time: Not constrained by the slowest instruction!
- A little more complex

# Process

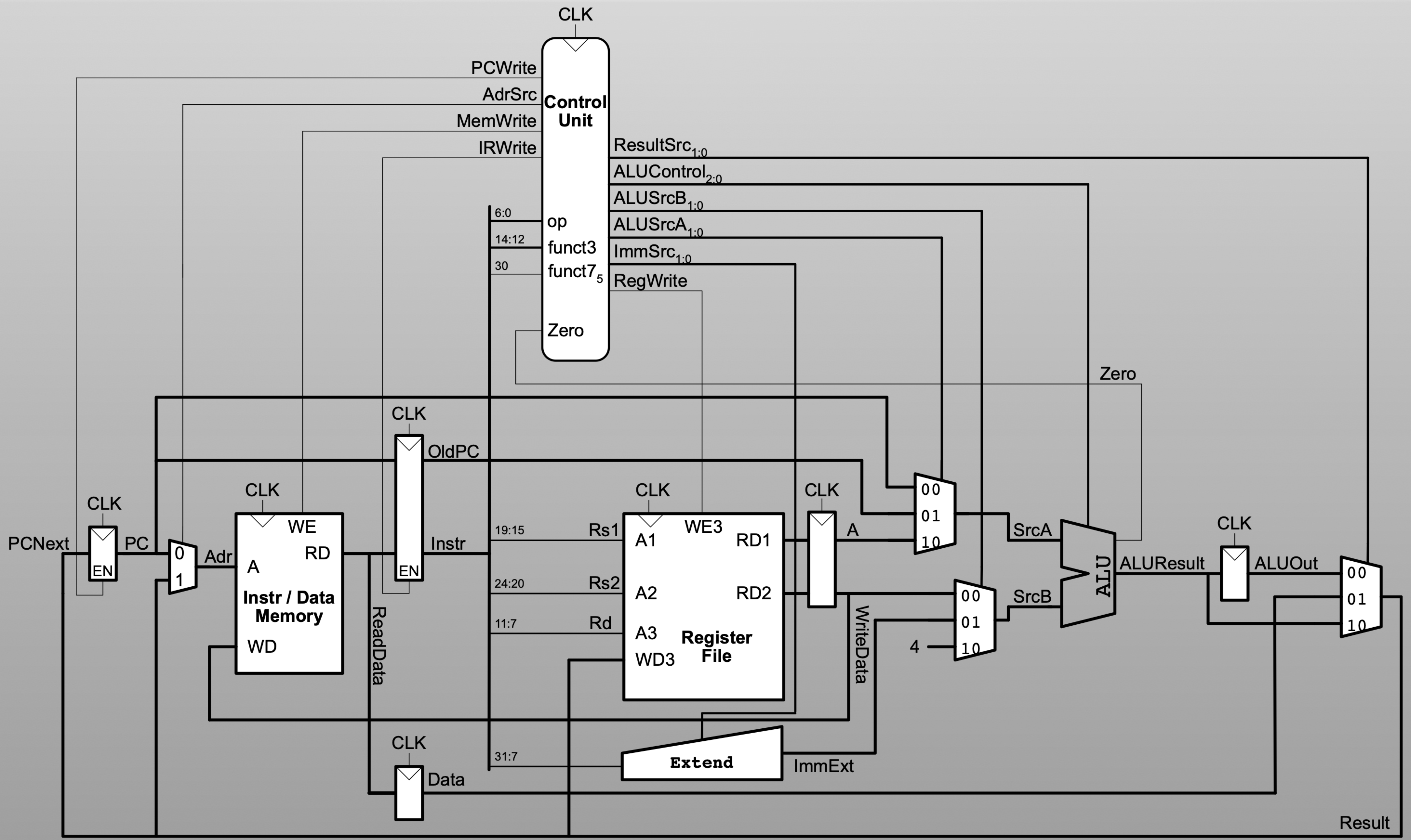


Reset
S0: Fetch
AdrSrc = 0
IRWrite
ALUSrcA = 00
ALUSrcB =10
ALUOp = 00
ResultSrc = 10
PCUpdate
S1: Decode
ALUSrcA = 01
ALUSrcB = 01
ALUOp = 00
op = 0000011 (lw)
OR
op = 0100011 (sw)
op =
0110011
(R-type)
op =
0010011
(I-type ALU)
op =
1101111
(jal)
op =
1100011
(beq)
S2: MemAdr
ALUSrcA = 10
ALUSrcB = 01
ALUOp = 00
S6: ExecuteR
ALUSrcA = 10
ALUSrcB = 00
ALUOp = 10
S8: ExecuteI
