CS162
Operating Systems and Systems Programming
Lecture 3

Processes (con't), Fork, Introduction to I/O

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http://cs162.eecs.Berkeley.edu

Recall: Four fundamental OS concepts

- Thread
  - Single unique execution context
  - Program Counter, Registers, Execution Flags, Stack
- Address Space w/ Translation
  - Programs execute in an *address space* that is distinct from the memory space of the physical machine
- Process
  - An instance of an executing program is *a process consisting of an address space and one or more threads of control*
- Dual Mode operation/Protection
  - Only the "system" has the ability to access certain resources
  - The OS and the hardware are protected from user programs and user programs are isolated from one another by *controlling the translation* from program virtual addresses to machine physical addresses

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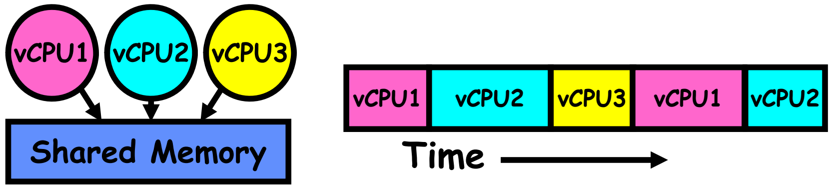
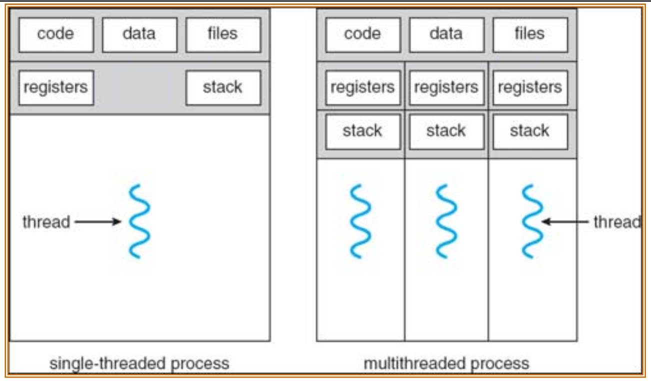
Recall: give the illusion of multiple processors?



- Assume a single processor. How do we provide the *illusion* of multiple processors?
  - Multiplex in time!
  - Multiple "virtual CPUs"
- Each virtual "CPU" needs a structure to hold:
  - Program Counter (PC), Stack Pointer (SP)
  - Registers (Integer, Floating point, others…?)
- How switch from one virtual CPU to the next?
  - Save PC, SP, and registers in current state block
  - Load PC, SP, and registers from new state block
- What triggers switch?
  - Timer, voluntary yield, I/O, other things

Single and Multithreaded Processes



- Threads encapsulate concurrency: "Active" component
- Address spaces encapsulate protection: "Passive" part
  - Keeps buggy program from trashing the system
- Why have multiple threads per address space?

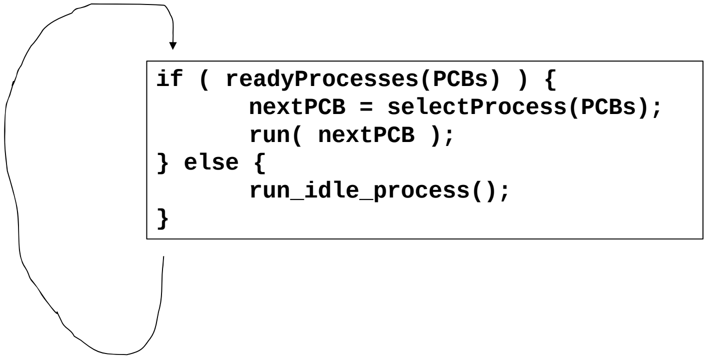
Running Many Programs

- We have the basic mechanism to
  - switch between user processes and the kernel,
  - the kernel can switch among user processes,
  - Protect OS from user processes and processes from each other
- Questions ???
  - How do we represent user processes in the OS?
  - How do we decide which user process to run?
  - How do we pack up the process and set it aside?
  - How do we get a stack and heap for the kernel?
  - Aren't we wasting are lot of memory?
  - …

Process Control Block

- Kernel represents each process as a process control block (PCB)
  - Status (running, ready, blocked, …)
  - Register state (when not ready)
  - Process ID (PID), User, Executable, Priority, …
  - Execution time, …
  - Memory space, translation, …
- Kernel Scheduler maintains a data structure containing the PCBs
- Scheduling algorithm selects the next one to run

Scheduler

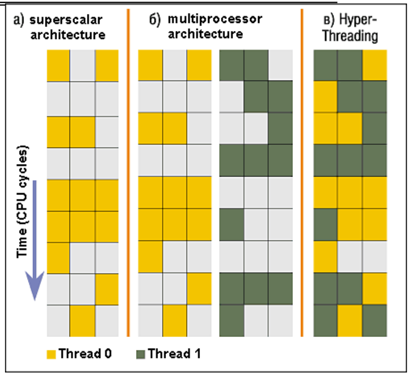


```
if ( readyProcesses(PCBs) ) {
        nextPCB = selectProcess(PCBs);
        run( nextPCB );
} else {
        run_idle_process();
}
```

- Scheduling: Mechanism for deciding which processes/threads receive the CPU
- Lots of different scheduling policies provide …
  - Fairness or
  - Realtime guarantees or
  - Latency optimization or ..

