

ECE/CSE 511: Computer Architecture

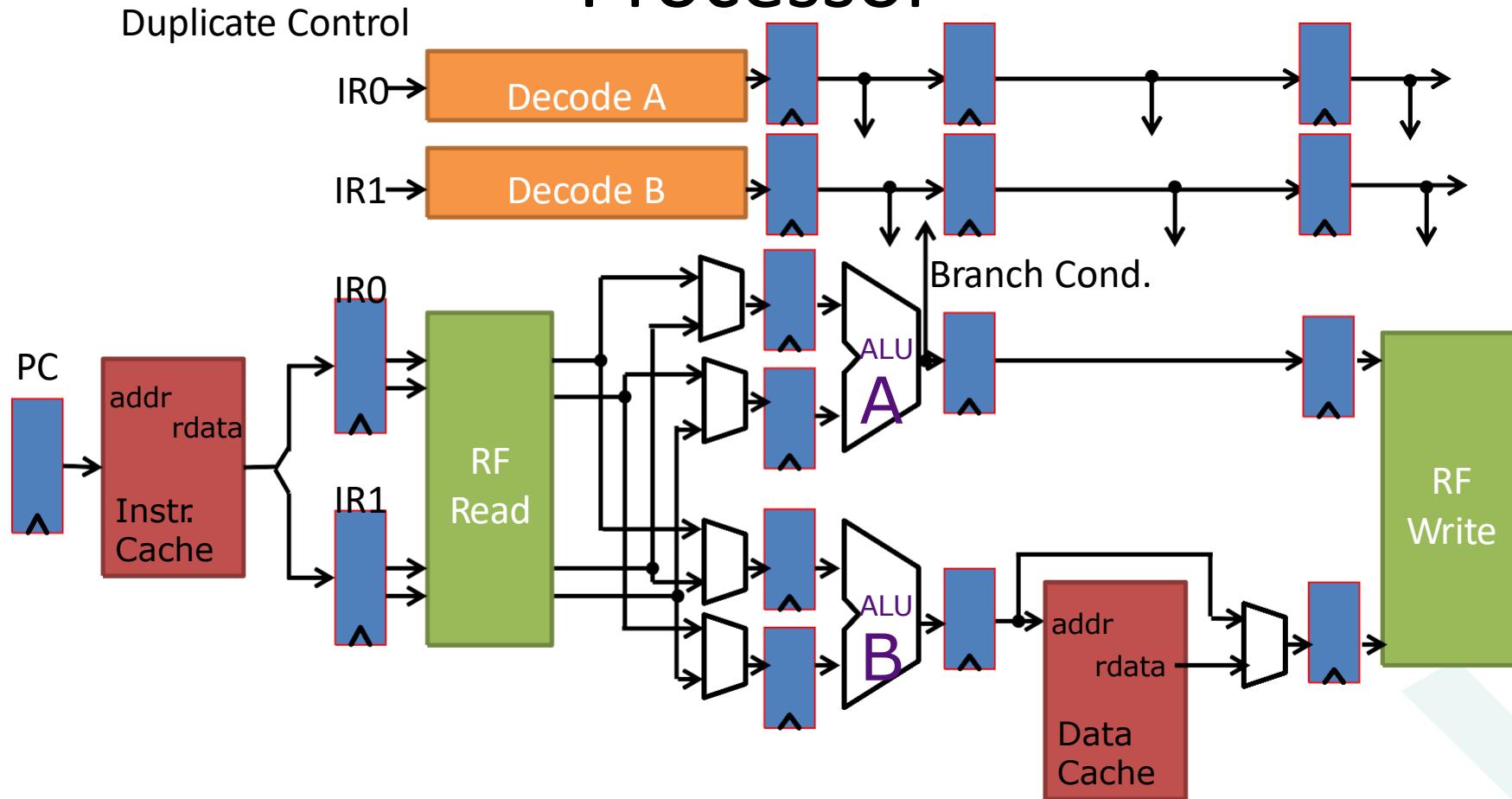
Lecture 10: Superscalar Processor



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Baseline 2-Way In-Order Superscalar Processor





