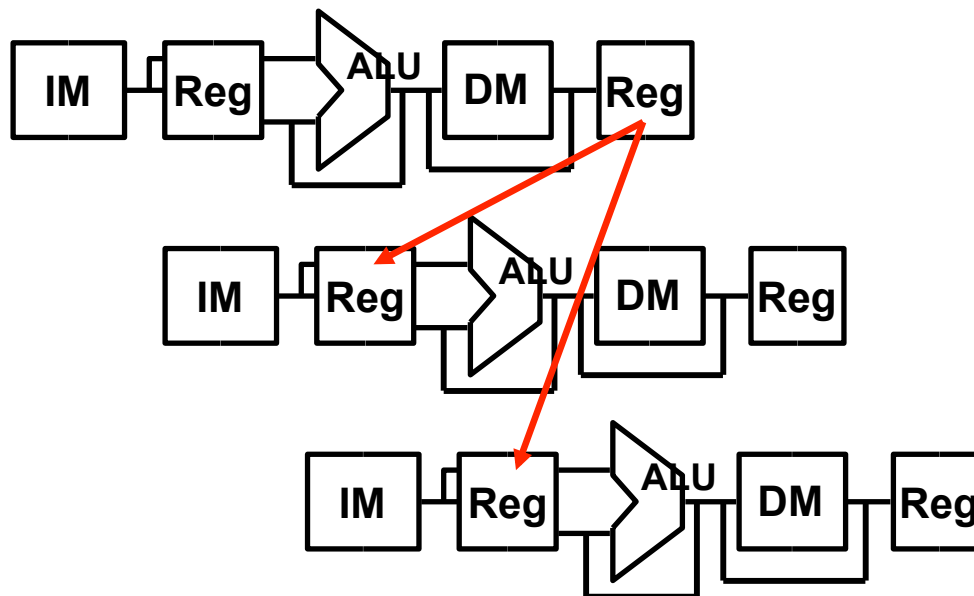




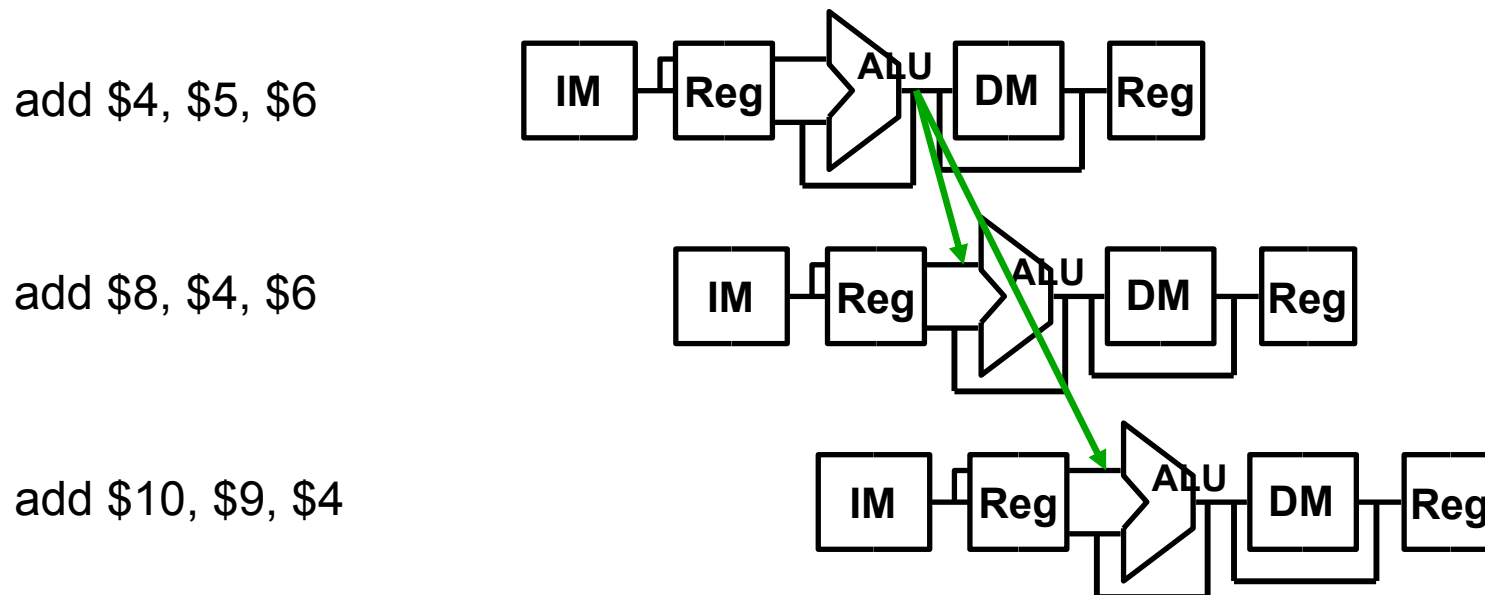
Data Hazard Review

- Caused when data is needed before it is ready
 - Read before write: Result of previous instruction needed by later instruction
 - Load use: Value in data memory needed by later instruction



Read After Write Hazard Solution

- Forwarding data improves CPI



EX/MEM Forwarding

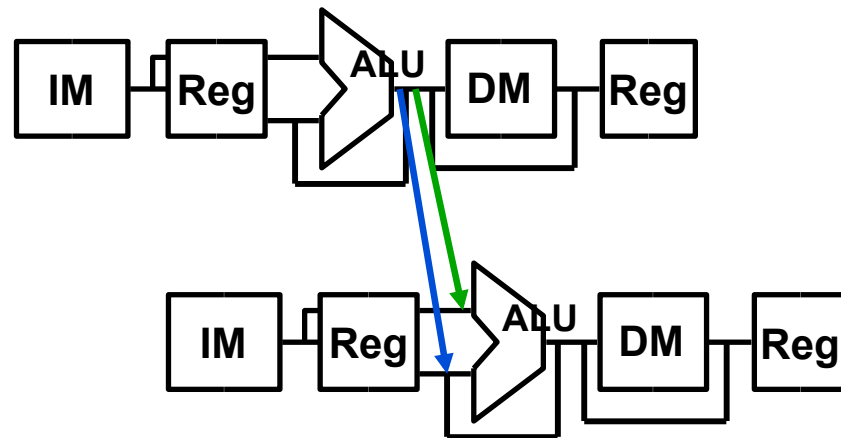
- Register value needed by next instruction
 - Calculated by ALU this clock cycle
 - Needed as input to ALU on next clock cycle