Simultaneous MultiThreading/Hyperthreading

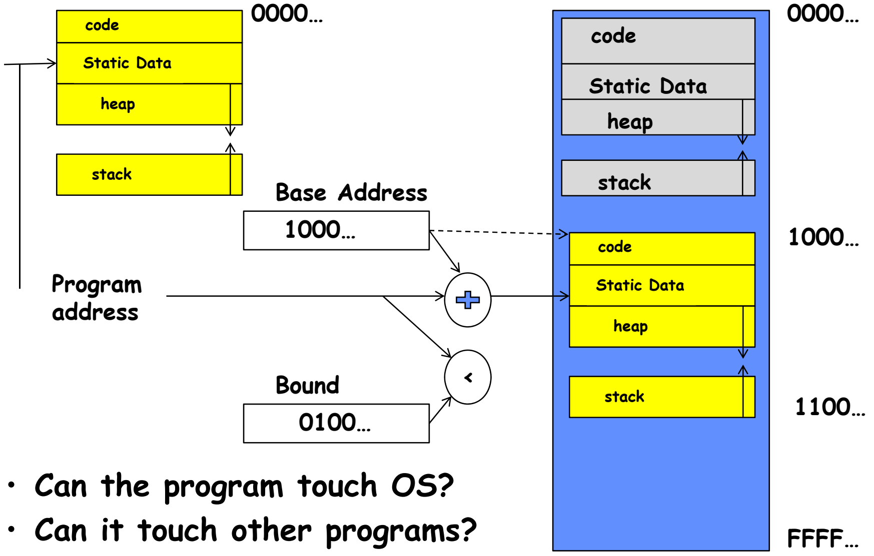
- Hardware technique
  - Superscalar processors can execute multiple instructions that are independent.
  - Hyperthreading duplicates register state to make a second "thread," allowing more instructions to run.
- Can schedule each thread as if were separate CPU
  - But, sub-linear speedup!



Colored blocks show instructions executed

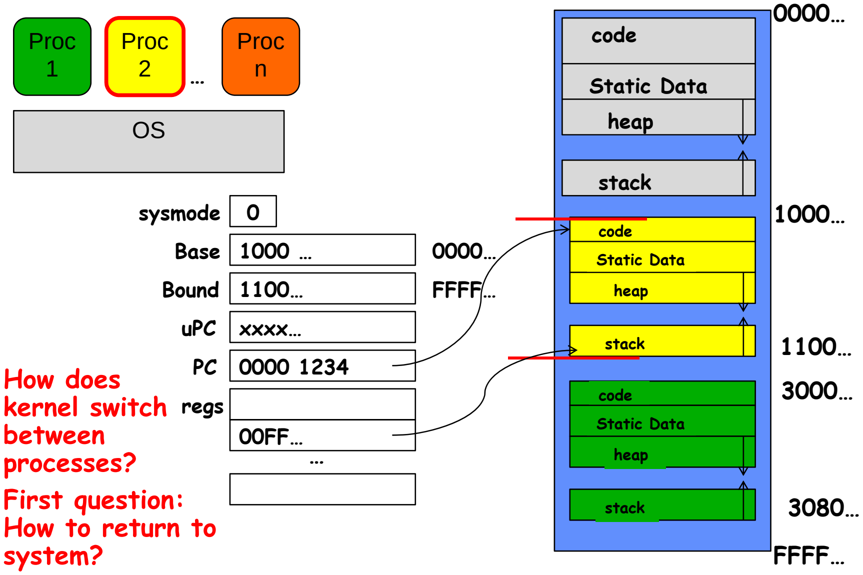
- Original technique called "Simultaneous Multithreading"
  - http://www.cs.washington.edu/research/smt/index.html
  - SPARC, Pentium 4/Xeon ("Hyperthreading"), Power 5

Recall: A simple address translation (B&B)