Issue Logic Pipeline Diagrams

OpA	F	D	A0	A1	W		
OpB	F	D	B0	B1	W		
OpC		F	D	A0	A1	W	
OpD		F	D	B0	B1	W	
OpE			F	D	A0	A1	W
OpF			F	D	B0	B1	W

CPI = 0.5 (IPC = 2)

Double Issue Pipeline
Can have two instructions in
same stage at same time

ADDIU	F	D	A0	A1	W		
LW	F	D	B0	B1	W		
LW	F	D	B0	B1	W		
ADDIU	F	D	A0	A1	W		
LW		F	D	B0	B1	W	
LW		F	D	D	B0	B1	W

Instruction Issue Logic swaps from
natural position

Structural
Hazard



With Alignment Constraints

Cyc	Addr	Instr
?	0x000	OpA
?	0x004	OpB
?	0x008	OpC
?	0x00C	J 0x100
...		
?	0x100	OpD
?	0x104	J 0x204
...		
?	0x204	OpE
?	0x208	J 0x30C
...		
?	0x30C	OpF
?	0x310	OpG
?	0x314	OpH

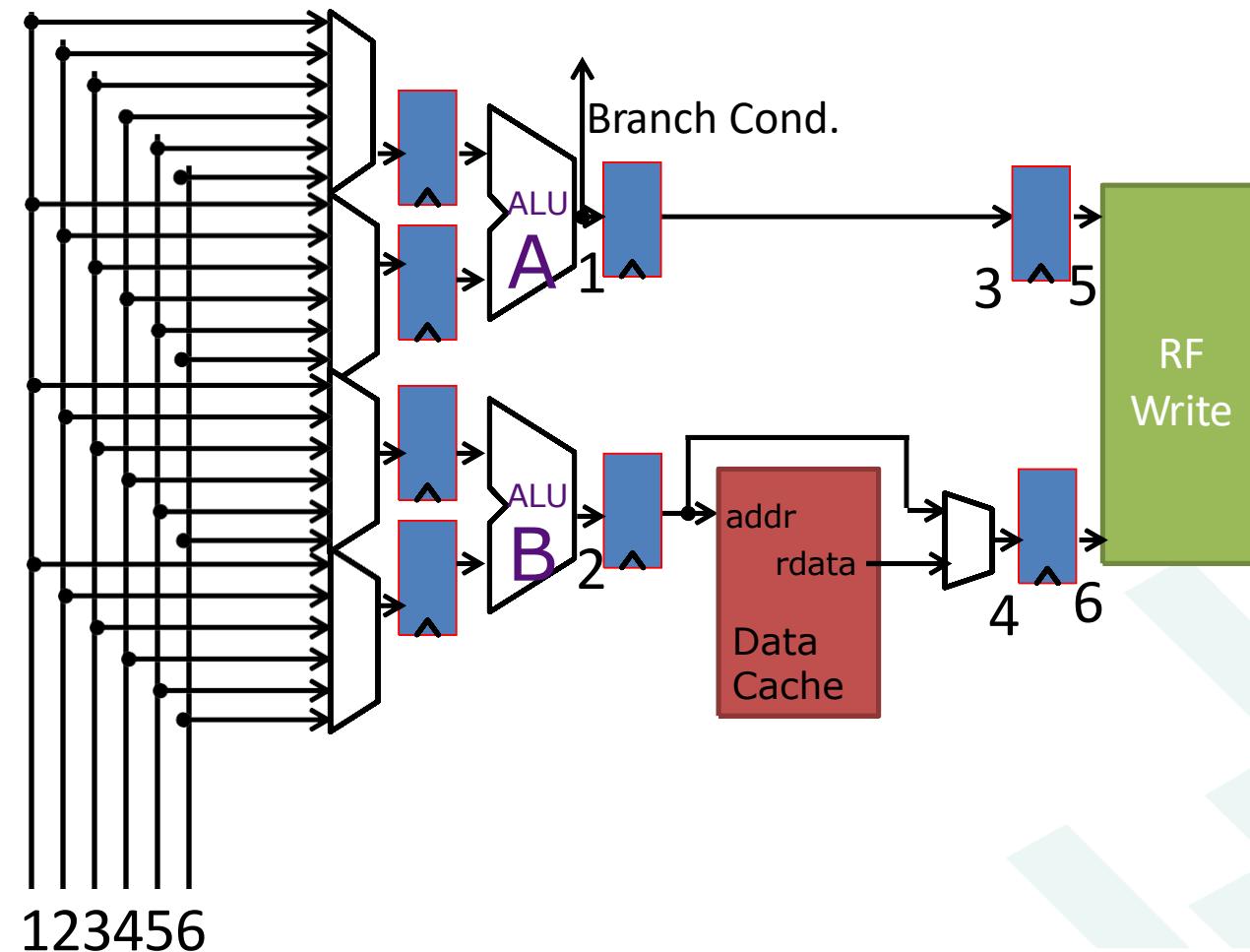
0	0	1	1
...			
2	2		
...			
3	X	3	X
...			
5	X	5	
...			
6	6		