add \$4, \$5, \$6

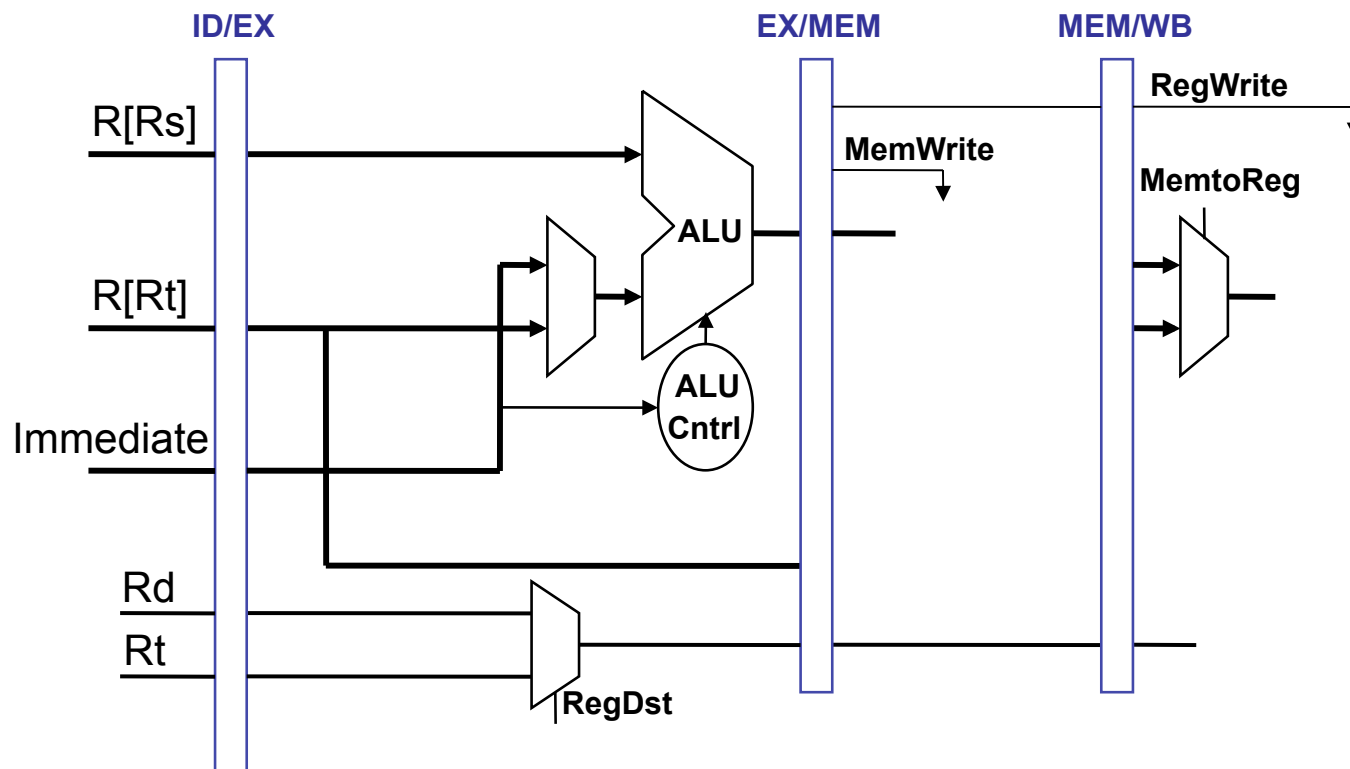
add \$8, \$4, \$7

or

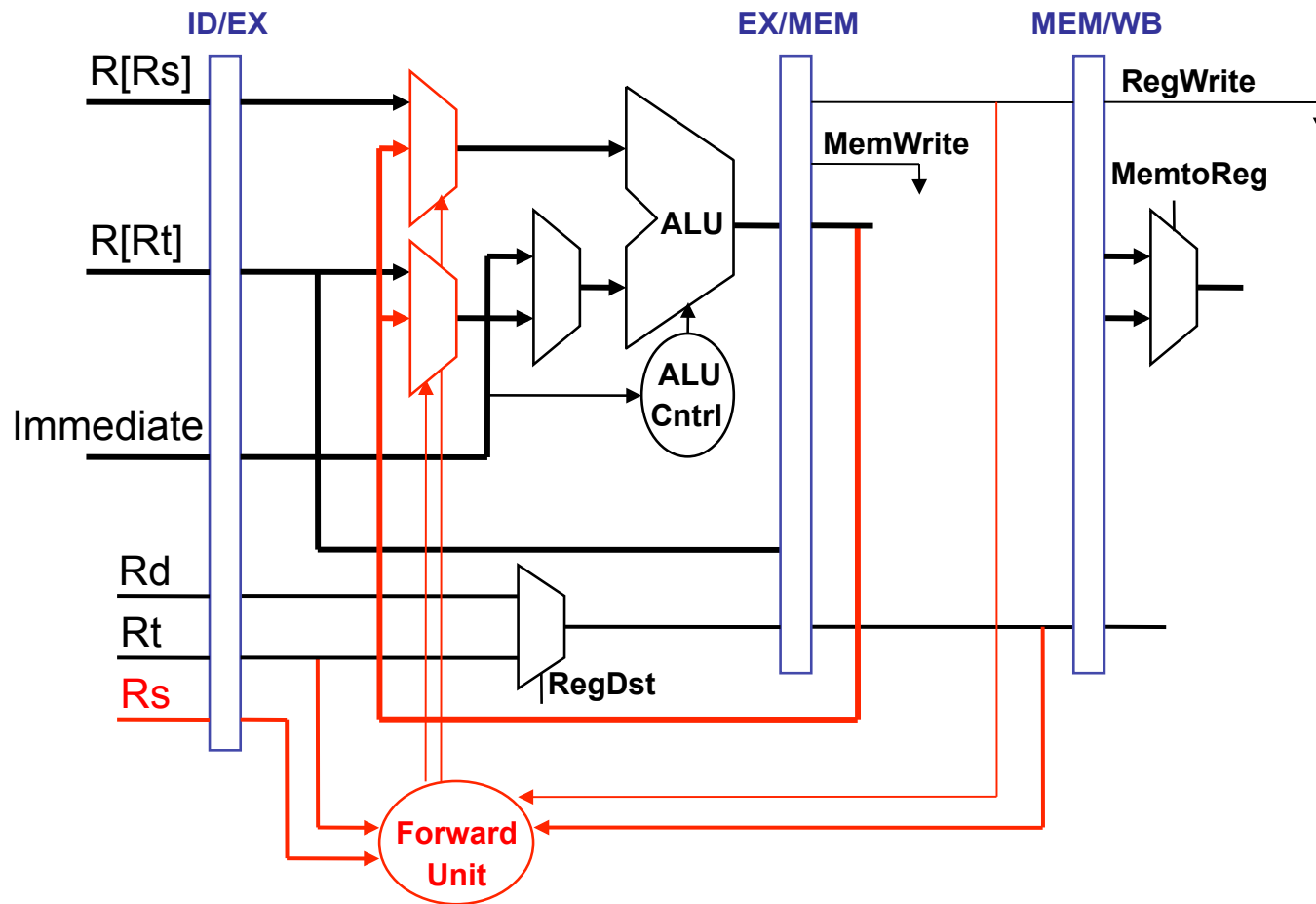
add \$8, \$7, \$4



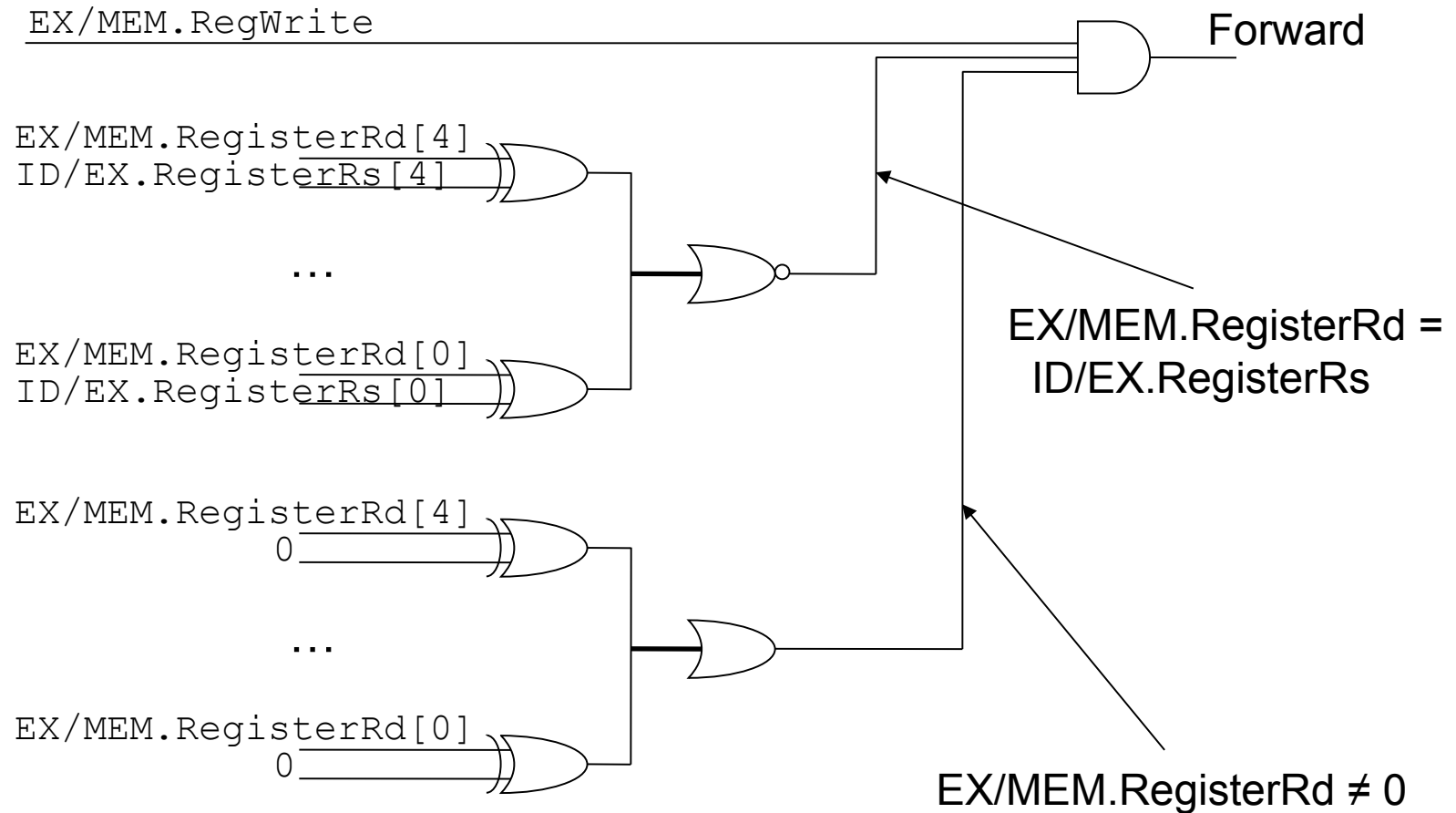
EX/MEM Forwarding



EX/MEM Forwarding

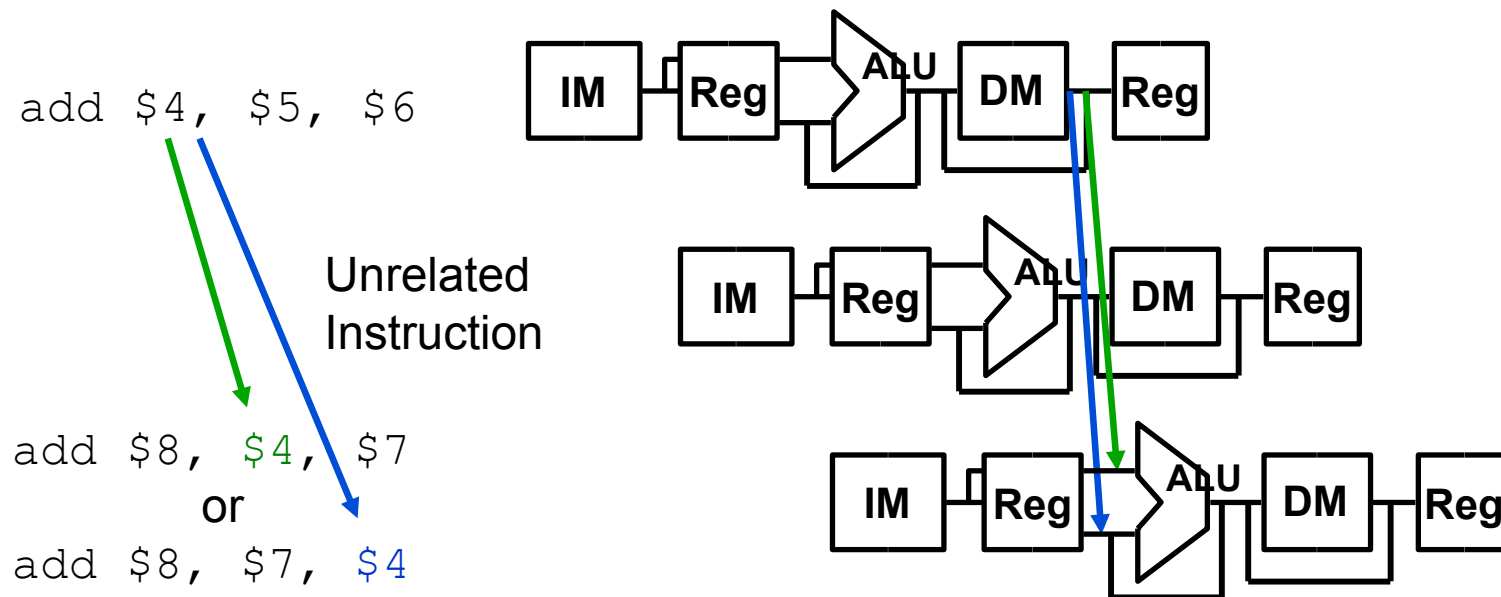


