

Topic 7

Data Hazards

Hazards

- Situations that prevent starting the next instruction in the next cycle
- Data hazard
 - Need to wait for previous instruction to complete its data read/write
- Control hazard
 - Decision on control action depends on previous instruction
- Structure hazards
 - A required resource is busy

Data Hazards in ALU Instructions

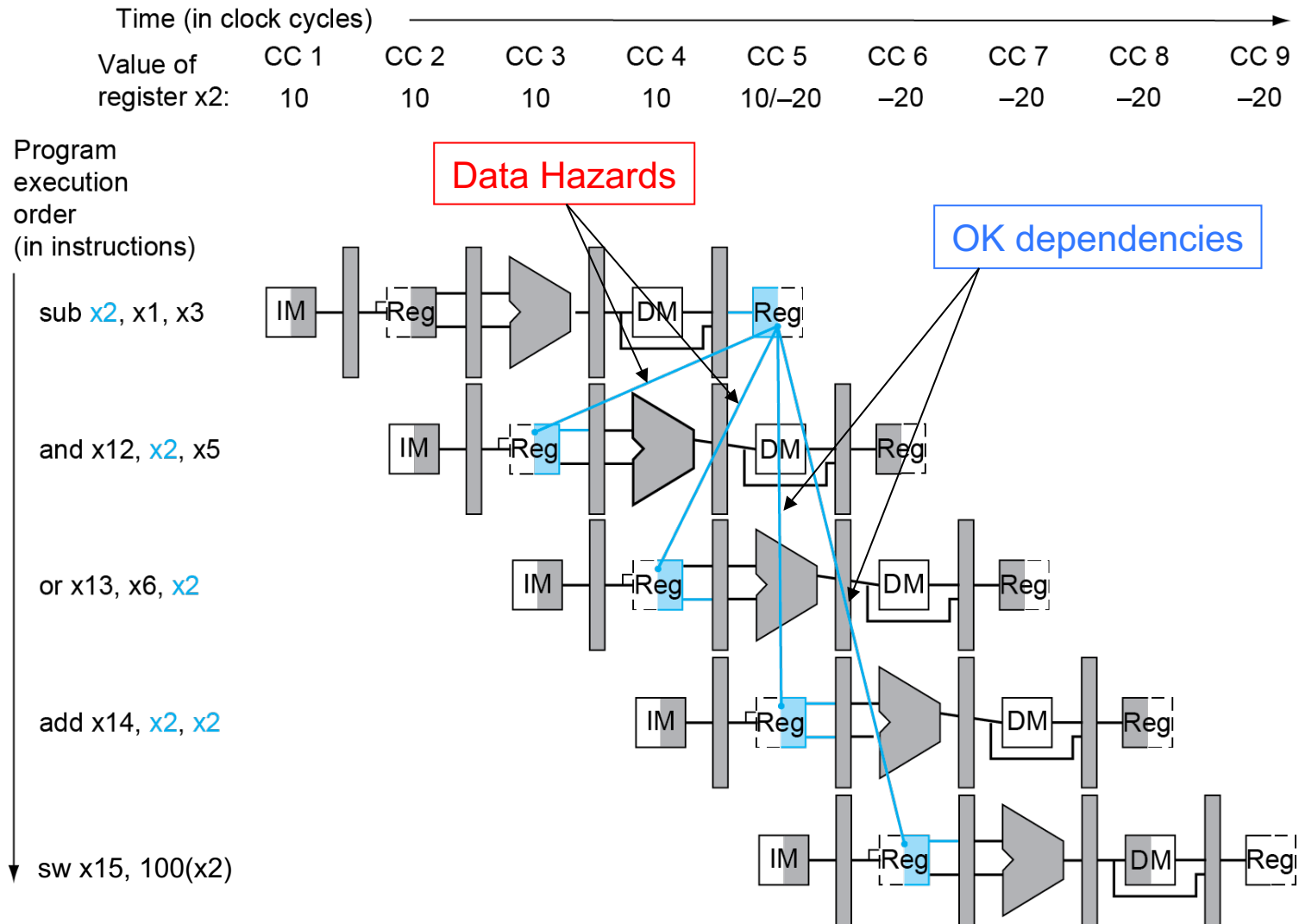
- Consider this sequence:

```
(1) sub  x2, x1, x3
(2) and  x12, x2, x5
(3) or   x13, x6, x2
(4) add  x14, x2, x2
(5) sw   x15, 100(x2)
```

- Data dependencies between:

```
(1) & (2)
(1) & (3)
(1) & (4)
(1) & (5)
```

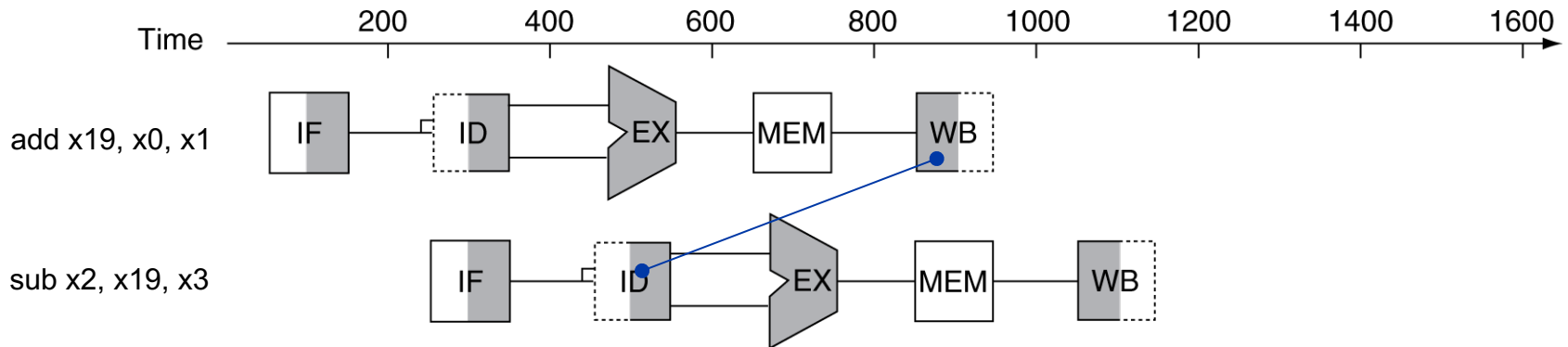
Data Dependency



Data Hazards

- If an instruction depends on completion of a data by a previous instruction
 - Then the instruction must be delayed
 - Example

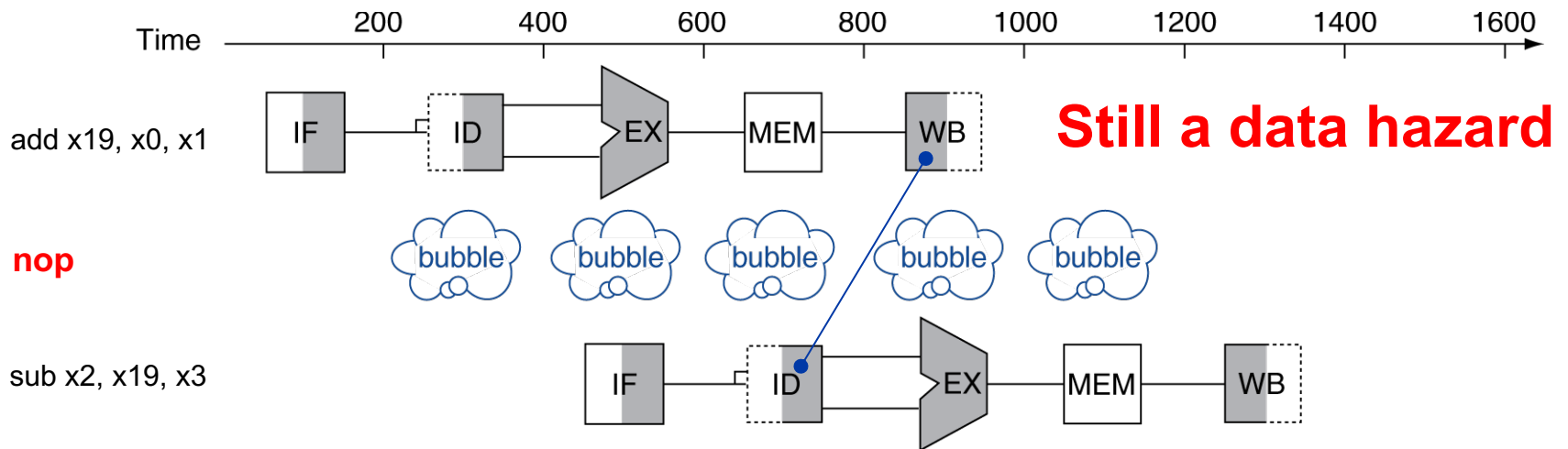
```
add    x19, x0, x1
sub     x2, x19, x3
```



Data Hazards

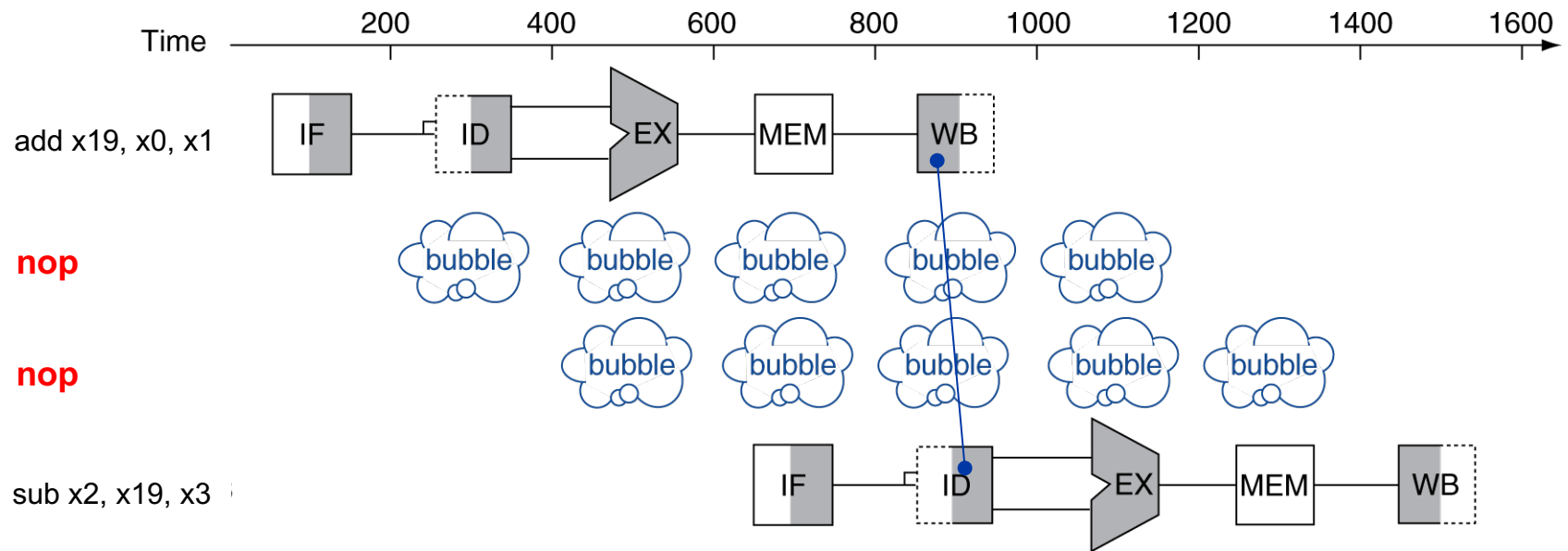
- The instruction must be delayed by
 - Inserting *bubbles* or *stalls*

nop # no operation, pseudo-instruction
 # addi x0, x0, 0



Data Hazards

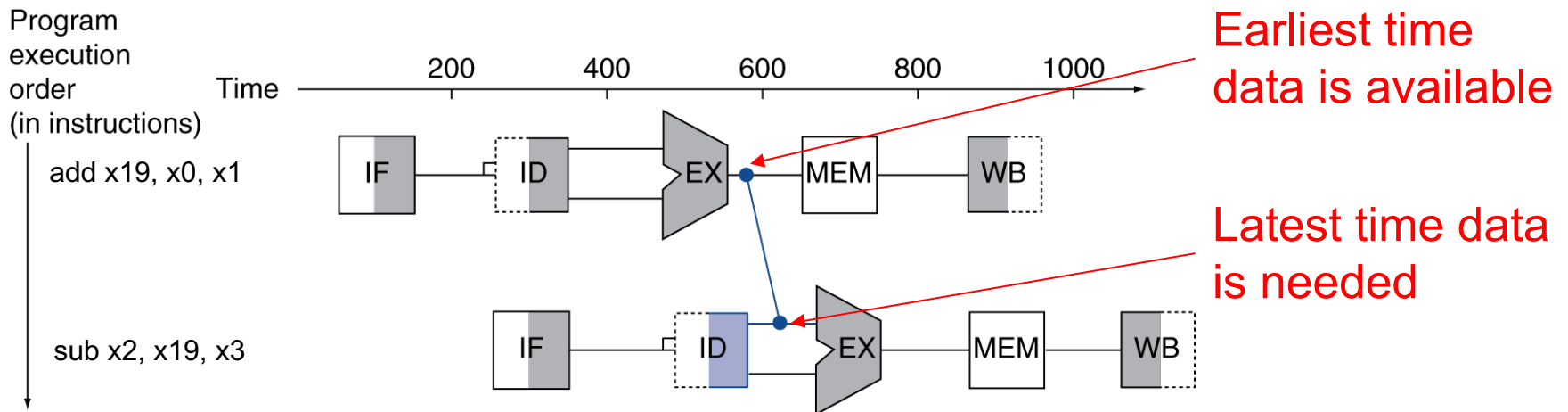
- Keep adding bubbles until the hazard is resolved