ALUSrcA = 10
ALUSrcB = 01
ALUOp = 10
S9: JAL
ALUSrcA = 01
ALUSrcB = 10
ALUOp = 00
ResultSrc = 00
PCUpdate
S10: BEQ
ALUSrcA = 10
ALUSrcB = 00
ALUOp = 01
ResultSrc = 00
Branch
op =
0000011
(lw)
op =
0100011
(sw)
S3: MemRead
ResultSrc = 00
AdrSrc = 1
S5: MemWrite
ResultSrc = 00
AdrSrc = 1
MemWrite
S7: ALUWB
ResultSrc = 00
RegWrite
S4: MemWB
ResultSrc = 01
RegWrite

# Process: Hw 3B & 4B - Washer



# Ex: add t0,t1,t2



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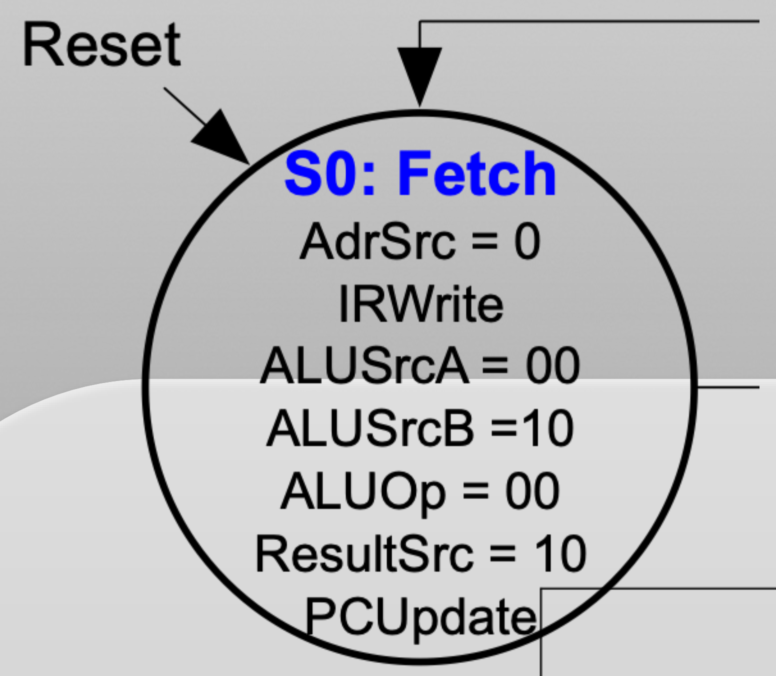