Forwarding Unit Details

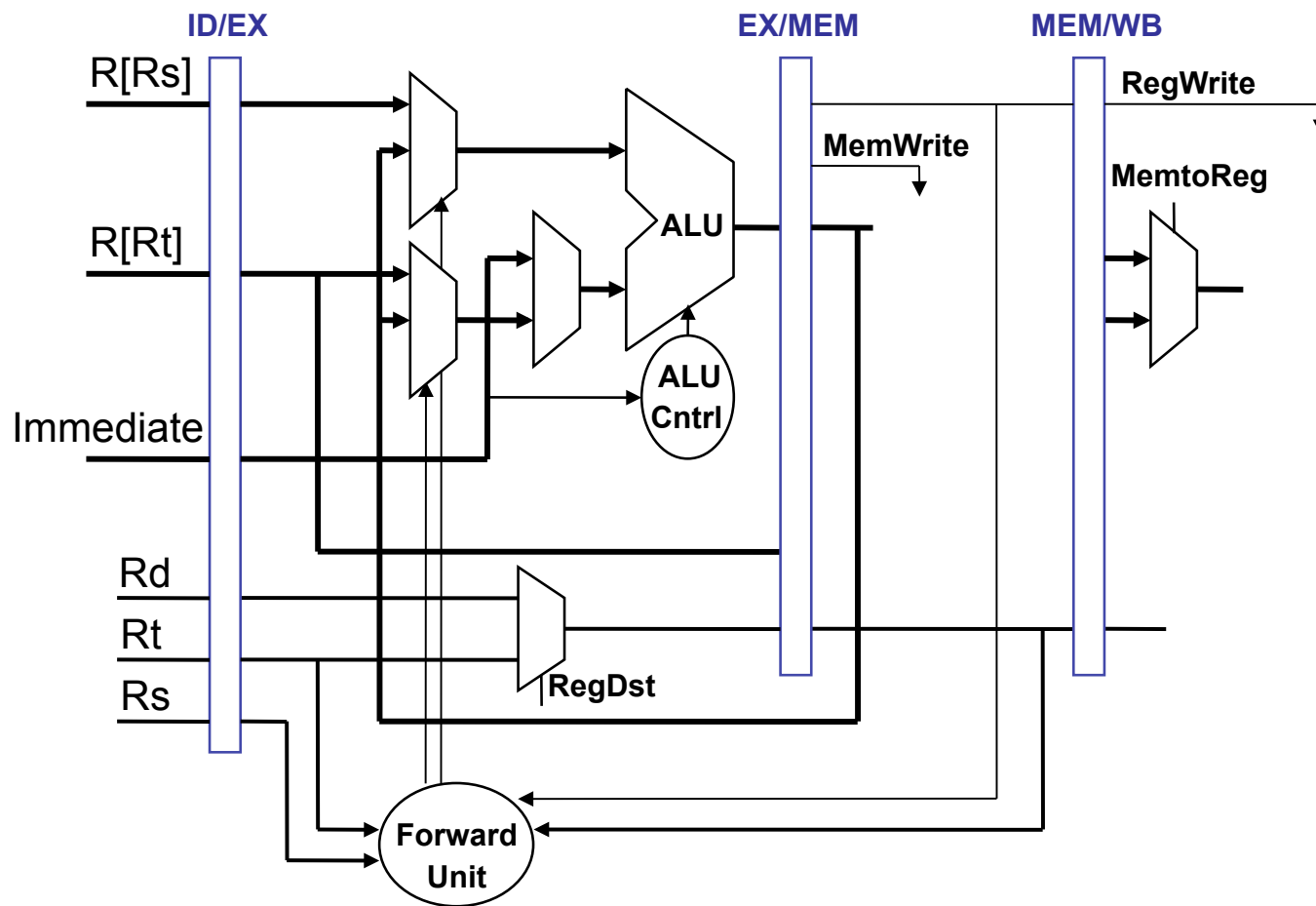


MEM/WB Forwarding

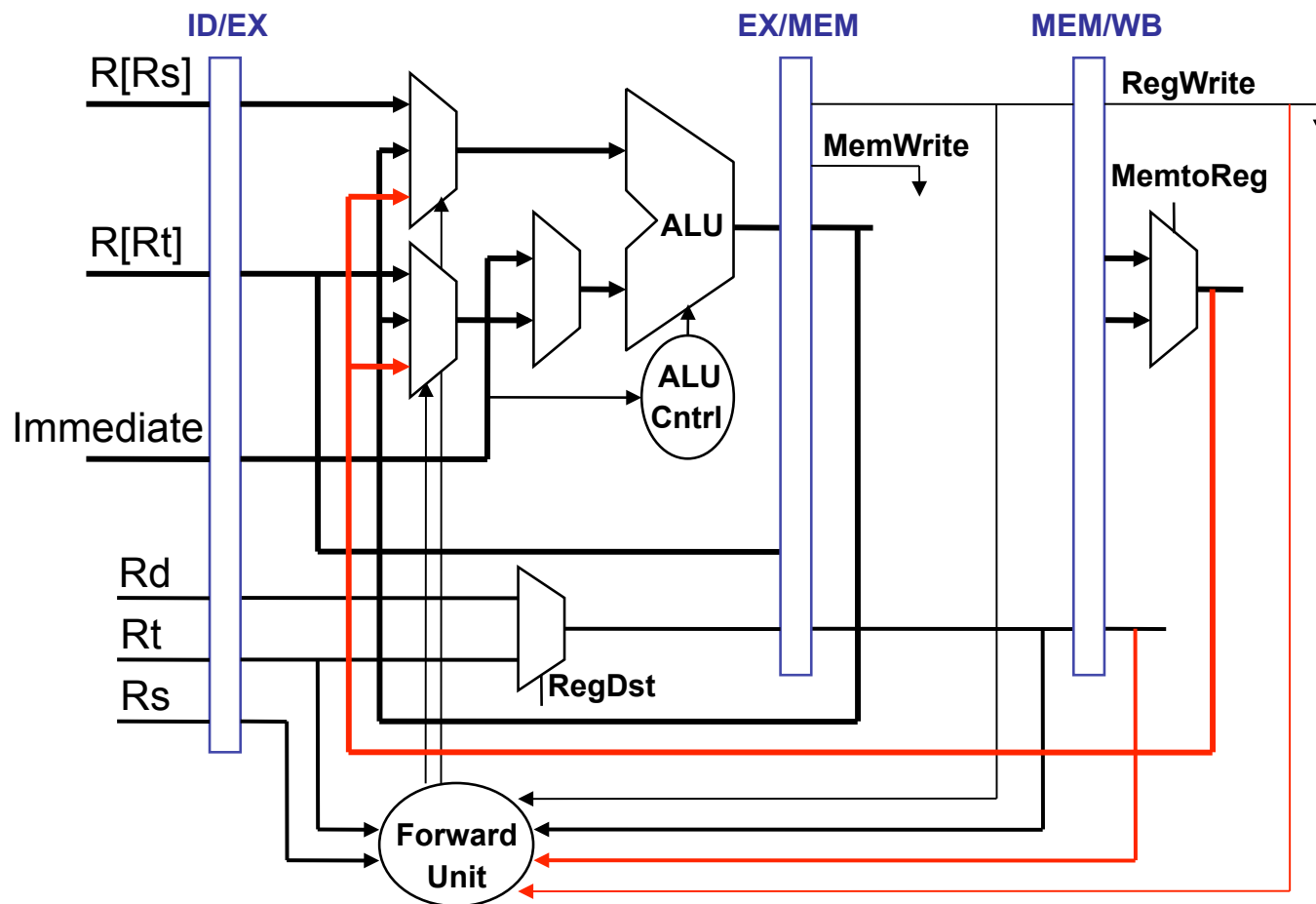
- Register value needed two instructions later
 - Calculated by ALU this clock cycle
 - Needed as input to ALU in two clock cycles



