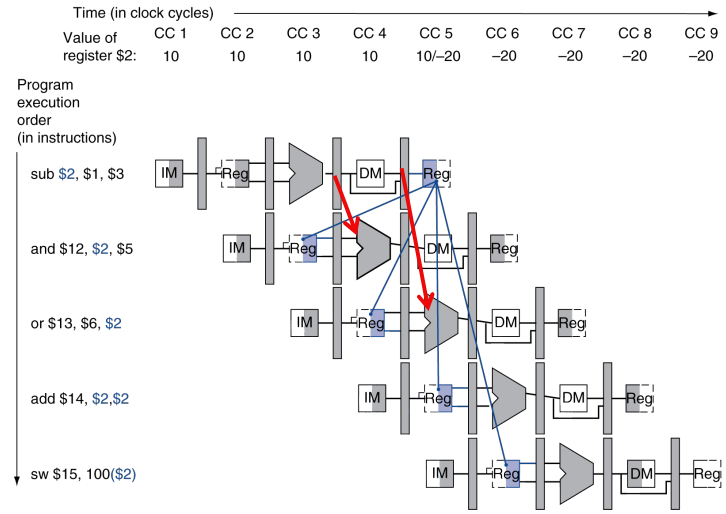
Data Hazards in ALU Instructions

- Consider this sequence:

```
sub $2, $1,$3
and $12,$2,$5
or  $13,$6,$2
add $14,$2,$2
sw  $15,100($2)
```

- We can resolve hazards with forwarding
  - How do we detect when to forward?

Dependencies & Forwarding



Detecting the Need to Forward

- Pass register numbers along pipeline
  - e.g., ID/EX.RegisterRs = register number for Rs sitting in ID/EX pipeline register
- ALU operand register numbers in EX stage are given by
  - ID/EX.RegisterRs, ID/EX.RegisterRt
- Data hazards when
  - 1a. EX/MEM.RegisterRd = ID/EX.RegisterRs
  - 1b. EX/MEM.RegisterRd = ID/EX.RegisterRt

  } Fwd from EX/MEM pipeline reg

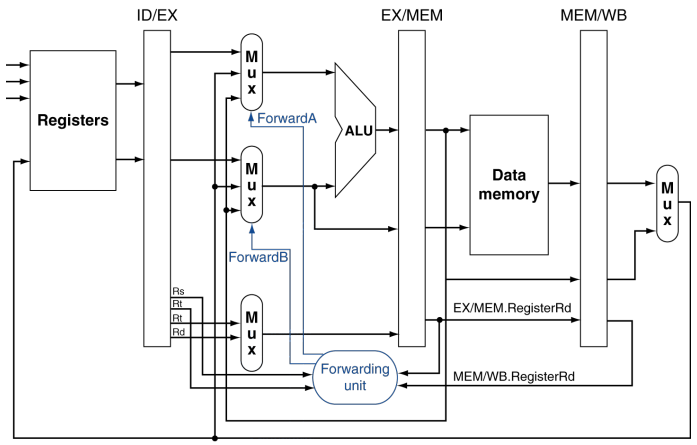
  - 2a. MEM/WB.RegisterRd = ID/EX.RegisterRs
  - 2b. MEM/WB.RegisterRd = ID/EX.RegisterRt

  } 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 $zero
  - EX/MEM.RegisterRd ≠ 0, MEM/WB.RegisterRd ≠ 0