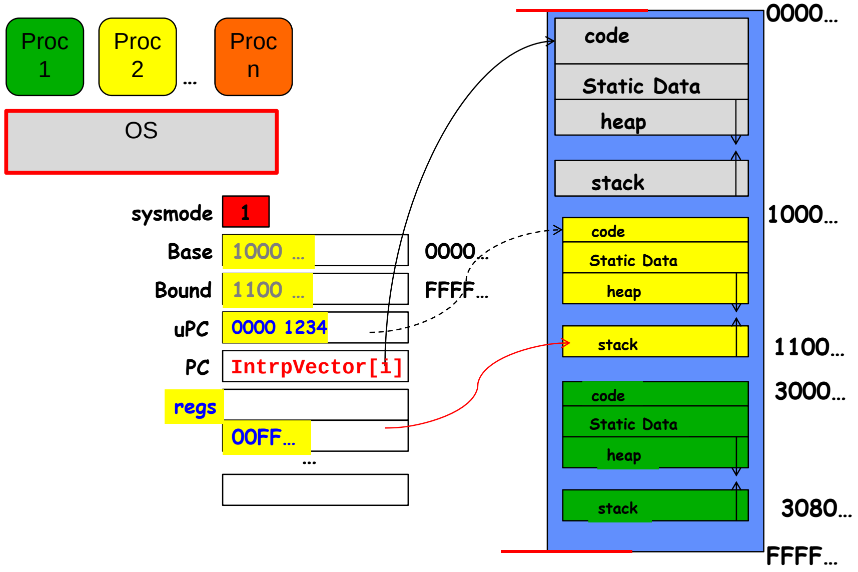
- Can the program touch OS?
- Can it touch other programs?

Simple B&B: User code running

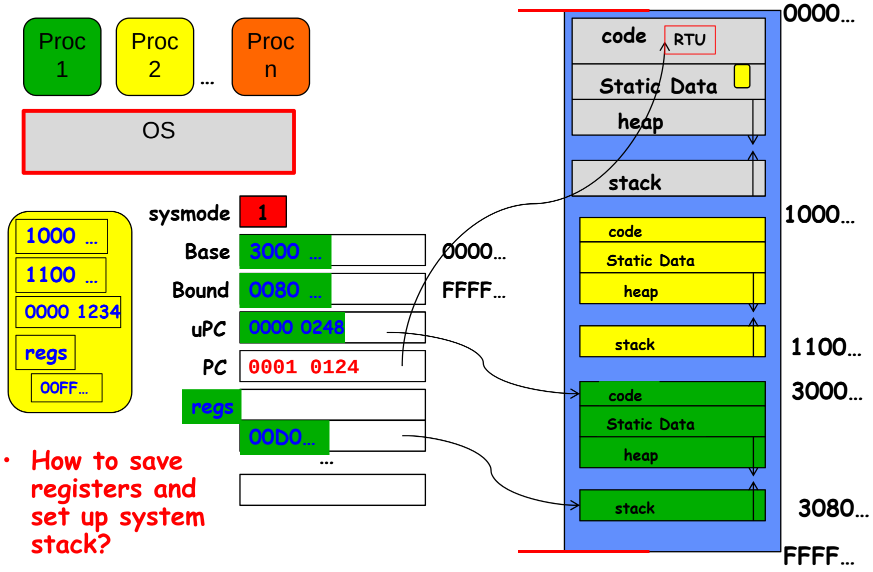


- How does kernel switch between processes?
- First question: How to return to system?

Simple B&B: Interrupt

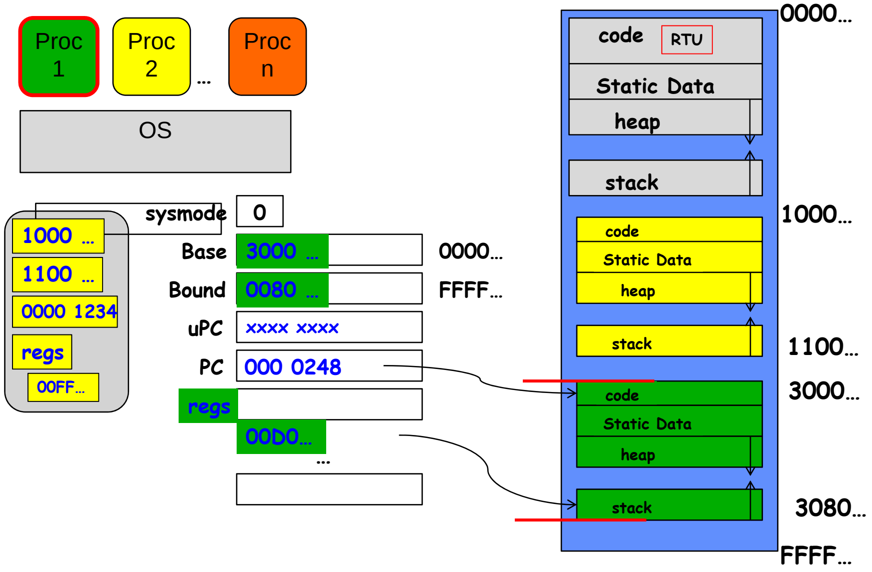


Simple B&B: Switch User Process



- How to save registers and set up system stack?

Simple B&B: "resume"



What's wrong with this simplistic address translation mechanism?