MEM/WB Forwarding

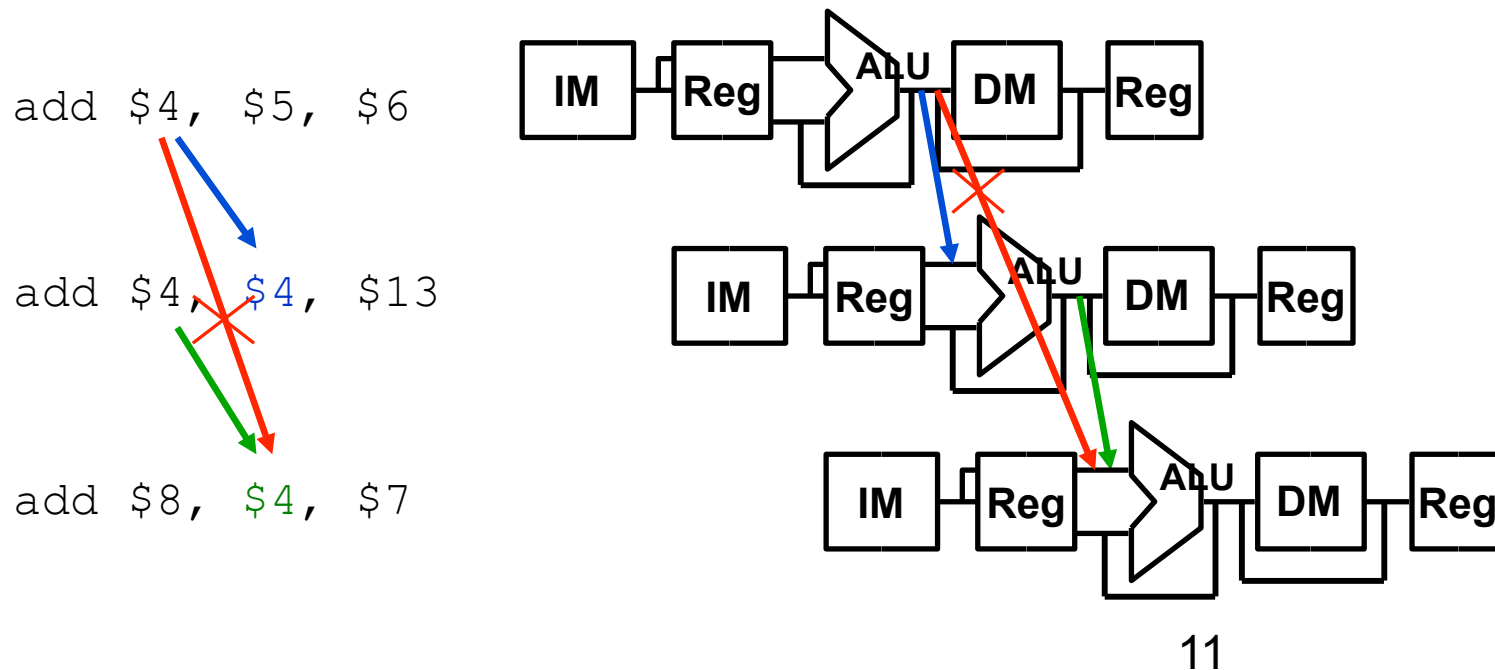


MEM/WB Forwarding

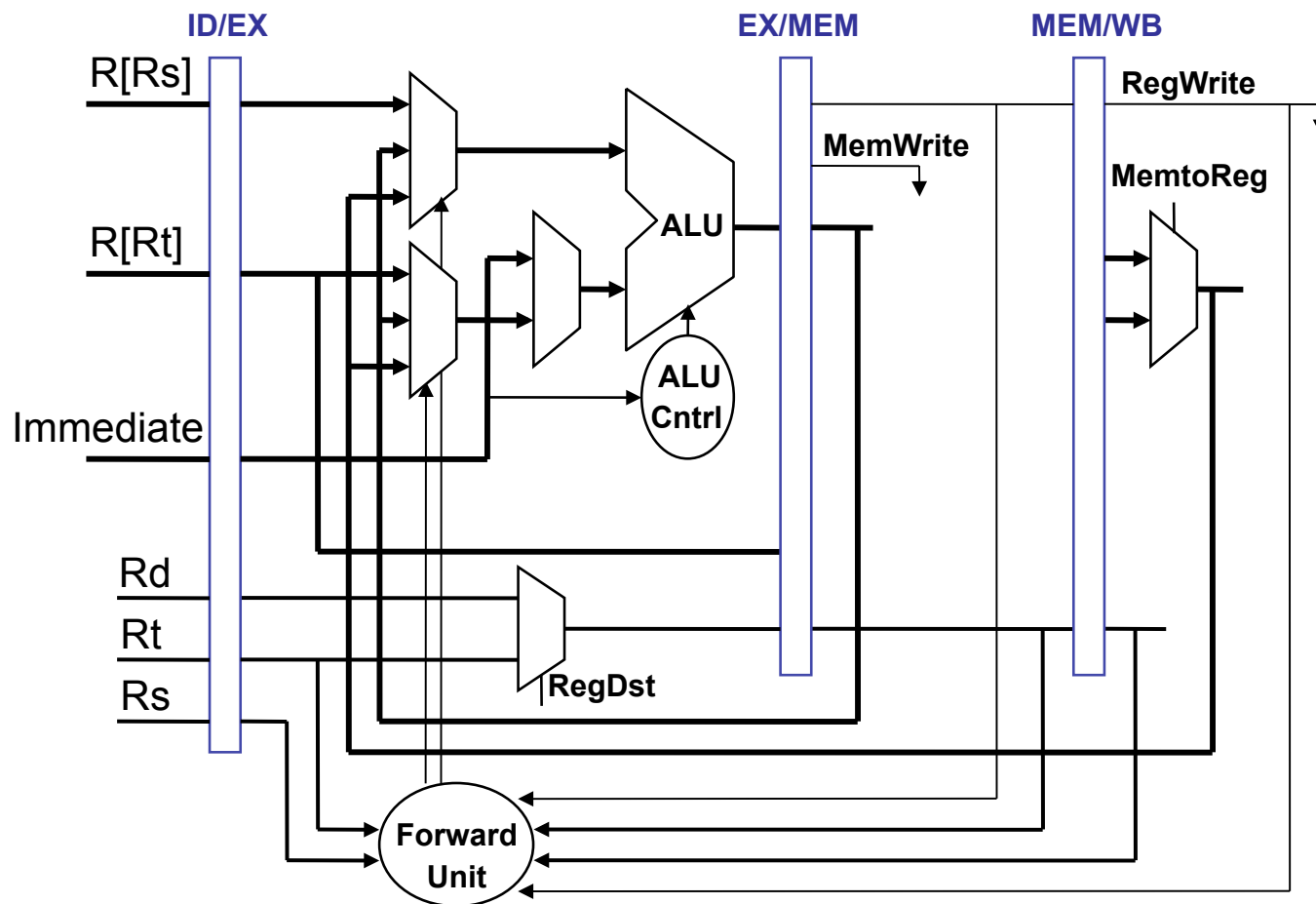


Forwarding Complication

- Forward unit must forward most recent value
 - It may appear necessary to do **MEM/WB** and **EX/MEM** forwarding simultaneously
 - Only do **EX/MEM** forwarding this cycle
 - Do **EX/MEM** forwarding again next cycle



Complete ALU Input Forwarding

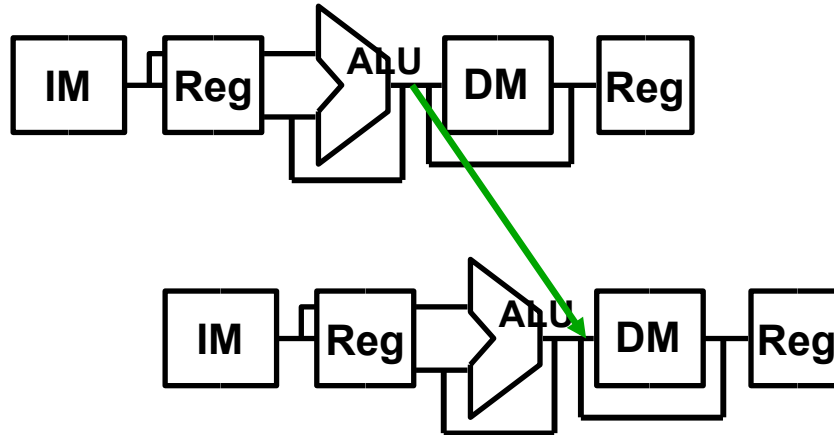


Other Forwarding Possible

- Forwarding to Data Memory

add \$4, \$5, \$6

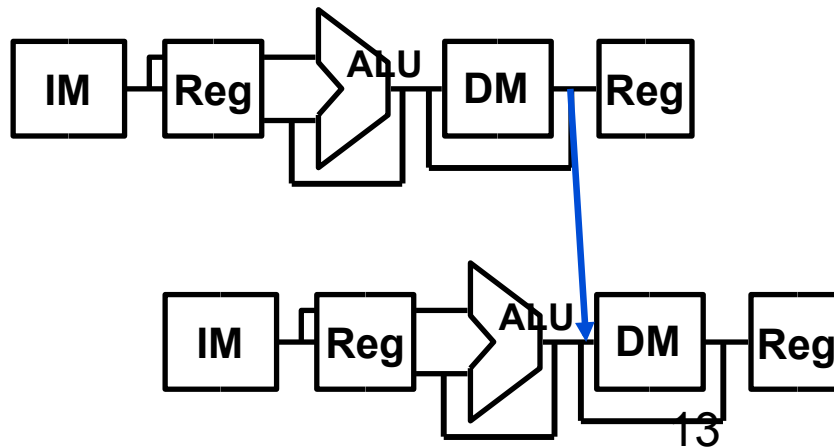
sw \$4, 40(\$7)



