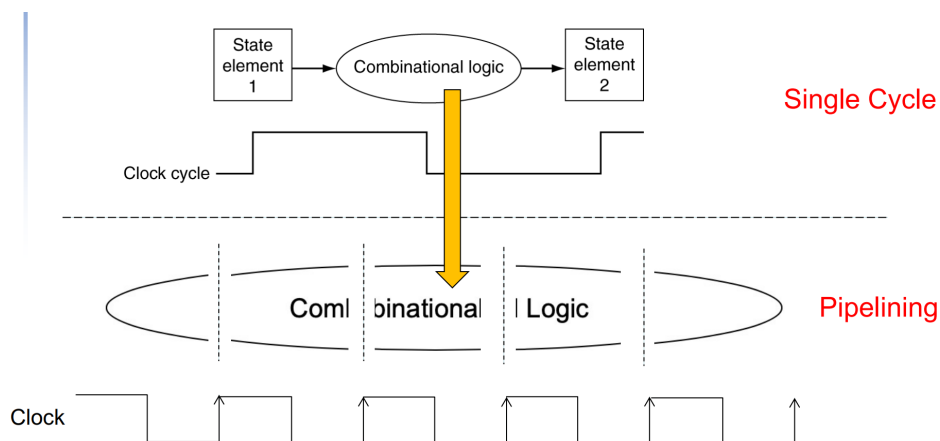


# Pipeline Processors and Data Hazards (T6-T7)

VE370SU22 TA Runxi Wang

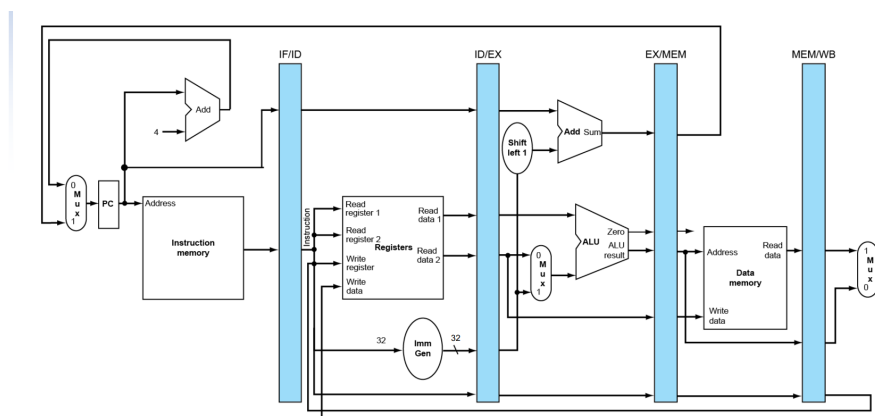
## From Single-Cycle to Pipeline

- Clock cycle time is shorter
- Ideally, pipeline speeds up the instruction process a lot
- But pipeline brings some hazard needed to be solved



## Pipeline Processor Architecture

A general view, but not complete!



With this structure, we can

- Execute multiple instructions (in different stages) at the same cycle
- Execute  $n$  instructions in  $n+4$  cycles (if no stalls due to hazards/branch mispredict)

## Stages

IF: Instruction fetch. Components includes PC, instruction memory, etc.

ID: Instruction decode. Read data from register file, generate immediate, etc.