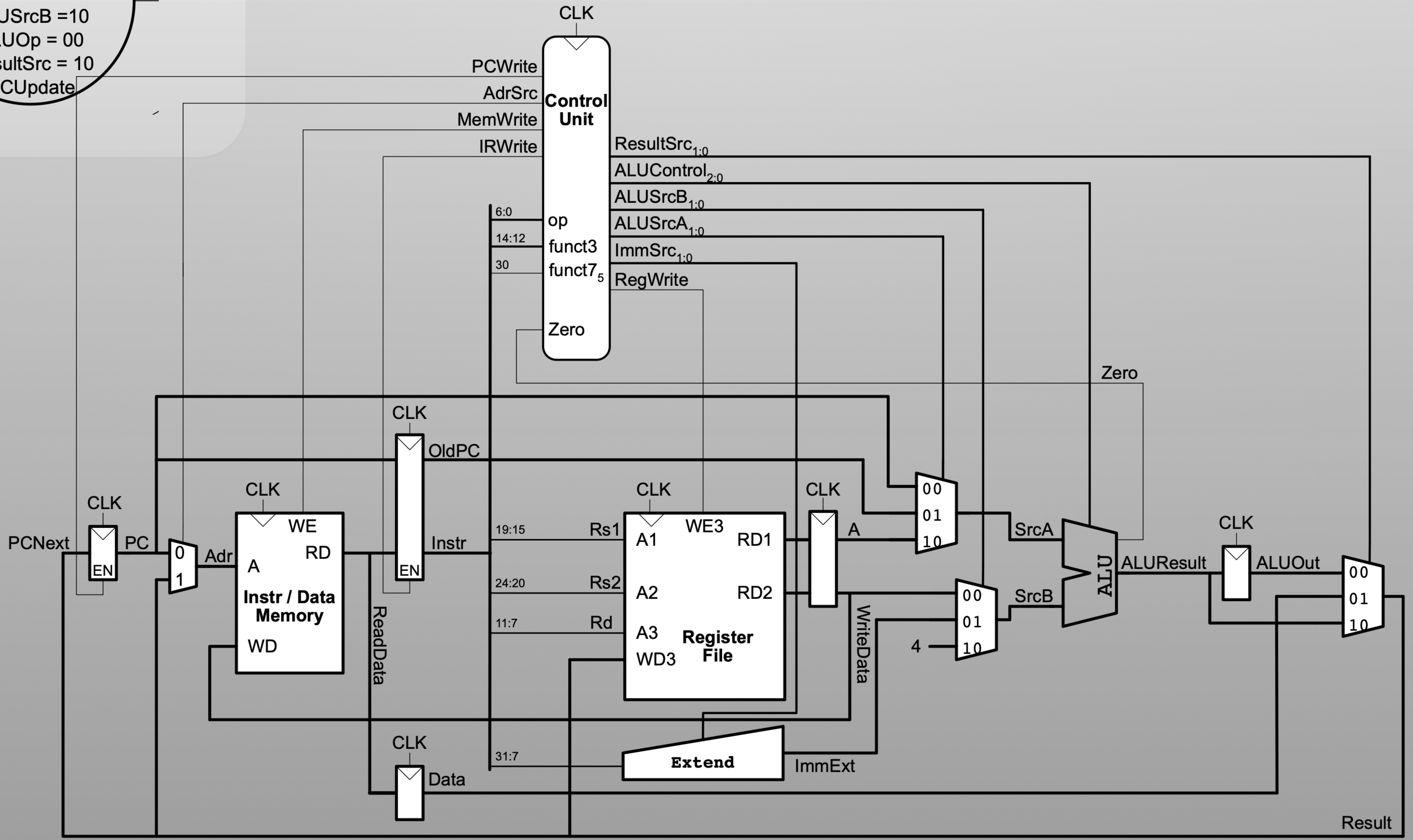

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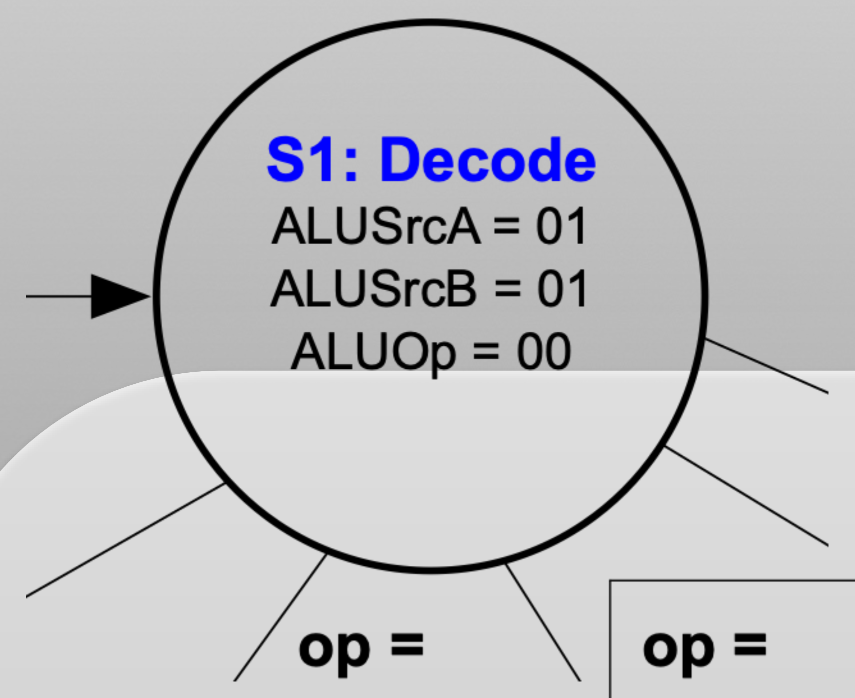


