Control Hazards

- **Branches** (conditional, unconditional, call-return)
- **Interrupts**: asynchronous event (e.g., I/O)
  - Occurrence of an interrupt checked at every cycle
  - If an interrupt has been raised, don’t fetch next instruction, flush the pipe, handle the interrupt (see later in the quarter)
- **Exceptions** (e.g., arithmetic overflow, page fault etc.)
  - Program and data dependent (repeatable), hence “synchronous”

Exceptions

- Occur “within” an instruction, for example:
  - During IF: page fault (see later)
  - During ID: illegal opcode
  - During EX: division by 0
  - During MEM: page fault; protection violation
- **Handling exceptions**
  - A pipeline is restartable if the exception can be handled and the program restarted w/o affecting execution

Precise exceptions

- If exception at instruction i
  - Instructions i-1, i-2 etc complete normally (flush the pipe)
  - Instructions i+1, i+2 etc. already in the pipeline will be “no-oped” and will be restarted from scratch after the exception has been handled
- **Handling precise exceptions: Basic idea**
  - Force a trap instruction on the next IF (i.e., transfer of control to a known location in the O.S.)
  - Turn off writes for all instructions i and following
  - When the target of the trap instruction receives control, it saves the PC of the instruction having the exception
  - After the exception has been handled, an instruction “return from trap” will restore the PC.

Exception Handling

- When an exception occurs
  - Address (PC) of offending instruction saved in Exception Program Counter (a register not visible to ISA).
  - In MIPS should save PC = 4
  - Transfer control to OS
- **OS handling of the exception. Two methods**
  - Register the cause of the exception in a status register which is part of the state of the process
  - Transfer to a specific routine tailored for the cause of the exception; this is called vectored interrupts

Exception Handling (continued)

- **OS saves the state of the process (registers etc.)**
- **OS “clears” the exception**
  - Can decide to abort the program
  - Can “correct” the exception
  - Can perform useful functions (e.g., I/O interrupt, syscall etc.)
- **Return to the running process**
  - Restores state
  - Restores PC
Precise exceptions (continued)

- Relatively simple for integer pipeline
  - All current machines have precise exceptions for integer and load-store operations
- Can lead to loss of performance for pipes with multiple cycles execution stage

Integer pipeline (RISC) precise exceptions

- Recall that exceptions can occur in all stages but WB
- Exceptions must be treated in instruction order
  - Instruction i starts at time t
  - Exception in MEM stage at time t + 3 (treat it first)
  - Instruction i + 1 starts at time t + 2
  - Exception in IF stage at time t + 1 (occurs earlier but treat in 2nd)

Difficulties in less RISCy environments

- Due to instruction set ("long" instructions)
  - String instructions (but use of general registers to keep state)
  - Instructions that change state before last stage (e.g., autoincrement mode in Vax and update addressing in Power PC) and these changes are needed to complete inst. (require ability to back up)
- Condition codes (another way to handle branches)
  - Must remember when last changed