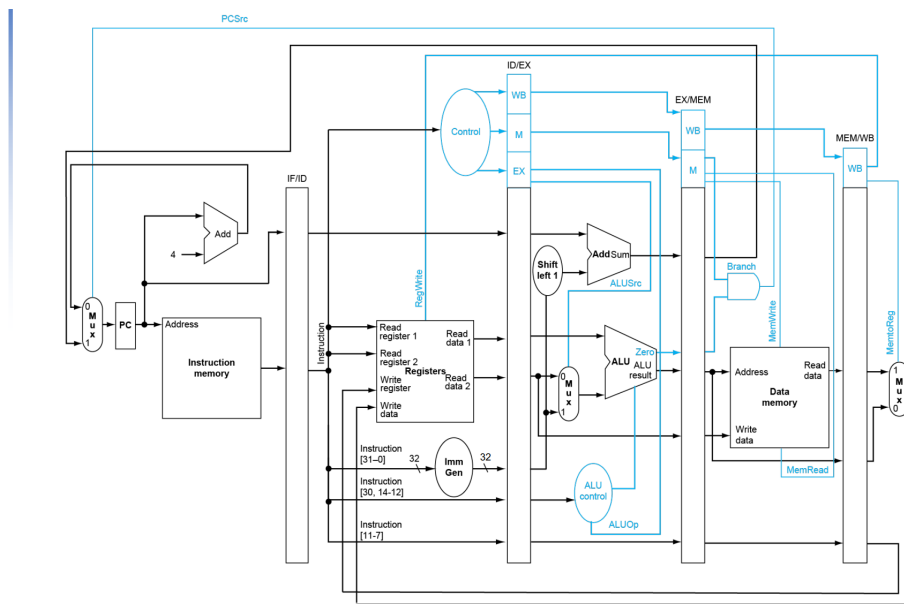
EX: Execution. Calculate using ALU, etc.

MEM: Access data memory. Read or write data memory.

WB: Write back. Write data back to register file.

## Control signals in Pipeline Processors

- Each module should have their control signals as assigned in single-cycle processors
- Control signals will be useless after it finishes its job in corresponding stage
- Use stage registers to record control signals



## How a Pipeline Processor Work (with example)

Suppose we have the following instructions to be processed in the pipeline structure. (You don't need to consider hazards here)

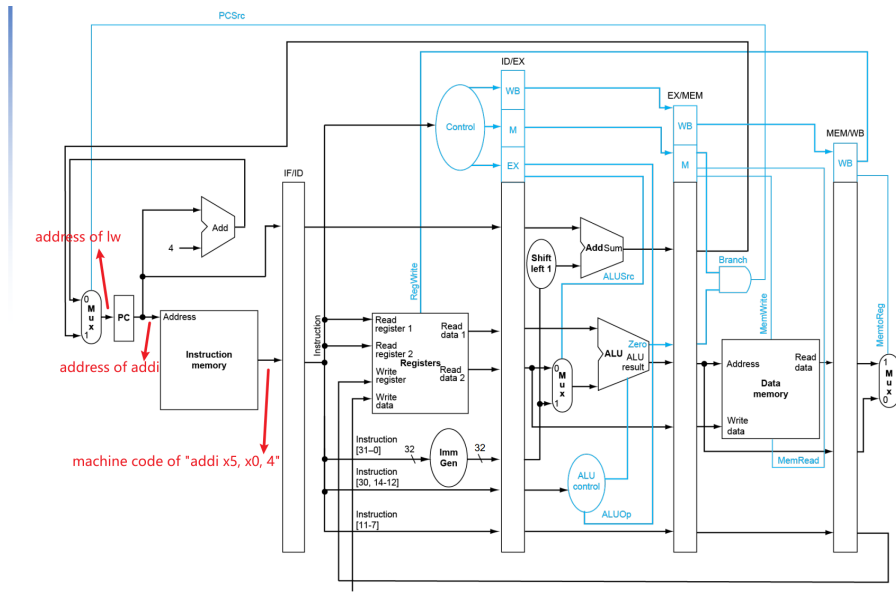
```
addi x5, x0, 4
lw x6, 0(x7)
sub x28, x28, x29
sw x7, 0(x29)
```