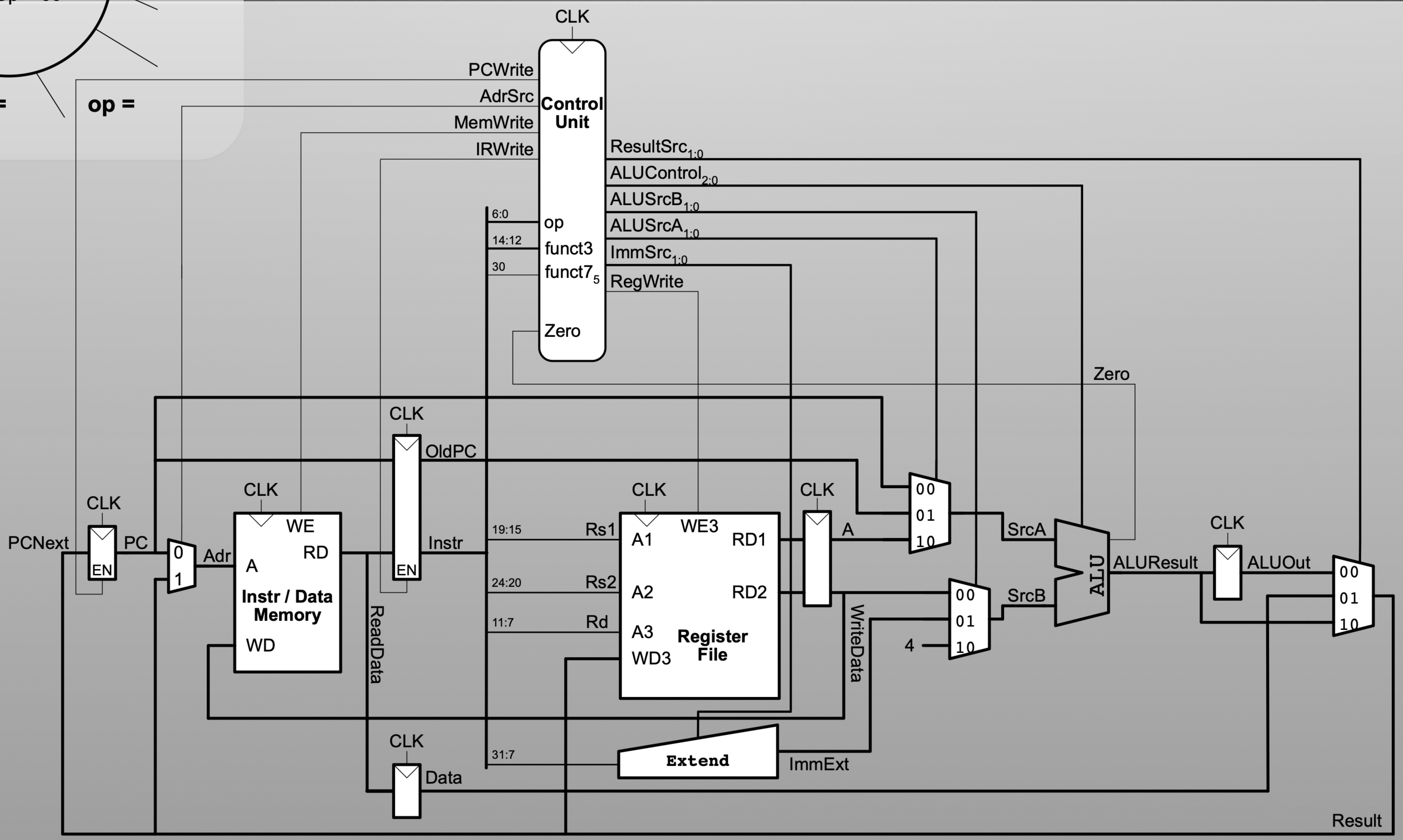

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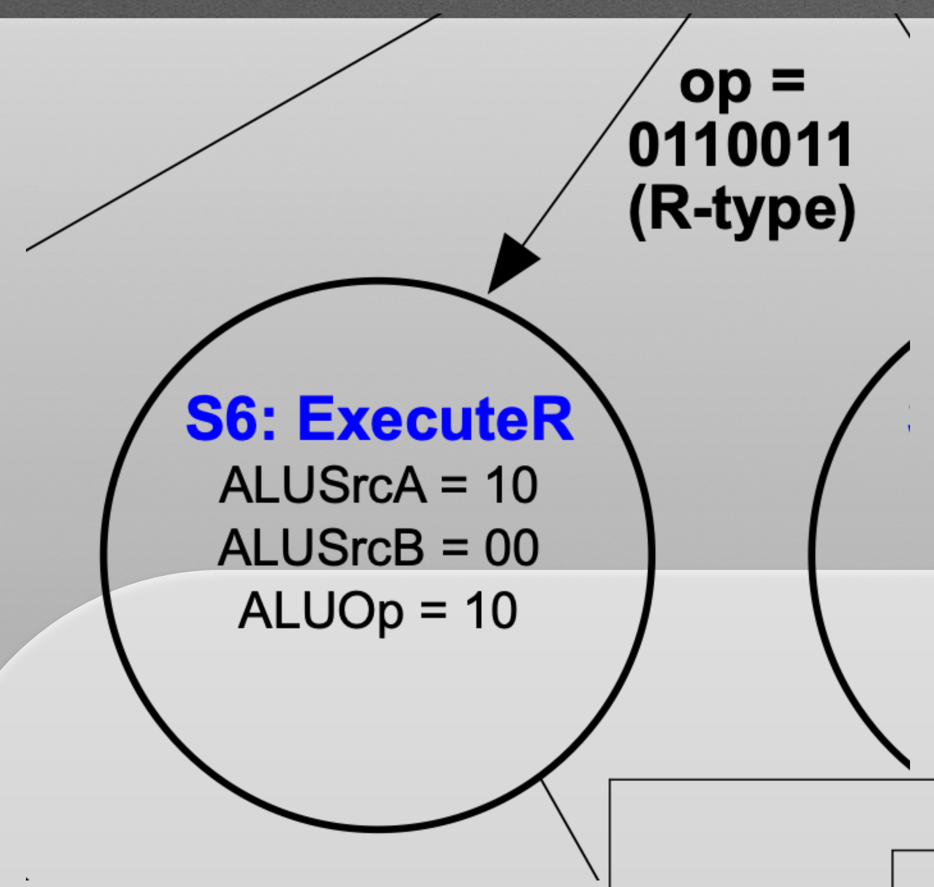