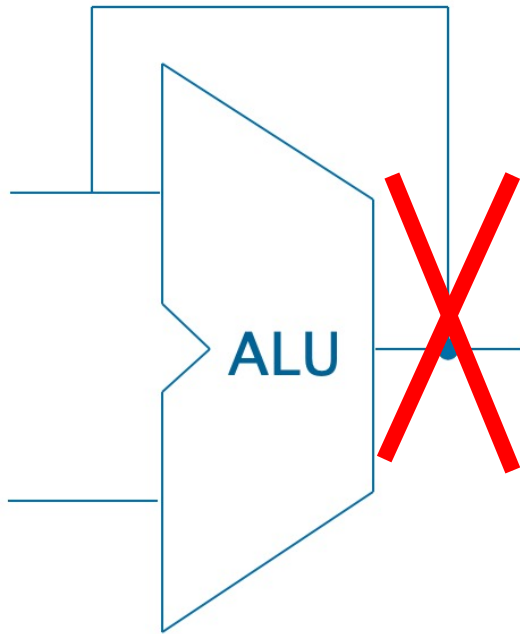
Data hazard resolved

Forwarding (aka Bypassing)

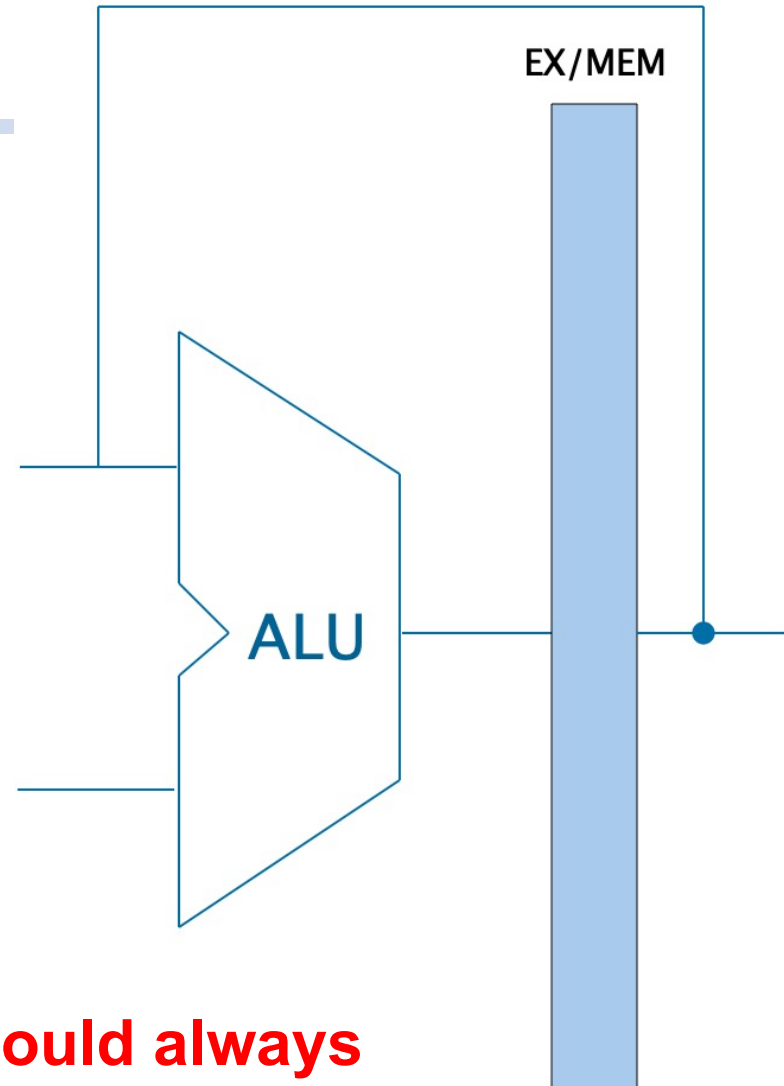
- Inserting nop (delay) compromises performance
- Data hazard **may** be solved with **Forwarding**
- Use result as soon as it is available
 - Don't wait for it to be stored in a register
 - Requires extra hardware in the datapath



Forwarding Path

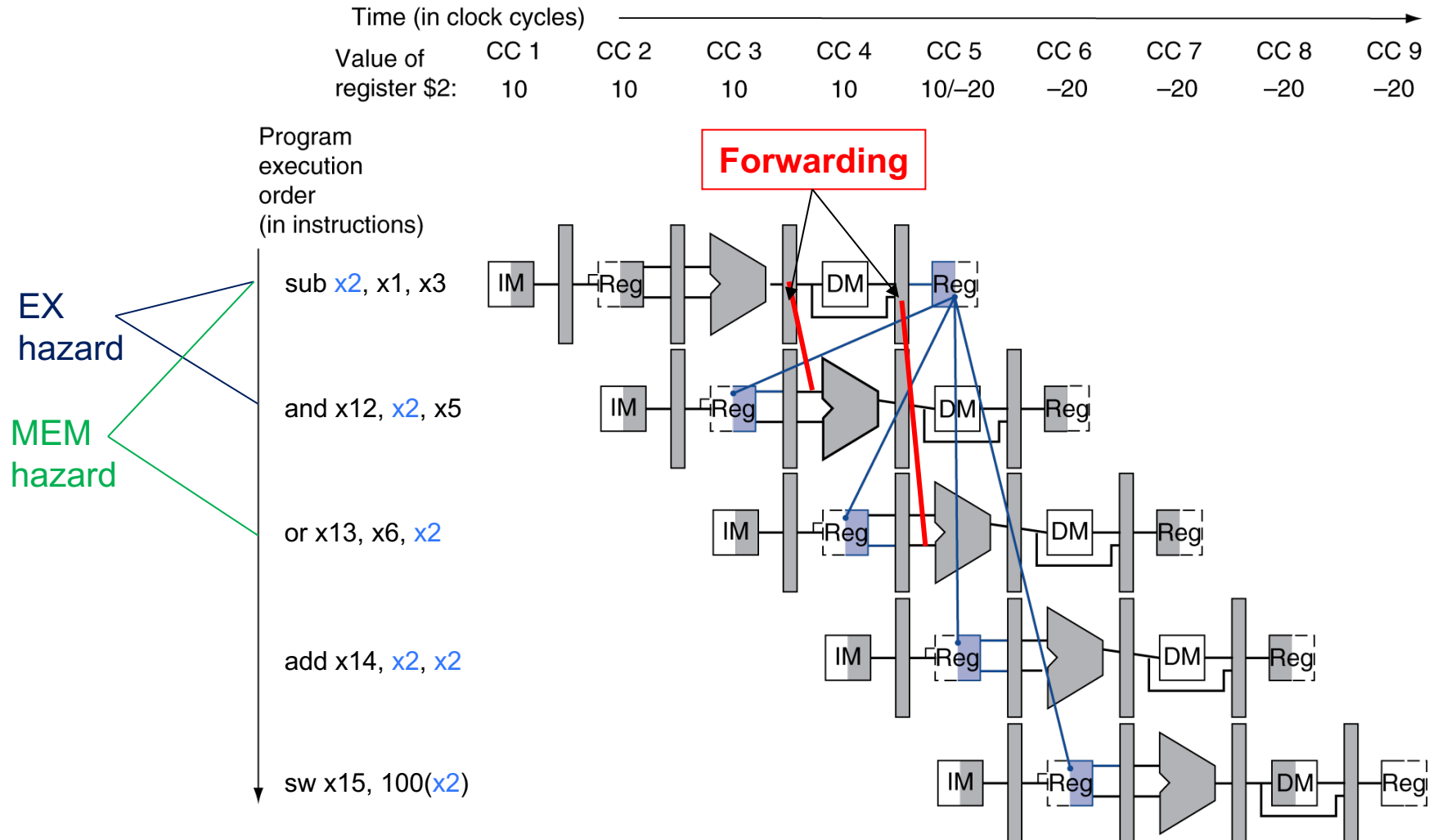


Can't connect input and output of a component directly



Should always connect data from a pipeline register

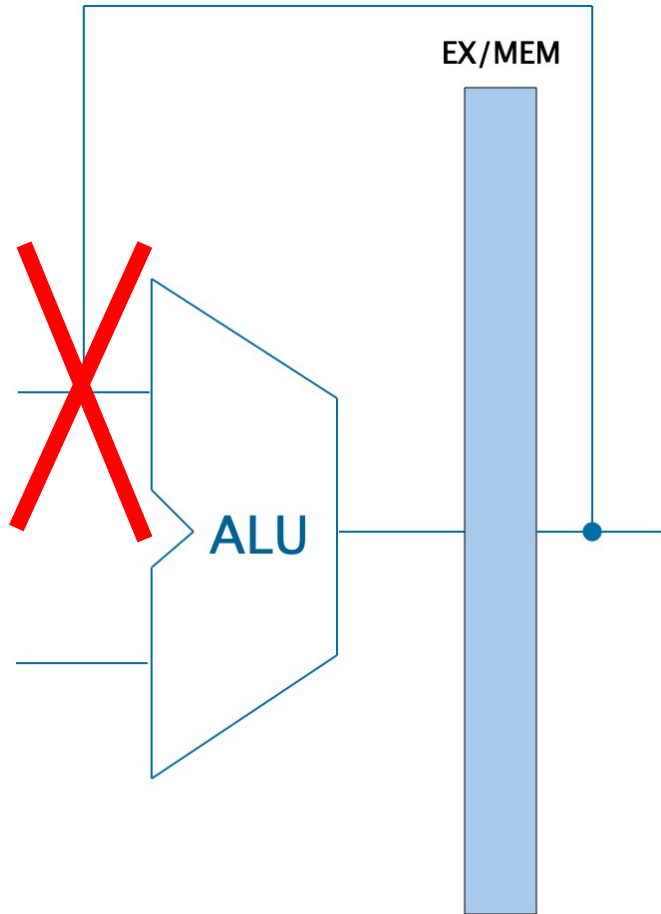
Forwarding from Registers



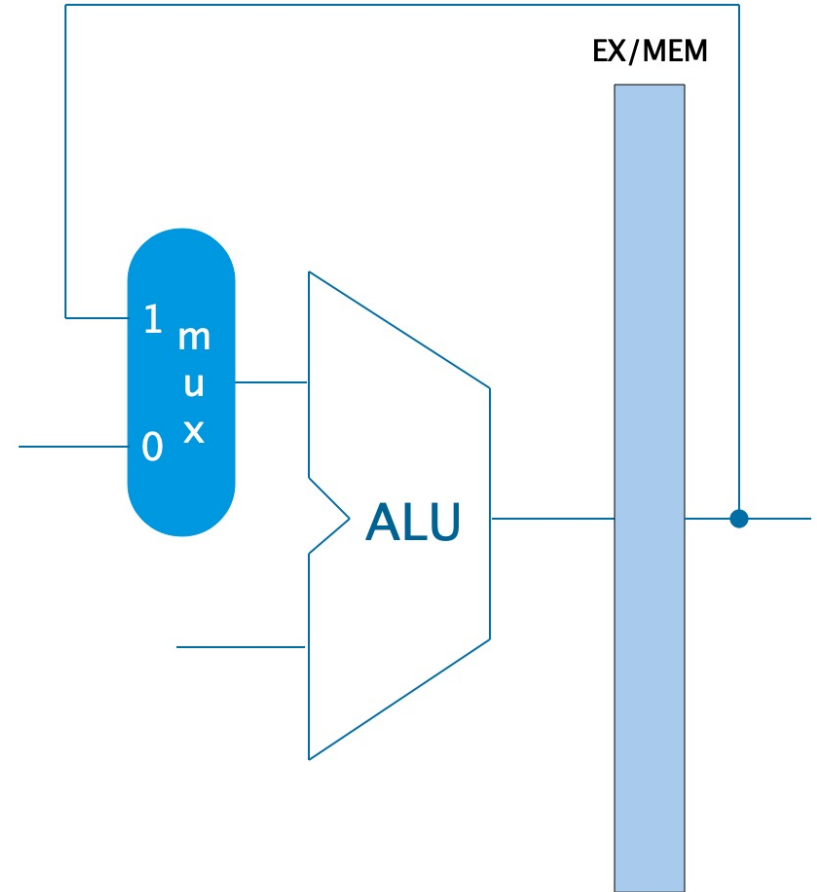
Type of data hazards

- EX hazard
 - Data hazard between two adjacent instructions
 - Forwarding path from EX/MEM pipeline register to ALU
- MEM hazard
 - Data hazard between two instructions with one more instruction in between
 - Forwarding path from MEM/WB pipeline register to ALU