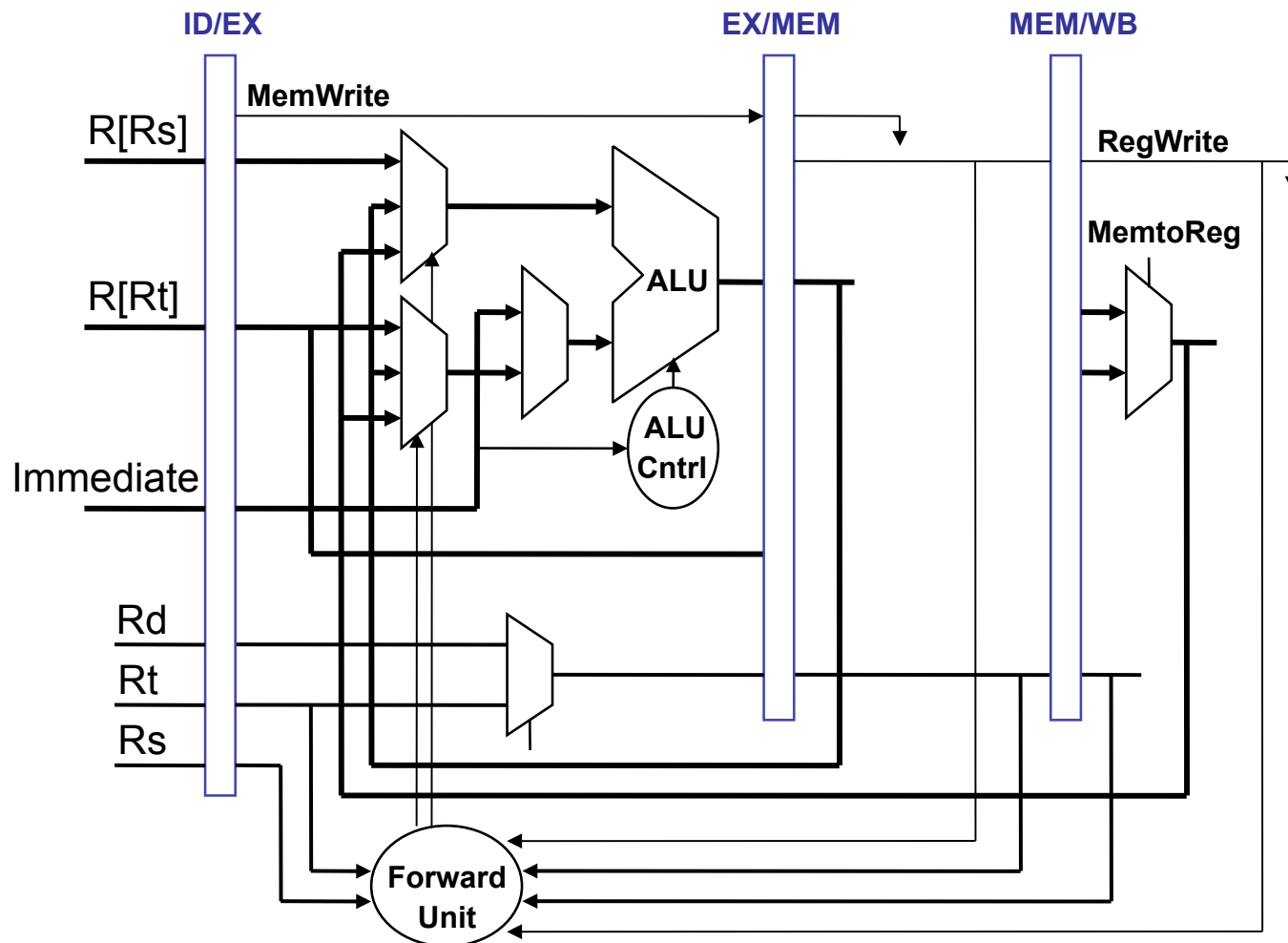
- Data memory to data memory copy

lw \$4, 16(\$7)

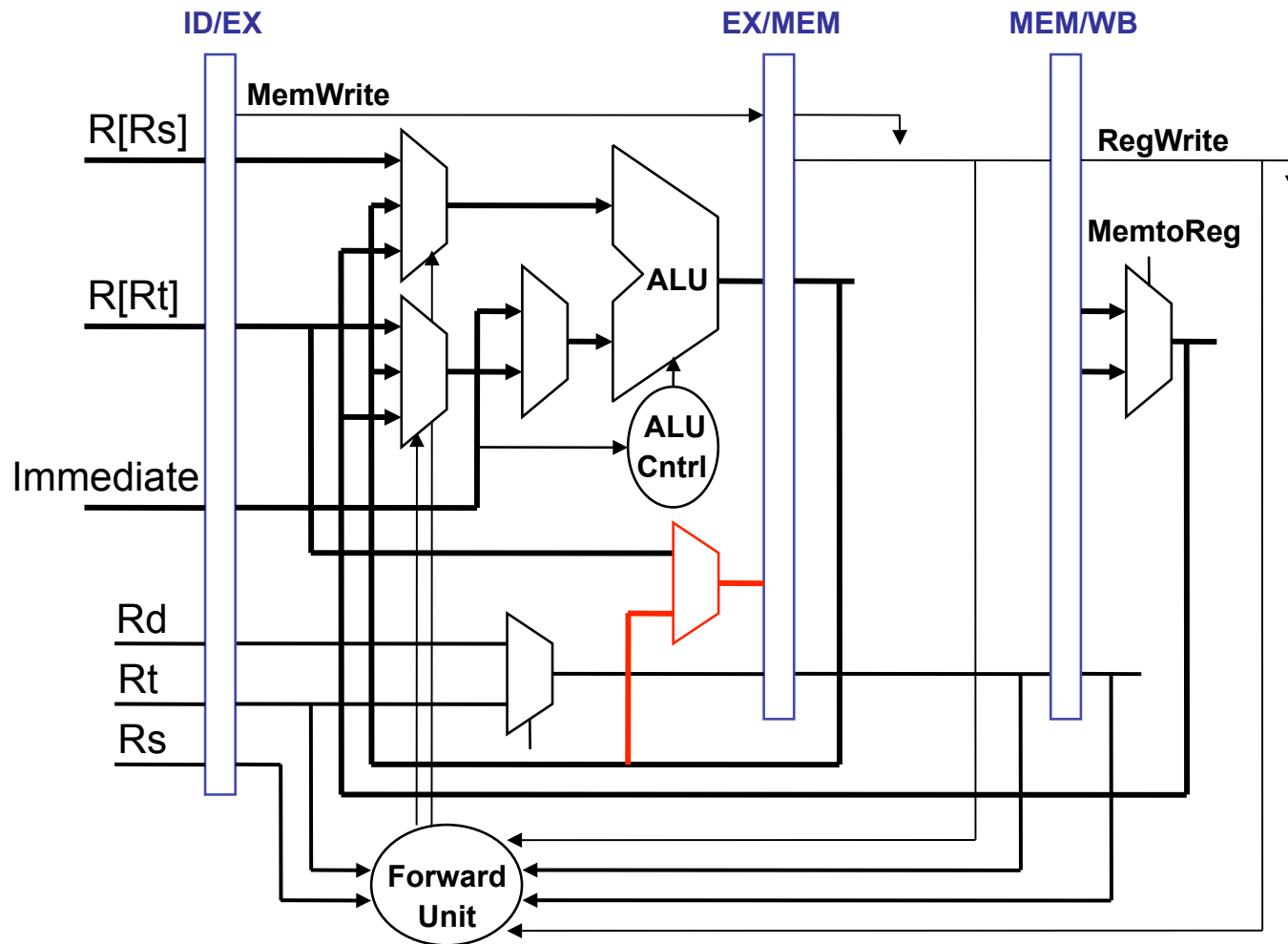
sw \$4, 40(\$7)



Forwarding to Memory



Forwarding to Memory



Load Use Hazards Require Stalls

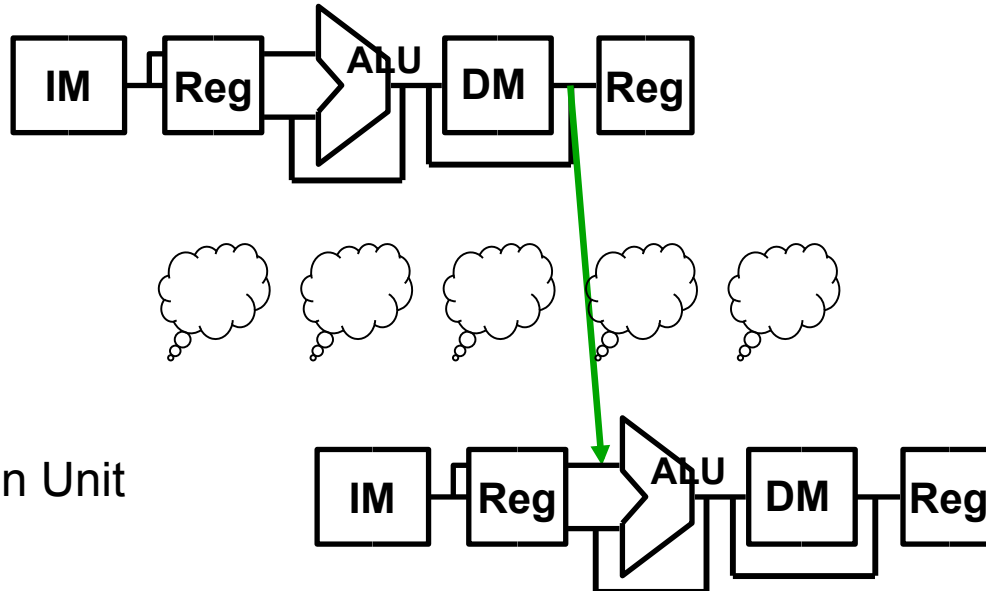
- No forwarding can help

lw \$4, 16(\$5)

nop

add \$8, \$4, \$7

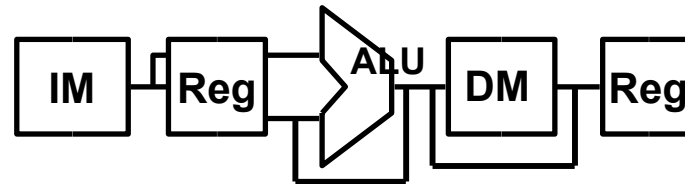
- Requires a Hazard Detection Unit
 - Detects hazards
 - Inserts pipeline bubble



