Lecture 16: Context Switching and File Linking

Interrupts, Context Switching, Hard Links, and Symbolic Links

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Processor and Interrupts

The Ideal Processor

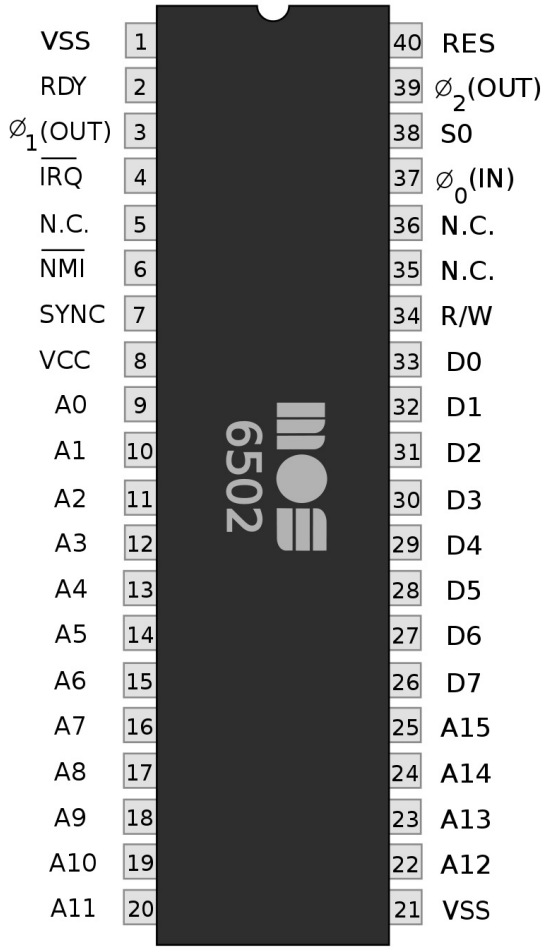
- A machine that executes instructions unconditionally.

```
for (day = TODAY; day != FOREVER; day++) {
   say("I␣love␣you\n");
}
```

The Real Processor is NOT "Unconditionally Executing Instructions"

- It "cares" and responds to external interrupts.
- If you fall into an infinite loop in the library...
  - A friendly security guard will "interrupt" you.

Interrupt = A Single Wire



- **”Telling the processor: Stop, something has happened!”**
- **”The rest is up to the processor.”**

Processor Interrupt Behavior

If the Processor Interrupts are Enabled

- **x86 Family (CISC, a legacy of history; a nightmare for processor designers)**
  - Reads interrupt vector number *n* via the interrupt controller.
  - Saves CS, EIP, EFLAGS, SS, and ESP onto the stack.
  - Jumps to the "Gate" in `IDT[n]`.
  - **A data structure that describes privilege-level switching and long jumps.**
- **RISC-V (M-Mode, Direct Exception Mode)**
  - Checks whether this interrupt should be masked.
  - Jumps: `PC = (mtvec & ~0xF)`
  - Updates: `mcause.Interrupt = 1`

Another Way to Understand Interrupts

Forcibly "Injected" syscalls

- **Interrupt**
  - Saves: `mepc = PC`
  - Jumps: `PC = (mtvec & ~0xF)`
  - Updates: `mcause.Interrupt = 1`
- **System Call (ecall)**
  - Saves: `mepc = PC`
  - Jumps: `PC = (mtvec & ~0xF)`
  - Updates: `mcause.Ecall = 1`

"No matter what you are doing right now, go execute the system core code!"

Interrupts Grant OS "Supremacy"

Operating System Kernel (Code)

- Can enable and disable interrupts at will.

User Applications

- Sorry, no direct control over interrupts.
  - You can inspect the flags register (`FL_IF`) in `gdb`.
  - **CLI - Clear Interrupt Flag**
    - #GP(0) occurs if **CPL** is greater than **IOPL** and less than 3.
    - Try using: `asm volatile ("cli");`
- Regardless of what code you write, it will always be interrupted.

Assume an Interrupt Occurs

What Should the Operating System Code Do?

- `mov (kernel_rsp), %rsp`
  - This can be fatal.
  - The process (state machine) state will be lost forever.

First: Save the State Machine (Registers)

- Preserve control over memory and data.
- Save register states to physical memory for later restoration.

Then: Execute the Operating System Code

- C code can freely use registers.
- The OS code selects a state machine for return.
- Restore register states from physical memory.
- Execute `sysret` (`iret`).

This is the most elegant pieces of code in operating systems.

Implementing Context Switching

Operating System Implementation Tricks

- Set up a ”current context”.
- Save and restore register states.
  - **AbstractMachine** already helps you obtain registers.

```
Context *on_interrupt(Event ev, Context *ctx) {
  // Save context.
  current->context = *ctx;

  // Thread schedule.
  current = current->next;

  // Restore current thread's context.
  return &current->context;
}
```

Directory API (System Calls)

Directory Management: Create/Delete/Traverse

This is straightforward:

- `mkdir`
  - Creates a directory
  - Allows setting access permissions
- `rmdir`
  - Deletes an empty directory
  - No system call for ”recursive delete”
    - (If achievable at the application level, it is not implemented at the OS level)
    - `rm -rf` traverses directories, deleting each item (try `strace`)
- `getdents`
  - Returns `count` number of directory entries (used by `ls`, `find`, `tree`)
  - Dot-prefixed entries are returned by the system call, but `ls` does not display them by default

More User-Friendly Directory Access

Appropriate API + Programming Language

- **Globbing**
- This is a user-friendly approach
  - C++ filesystem API is quite difficult to use

Hard Links

Requirements: The system may have multiple versions of the same library.

- Examples: `libc-2.27.so`, `libc-2.26.so`, ...
- Also requires a "current version of libc"
  - Programs need to link to `libc.so.6` to avoid duplicating the file.

Hard Link: Allows a file to be referenced by multiple directory entries.

- Directories only store pointers to the file data.
- **Limitations:**
  - Cannot link directories
  - Cannot link across file systems

Most UNIX file systems use hard links for files (check with `ls -i`).

- System call to delete a link is `unlink` (reference count).

Symbolic Links

Symbolic Link: Stores a "jump pointer" in a file.

- Symbolic links are also files.
  - When referencing this file, it points to another file.
  - Stores the absolute/relative path of another file as text in the file.
  - Can link across file systems, can link directories, etc.
- Similar to a "shortcut."
  - It doesn't matter if the linked target currently exists.
  - Examples:
    - `~/usb` ⇒ `/media/xinliu-usb`
    - `~/Desktop` ⇒ `/mnt/c/Users/xinliu/Desktop` (WSL)

`ln -s` to create symbolic links.

- `symlink` system call.

Symbolic Links: Can Be Used to Make Galgames

(In the previous era, a huge number of games looked like this)

Takeaways

System call instructions are a special type of ”long jump”

- The jump target is pre-configured by the OS and **cannot be controlled by applications**.

Processor interrupts also trigger long jumps to the OS kernel

- The OS kernel **preserves** the process state machine:
  - **Memory pages remain unchanged**.
  - Carefully designed code ensures all registers are safely stored in memory.

At this moment, the system is in a state where:

- **All programs are suspended**, and only OS code is executing.
- The OS selectively schedules the next register context onto the CPU to achieve **context switching**.