With Alignment Constraints

Cyc	Addr	Instr	F	D	A0	A1	W
1	0x000	OpA	F	D	A0	A1	W
1	0x004	OpB	F	D	B0	B1	W
2	0x008	OpC	F	D	B0	B1	W
2	0x00C	J 0x100	F	D	A0	A1	W
3	0x100	OpD	F	D	B0	B1	W
3	0x104	J 0x204	F	D	A0	A1	W
4	0x200	?	F	-	-	-	-
4	0x204	OpE	F	D	A0	A1	W
5	0x208	J 0x30C	F	D	A0	A1	W
5	0x20C	?	F	-	-	-	-
6	0x308	?	F	-	-	-	-
6	0x30C	OpF	F	D	A0	A1	W
7	0x310	OpG	F	D	A0	A1	W
7	0x314	OpH	F	D	B0	B1	W

Bypassing in Superscalar Pipelines



Breaking Decode and Issue Stage



- Bypass Network can become very complex
- Can motivate breaking Decode and Issue Stage

D = Decode, Possibly resolve structural Hazards

I = Register file read, Bypassing, Issue/Steer
Instructions to proper unit

OpA F D I A0 A1 W

OpB F D I B0 B1 W

OpC F D I A0 A1 W

OpD F D I B0 B1 W

Exceptions

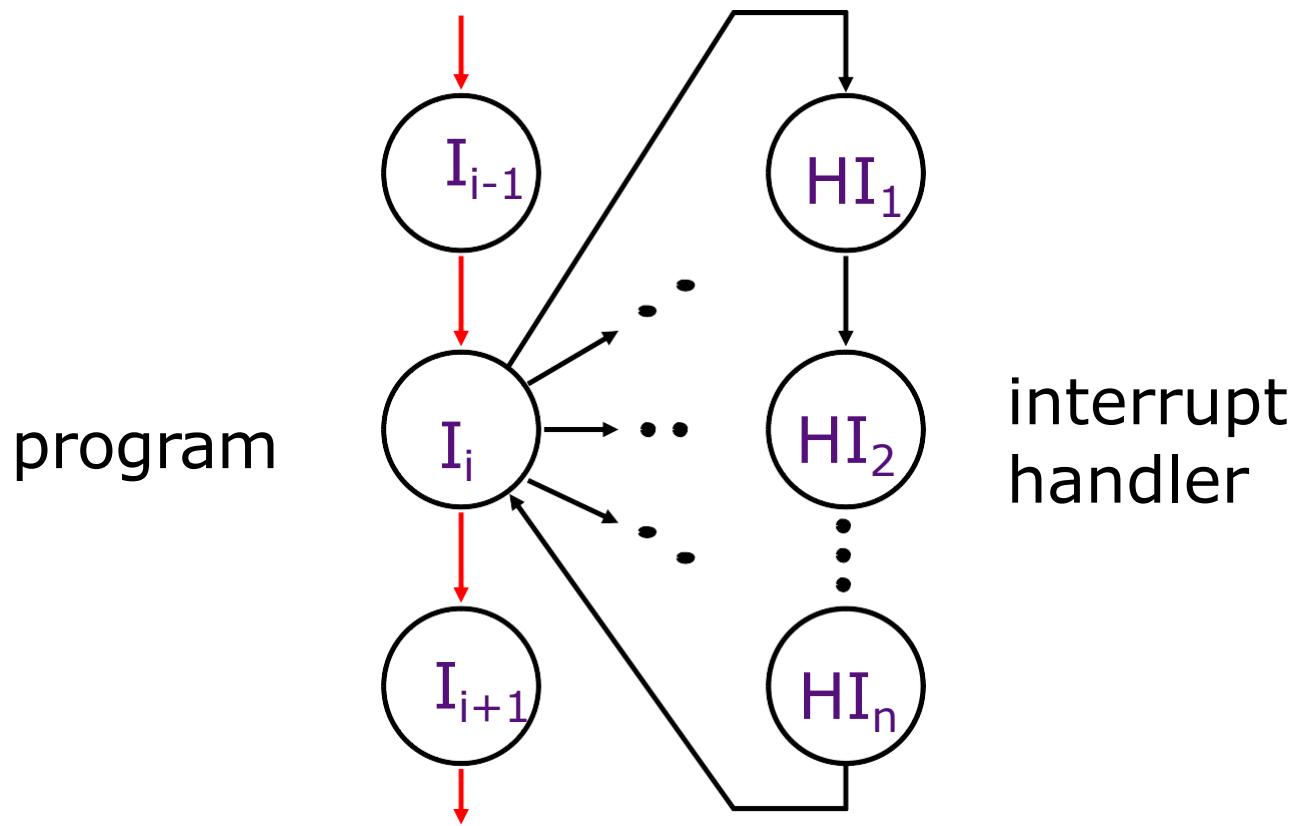


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Interrupts:

altering the normal flow of control



An external or internal event that needs to be processed by another (system) program. The event is usually unexpected or rare from program's point of view.



Causes of Exceptions

Interrupt: an *event* that requests the attention of the processor

- Asynchronous: an *external event*
 - input/output device service request
 - timer expiration
 - power disruptions, hardware failure
- Synchronous: an *internal exception*
(a.k.a.exceptions/trap)
 - undefined opcode, privileged instruction
 - arithmetic overflow, FPU exception
 - misaligned memory access
 - *virtual memory exceptions*: page faults, TLB misses, protection violations
 - *software exceptions*: system calls, e.g., jumps into kernel

Asynchronous Interrupts:

invoking the interrupt handler



- An I/O device requests attention by asserting one of the *prioritized interrupt request lines*
- When the processor decides to process the interrupt
 - It stops the current program at instruction I_i , completing all the instructions up to I_{i-1} (a *precise interrupt*)
 - It saves the PC of instruction I_i in a special register (EPC)
 - It disables interrupts and transfers control to a designated interrupt handler running in the kernel mode



