Pipelining Hazards

We need to worry about 3 things that can (a) affect pipelining performance (e.g. that can prevent an instruction from finishing each CC) and (b) affect pipelining correctness (e.g. that can prevent registers from changing to the state they logically should).

Structural Hazards:
Example:

	1	2	3	4	5	6	7	8	9	10
lw $1, 0($2)	F	D	E	M	**W**					
add $3, $4, $5		F	D	E	M	W				
sub $6, $7, $8			F	D	E	M	W			
or $9, $10, $11				F	**D**	E	M	W		
and $12, $13, $14					…	…	…	…		

In Cycle 5, we need to support the writing and reading of a register simultaneously.

If there is no support for simultaneous reading/writing, a structural hazard occurs – and the or instruction would have to wait. More specifically:

	1	2	3	4	5	6	7	8	9	10
lw $1, 0($2)	F	D	E	M	W					
add $3, $4, $5		F	D	E	M	**W**				
sub $6, $7, $8			F	D	E	M	W			
or $9, $10, $11				"Bubble"	F	**D**	E	M	W	
and $12, $13, $14					…	…	…	…		

(but then the problem just repeats itself…)

More formally:

- The simplest way to resolve a structural hazard is to add HW
  - In the above example, this would mean more register "ports"
- Basically, structural hazards arise from resource conflicts
  - HW can't support all combinations of instructions going through the pipeline
- Sometimes its actually better to stall instead of adding more HW
  - E.g. if the combination occurs rarely.

Data Hazards:
Let's look at another sequence of instructions:

	1	2	3	4	5	6	7	8
lw $1, 0($2)	F	D	E	M	W	**$1 available**		
add $3, $1, $4		F	D **$1 needed**	E	M	W		
sub $5, $1, $6			F	D **$1 needed**	E	M	W	
or $7, $1, $8				F	D **$1 needed**	E	M	W

This is a data hazard:
- Data hazards arise from *dependencies* between instructions
- Here, add, sub, and or all depend on lw

How do we fix it?

Option 1: Wait.

	1	2	3	4	5	6	7	8	9	10	11	12
lw $1, 0($2)	F	D	E	M	W							
add $3, $1, $4		F	---	---	---	D	E	M	W			
sub $5, $1, $6						F	D	E	M	W		
or $7, $1, $8							F	D	E	M	W	

Idea: Stall the pipeline; wait for the result we need to be produced.

Option 2: (Read data when it is being written – slightly better)

	1	2	3	4	5	6	7	8	9	10	11	12
lw $1, 0($2)	F	D	E	M	W							
add $3, $1, $4		F	---	---	D	E	M	W				
sub $5, $1, $6					F	D	E	M	W			
or $7, $1, $8						F	D	E	M	W		

Hint:
- How do you know you have the table right?
- (Look down a column – there should *never* be two of the same letter/stage)

Option 3: (Use data as soon as its available – even better)

Looking at the chart associated with Option 2, it's clear that the data we want to use – e.g. that will be put in $1 is "available" before it goes to the register file. Let's use it as soon as it is produced. (This is more obvious with a slightly different instruction mix so note the change below…)

	1	2	3	4	5	6	7	8	9
add $1, $10, $9	F	D	E **$1 data available here**	M	W				
add $3, $1, $4		F	D	E	M	W			
sub $5, $1, $6			F	D	E	M	W		
or $7, $1, $8				F	D	E	M	W	

(This is called *forwarding*. We'll talk more about it later, but it can be easily implemented by feeding back the output of the ALU back to the input multiplexors.)

Control Hazards:
What if we have:

```
                beq     $5, $6, target
                add     $1, $2, $3
                …
Target:         add     $1, $5, $6
```

What's the problem?

- If \$5 == \$6, then \$1 should = \$5 + \$6
- If \$5 != \$6, then \$1 should = \$2 + \$3
- We need to make sure we put the right value into \$1 – otherwise our program will be incorrect.

There's another problem too…

- To finish 1 instruction each CC, we need to start 1 instruction each C
- At first glance, the only way to ensure logical correctness is to wait until the branch outcome is decided – so we'll have to stall our pipeline every time we get a brach.
    - (But about 1 of every 6 instructions is a branch…)

More formally:

- This is a <u>control</u> <u>hazard</u>. It arises from a change in program control flow.
- Which instruction do we start down the pipeline?
- If we start the wrong instruction, can we fix? Should we guess???