A 5-Stage Pipeline

Source: H&P textbook
Hazards

• Structural hazards: different instructions in different stages (or the same stage) conflicting for the same resource

• Data hazards: an instruction cannot continue because it needs a value that has not yet been generated by an earlier instruction

• Control hazard: fetch cannot continue because it does not know the outcome of an earlier branch – special case of a data hazard – separate category because they are treated in different ways
Structural hazards
A 5-Stage Pipeline

Source: H&P textbook
Structural Hazards

- Example: a unified instruction and data cache $\rightarrow$ stage 4 (MEM) and stage 1 (IF) can never coincide

- The later instruction and all its successors are delayed until a cycle is found when the resource is free $\rightarrow$ these are pipeline bubbles

- Structural hazards are easy to eliminate – increase the number of resources (for example, implement a separate instruction and data cache)
Data hazards
A 5-Stage Pipeline

Source: H&P textbook
Pipeline Implementation

- Signals for the muxes have to be generated – some of this can happen during ID
- Need look-up tables to identify situations that merit bypassing/stalling – the number of inputs to the muxes goes up
Example

add R1, R2, R3

lw R4, 8(R1)

Source: H&P textbook
Example

\texttt{lw \hspace{1em} R1, 8(R2)}

\texttt{lw \hspace{1em} R4, 8(R1)}

Source: H&P textbook
Example

lw   R1, 8(R2)

sw   R1, 8(R3)

Source: H&P textbook
Summary

• For the 5-stage pipeline, bypassing can eliminate delays between the following example pairs of instructions:
  add/sub         R1, R2, R3
  add/sub/lw/sw   R4, R1, R5

  lw            R1, 8(R2)
  sw            R1, 4(R3)

• The following pairs of instructions will have intermediate stalls:
  lw            R1, 8(R2)
  add/sub/lw    R3, R1, R4       or   sw   R3, 8(R1)

  fmul          F1, F2, F3
  fadd          F5, F1, F4
Control hazards
Hazards

- Structural hazards
- Data hazards
- Control hazards
Control Hazards

• Simple techniques to handle control hazard stalls:
  ➢ for every branch, introduce a stall cycle (note: every 6th instruction is a branch on average!)
  ➢ assume the branch is not taken and start fetching the next instruction – if the branch is taken, need hardware to cancel the effect of the wrong-path instructions
  ➢ predict the next PC and fetch that instr – if the prediction is wrong, cancel the effect of the wrong-path instructions
  ➢ fetch the next instruction (branch delay slot) and execute it anyway – if the instruction turns out to be on the correct path, useful work was done – if the instruction turns out to be on the wrong path, hopefully program state is not lost
Branch delay slot

(a) From before

DADD R1, R2, R3
if R2 = 0 then

| Delay slot |

becomes

if R2 = 0 then

| DADD R1, R2, R3 |

(b) From target

DSUB R4, R5, R6
DADD R1, R2, R3
if R1 = 0 then

| Delay slot |

becomes

DSUB R4, R5, R6
DADD R1, R2, R3
if R1 = 0 then

| DSUB R4, R5, R6 |

(c) From fall-through

DADD R1, R2, R3
if R1 = 0 then

| Delay slot |

becomes

OR R7, R8, R9
DSUB R4, R5, R6

Thank you!