Interrupt Handler

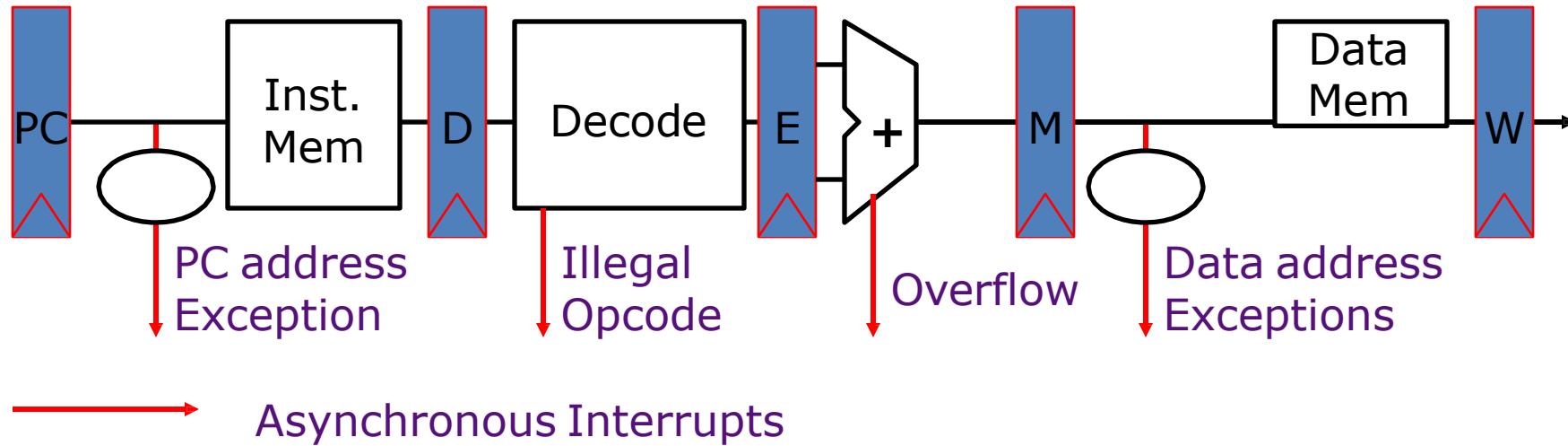
- Saves EPC before re-enabling interrupts to allow nested interrupts ⇒
 - need an instruction to move EPC into GPRs
 - need a way to mask further interrupts at least until EPC can be saved
- Needs to read a *status register* that indicates the cause of the interrupt
- Uses a special indirect jump instruction RFE (*return-from-exception*) to resume user code, this:
 - enables interrupts
 - restores the processor to the user mode
 - restores hardware status and control state



Synchronous Interrupts

- A synchronous interrupt (exception) is caused by a *particular instruction*
- In general, the instruction cannot be completed and needs to be *restarted* after the exception has been handled
 - requires undoing the effect of one or more partially executed instructions
- In the case of a system call trap, the instruction is considered to have been completed
 - syscall is a special jump instruction involving a change to privileged kernel mode
 - Handler resumes at instruction after system call

Exception Handling 5-Stage Pipeline



- How to handle multiple simultaneous exceptions in different pipeline stages?
- How and where to handle external asynchronous interrupts?