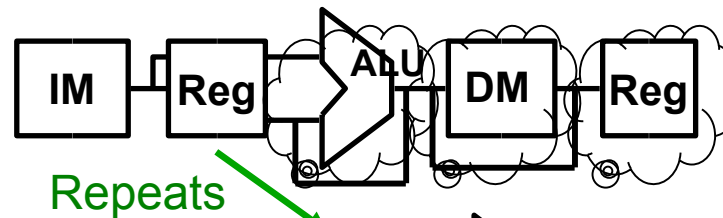
Stalling The Pipeline

- Stalls occur by inserting pipeline bubble
 - Hold some state registers (stage repeats)
 - Allow other stages to continue processing

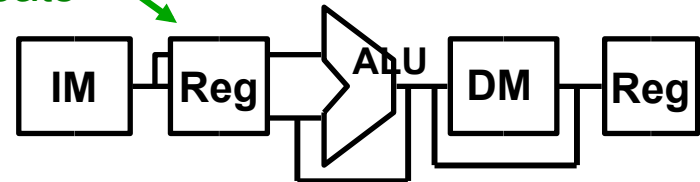
lw \$4, 16(\$5)



add becomes nop



add \$8, \$4, \$7

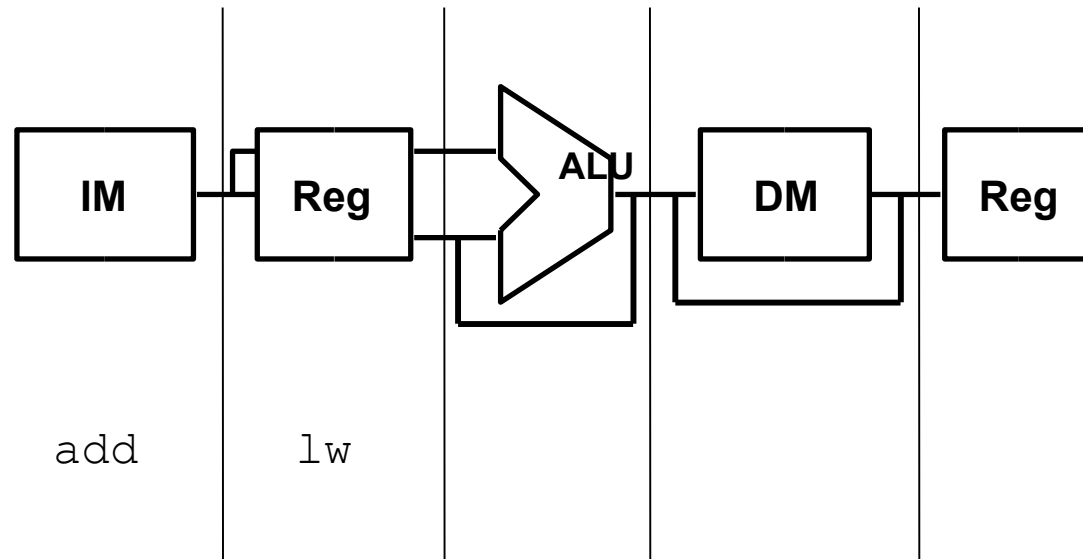


Stalling The Pipeline

- Load Use Hazard code

```
lw $4, 16($5)
```

```
add $8, $4, $7
```

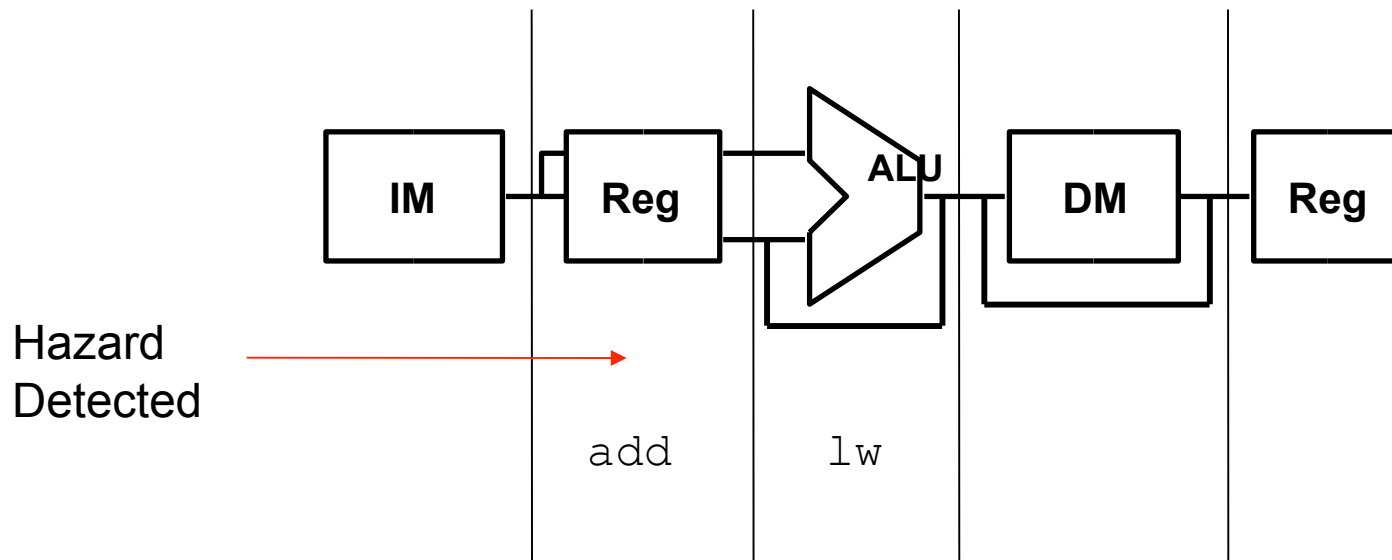


Stalling The Pipeline

- Load Use Hazard code

```
lw $4, 16($5)
```

```
add $8, $4, $7
```

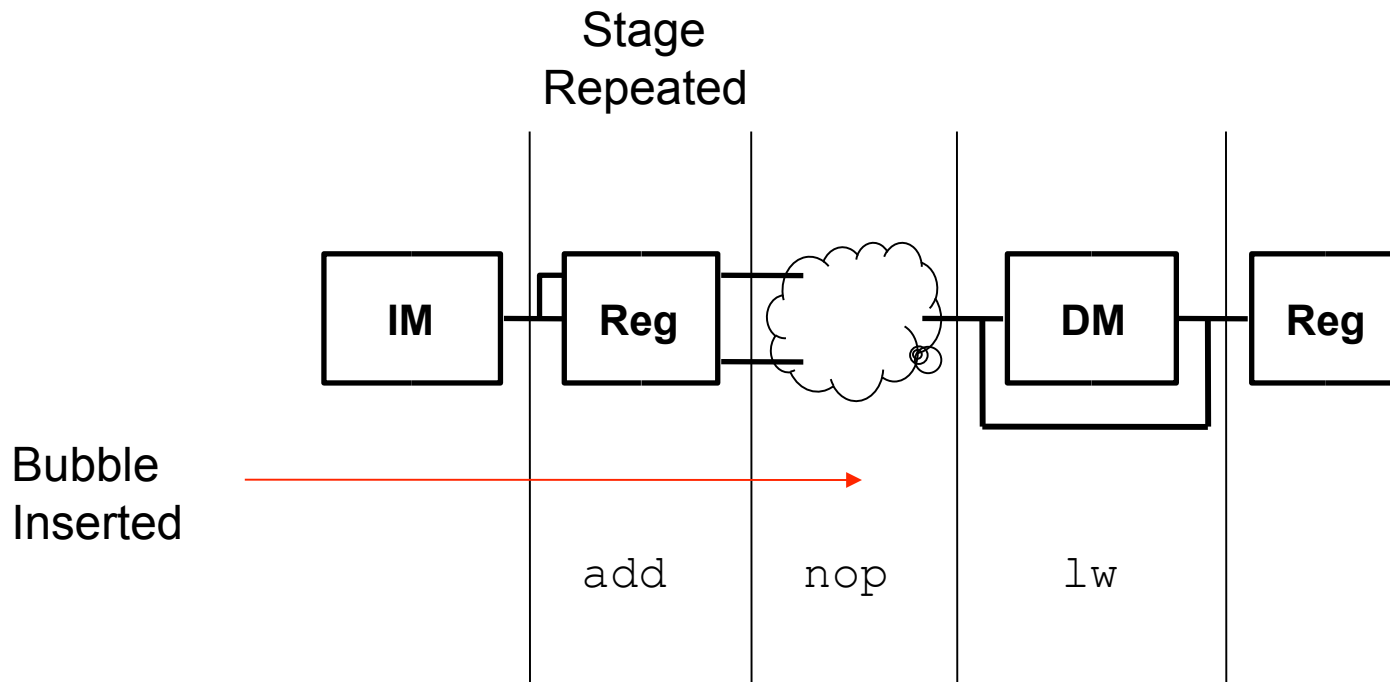