Forwarding Path



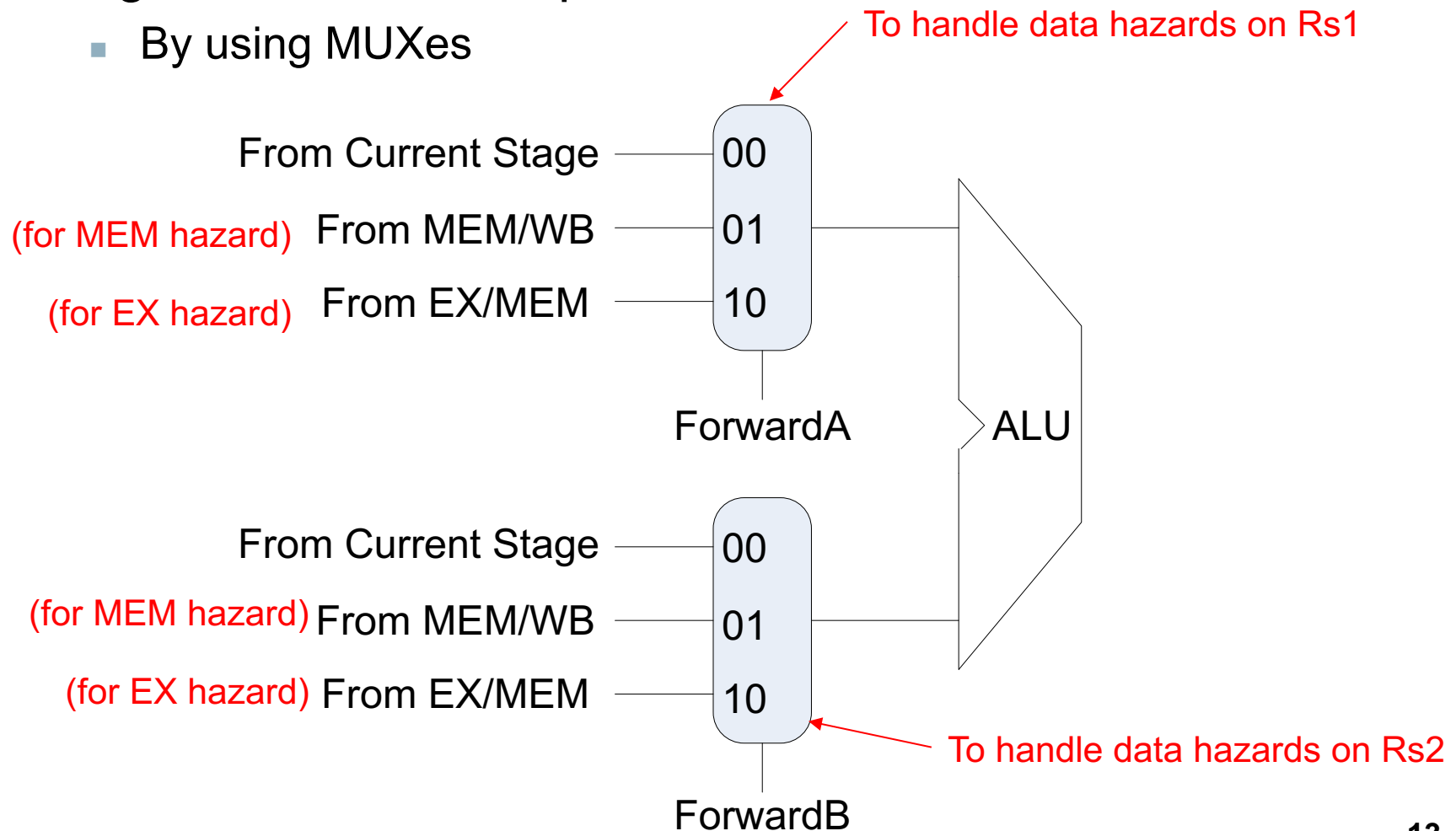
Can't just join 2
wires



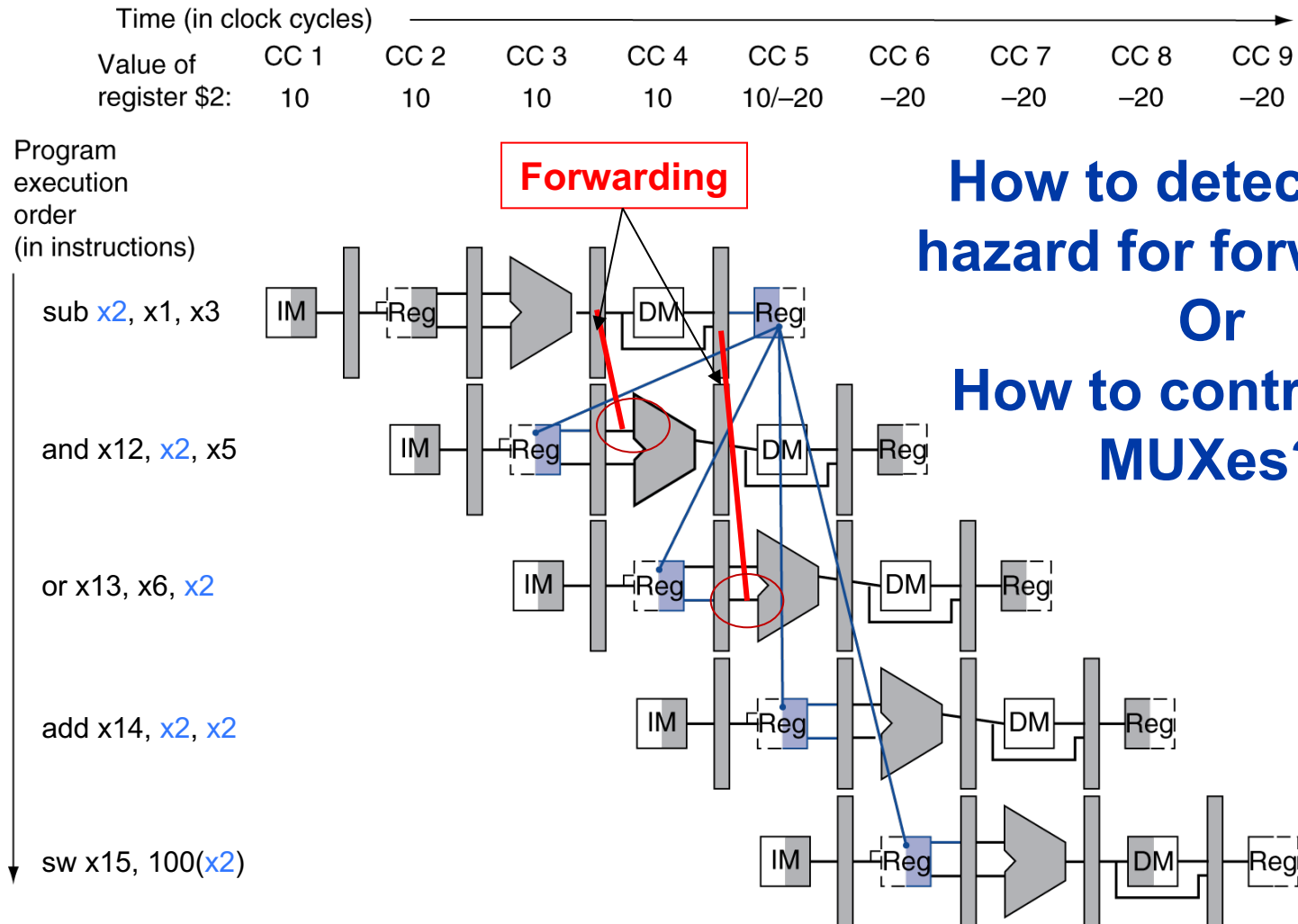
Use mux

Forwarding Paths

- Forwarding paths are created between stage pipeline registers and ALU inputs
 - By using MUXes



Dependencies & Forwarding



Detecting the Need to Forward

- Denotation:
 - e.g., ID/EX.RegisterRs1 = register number for Rs1 sitting in ID/EX pipeline register
- ALU operand register numbers in EX stage are given by
 - ID/EX.RegisterRs1, ID/EX.RegisterRs2
- Data hazards when

EX
Hazard

- 1a. EX/MEM.RegisterRd = ID/EX.RegisterRs1
- 1b. EX/MEM.RegisterRd = ID/EX.RegisterRs2

Fwd from
EX/MEM
pipeline reg

MEM
Hazard

- 2a. MEM/WB.RegisterRd = ID/EX.RegisterRs1
- 2b. MEM/WB.RegisterRd = ID/EX.RegisterRs2

Fwd from
MEM/WB
pipeline reg

Detecting the Need to Forward

- But only if forwarding instruction will write to a register!
 - EX/MEM.RegWrite
 - MEM/WB.RegWrite
- And only if Rd for that instruction is not x0
 - EX/MEM.RegisterRd \neq 0,
MEM/WB.RegisterRd \neq 0

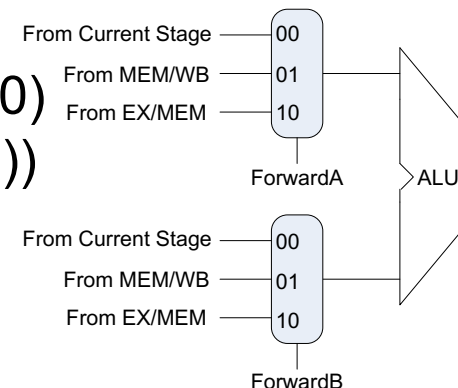
Revised Forwarding Conditions

EX hazard

- if (EX/MEM.RegWrite and (EX/MEM.RegisterRd \neq 0)
and (EX/MEM.RegisterRd == ID/EX.RegisterRs1))
MUX select signal ForwardA = 10
- if (EX/MEM.RegWrite and (EX/MEM.RegisterRd \neq 0)
and (EX/MEM.RegisterRd == ID/EX.RegisterRs2))
MUX select signal ForwardB = 10

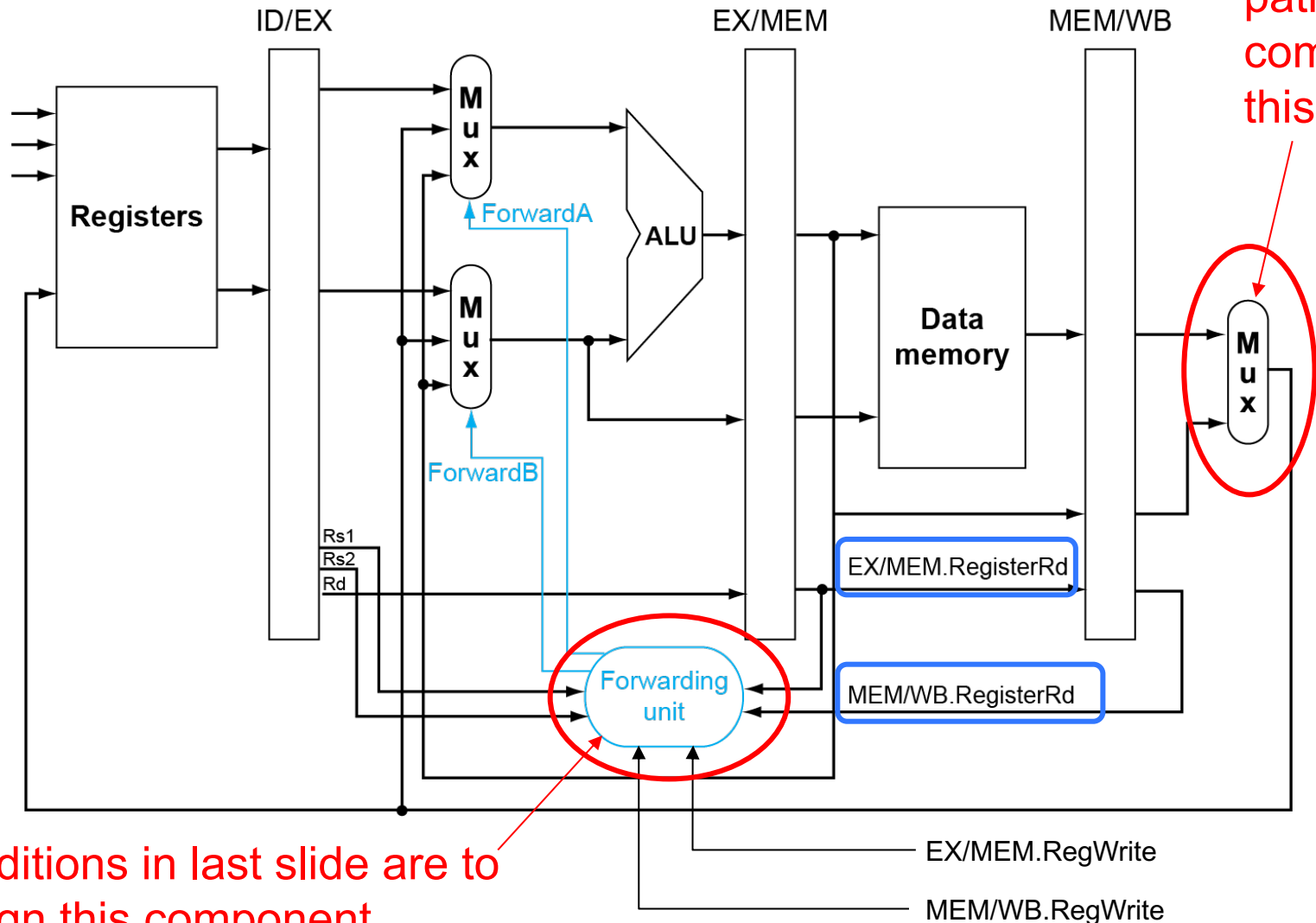
MEM hazard

- if (MEM/WB.RegWrite and (MEM/WB.RegisterRd \neq 0)
and (MEM/WB.RegisterRd == ID/EX.RegisterRs1))
MUX select signal ForwardA = 01
- if (MEM/WB.RegWrite and (MEM/WB.RegisterRd \neq 0)
and (MEM/WB.RegisterRd == ID/EX.RegisterRs2))
MUX select signal ForwardB = 01