Forwarding Paths



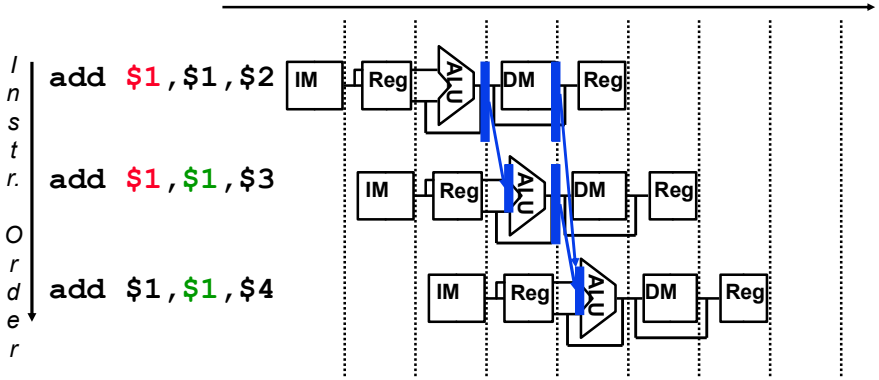
b. With forwarding

Forwarding Conditions

- EX hazard
  - if (EX/MEM.RegWrite and (EX/MEM.RegisterRd ≠ 0) and (EX/MEM.RegisterRd = ID/EX.RegisterRs))
    ForwardA = 10
  - if (EX/MEM.RegWrite and (EX/MEM.RegisterRd ≠ 0) and (EX/MEM.RegisterRd = ID/EX.RegisterRt))
    ForwardB = 10
- MEM hazard
  - if (MEM/WB.RegWrite and (MEM/WB.RegisterRd ≠ 0) and (MEM/WB.RegisterRd = ID/EX.RegisterRs))
    ForwardA = 01
  - if (MEM/WB.RegWrite and (MEM/WB.RegisterRd ≠ 0) and (MEM/WB.RegisterRd = ID/EX.RegisterRt))
    ForwardB = 01

Yet Another Complication!

- Another potential data hazard can occur when there is a conflict between the result of the WB stage instruction and the MEM stage instruction – which should be forwarded?



Double Data Hazard

- Consider the sequence:

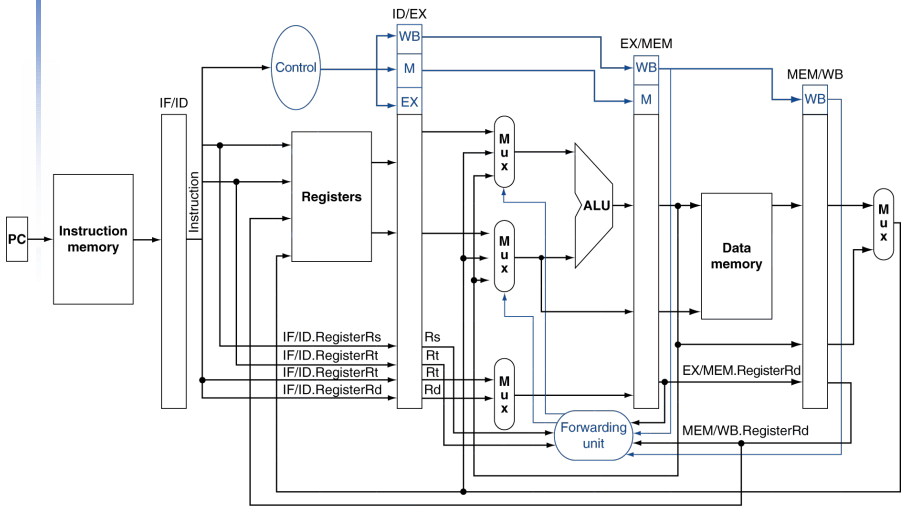
```
add $1,$1,$2
add $1,$1,$3
add $1,$1,$4
```

- Both hazards occur
  - Want to use the most recent
- Revise MEM hazard condition
  - Only fwd if EX hazard condition isn't true

Revised Forwarding Condition

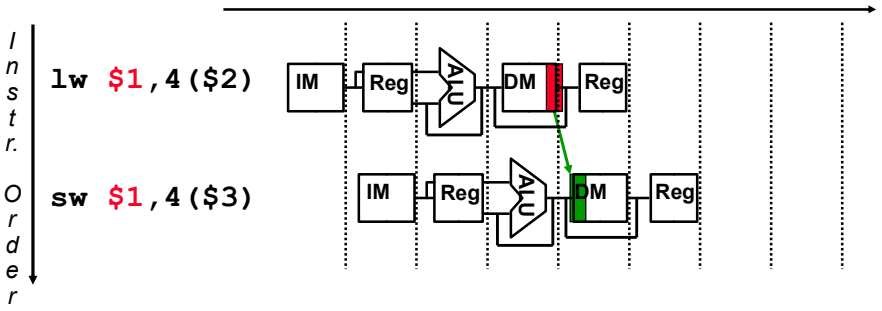
- MEM hazard
  - if (MEM/WB.RegWrite and (MEM/WB.RegisterRd ≠ 0)
    and not (EX/MEM.RegWrite and (EX/MEM.RegisterRd ≠ 0)
    and (EX/MEM.RegisterRd = ID/EX.RegisterRs))
    and (MEM/WB.RegisterRd = ID/EX.RegisterRs))
    ForwardA = 01
  - if (MEM/WB.RegWrite and (MEM/WB.RegisterRd ≠ 0)
    and not (EX/MEM.RegWrite and (EX/MEM.RegisterRd ≠ 0)
    and (EX/MEM.RegisterRd = ID/EX.RegisterRt))
    and (MEM/WB.RegisterRd = ID/EX.RegisterRt))
    ForwardB = 01