Stalling The Pipeline

- Load Use Hazard code

```
lw $4, 16($5)
```

```
add $8, $4, $7
```

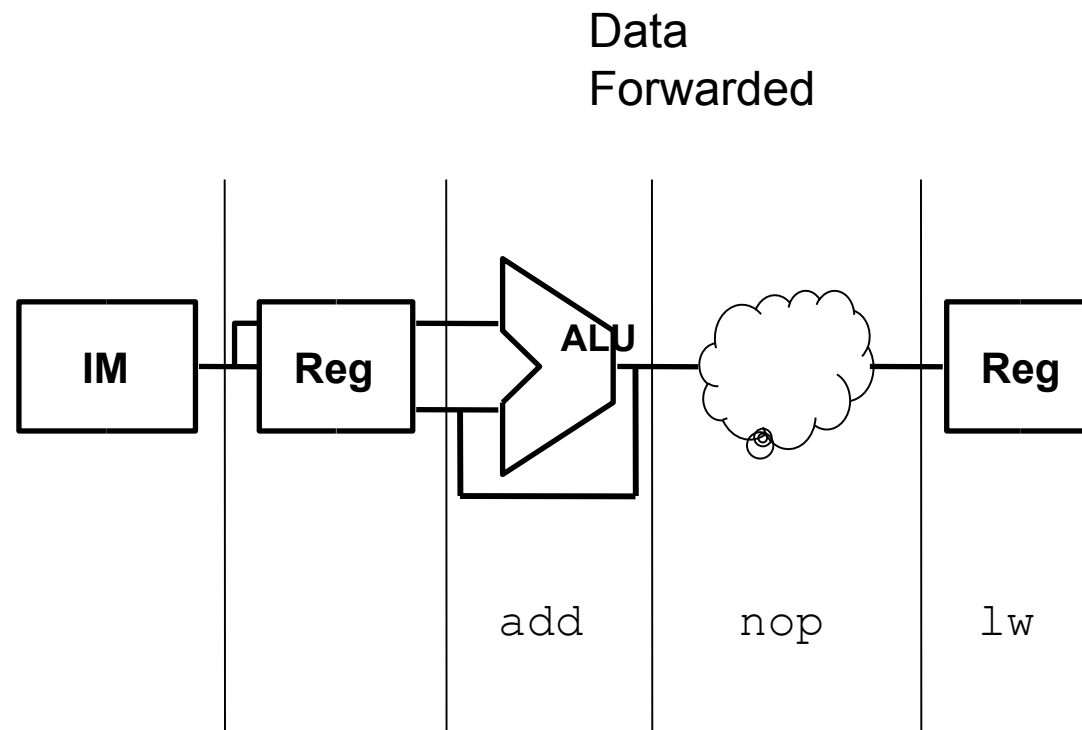


Stalling The Pipeline

- Load Use Hazard code

```
lw $4, 16($5)
```

```
add $8, $4, $7
```

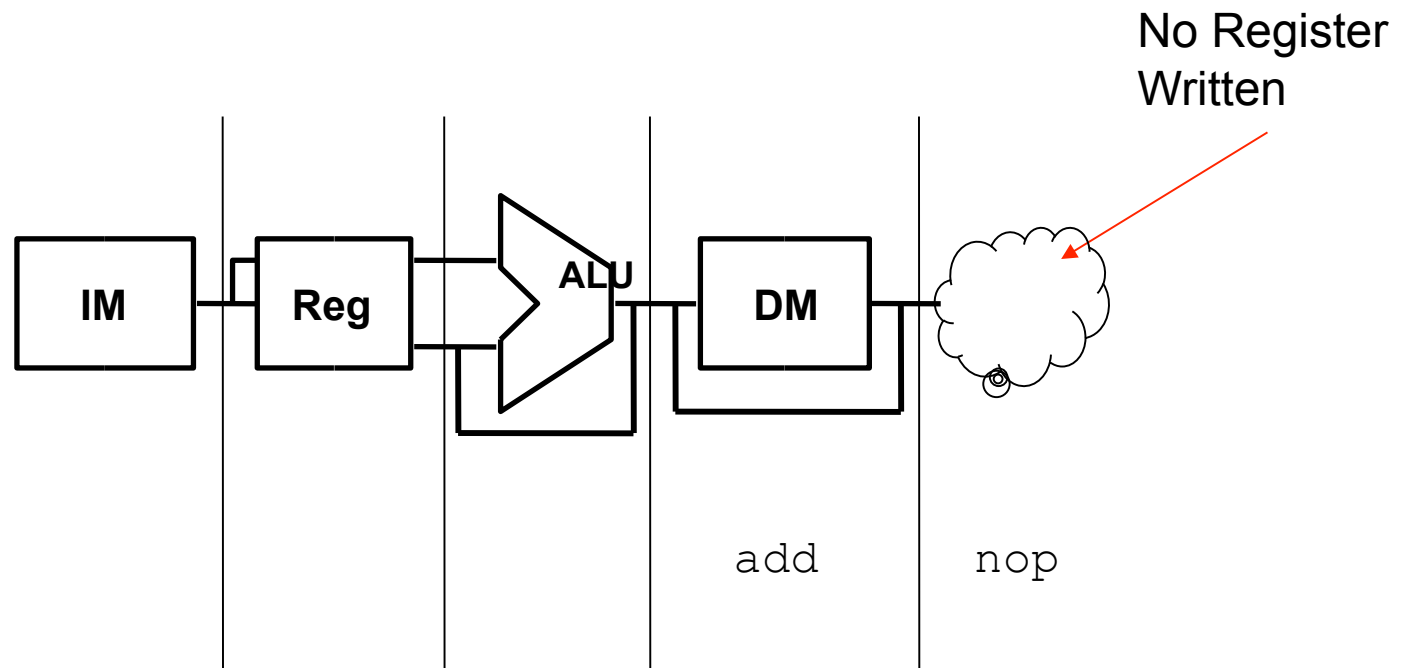


Stalling The Pipeline

- Load Use Hazard code

```
lw $4, 16($5)
```

```
add $8, $4, $7
```





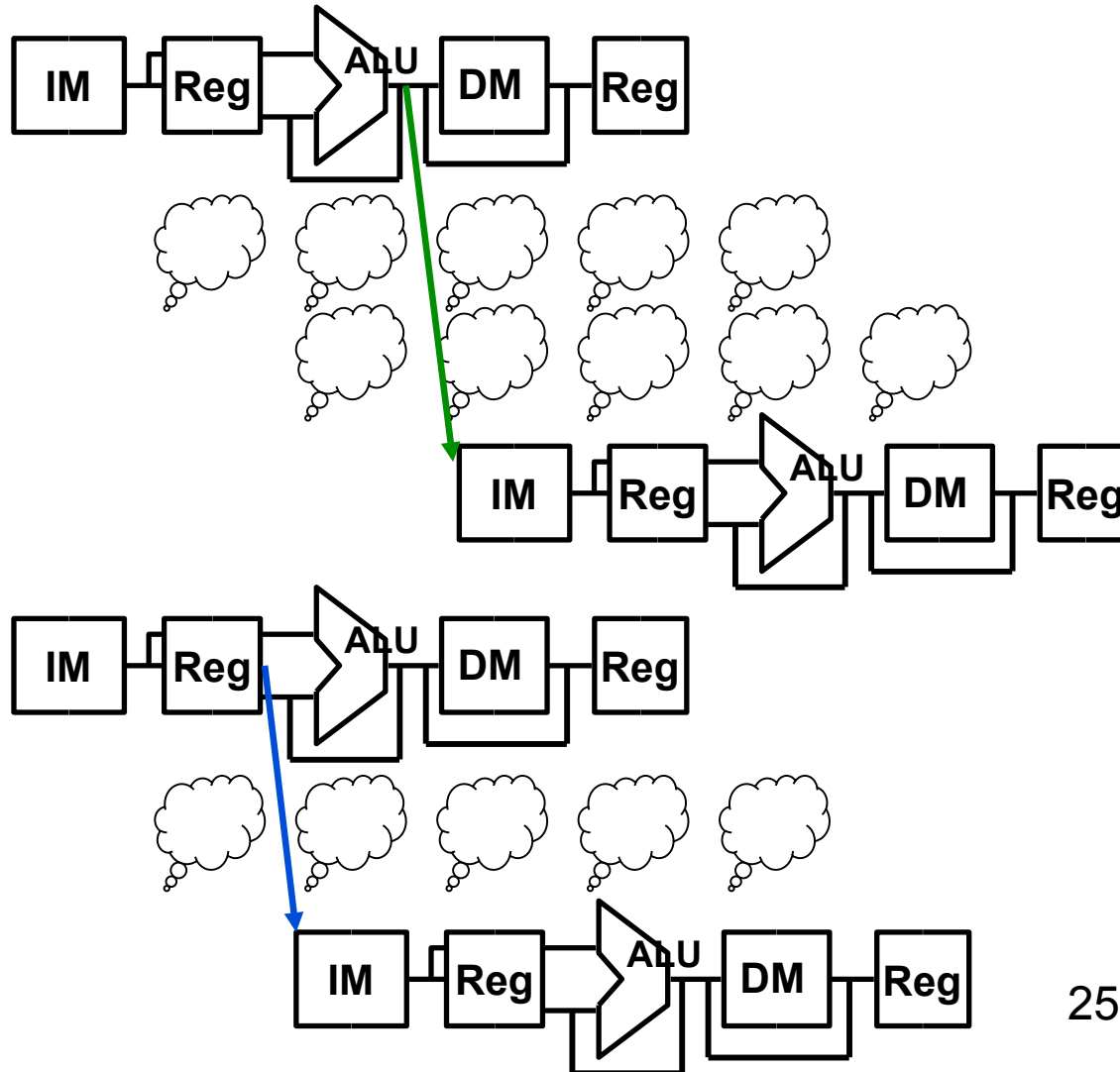
Hazard Detection Details

•Stall pipeline when all of the following occur

- `ID/EX.MemRead`
- `ID/EX.RegisterRt` $\neq$ 0
- `ID/EX.RegisterRt` = `IF/ID.RegisterRs`
 or
`ID/EX.RegisterRt` = `IF/ID.RegisterRt`