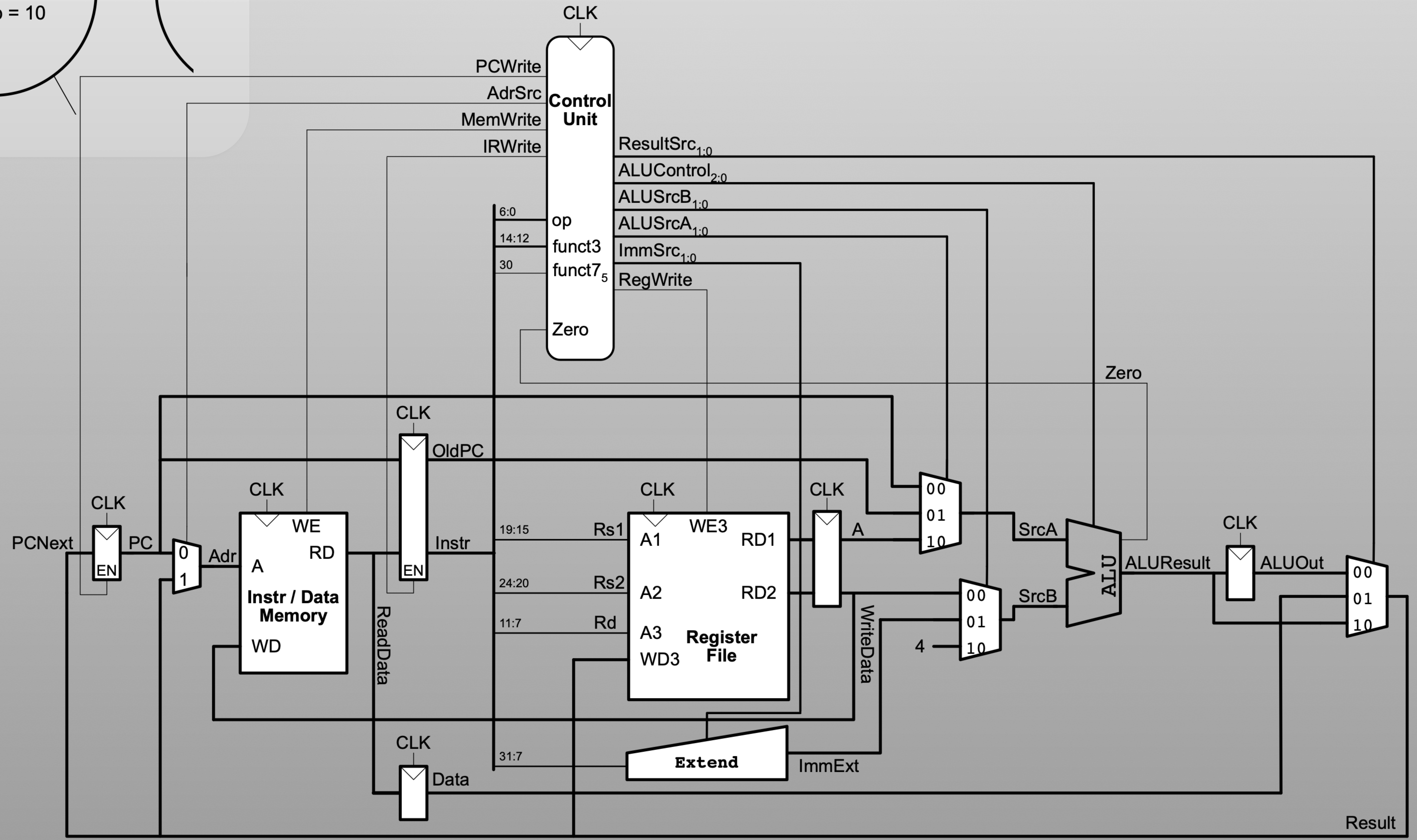

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