Forwarding Paths

Forwarding Unit in EX stage



Double Data Hazard

- Consider the sequence:
 - add x1, x1, x2
 - add x1, x1, x3
 - add x1, x1, x4
- Conditions for both hazards are satisfied
 - Want to use the most recent
 - Forwarding between 1st and 3rd – MEM hazard condition should be disabled
- Revise MEM hazard condition
 - Only fwd if EX hazard condition isn't true

Revised Forwarding Condition

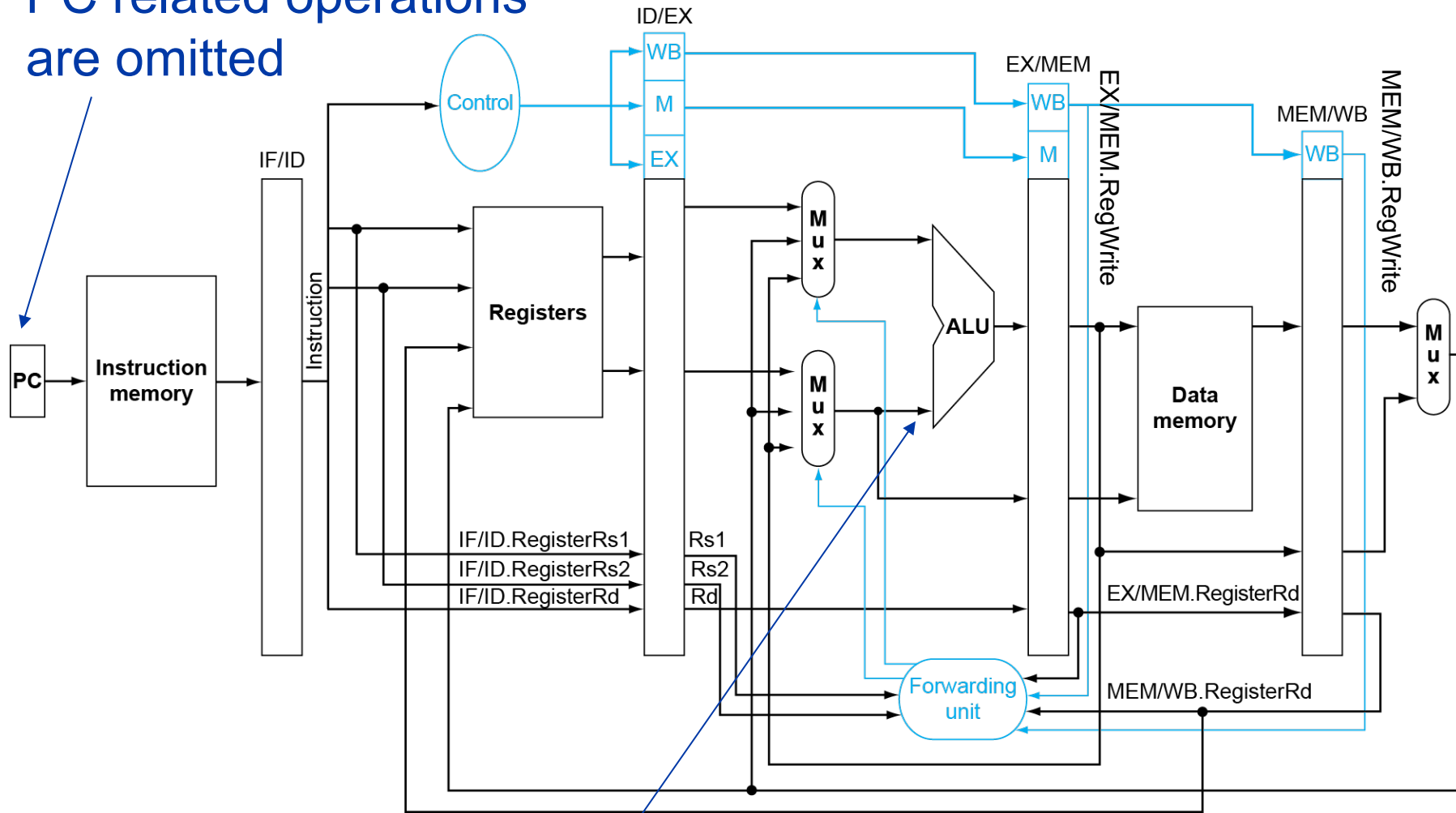
- MEM hazard (not EX hazard)
 - if (MEM/WB.RegWrite and (MEM/WB.RegisterRd \neq 0)
and (MEM/WB.RegisterRd = ID/EX.RegisterRs1)
and not (EX/MEM.RegWrite and (EX/MEM.RegisterRd \neq 0)
and (EX/MEM.RegisterRd = ID/EX.RegisterRs1)))
ForwardA = 01
 - if (MEM/WB.RegWrite and (MEM/WB.RegisterRd \neq 0)
and (MEM/WB.RegisterRd = ID/EX.RegisterRs2)
and not (EX/MEM.RegWrite and (EX/MEM.RegisterRd \neq 0)
and (EX/MEM.RegisterRd = ID/EX.RegisterRs2)))
ForwardB = 01

Forwarding Conditions

MUX control	Source	Explanation
ForwardA = 00	ID/EX	The first ALU operand comes from the register file.
ForwardA = 10	EX/MEM	The first ALU operand is forwarded from the prior ALU result.
ForwardA = 01	MEM/WB	The first ALU operand is forwarded from data memory or an earlier ALU result.
ForwardB = 00	ID/EX	The second ALU operand comes from the register file.
ForwardB = 10	EX/MEM	The second ALU operand is forwarded from the prior ALU result.
ForwardB = 01	MEM/WB	The second ALU operand is forwarded from data memory or an earlier ALU result.

Datapath with Forwarding

PC related operations
are omitted



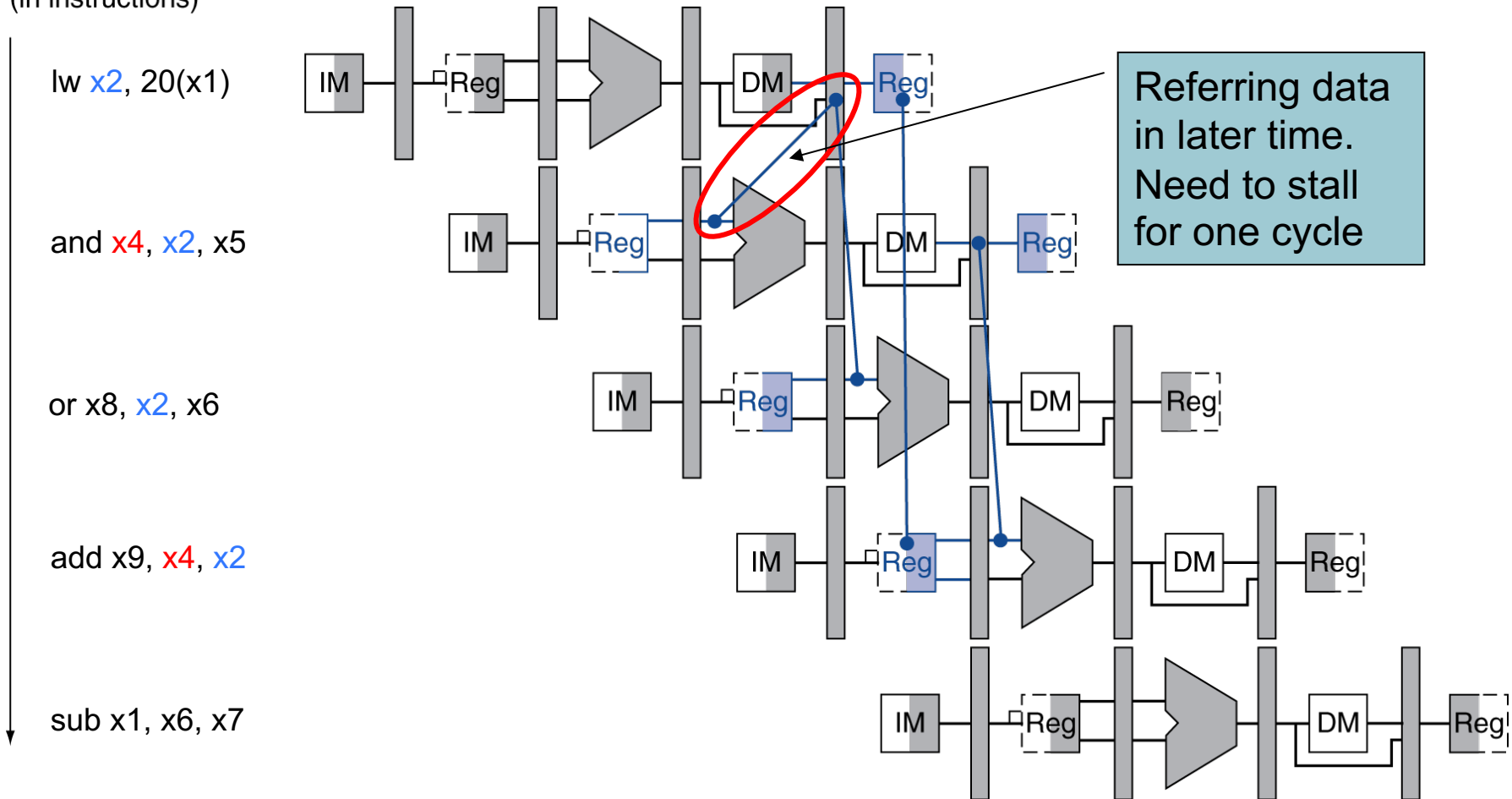
Note: Imm Gen and ALUSrc mux
are omitted for simplicity purpose

Forwarding May Fail

- Can't always avoid stalls by forwarding
 - If value not computed when needed
 - Can't forward back in time!

Load-Use Data Hazard

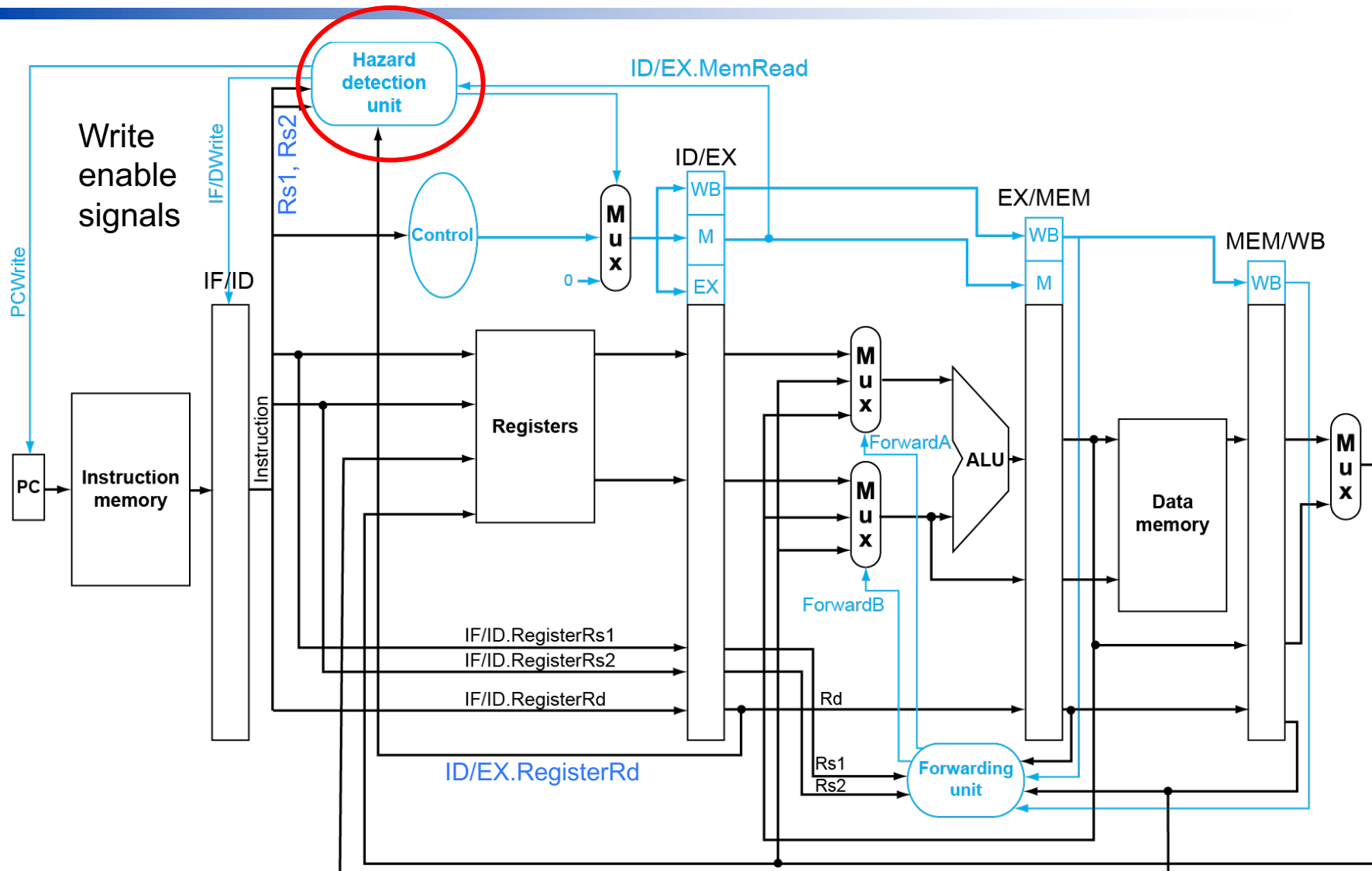
Program
execution
order
(in instructions)