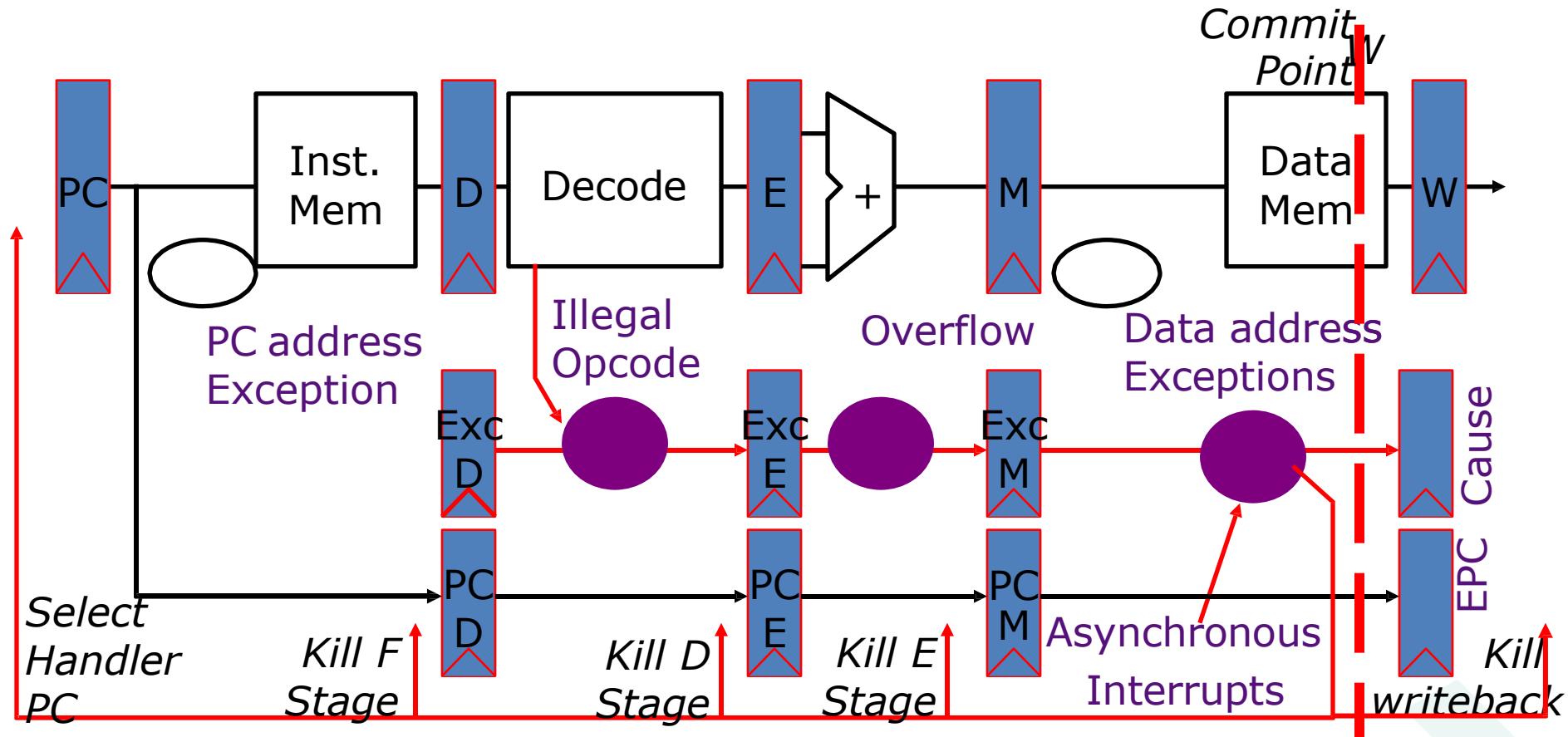
Class Interaction # 10



Exception Handling



5-Stage Pipeline





Exception Handling 5-Stage Pipeline

- Hold exception flags in pipeline until commit point (M stage)
- Exceptions in earlier pipe stages override later exceptions *for a given instruction*
- Inject external interrupts at commit point (override others)
- If exception at commit: update Cause and EPC registers, kill all stages, inject handler PC into fetch stage



Speculating on Exceptions

- Prediction mechanism
 - Exceptions are rare, so simply predicting no exceptions is very accurate!
- Check prediction mechanism
 - Exceptions detected at end of instruction execution pipeline, special hardware for various exception types
- Recovery mechanism
 - Only write architectural state at commit point, so can throw away partially executed instructions after exception
 - Launch exception handler after flushing pipeline
- Bypassing allows use of uncommitted instruction results by following instructions

