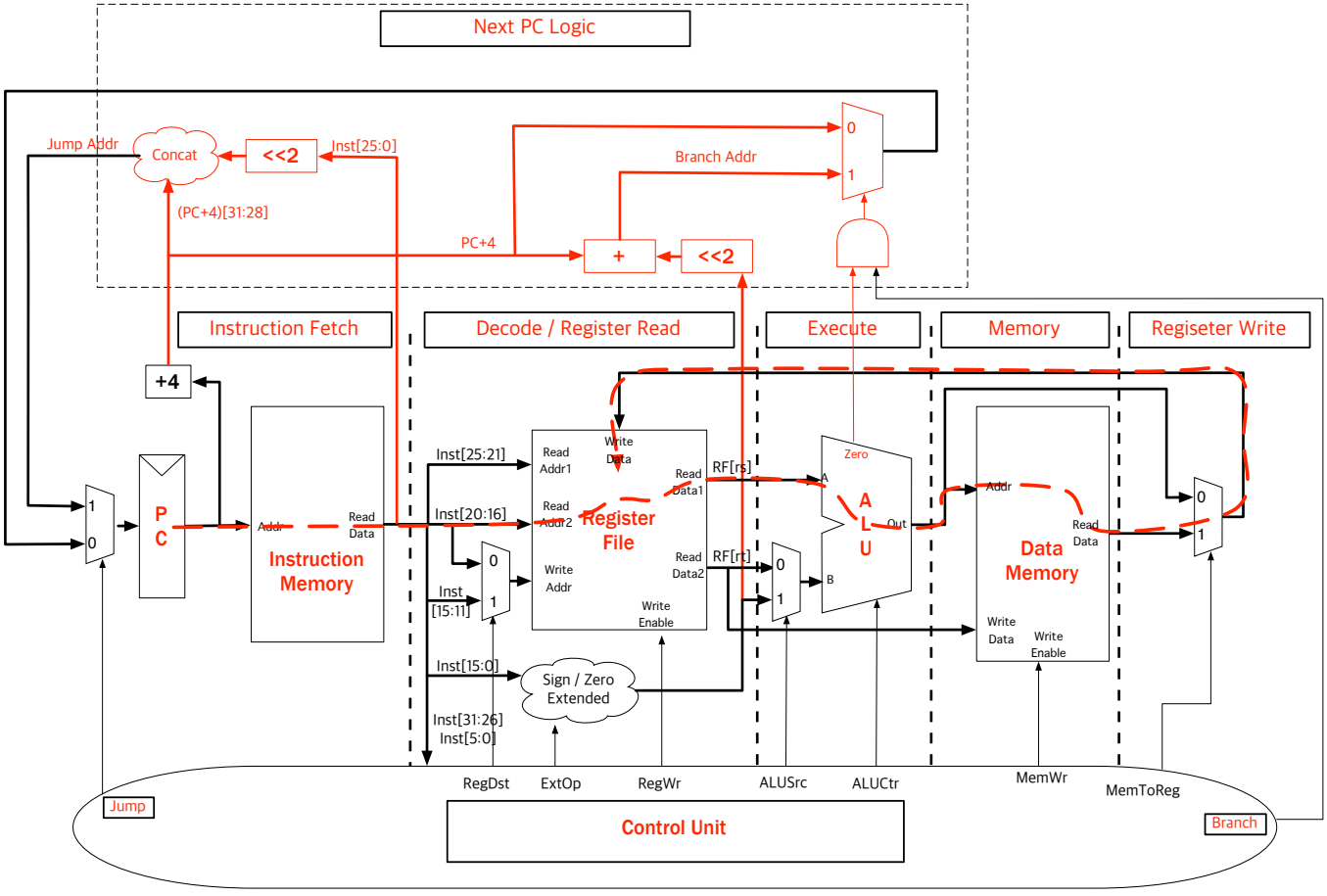
Single Cycle CPU Design

Here we have a single cycle CPU diagram. Answer the following questions:

1. Name each component.
2. Name each datapath stage and explain its functionality.

Stage	Functionality
Instruction Fetch	Send an address to the instruction memory Read the instruction (MEM[PC])
Decode / Register Read	Generate the control signal values using the opcode & funct fields Read the register values with the rs & rt fields Sign / zero extend the immediate
Execute	Perform arithmetic / logical operations
Memory	Read from / write to the data memory
Register Write	Write back the ALU result / the memory load to the register file

3. Provide data inputs and control signals to the next PC logic.
4. Implement the next PC logic.



Single Cycle CPU Control Logic

Fill out the values for the control signals from the previous CPU diagram.

Instrs.	Control Signals								
	Jump	Branch	RegDst	ExtOp	ALUSrc	ALUCtr	MemWr	MemtoReg	RegWr
add	0	0	1	X	0	0010	0	0	1
ori	0	0	0	0	1	0001	0	0	1
lw	0	0	0	1	1	0010	0	1	1
sw	0	0	X	1	1	0010	1	X	0
beq	0	1	X	1	0	0110	0	X	0
j	1	X	X	X	X	XXXX	0	X	0

X: don't care value(either 0 or 1 is ok)

This table shows the ALUCtr values for each operation of the ALU:

Operation	AND	OR	ADD	SUB	SLT	NOR
ALUCtr	0000	0001	0010	0110	0111	1100

Clocking Methodology

- The input signal to each state element must stabilize before each rising edge.
- Critical path: Longest delay path between state elements in the circuit.
- $t_{clk} \geq t_{clk\text{-}to\text{-}q} + t_{CL} + t_{setup}$, where t_{CL} is the critical path in the combinational logic.
- If we place registers in the critical path, we can shorten the period by reducing the amount of logic between registers.

Single Cycle CPU Performance Analysis

The delays of circuit elements are given as follows:

Element	Register clk-to-q	Register Setup	MUX	ALU	Mem Read	Mem Write	RegFile Read	RegFile Setup
Parameter	$t_{clk\text{-}to\text{-}q}$	t_{setup}	t_{mux}	t_{ALU}	$t_{MEMread}$	$t_{MEMwrite}$	t_{RFread}	$T_{RFsetup}$
Delay(ps)	30	20	25	200	250	200	150	20

1. Give an instruction that exercises the critical path.

Load Word (lw)

2. What is the critical path in the single cycle CPU?

Red dashed line in the diagram

3. What are the minimum clock cycle, t_{clk}, and the maximum clock frequency, f_{clk}? Assume the $t_{clk\text{-}to\text{-}q}$ > hold time.

$t_{clk} >= t_{PC,\ clk\text{-}to\text{-}q} + t_{IMEMread} + t_{RFread} + t_{ALU} + t_{DMEMread} + t_{mux} + t_{RFsetup}$

$= 30 + 250 + 150 + 200 + 250 + 25 + 20 = 925$ ps

$f_{clk} = 1/t_{clk} <= 1/\ (925\ ps) = 1.08$ GHz

4. Why is a single cycle CPU inefficient?

-Not all instructions exercise the critical path.

-It is not parallelized. Each component can be active concurrently.

5. How can you improve its performance? What is the purpose of pipelining?

Pipelining: Put pipeline registers between two datapath stages. → reduce the clock time