- Fragmentation:
  - Kernel has to somehow fit whole processes into contiguous block of memory
  - After a while, memory becomes fragmented!
- Sharing:
  - Very hard to share any data between Processes or between Process and Kernel
  - Simple segmentation prevents any memory sharing by its very nature

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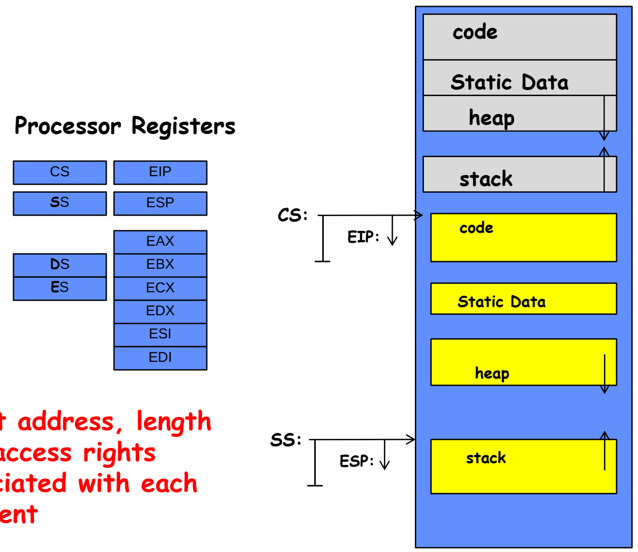
x86 – segments and stacks



Start address, length and access rights associated with each segment

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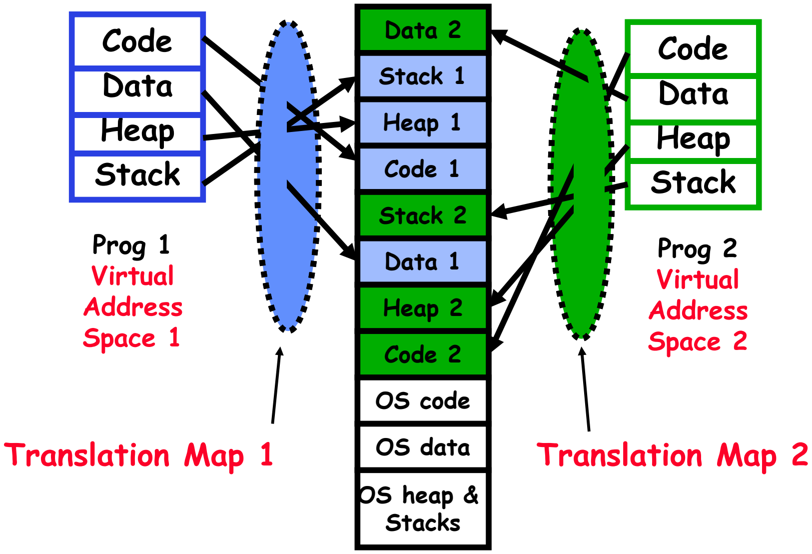
Alternative: Address Mapping



Physical Address Space

Administrivia: Getting started

- Kubiatowicz Office Hours:
  - 1pm-2pm, Monday/Wednesday
- Homework 0 immediately ⇒ Due on Monday!
  - Get familiar with all the cs162 tools
  - Submit to autograder via git
- Should be going to section already!
  - Participation: Get to know your TA!
- Friday is Drop Deadline!
- Group sign up form out next week (after drop deadine)
  - Get finding groups ASAP
  - 4 people in a group! Try to keep same section; if cannot make this work, keep same TA

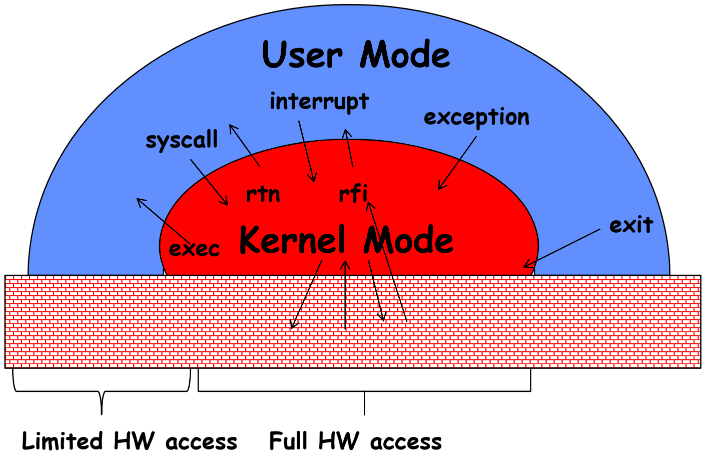
Administrivia (Con't)

- Conflict between Midterm 2 and EE16A
  - We are thinking of moving Midterm 2 from Wed 11/18
  - Posibilites: Mon 11/23 (my favorite) or Mon 11/16
- Midterm 1 conflicts
  - I know about one problem with Midterm 1 scheduling, and it can be dealt with. Have I missed any others?
- Finals conflicts: We will not be moving the exam or providing makeup finals…
  - I don't know of any current conflicts
  - If you have a significant conflict that you think should cause us to change our policy, let me know now (note that CS186 is not conflicting any more).