Load-Use Hazard Detection

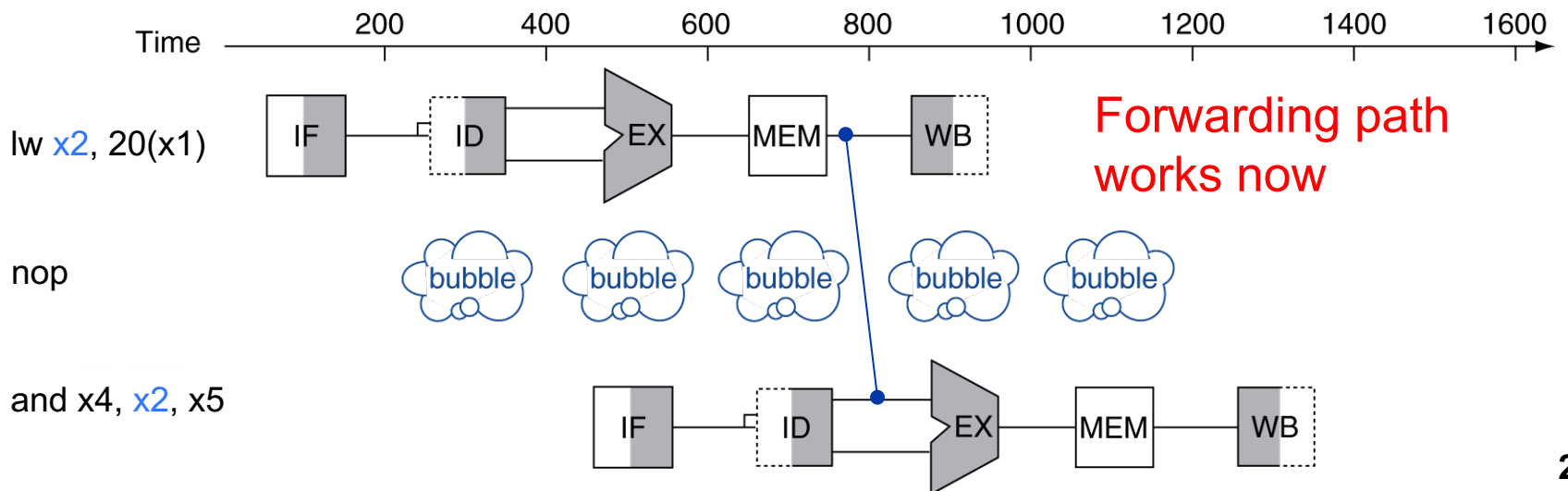
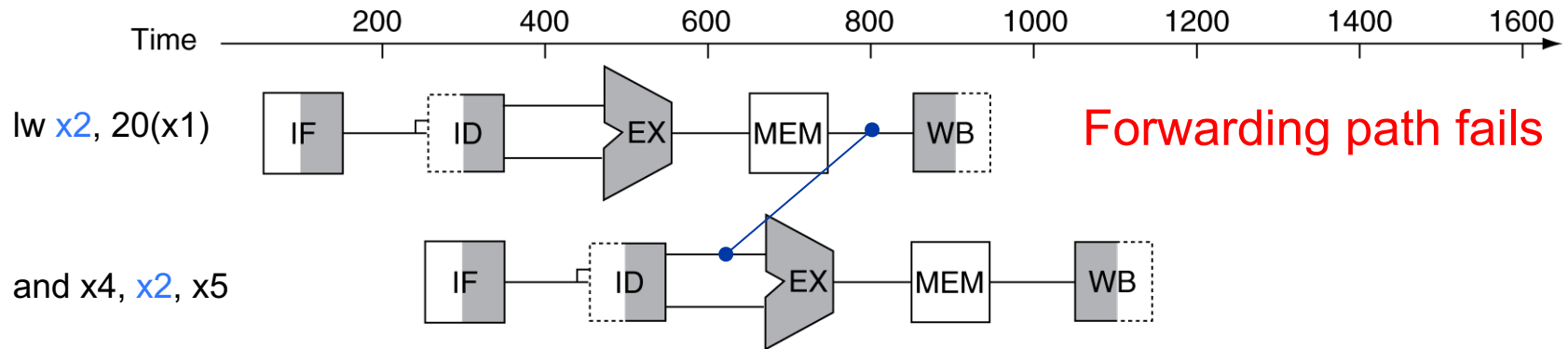
- Need to check only for a ***load*** instruction, which is indicated by
 - ID/EX.MemRead
- Load-use hazard when
 - ID/EX.MemRead and
((ID/EX.RegisterRd = IF/ID.RegisterRs1) or
(ID/EX.RegisterRd = IF/ID.RegisterRs2))
- Hazard Detection unit is added in **ID** stage
- If detected, stall and insert bubble

Datapath with Hazard Detection



Load-Use Data Hazard

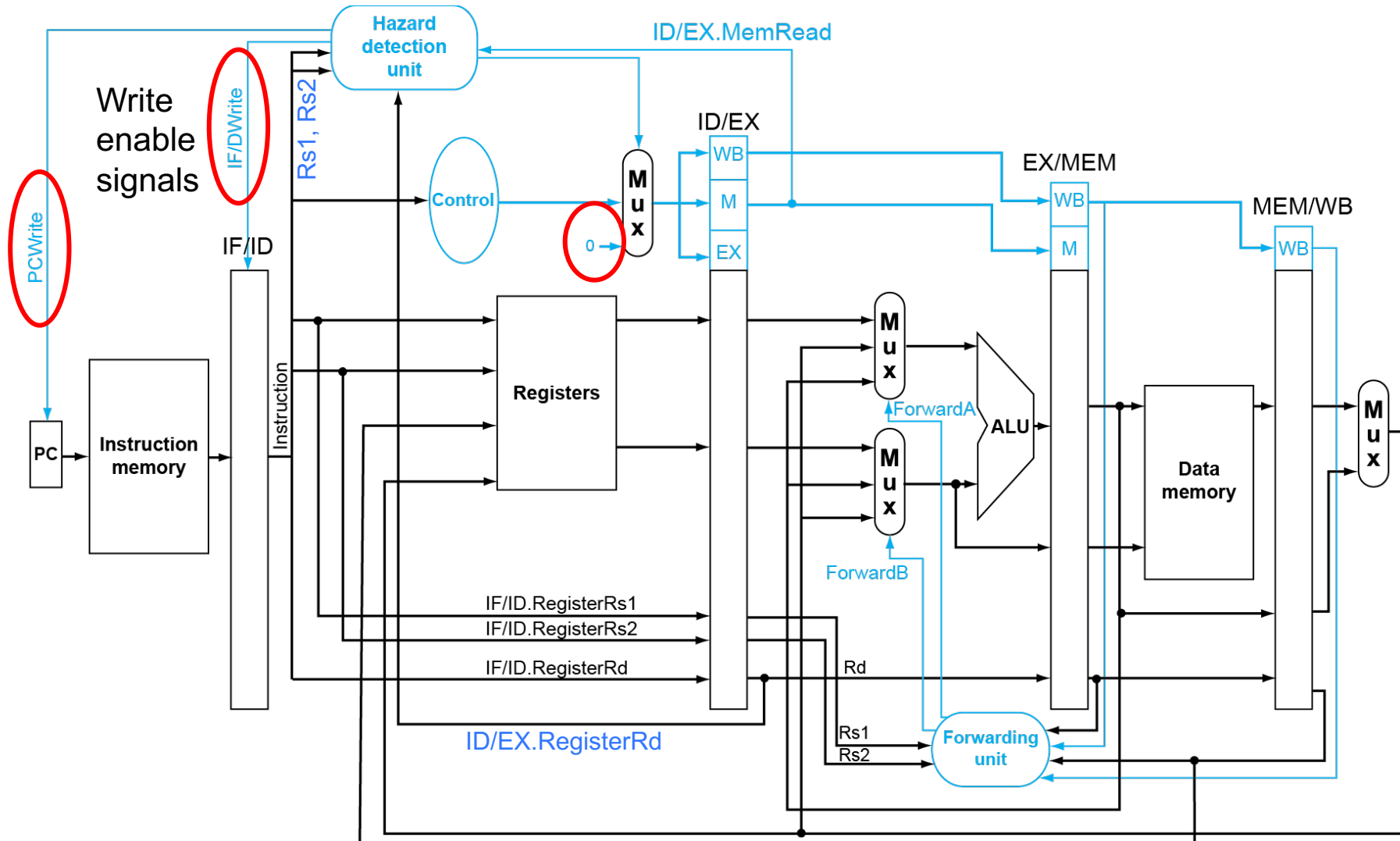
■ Resolve by inserting stalls



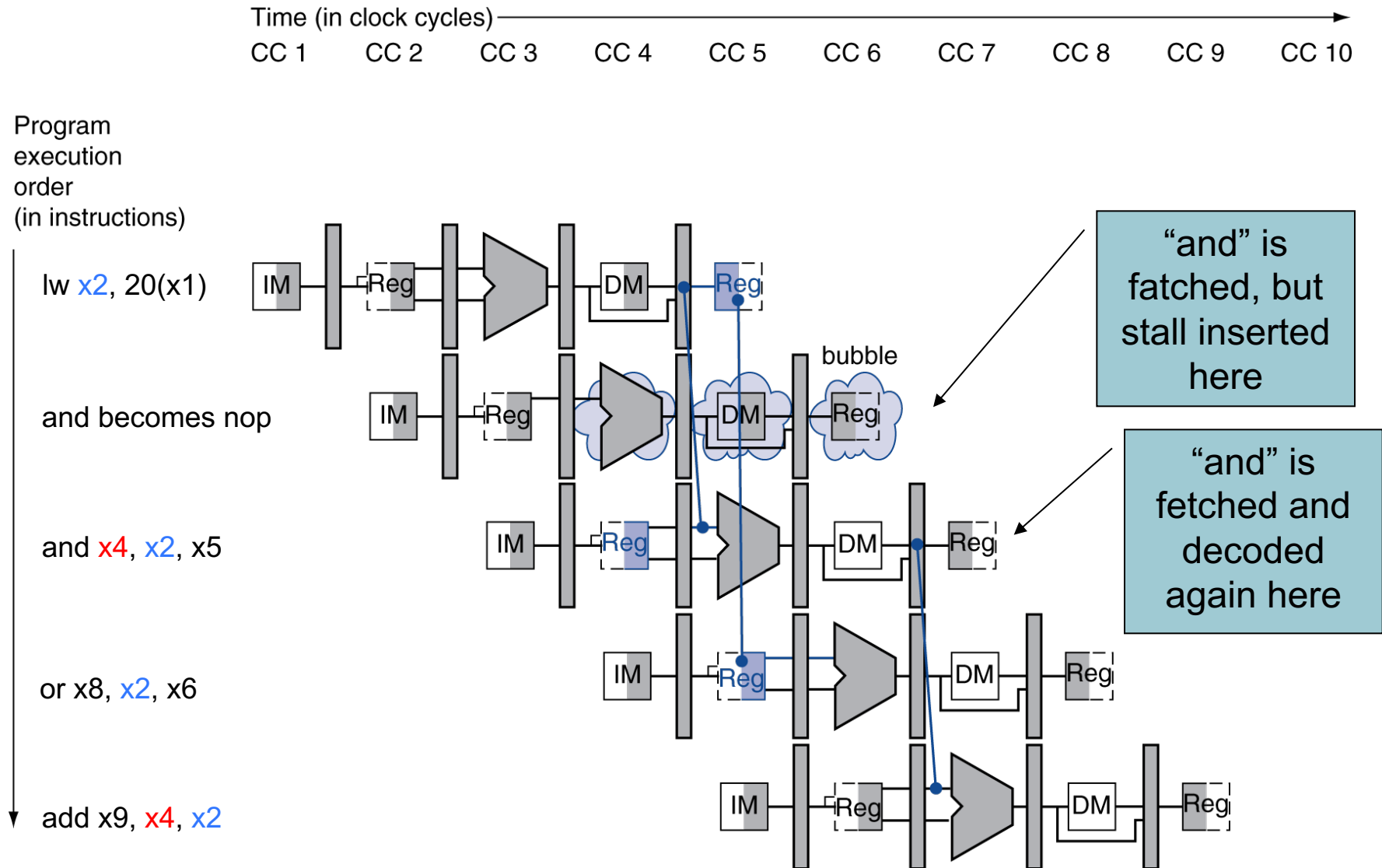
How to Stall the Pipeline?