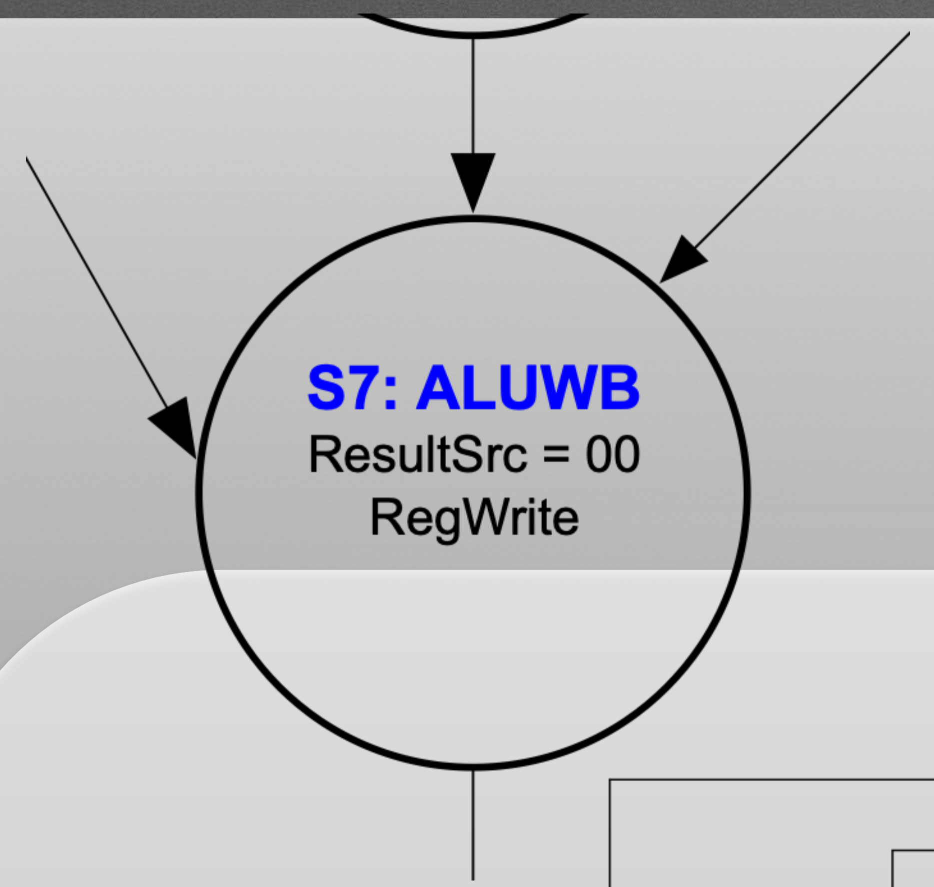