Recall: 3 types of Kernel Mode Transfer

- Syscall
  - Process requests a system service, e.g., exit
  - Like a function call, but "outside" the process
  - Does not have the address of the system function to call
  - Like a Remote Procedure Call (RPC) – for later
  - Marshall the syscall id and args in registers and exec syscall
- Interrupt
  - External asynchronous event triggers context switch
  - eg. Timer, I/O device
  - Independent of user process
- Trap or Exception
  - Internal synchronous event in process triggers context switch
  - e.g., Protection violation (segmentation fault), Divide by zero, …

Recall: User/Kernal(Priviledged) Mode

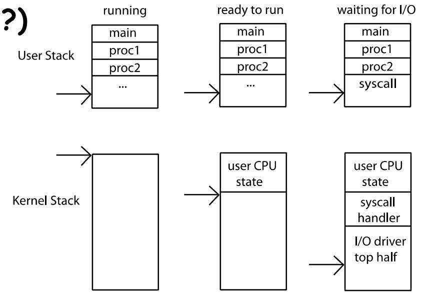


Implementing Safe Kernel Mode Transfers

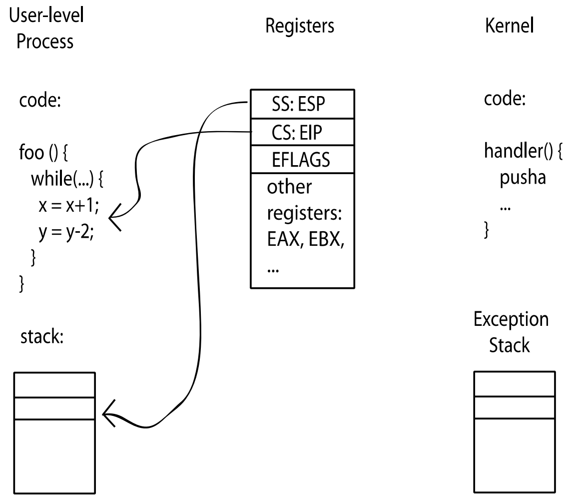
- Important aspects:
  - Separate kernel stack
  - Controlled transfer into kernel (e.g. syscall table)
- Carefully constructed kernel code packs up the user process state and sets it aside.
  - Details depend on the machine architecture
- Should be impossible for buggy or malicious user program to cause the kernel to corrupt itself.

Need for Separate Kernel Stacks

- Kernel needs space to work
- Cannot put anything on the user stack (Why?)
- Two-stack model
  - OS thread has interrupt stack (located in kernel memory) plus User stack (located in user memory)
  - Syscall handler copies user args to kernel space before invoking specific function (e.g., open)
  - Interrupts (???)



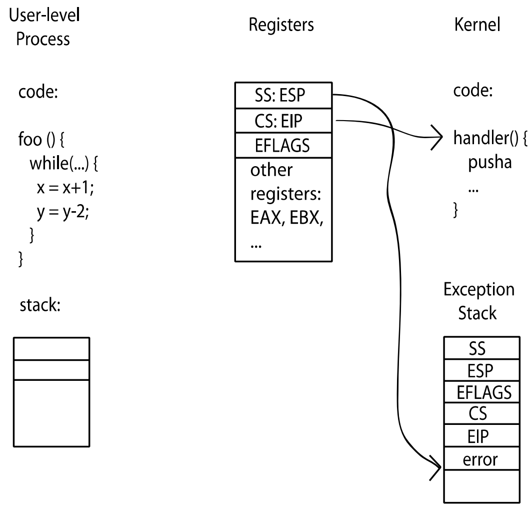
Before



```
foo () {
  while(...) {
    x = x+1;
    y = y-2;
  }
}
```

```
handler() {
  pusha
  ...
}
```

During



```
foo () {
  while(...) {
    x = x+1;
    y = y-2;
  }
}
```

```
handler() {
  pusha
  ...
}
```