Exception Pipeline Diagram

	time									
	t0	t1	t2	t3	t4	t5	t6	t7	...	
(I ₁) 096: ADD	IF ₁	ID ₁	EX ₁	MA ₁	nop					overflow!
(I ₂) 100: XOR		IF ₂	ID ₂	EX ₂	nop	nop				
(I ₃) 104: SUB			IF ₃	ID ₃	nop	nop	nop			
(I ₄) 108: ADD				IF ₄	nop	nop	nop	nop		
(I ₅) Exc. Handler code					IF ₅	ID ₅	EX ₅	MA ₅	WB ₅	

Resource Usage	time									
	t0	t1	t2	t3	t4	t5	t6	t7	...	
IF	I ₁	I ₂	I ₃	I ₄	I ₅	I ₅				
ID		I ₁	I ₂	I ₃	nop					
EX			I ₁	I ₂	nop	nop	I ₅	I ₅		
MA				I ₁	nop	nop	nop			
WB					nop	nop	nop	nop	I ₅	

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Out-of-Order Processors



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Out-Of-Order (OOO) Introduction

Name	Frontend	Issue	Writeback	Commit	
I4	IO	IO	IO	IO	Fixed Length Pipelines Scoreboard
I2O2	IO	IO	000	000	Scoreboard
I2OI	IO	IO	000	IO	Scoreboard, Reorder Buffer, and Store Buffer
I03	IO	000	000	000	Scoreboard and Issue Queue
IO2I	IO	000	000	IO	Scoreboard, Issue Queue, Reorder Buffer, and Store Buffer