Datapath with Forwarding

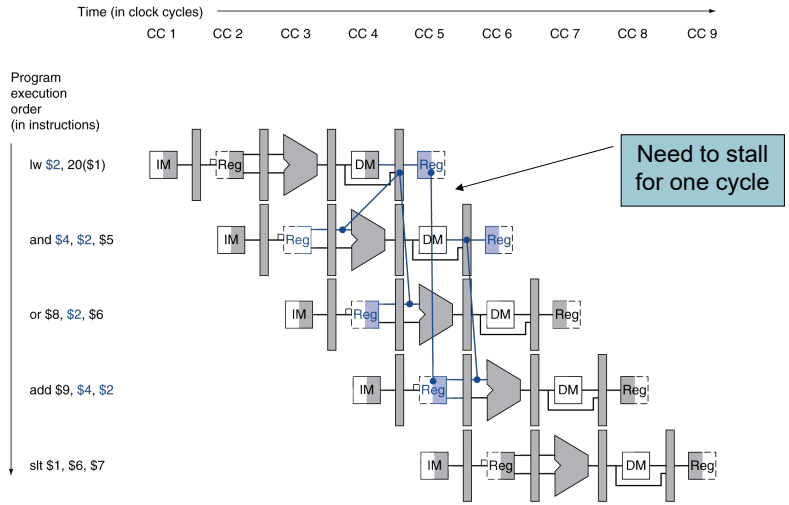


Memory-to-Memory Copies

- For loads immediately followed by stores (memory-to-memory copies) can avoid a stall by adding forwarding hardware from the MEM/WB register to the data memory input.
  - Would need to add a Forward Unit and a mux to the MEM stage



Load-Use Data Hazard



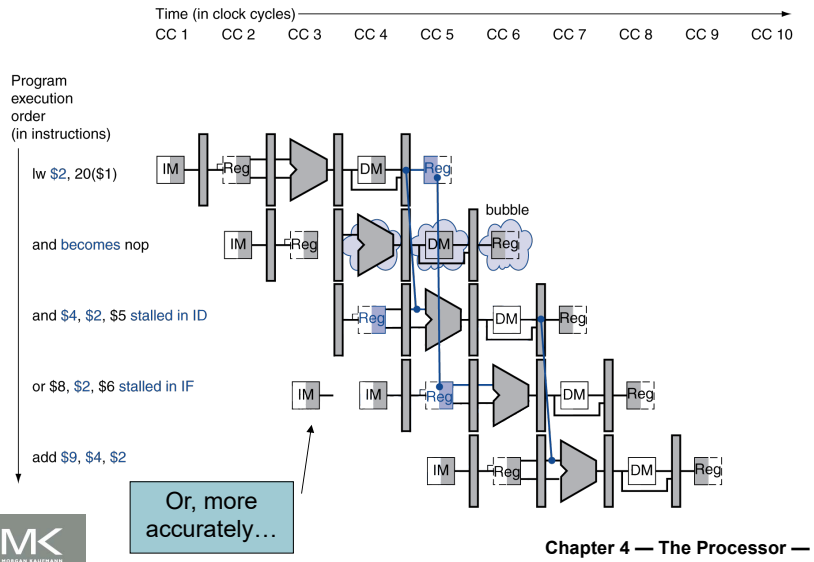
Load-Use Hazard Detection

- Check when using instruction is decoded in ID stage
- ALU operand register numbers in ID stage are given by
  - IF/ID.RegisterRs, IF/ID.RegisterRt
- Load-use hazard when
  - ID/EX.MemRead and
    ((ID/EX.RegisterRt = IF/ID.RegisterRs) or
    (ID/EX.RegisterRt = IF/ID.RegisterRt))
- If detected, stall and insert bubble

How to Stall the Pipeline

- Force control values in ID/EX register to 0
  - EX, MEM and WB do nop (no-operation)
- Prevent update of PC and IF/ID register
  - Using instruction is decoded again
  - Following instruction is fetched again
  - 1-cycle stall allows MEM to read data for lw
    - Can subsequently forward to EX stage

Stall/Bubble in the Pipeline



Datapath with Hazard Detection