CPSC 213

Introduction to Computer Systems

Unit 2e

The Operating System

Readings for Next Two Lectures

- Text
  - Exceptional Control Flow: Processes, System Call Error Handling
  - VM as a Tool for Memory Protection
  - 2nd edition: 8.2, 8.3, 9.5
  - 1st edition: 8.2, 8.3, 10.5

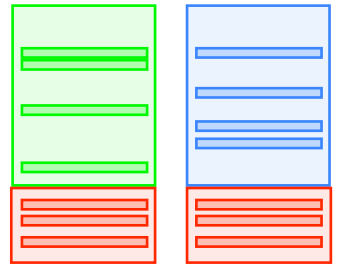
Implementing the System Abstractions

- We've got some cool abstractions
  - virtual processors (threads)
  - virtual memory
  - processes
  - authenticated users
  - file systems
  - inter-process and network communication
- What properties do we want from their implementation
  - encapsulation of implementation by an interface
  - failure and security isolation
  - programming-language heterogeneity
- We've got a problem ...

Hardware Enforced Encapsulation

- Goal
  - define a set of interfaces (APIs) whose implementations are protected
  - implementation code and data can only be accessed through interface
- Obstacle
  - can not use language protection without excluding languages like C
- Use Hardware for Protection
  - virtual memory already provides a way to protect memory
  - data in one address space can not even be named by thread in another
  - so, we've got the protected implementation part
  - we'll need to add the interface part

The Operating System



- The operating system is
  - a C/assembly program
  - implements a set of abstractions for applications
  - it encapsulates the implementation of these abstractions, including hardware
- The Operating System's Address Space
  - a part of every application's page table is reserved for the OS
  - all code and data of OS is part of every page table (exact copies)
  - and so the operating system is part of every application's address space
- Dual Protection Domains
  - each address space splits into application and system ***protection domain***
  - CPU can run in one of two modes: user and kernel
  - when in user mode, the OS part of virtual memory is inaccessible
  - when in kernel mode, all of virtual memory is accessible

Implementing Hardware Encapsulation

- Hardware
  - mode register (user or kernel)

```
boolean isKernelMode;
```

  - certain instructions only legal in kernel mode
  - page table entries have protection flag (user or kernel)
  - attempting to access a kernel page while in user mode causes fault
  - special instructions for switching between user and kernel modes
- Translation

```
class PageTableEntry {
  boolean isValid;
  boolean isKernel;
  int     pfn;
}
```

```
int translate (int va) {
  int vpn    = va >>> 12;
  int offset = va & 0xfff;
  if (pte[vpn].isValid && (isKernelMode || !pte[vpn].isKernel))
    return pte[vpn].pfn << 12 | offset;
  else
    throw new IllegalAddressException (va);
}
```


Protected Procedure Call

- Switching from User Mode to Kernel Mode must be protected
  - OS has a fixed set of "entry points", its public API
  - an application can call any of these entry points, but no others
  - when in kernel mode the application can access anything
  - so, application can only switch to kernel mode after calling entry point
  - but, even entry points are in inaccessible memory
- Implementing Protected Calls
  - OS boot sets up entry-point jump table in kernel memory
  - jump table is indexed by system call number and stores procedure address
  - system call instruction changes mode and jumps through jump table
  - in IA32 this instruction is called "int 80" (i.e., interrupt number 0x80)
  - this works like an IO-Controller interrupt, it transfers control to interrupt-handler
  - but this also switches the processor into kernel mode (all interrupts do this)

```
movl  $1, %eax    # system call number (exit)
int   $0x80       # interrupt 80 is a system call
```


- Implementing Protected Call Instruction

Two special hardware registers

```
boolean isKernelMode
void    (**systemCallTable)();
```

Initialized at OS boot time

```
isKernelMode    = true;
*systemCallTable = malloc (sizeof (void*) * MAX_SYS_CALL_NUM);
systemCallTable[0] = syscall;
systemCallTable[1] = exit;
systemCallTable[2] = fork;
systemCallTable[3] = read;
...
```

Protected call instruction, assuming syscall number is in r0

```
sysCallNum   = r[0];
if (sysCallNum >= 0 && sysCallNum <= MAX_SYSCALL_NUM) {
  isKernelMode = true;
  pc           = systemCallTable [sysCallNum];
} else
  throw new IllegalSystemCall ();
```

IO-Controller interrupts revisited ...

Setting Up Other Protection Domains

- Any application can be a protection domain
  - we often call them “servers” or “daemons”
- Encapsulation
  - the application’s address space is private
- Public interface
  - implemented manually in application using message-passing
  - OS provides Inter-process Communication (IPC) interface (send/receive)
  - server sets up “communication endpoint” and waits to receive messages
  - callers send messages to request the server to perform a protected function
  - send/receive are system calls
- Calling a server
  - server calls receive, traps to the OS and blocks there
  - caller calls send, traps to OS
  - OS context switches to server, and unblocks server

Summary

- Single System Image
  - hardware implements a set of instructions needed by compilers
  - compilers translate programs into these instructions
  - translation assumes private memory and processor
- Threads
  - an abstraction implemented by software to manage asynchrony and concurrency
  - provides the illusion of single processor to applications
  - differs from processor in that it can be stopped and restarted
- Virtual Memory
  - an abstraction implemented by software and hardware
  - provides the illusion of a single, private memory to application
  - not all data need be in memory, paged in on demand
- Hardware Enforced Encapsulation
  - kernel mode register and VM mapping restriction
  - allows OS to export a public interface and to encapsulate (hide) the implementation