Multi-cycle pipeline diagram

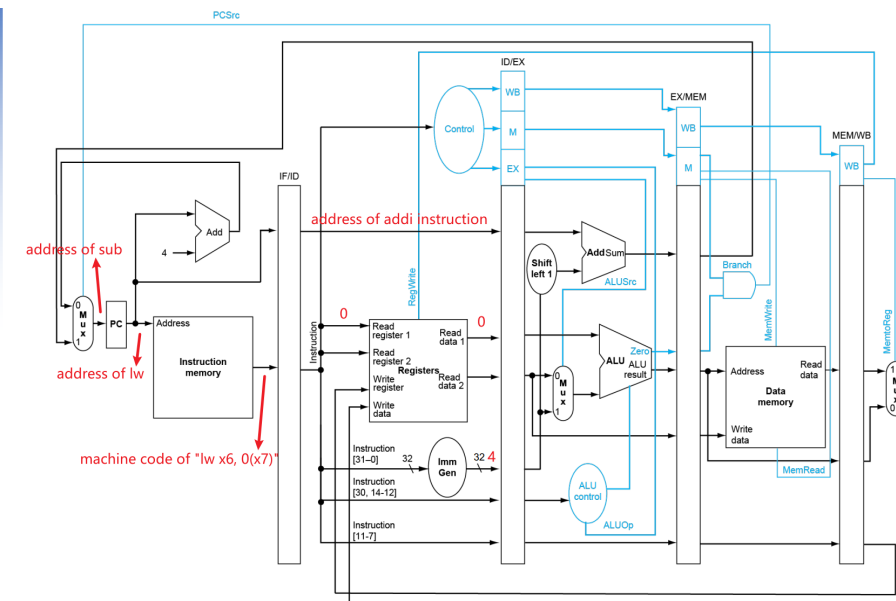
	C1	C2	C3	C4	C5	C6	C7	C8	C9
addi	IF	ID	EX	MEM	WB				
lw		IF	ID	EX	MEM	WB			
sub			IF	ID	EX	MEM	WB		
sw				IF	ID	EX	MEM	WB	

## Execution details

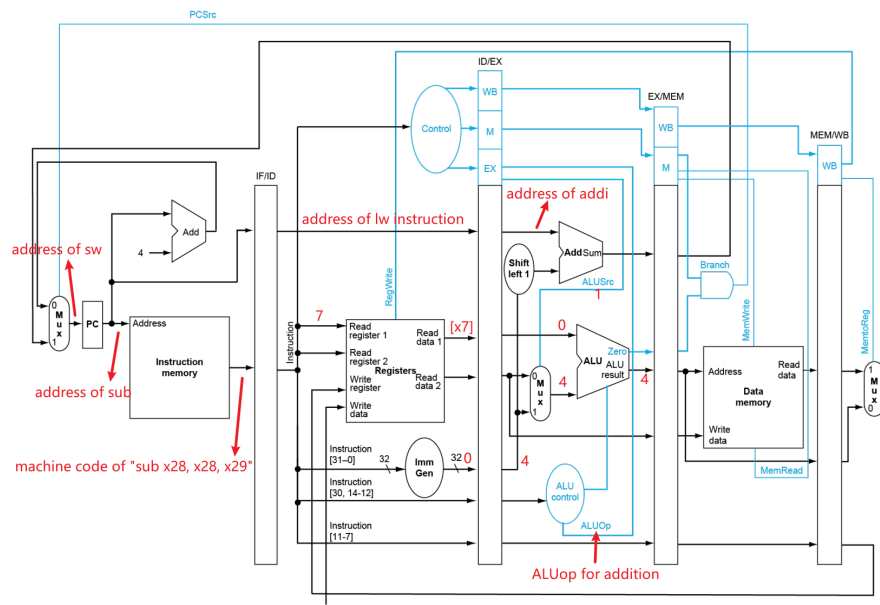
C1:



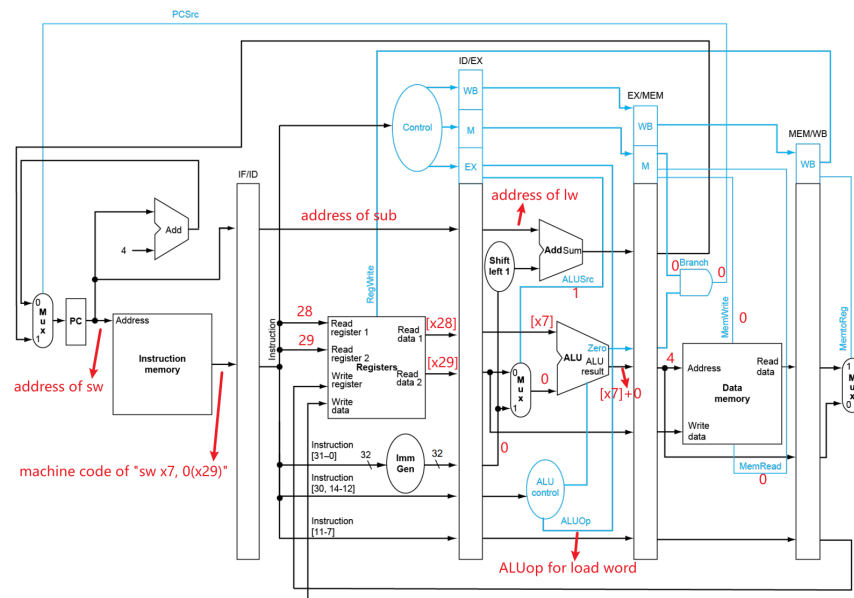
C2:



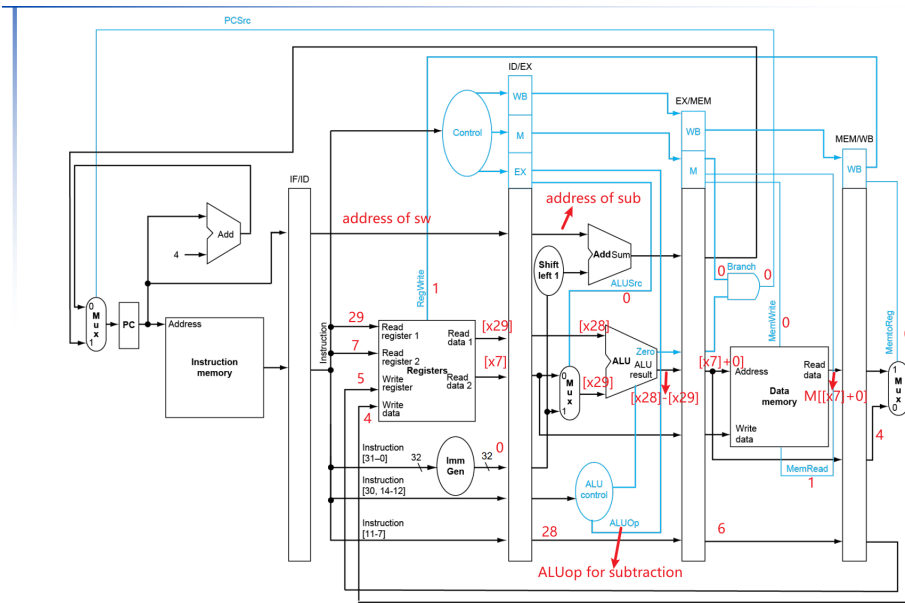
C3:



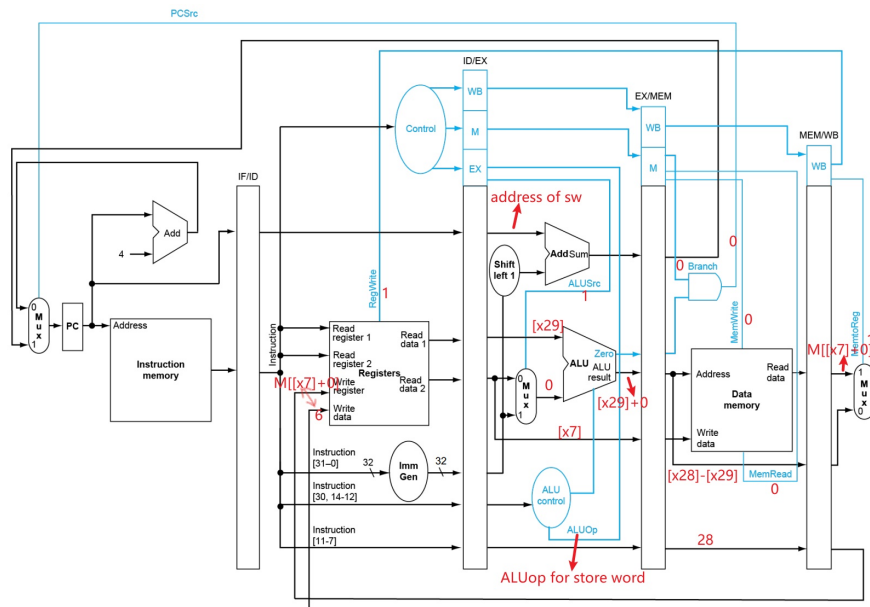
C4:



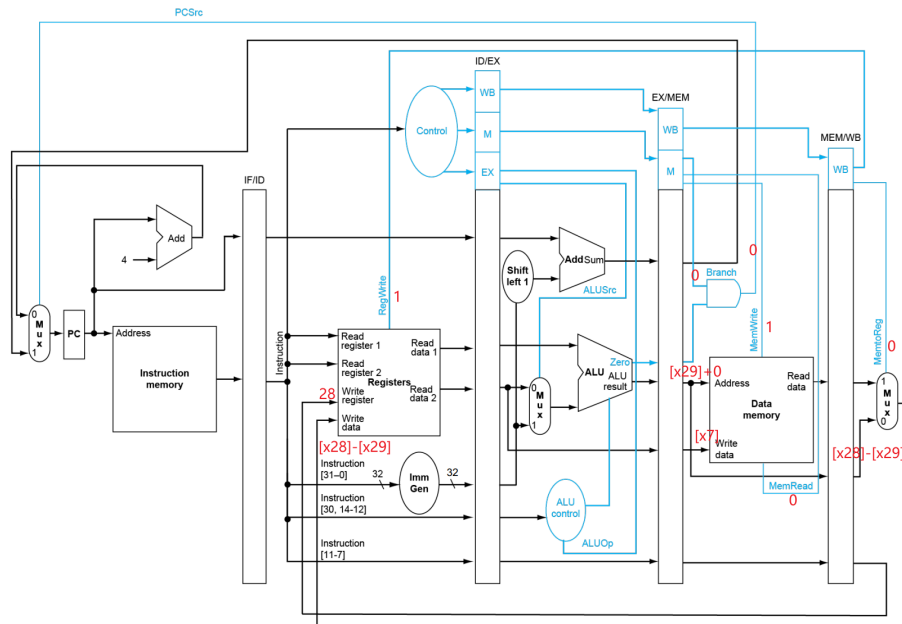
C5:



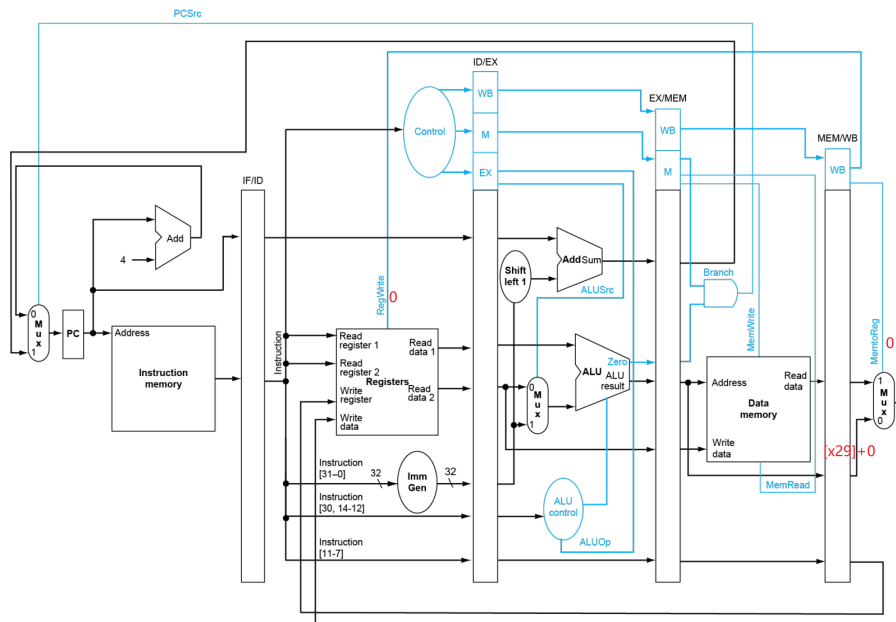
C6:



C7:



C8:



## Data Hazards

### Different type of hazards

- Data hazards: Need to wait for previous instruction to complete its data read/write
- Control hazards: Decision on control action depends on previous instruction
- Structure hazards: A required resource is busy

## Categories of Data Hazards

Case 1:

```
add x5, x6, x5
sub x28, x5, x6
```

Draw a pipeline diagram:

	C1	C2	C3	C4	C5	C6	C7	C8
add	IF	ID	EX	MEM	WB			
sub		IF	ID	ID*	ID*	EX	MEM	WB

we need additional 2 cycles(stalls) to fetch correct data of `x5` and then continue to calculate `x5-x6`.

Case 2:

```
lw x5, 0(x6)
addi x5, x5, 1
```

Draw a pipeline diagram:

	C1	C2	C3	C4	C5	C6	C7	C8
lw	IF	ID	EX	MEM	WB			
addi		IF	ID	ID*	ID*	EX	MEM	WB

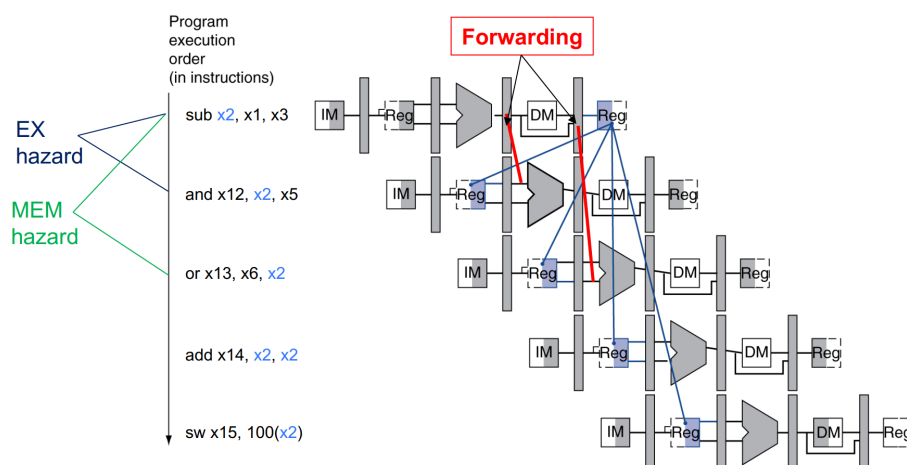
we need additional 2 cycles(stalls) to fetch correct data of `x5` that is loaded from data memory and then do calculation for it.