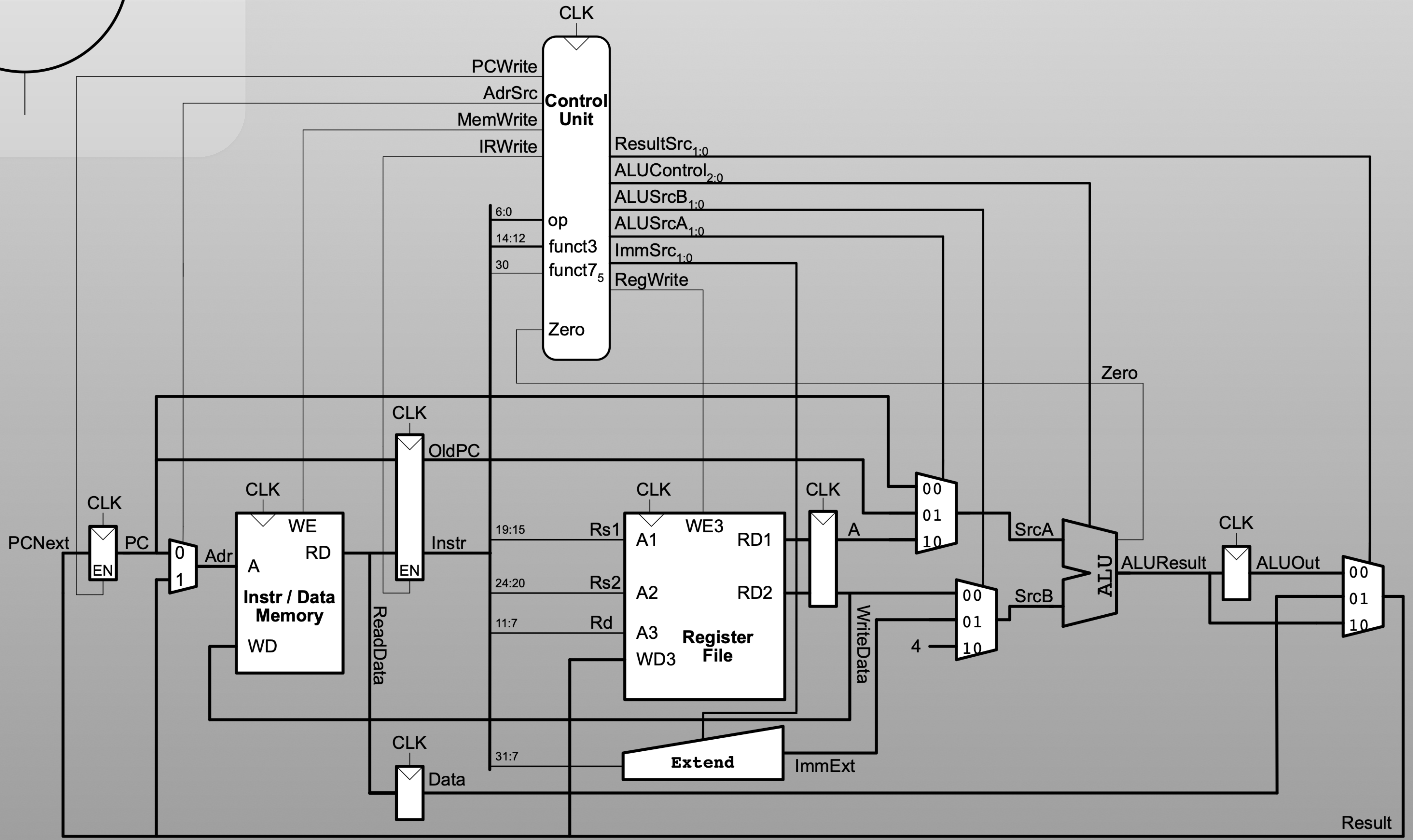

# Questions

- Do all processors generally look the same in concept as the one in the RISC-V book or is that uniquely for RISC-V systems?
- When is single-cycle actually better than multi- or pipelined (for tiny designs or low power)?
- One question I still have is how the control unit decides which exact control signals to generate for each instruction type.  I understand that decoding happens based on the instruction bits, but I’m not fully sure how those bits map to all the different components in the datapath.  It would help to see a more detailed example of decoding step-by-step.
- How important is it to understand the actual circuit construction of each of the microarchitectures covered in this reading?  Or is it just important to understand what they do and how their performances differ from one another?
- What is the big picture of how we are incorporating what we have learned from the Verilog and RISC-V topics?