- (How to insert bubbles?)
 1. Force control signals in ID/EX pipeline register to 0's
 - EX, MEM and WB in following cycles do no-operation (nop) with those 0 control signals
 2. Prevent updates of PC and IF/ID registers
 - Instruction in IF/ID is held and decoded again
 - PC is held, so the same instruction is fetched again

Datapath with Hazard Detection



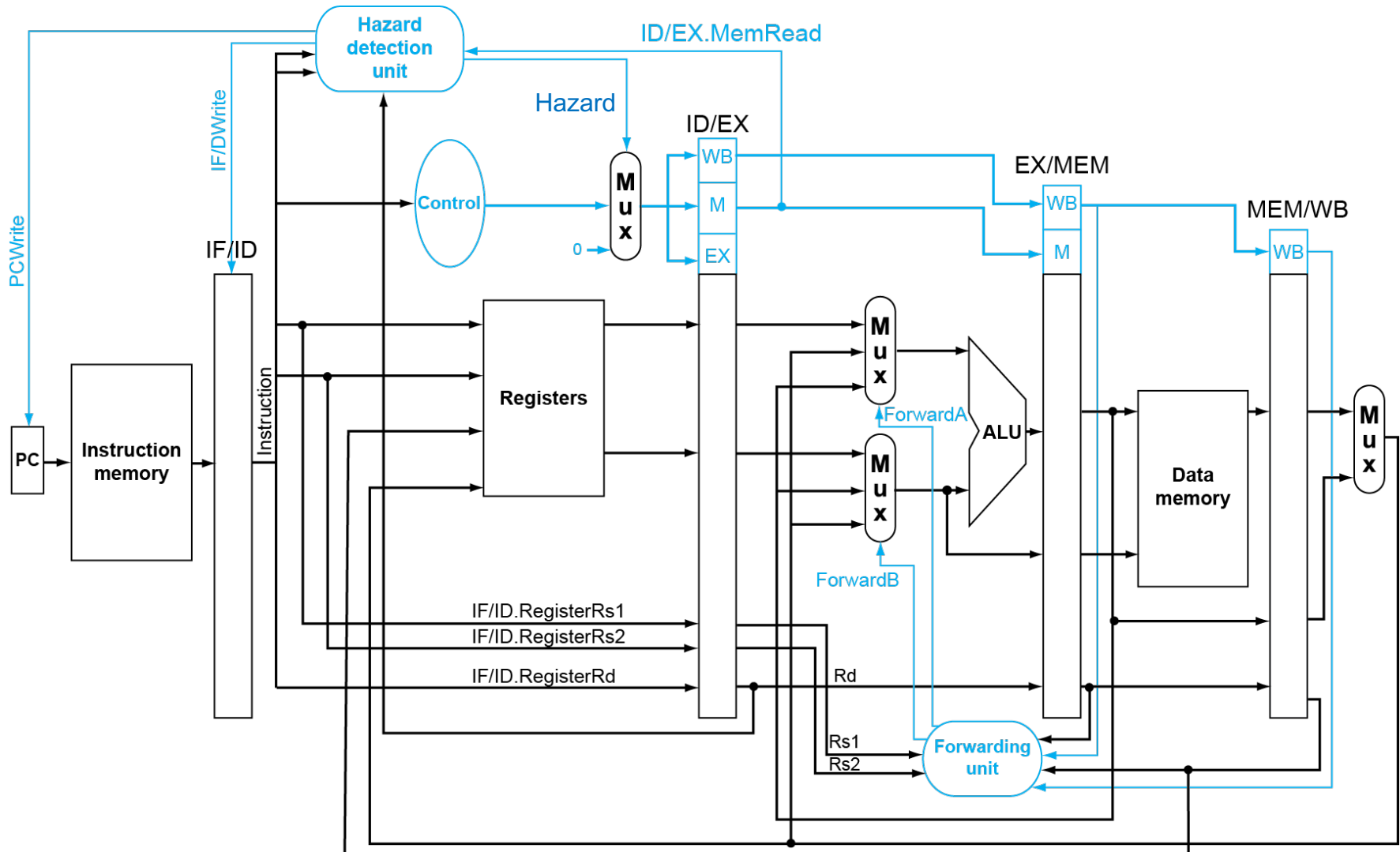
Stall/Bubble in the Pipeline



CC1

lw x2, 20(x1)

PC Write	IF/ID Write	Hazard	ID/EX. MemRead	IF/ID .Rs1	IF/ID .Rs2	ID/EX. Rd
1	1	X	X	X	X	X

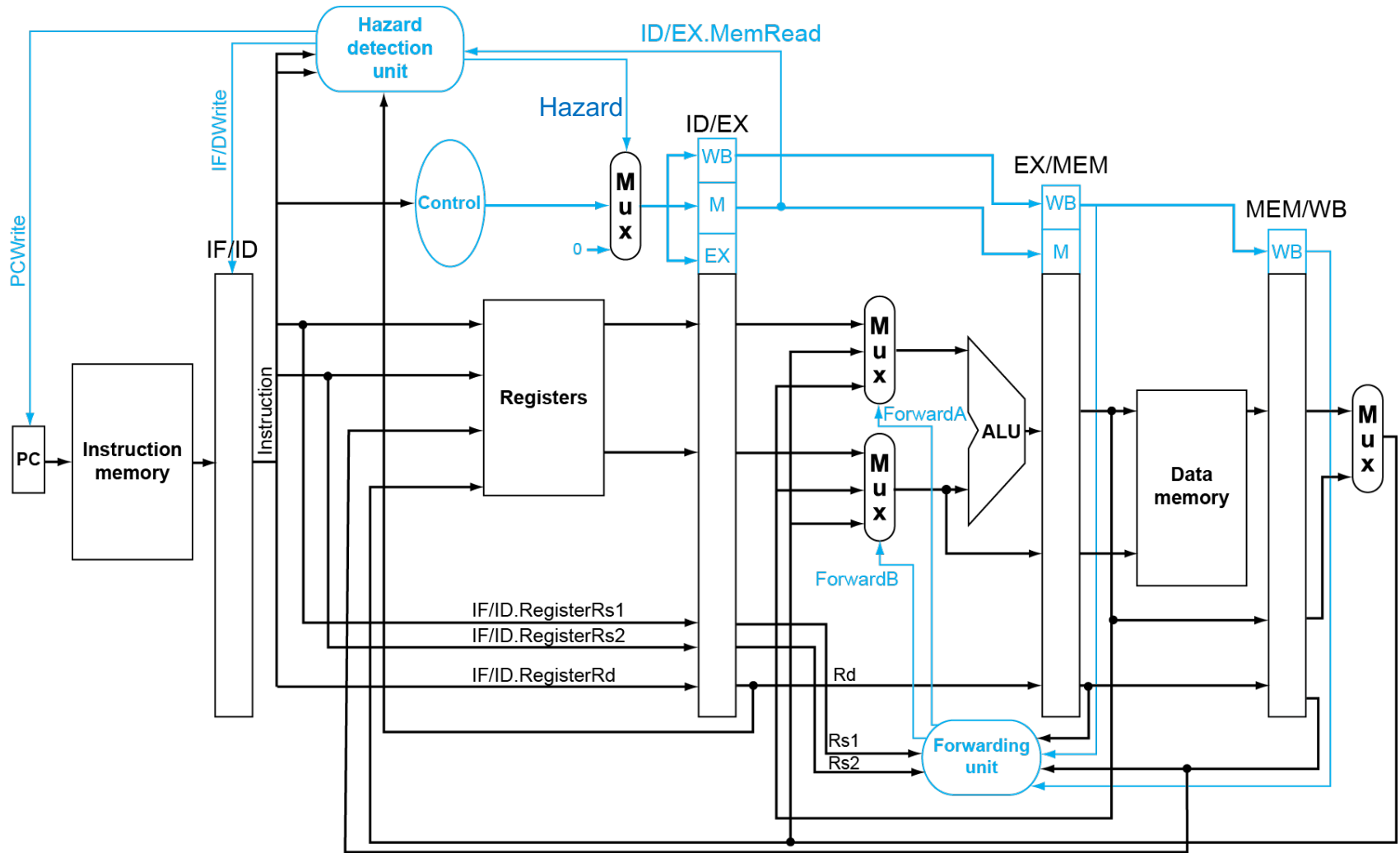


CC2

PC Write	IF/ID Write	Hazard	ID/EX. MemRead	IF/ID .Rs1	IF/ID .Rs2	ID/EX. Rd
1	1	x	x	1	20	x

and x4,x2,x5

lw x2, 20(x1)



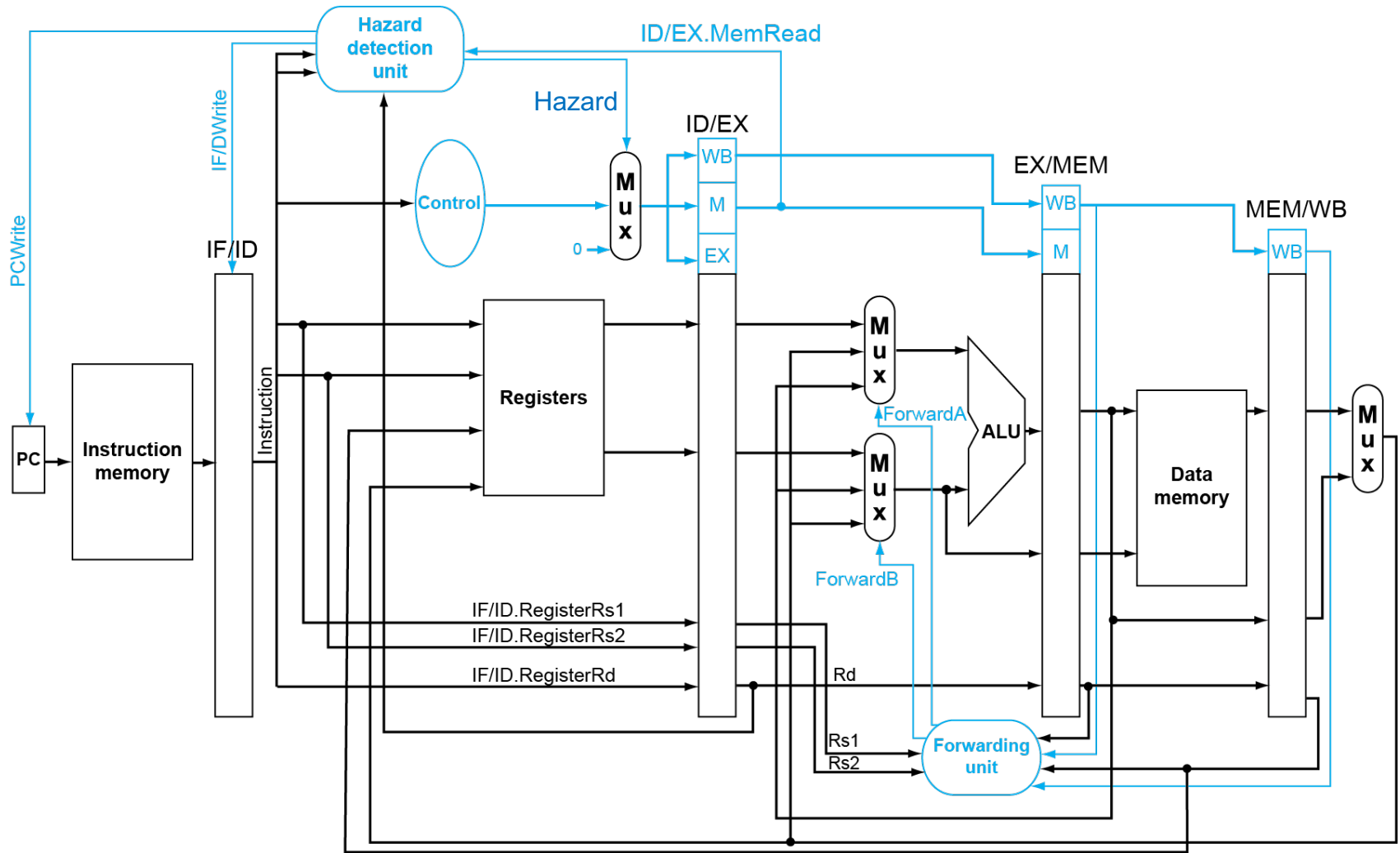
CC3

PC Write	IF/ID Write	Hazard	ID/EX. MemRead	IF/ID .Rs1	IF/ID .Rs2	ID/EX. Rd
0	0	1	1	2	5	2

or x8,x2,x6

and x4,x2,x5

lw x2, 20(x1)