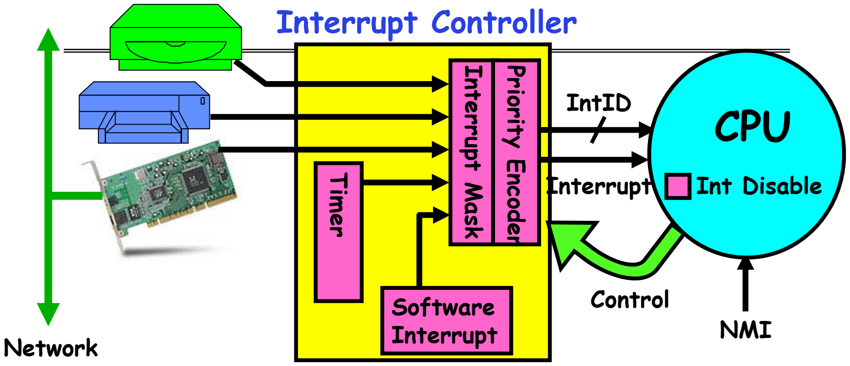
Kernel System Call Handler

- Vector through well-defined syscall entry points!
  - Table mapping system call number to handler
- Locate arguments
  - In registers or on user(!) stack
- Copy arguments
  - From user memory into kernel memory
  - Protect kernel from malicious code evading checks
- Validate arguments
  - Protect kernel from errors in user code
- Copy results back
  - into user memory

Hardware support: Interrupt Control

- Interrupt processing not be visible to the user process:
  - Occurs between instructions, restarted transparently
  - No change to process state
  - What can be observed even with perfect interrupt processing?
- Interrupt Handler invoked with interrupts 'disabled'
  - Re-enabled upon completion
  - Non-blocking (run to completion, no waits)
  - Pack up in a queue and pass off to an OS thread for hard work
    - » wake up an existing OS thread
- OS kernel may enable/disable interrupts
  - On x86: CLI (disable interrupts), STI (enable)
  - Atomic section when select next process/thread to run
  - Atomic return from interrupt or syscall
- HW may have multiple levels of interrupt
  - Mask off (disable) certain interrupts, eg., lower priority
  - Certain non-maskable-interrupts (nmi)
    - » e.g., kernel segmentation fault

Interrupt Controller

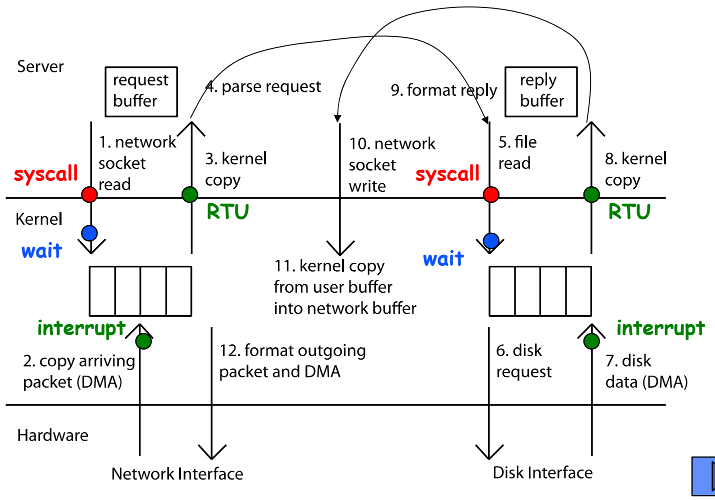


- Interrupts invoked with interrupt lines from devices
- Interrupt controller chooses interrupt request to honor
  - Mask enables/disables interrupts
  - Priority encoder picks highest enabled interrupt
  - Software Interrupt Set/Cleared by Software
  - Interrupt identity specified with ID line
- CPU can disable all interrupts with internal flag
- Non-maskable interrupt line (NMI) can't be disabled

How do we take interrupts safely?

- Interrupt vector
  - Limited number of entry points into kernel
- Kernel interrupt stack
  - Handler works regardless of state of user code
- Interrupt masking
  - Handler is non-blocking
- Atomic transfer of control
  - "Single instruction"-like to change:
    - » Program counter
    - » Stack pointer
    - » Memory protection
    - » Kernel/user mode
- Transparent restartable execution
  - User program does not know interrupt occurred

Putting it together: web server



Can a process create a process ?

- **Yes**
  - **Unique identity of process is the "process ID" (or pid).**
- **Fork() system call creates a *copy* of current process with a new pid**
- **Return value from Fork(): integer**
  - **When > 0:**
    - » **Running in (original) Parent process**
    - » **return value is pid of new child**
  - **When = 0:**
    - » **Running in new Child process**
  - **When < 0:**
    - » **Error! Must handle somehow**
    - » **Running in original process**
- **All of the state of original process duplicated in both Parent and Child!**
  - **Memory, File Descriptors (next topic), etc…**

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fork1.c

```
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include <unistd.h>
#include <sys/types.h>

#define BUFSIZE 1024
int main(int argc, char *argv[])
{
  char buf[BUFSIZE];
  size_t readlen, writelen, slen;
  pid_t cpid, mypid;
  pid_t pid = getpid();         /* get current processes PID */
  printf("Parent pid: %d\n", pid);
  cpid = fork();
  if (cpid > 0) {                   /* Parent Process */
    mypid = getpid();
    printf("[%d] parent of [%d]\n", mypid, cpid);
  }  else if (cpid == 0) {          /* Child Process */
    mypid = getpid();
    printf("[%d] child\n", mypid);
  } else {
    perror("Fork failed");
    exit(1);
  }
  exit(0);
}
```