Stalling Control Hazards

- Stalling always possible, but affects CPI



Branch Delay

- A taken branch must flush instructions

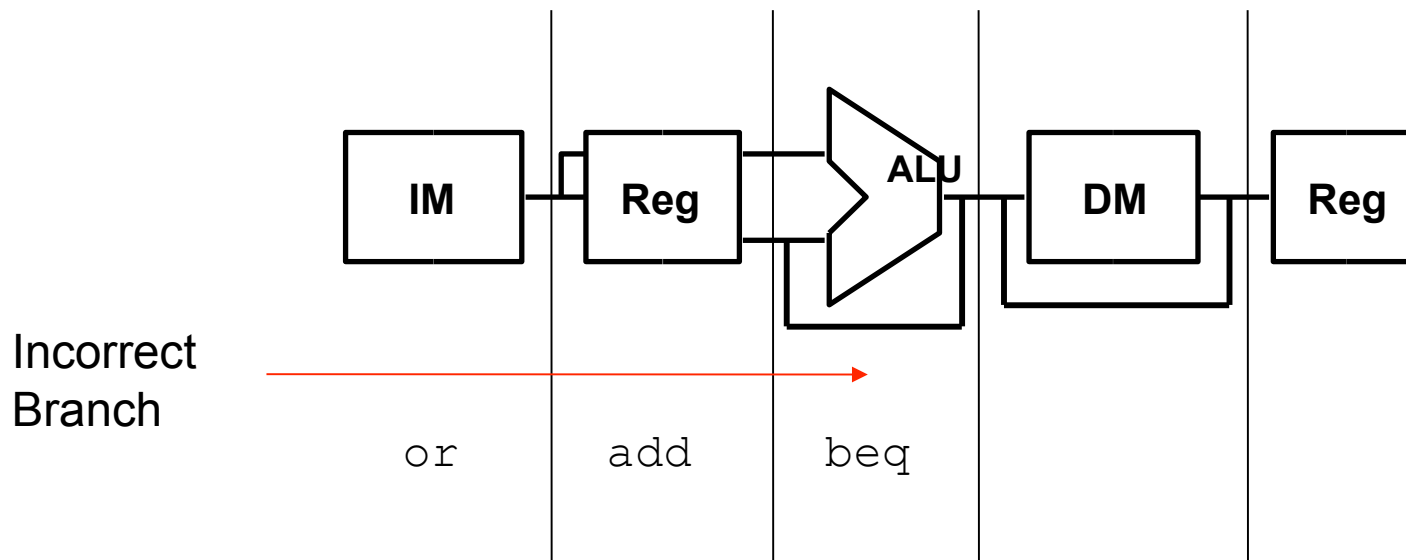
```
beq $4, $5, label
```

```
add $7, $8, $9
```

```
or $10, $11, $12
```

```
...
```

```
label: sub $7, $8, $9
```



Branch Delay

- A taken branch must flush instructions

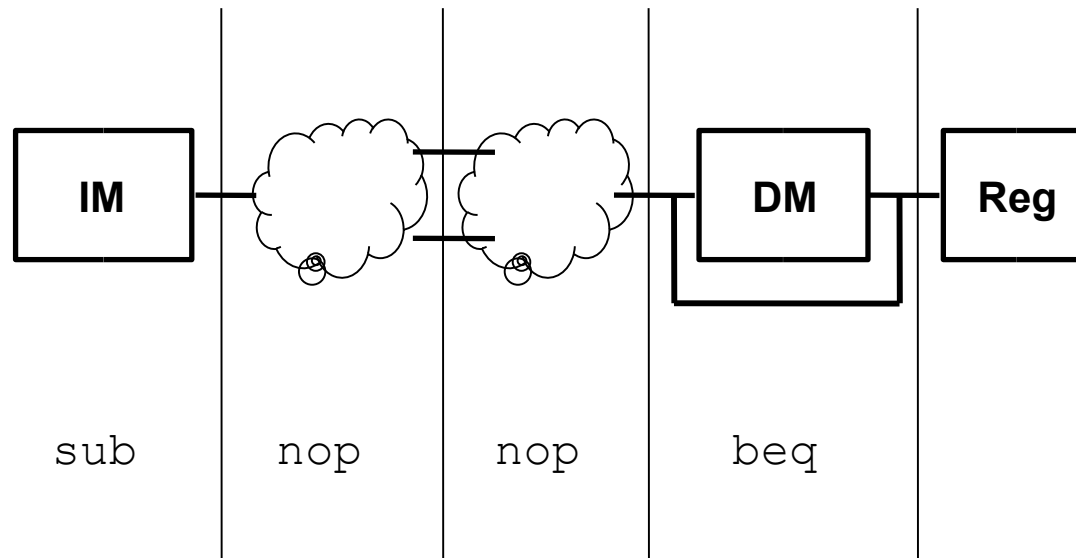
```
beq $4, $5, label
```

```
add $7, $8, $9
```

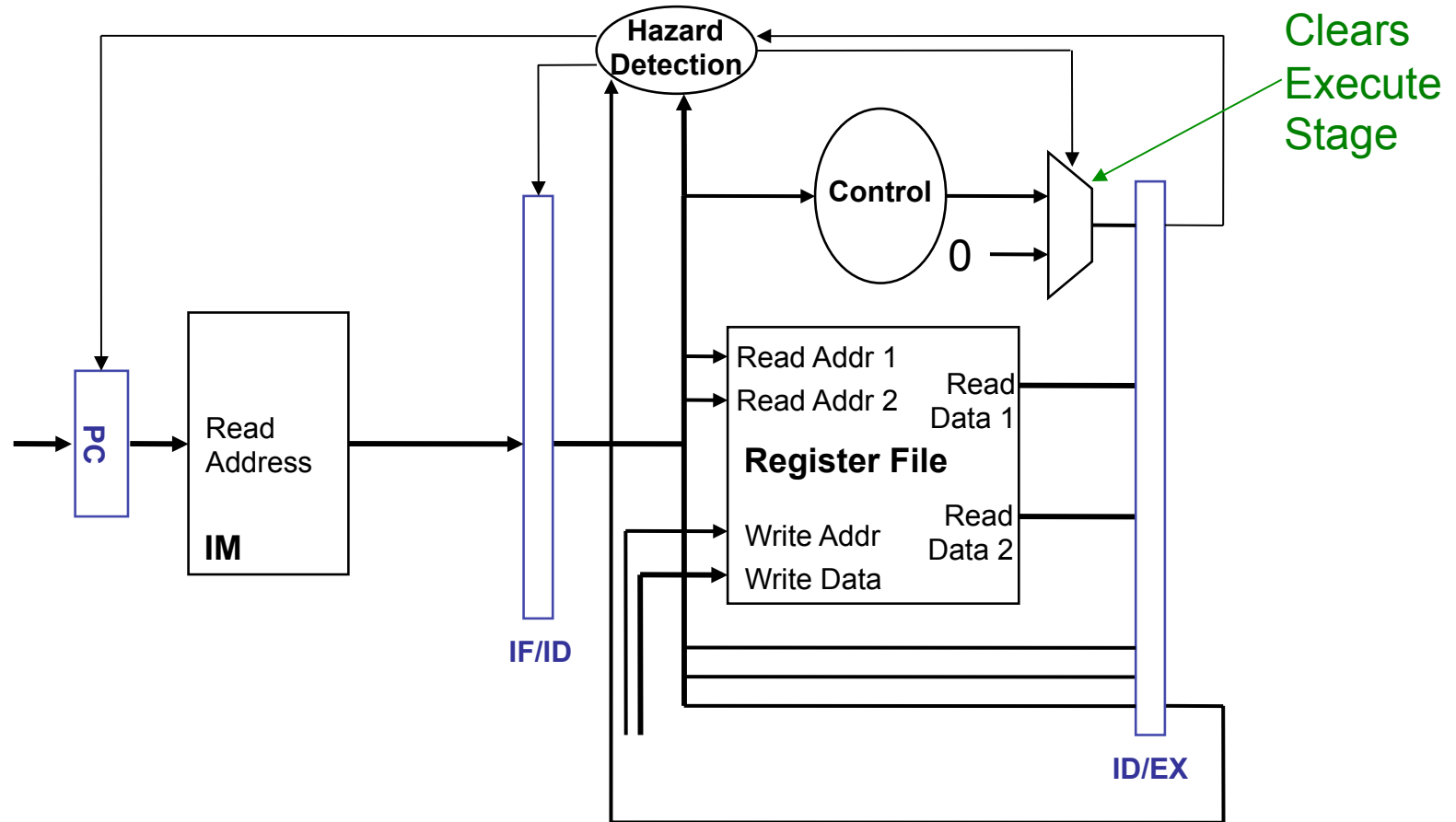
```
or $10, $11, $12
```

```
...
```

```
label: sub $7, $8, $9
```



Adding nop To Decode Stage



Adding nop To Decode Stage