CC4

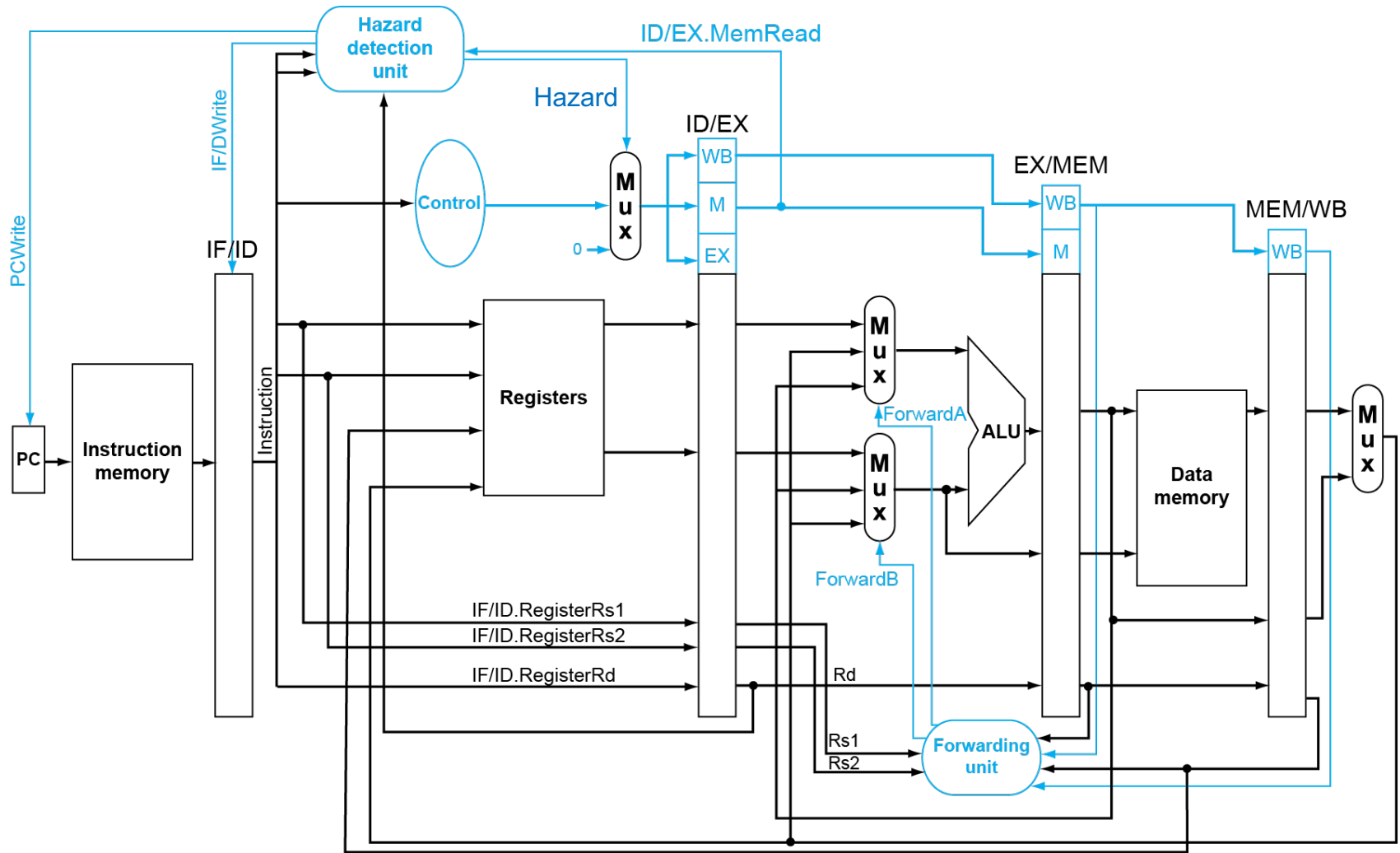
PC Write	IF/ID Write	Hazard	ID/EX. MemRead	IF/ID .Rs1	IF/ID .Rs2
1	1	0	0	2	5

or x8,x2,x6

and x4,x2,x5

nop (and)

lw x2, 20(x1)



CC4

ID/EX.Rs1	ID/EX.Rs2	ID/EX.Rd	EX/MEM.Rd	MEM/WB.Rd
2	5	4	2	X
EX/MEM.RegWrite	MEM/WB.RegWrite	ForwardA	ForwardB	
1	X	10	00	

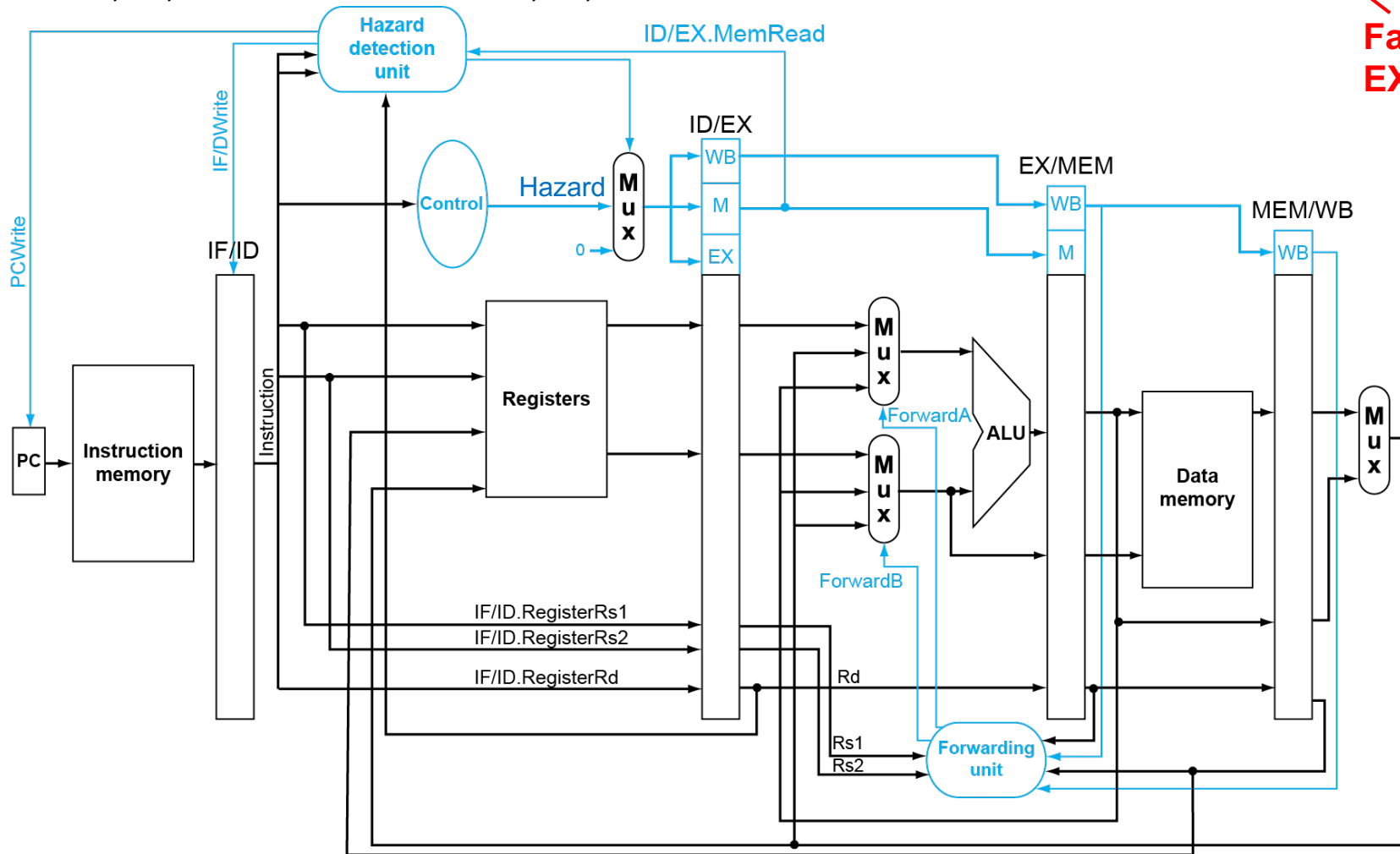
or x8,x2,x6

and x4,x2,x5

nop (and)

lw x2, 20(x1)

Fake
EX hazard



CC5

PC Write	IF/ID Write	Hazard	EX/MEM. MemRead	EX/MEM. MemWrite
1	1	0	0	0

No effective operation

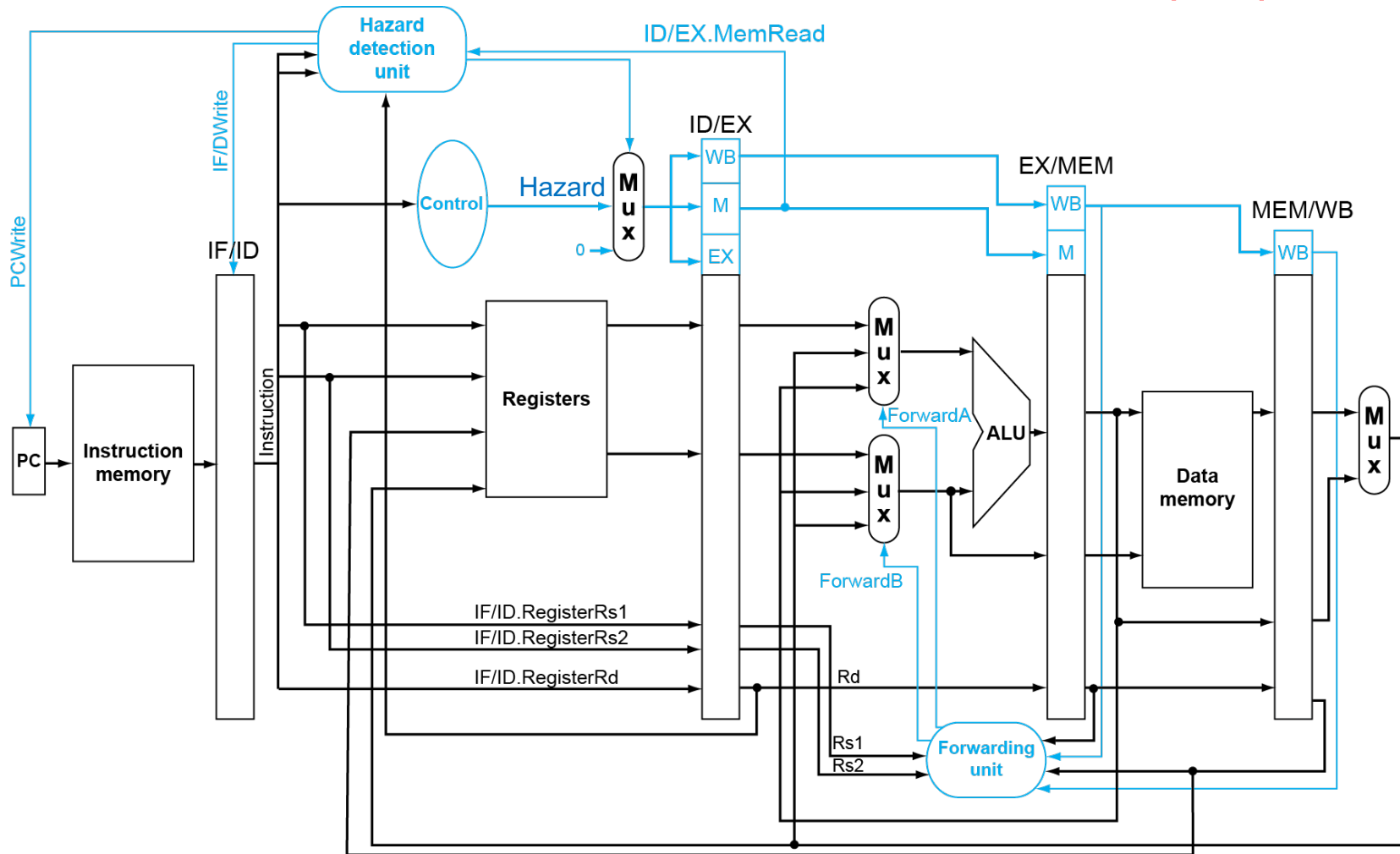
add x9,x4,x2

or x8,x2,x6

and x4,x2,x5

nop (and)

lw x2, 20(x1)



CC5

ID/EX.Rs1	ID/EX.Rs2	ID/EX.Rd	EX/MEM.Rd	MEM/WB.Rd
2	5	4	4	2
EX/MEM.RegWrite	MEM/WB.RegWrite	ForwardA	ForwardB	
0	1	01	00	