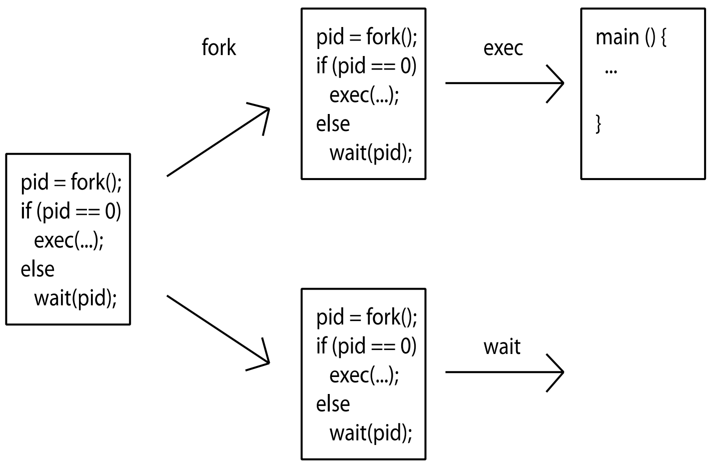
UNIX Process Management

- **UNIX fork – system call to create a copy of the current process, and start it running**
  - **No arguments!**
- **UNIX exec – system call to *change the program* being run by the current process**
- **UNIX wait – system call to wait for a process to finish**
- **UNIX signal – system call to send a notification to another process**

fork2.c

```
int status;
…
cpid = fork();
if (cpid > 0) {               /* Parent Process */
  mypid = getpid();
  printf("[%d] parent of [%d]\n", mypid, cpid);
  tcpid = wait(&status);
  printf("[%d] bye %d(%d)\n", mypid, tcpid, status);
}  else if (cpid == 0) {      /* Child Process */
  mypid = getpid();
  printf("[%d] child\n", mypid);
}
…
```

UNIX Process Management



```
pid = fork();
if (pid == 0)
  exec(...);
else
  wait(pid);
```

fork

```
pid = fork();
if (pid == 0)
  exec(...);
else
  wait(pid);
```

exec

```
main () {
  …

}
```

```
pid = fork();
if (pid == 0)
  exec(...);
else
  wait(pid);
```

wait

Shell

- A shell is a job control system
  - Allows programmer to create and manage a set of programs to do some task
  - Windows, MacOS, Linux all have shells
- Example: to compile a C program

```
cc –c sourcefile1.c
cc –c sourcefile2.c
ln –o program sourcefile1.o sourcefile2.o
./program
```

Signals – infloop.c

Got top?

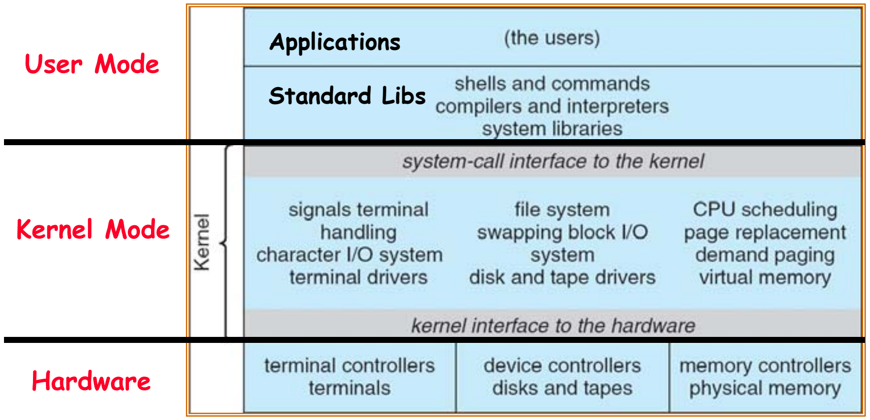
```
#include <stdlib.h>
#include <stdio.h>
#include <sys/types.h>

#include <unistd.h>
#include <signal.h>

void signal_callback_handler(int signum)
{
  printf("Caught signal %d - phew!\n",signum);
  exit(1);
}

int main() {
  signal(SIGINT, signal_callback_handler);

  while (1) {}
}
```

Process races: fork.c

```
if (cpid > 0) {
   mypid = getpid();
   printf("[%d] parent of [%d]\n", mypid, cpid);
   for (i=0; i<100; i++) {
     printf("[%d] parent: %d\n", mypid, i);
     //      sleep(1);
   }
 }  else if (cpid == 0) {
   mypid = getpid();
   printf("[%d] child\n", mypid);
   for (i=0; i>-100; i--) {
     printf("[%d] child: %d\n", mypid, i);
     //      sleep(1);
   }
 }
```

- Question: What does this program print?
- Does it change if you add in one of the sleep() statements?

