Exceptions

CSE 410 - Computer Systems
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Readings and References

- Reading
  - Section 6.7, *Computer Organization & Design*, Patterson and Hennessy
- Other References
  - Chapter 5, *See MIPS Run*, D. Sweetman

Exceptions and Interrupts

- Many things can happen while executing the assembled instructions
  - External events (I/O device interrupt)
  - Memory Translation exceptions
  - Unusual floating point values
  - Program errors (eg, invalid instruction)
  - Data integrity failure
  - System calls

Exceptions

- An *exception* is an internal event
  - The unexpected or unusual condition was caused by something the program did
  - examples include
    - arithmetic overflows, floating point problems
    - syscalls
  - If you ran the program again, the exception would (probably) happen again at the same point in the program's execution

Exception/Pipelining Interface

- Suppose an `add` instruction overflows, causing an overflow exception
- Instructions after the `add` are already in the pipeline
  - The partially computed instructions must be *flushed*
- Exception must be caught before register contents have changed

"Precise" Exceptions

- A pipelined CPU always has several instructions in various phases of completion
- When an exception occurs, the CPU will record the location of the *exception victim*
- With Precise Exceptions
  - All preceding instructions are completed
  - All work on the victim and following is erased

Interrupts

- An *interrupt* is an external event
  - The unexpected condition was not directly caused by the program
  - An I/O device request is an example
  - If you ran the program again, the interrupt would probably *not* happen at the same point
  - Interrupts are another type of exception, caused by an external event

What should happen?

- These events result in a *change in the flow of control*
- Normally, the next instruction executed is the one following the current instruction
- When one of these events takes place, something else happens
  - The system must respond to the event
  - The response depends on the type of event

Exception Handling

- The CPU saves the address of the offending instruction in a register
- Makes the reason for the exception known
  - Set the value of the *status register*, or
  - Use *vectored interrupts* to do step 3
- Transfers control to the operating system
- Operating system decides what to do

Exceptions example

```
        .data
big:       .word 0x7FFFFFFF
kernelref: .word 0x80000000
        .text
main:
        la    $t0,big          # a valid aligned address
        lw    $t1,1($t0)       # err - unaligned load
        lw    $t0,kernelref    # kernel area address
        sw    $t1,0($t0)       # err - bad address
        lw    $t0,big          # big number
        lw    $t1,big          # another big number
        add   $t2,$t0,$t1      # err - arithmetic overflow
        j     $ra
```


Exception Example results

“trap.handler” is our OS

```
        .ktext 0x80000080
        .set noat
        # Because we are running in the kernel, we can use
        # $k0/$k1 without saving their old values.
        move $k1 $at  # Save $at
        .set at
        sw $v0 s1     # Not re-entrant and we can't trust $sp
        sw $a0 s2
        mfc0 $k0 $13  # Cause
        sgt $v0 $k0 0x44 # ignore interrupt exceptions
        bgtz $v0 ret
        . . .
```

$k0, $k1

- Note that the trap handler uses $k0 and $k1 to get itself started
- Those are the only registers that it knows are not being used by the user program
- An exception or interrupt may happen at any time
- So the value of $k0 and $k1 will change while your program is executing

Frequent Exceptions

- Syscall
  - user program call to the operating system for service
- TLB miss
  - memory event, likely response is memory allocation
- Interrupt
  - device input / output event