Lecture: Pipelining Hazards

• Topics: Basic pipelining implementation, hazards, bypassing

• HW2 posted, due Wednesday
Problem 3

• For the following code sequence, show how the instrs flow through the pipeline:
  ADD R1, R2, → R3
  BEZ R4, [R5]
  LD [R6] → R7
  ST [R8] ← R9
## Pipeline Summary

<table>
<thead>
<tr>
<th>Instruction</th>
<th>RR</th>
<th>ALU</th>
<th>DM</th>
<th>RW</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADD R1, R2, ( \rightarrow ) R3</td>
<td>Rd R1,R2</td>
<td>R1+R2</td>
<td>--</td>
<td>Wr R3</td>
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<tr>
<td>BEZ R1, [R5]</td>
<td>Rd R1, R5</td>
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<td>Compare, Set PC</td>
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<tr>
<td>LD 8[R3] ( \rightarrow ) R6</td>
<td>Rd R3</td>
<td>R3+8</td>
<td>Get data</td>
<td>Wr R6</td>
</tr>
<tr>
<td>ST 8[R3] ( \leftarrow ) R6</td>
<td>Rd R3,R6</td>
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<td>Wr data</td>
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Problem 4

• Convert this C code into equivalent RISC assembly instructions

\[ a[i] = b[i] + c[i]; \]
Problem 4

• Convert this C code into equivalent RISC assembly instructions

\[
a[i] = b[i] + c[i];
\]

LD [R1], R2  # R1 has the address for variable i
MUL R2, 8, R3  # the offset from the start of the array
ADD R4, R3, R7  # R4 has the address of a[0]
ADD R5, R3, R8  # R5 has the address of b[0]
ADD R6, R3, R9  # R6 has the address of c[0]
LD [R8], R10   # Bringing b[i]
LD [R9], R11   # Bringing c[i]
ADD R10, R11, R12  # Sum is in R12
ST [R7], R12   # Putting result in a[i]
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

• Example: a unified instruction and data cache →
  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 → these
  are pipeline bubbles

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

Time (in clock cycles)

Source: H&P textbook
Problem 5

- Show the instruction occupying each stage in each cycle (no bypassing)

  if I1 is R1+R2→R3 and I2 is R3+R4→R5 and I3 is R7+R8→R9

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1. if I1 is R1+R2→R3
2. and I2 is R3+R4→R5
3. and I3 is R7+R8→R9
Problem 6

- Show the instruction occupying each stage in each cycle (with bypassing) if I1 is R1+R2→R3 and I2 is R3+R4→R5 and I3 is R3+R8→R9. Identify the input latch for each input operand.

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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

 lw    R1, 8(R2)
 lw    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
Problem 7

• Consider this 8-stage pipeline

- IF
- DE
- RR
- AL
- AL
- DM
- DM
- RW

• For the following pairs of instructions, how many stalls will the 2nd instruction experience (with and without bypassing)?

- ADD R1+R2 → R3
  ADD R3+R4 → R5
- LD [R1] → R2
  ADD R2+R3 → R4
- LD [R1] → R2
  SD [R2] ← R3
- LD [R1] → R2
  SD [R3] ← R2
Problem 7

- Consider this 8-stage pipeline (RR and RW take a full cycle)

```
IF DE RR AL AL DM DM RW
```

- For the following pairs of instructions, how many stalls will the 2\textsuperscript{nd} instruction experience (with and without bypassing)?

- ADD R1+R2→R3
  ADD R3+R4→R5
  \quad without: 5  \quad with: 1

- LD [R1]→R2
  ADD R2+R3→R4
  \quad without: 5  \quad with: 3

- LD [R1]→R2
  SD [R2]←R3
  \quad without: 5  \quad with: 3

- LD [R1]→R2
  SD [R3]←R2
  \quad without: 5  \quad with: 1
Title

• Bullet