## Dealing with Data Hazards

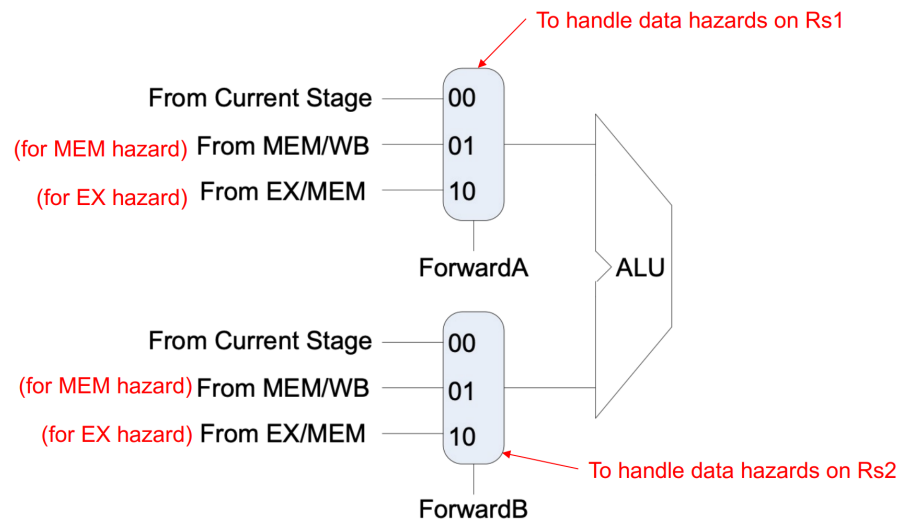
Solution 1 - **forwarding**

Can solve all case-1 data hazards mentioned above, but not completely for load-use data hazards.

Forward data from `EX/MEM` register or `MEM/WB` register



and choose the data needed for calculation



The control signal `ForwardA` and `ForwardB` is generated from **Forwarding unit**.

Logic in Forwarding unit:

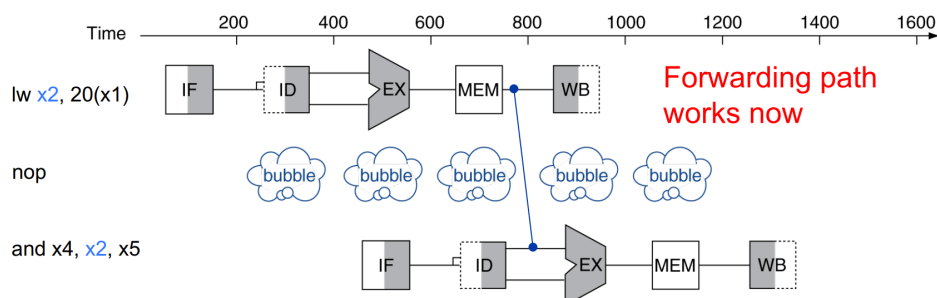
```

if (EX/MEM.RegWrite && (EX/MEM.RegisterRd != 0) && (EX/MEM.RegisterRd ==
ID/EX.RegisterRs1)) // EX hazard
    ForwardA = 10
else if (MEM/WB.RegWrite && (MEM/WB.RegisterRd != 0) && (MEM/WB.RegisterRd =
ID/EX.RegisterRs1) // MEM hazard
    ForwardA = 01
if (EX/MEM.RegWrite && (EX/MEM.RegisterRd != 0) && (EX/MEM.RegisterRd ==
ID/EX.RegisterRs2)) // EX hazard
    ForwardB = 10
else if (MEM/WB.RegWrite && (MEM/WB.RegisterRd != 0) && (MEM/WB.RegisterRd =
ID/EX.RegisterRs2) // MEM hazard
    ForwardB = 01;

```

## Solution 2 - Stall

For load-use data hazards, forwarding cannot fix it completely. We need to compromise some time to wait for data loaded from data memory.



We will use a **hazard detection unit** here to detect whether we need to insert a stall.

Logic of stalls:

- Force control signals in `ID/EX` stage register to be 0
- Keep the value of `PC` and instruction in `ID/EX`



## Tips for Project 4

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(This is for those who do not know how to start it. If you have your own design, that is great!)

- Check for each instruction required in the project manual to see if it can be processed by the pipeline structure mentioned in the lecture
- Construct each module (maybe just copy/modify from P3) and debug for each module
- Check interfaces for each stage and construct your stage register
- Construct each stage and debug each of them
- Combine all stages to one and do final debug:)
- It will take much longer time if you found P3 is difficult, do start early!!!

## Reference

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[1] VE370 SU22 Slides T6

[2] VE370 SU22 Slides T7