add x9,x4,x2

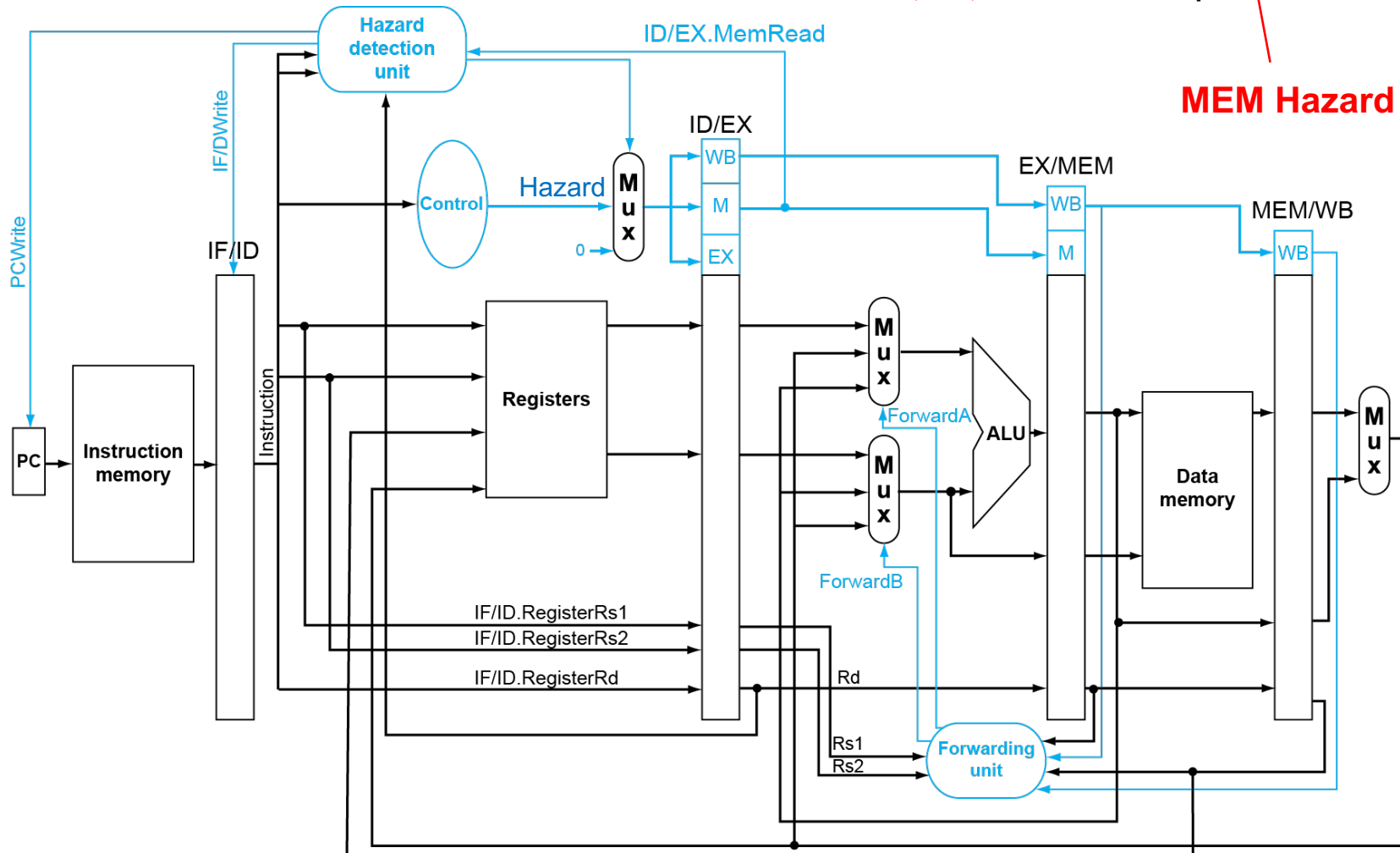
or x8,x2,x6

and x4,x2,x5

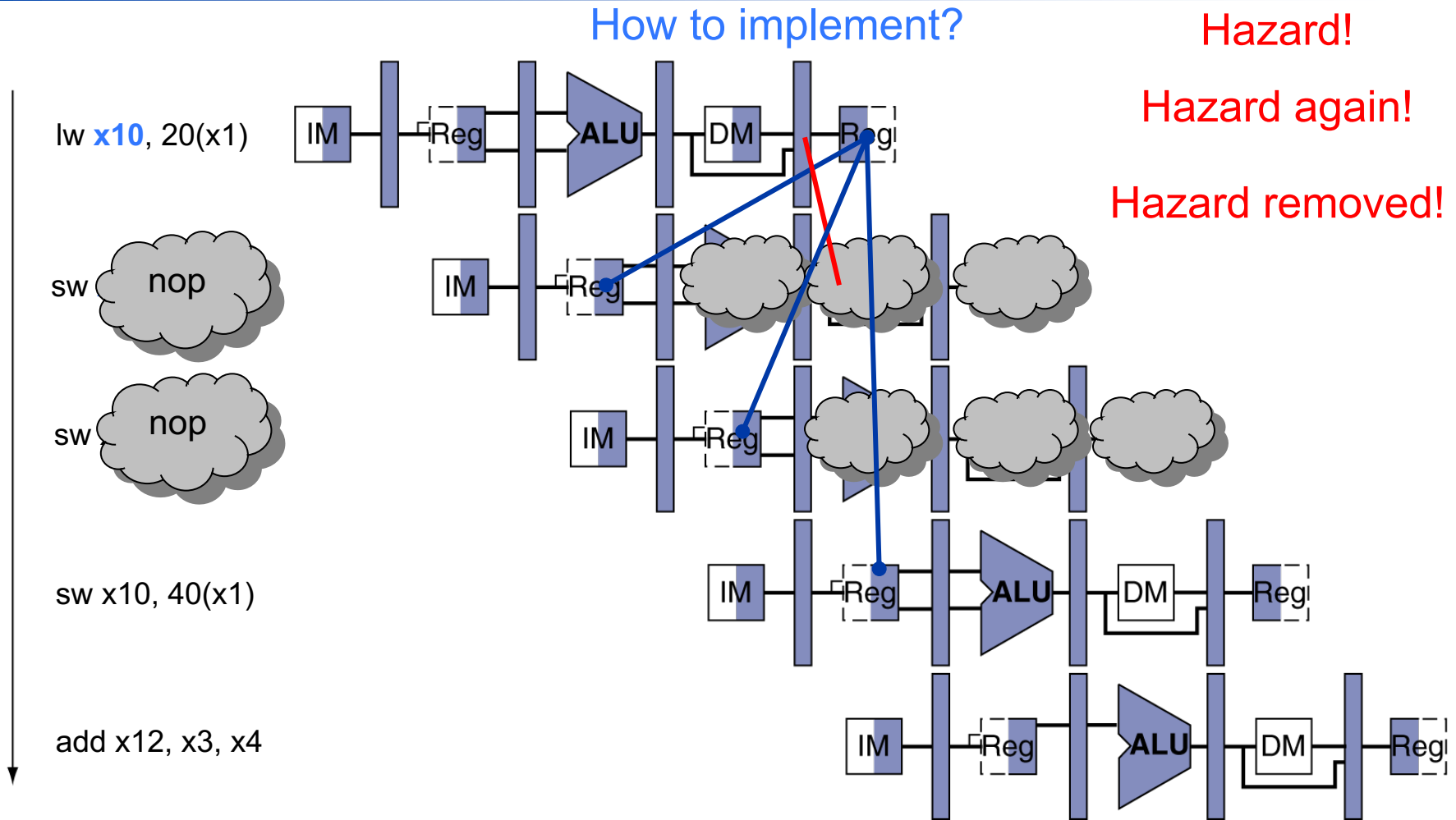
nop

lw x2, 20(x1)

MEM Hazard

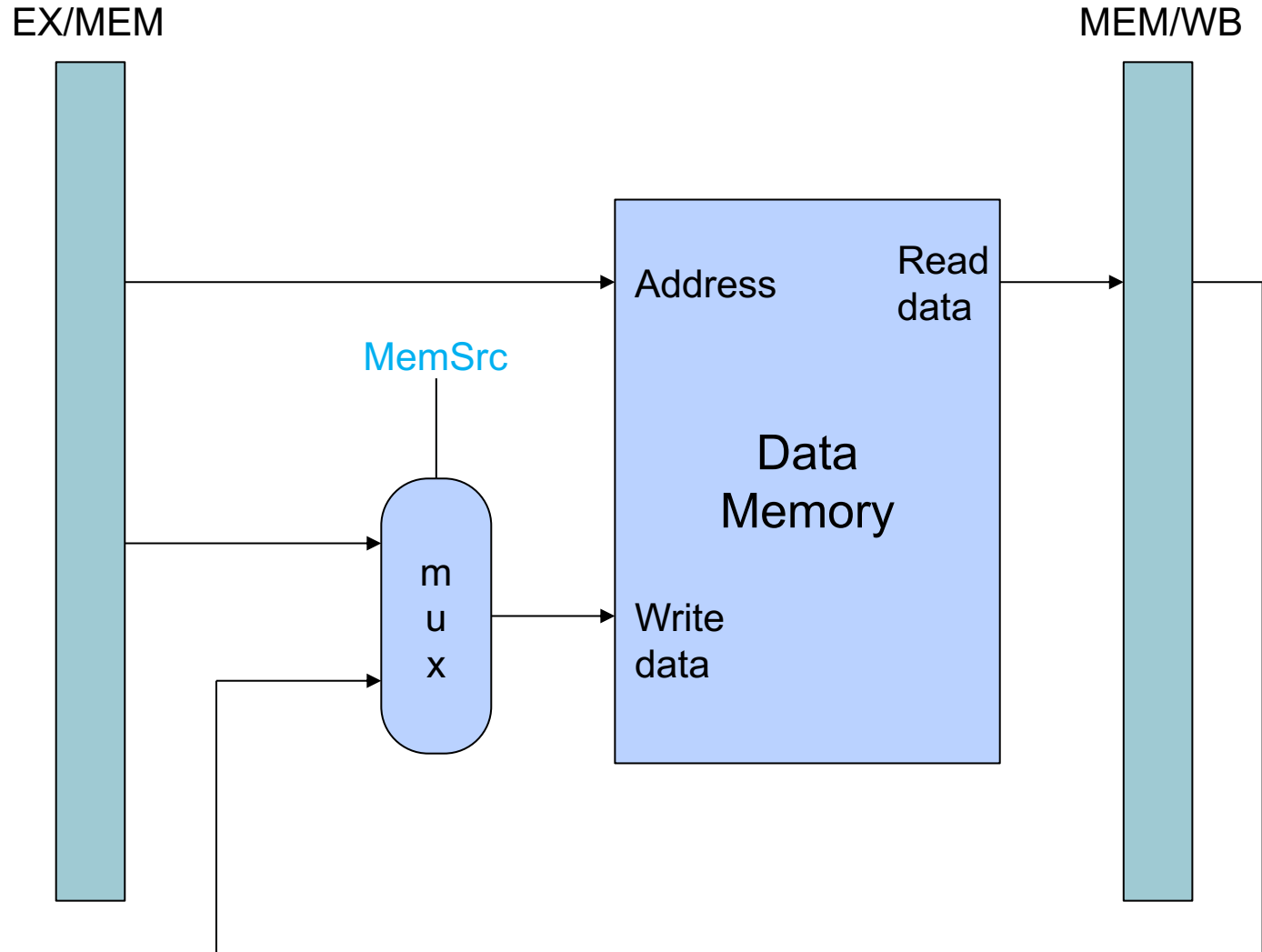


Example: New Kind of Hazard



This delays the execution too much, can it be fixed with forwarding?

Question: how to implement

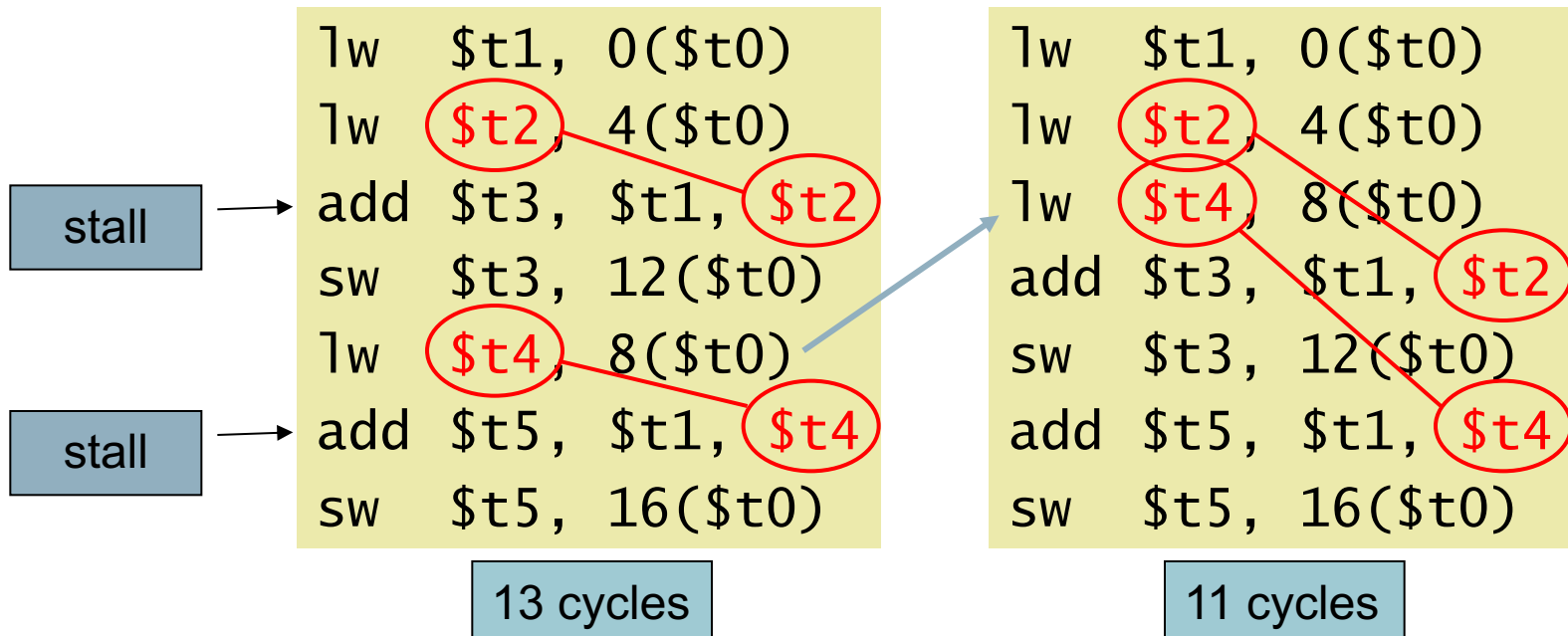


Question: how to decide MemSrc?

- MemSrc = 1 when
(MEM/WB.Rt == EX/MEM.Rt) and
MEM/WB.MemRead (already used) and
EX/MEM.MemWrite

Code Scheduling to Avoid Stalls

- Reorder code to avoid use of load result in the next instruction
- C code for $A = B + E$; $C = B + F$;



Structure Hazards

- Conflict for use of a resource
- If common memory for program and data
 - Load/store requires data access
 - Instruction fetch would have to *stall* for that cycle
 - Would cause a pipeline “bubble”
- Hence, pipelined datapaths require separate instruction/data memories
 - separate instruction/data caches (Harvard)
 - Common low-level memory (Von Neumann)

Stalls and Performance

The BIG Picture

- Stalls reduce performance
 - But are required to get correct results
- Hardware can be improved to take care of the hazards automatically
 - forwarding
- Compiler can arrange code to avoid hazards and stalls
 - Requires knowledge of the pipeline structure