Recall: UNIX System Structure



User Mode

Kernel Mode

Hardware

Applications (the users)

Standard Libs shells and commands
compilers and interpreters
system libraries

Kernel

system-call interface to the kernel

signals terminal handling
character I/O system
terminal drivers

file system
swapping block I/O system
disk and tape drivers

CPU scheduling
page replacement
demand paging
virtual memory

kernel interface to the hardware

terminal controllers
terminals

device controllers
disks and tapes

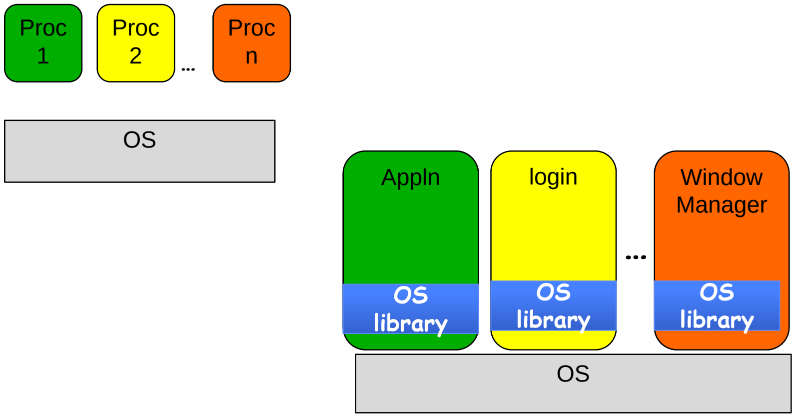
memory controllers
physical memory

How does the kernel provide services?

- You said that applications request services from the operating system via *syscall*, but …
- I've been writing all sort of useful applications and I never ever saw a "syscall" !!!

- That's right.
- It was buried in the programming language runtime library (e.g., libc.a)
- … Layering

OS run-time library



Proc 1

Proc 2

…

Proc n

OS

Appln

login

…

Window Manager

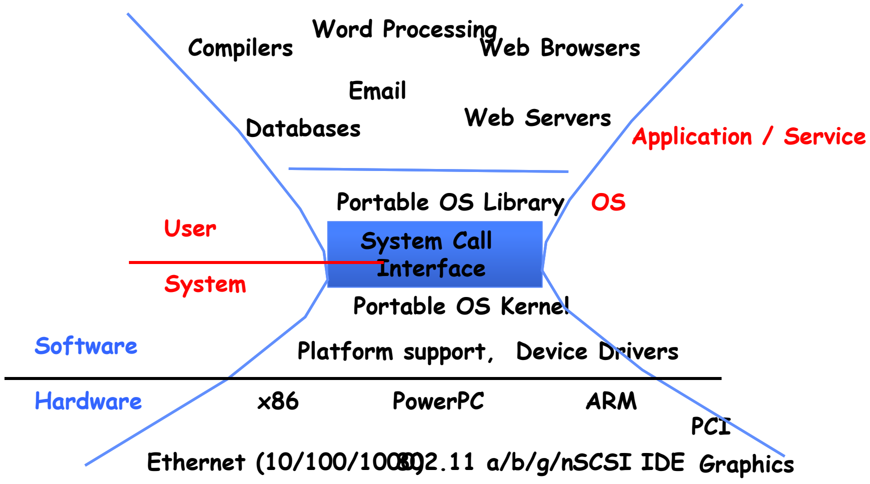
OS library

OS library

OS library

OS

A Kind of Narrow Waist



Compilers
Word Processing
Web Browsers
Email
Databases
Web Servers
Application / Service
Portable OS Library
OS
User
System Call Interface
System
Portable OS Kernel
Software
Platform support, Device Drivers
Hardware
x86
PowerPC
ARM
PCI
Ethernet (10/100/1000)
802.11 a/b/g/n
SCSI
IDE
Graphics

Key Unix I/O Design Concepts

- Uniformity
  - file operations, device I/O, and interprocess communication through open, read/write, close
  - Allows simple composition of programs
    - » find | grep | wc …
- Open before use
  - Provides opportunity for access control and arbitration
  - Sets up the underlying machinery, i.e., data structures
- Byte-oriented
  - Even if blocks are transferred, addressing is in bytes
- Kernel buffered reads
  - Streaming and block devices looks the same
  - read blocks process, yielding processor to other task
- Kernel buffered writes
  - Completion of out-going transfer decoupled from the application, allowing it to continue
- Explicit close

Summary

- Process: execution environment with Restricted Rights
  - Address Space with One or More Threads
  - Owns memory (address space)
  - Owns file descriptors, file system context, …
  - Encapsulate one or more threads sharing process resources
- Interrupts
  - Hardware mechanism for regaining control from user
  - Notification that events have occurred
  - User-level equivalent: Signals
- Native control of Process
  - Fork, Exec, Wait, Signal
- Basic Support for I/O
  - Standard interface: open, read, write, seek
  - Device drivers: customized interface to hardware