csci 297: Advanced Operating Systems

- Professor Gabriel Parmer (aka. Gabe) gparmer@gwu.edu, office hours 10am-12 Tuesday (Tentative. Does this work for you?)

- Class: Tompkins 205, Monday 6:10-8:40

Acknowledgements: Some slide material derived from Silberschatz, et al.

Today

1) Administrative information
   - Course requirements
   - Grading
2) What's an OS
3) Research OSes vs. Real-World Oses
4) Meet the Hardware
   - Background for reading this week

Administrative Info

- Paper-based class
  - We will read research papers
  - You will present them
  - We will discuss them

- Semester-long project
  - In-depth implementation study within OS

Grading

- Class participation
- Class presentations
- Final project

...that's it.

Class Participation

1) Class attendance
2) Contributions to the class discussion

   ...no zombies in class

   - questions/comments/stories/...
   - Always interrupt me

3) Paper summaries

   - 1-3 sentence summary of the purpose of the paper
   - Questions: you are not expected to know everything
   - What you liked, and what you identified as limitations
   - Due night before class (Sunday 11:59pm)

Class Presentations

- 1-2 presentations each
- Read a research paper, and do a 30 minute presentation on it
  - You will be stopped frequently
  - Goal: foster and encourage discussion
- A useful skill
- Read papers for next class on Schedule

Project

- Implementation experience with a real OS
  - Significant contribution
- C
  - You don't have to be an expert, but you have to know your way around (pointers, data-structs,...)
    - And know another language well
  - Debugging is the hard part

Project II

- Do you have a systems-y project in mind?
  - Are you already doing work with a systems flavor?
- Double-dipping policy:
  - You can certainly do a project that you are using for another class, for your research, or for entertainment
  - You just have to OK it with me and talk about goals

Project III

- Most of you will *not* have a project in mind
  - Great!
- I have a number of them
  - Most are in the *Composite* OS, a GW-native OS
    - Can come to me with implementation difficulties
  - Linux
    - I can help to some degree
  - Other
    - More than welcome, but I can't guarantee I can help

Project IV

- Possibility for publication
  - But this will be a *lot* more work
  - Don't have to just get something working, but also
    - Evaluate it rigorously
    - Write a paper

Project Timetable

...webpage...

Course Materials

- Course papers and *Composite* virtual machine
  - Too large for blackboard (VM is 1.5G)
- ssh/sftp to <contact me for ip> (write this down)
  - User: <contact me>
  - Password: <contact me>
- VMWare player/workstation
  - I have licenses if needed (e.g. if you use OS X)

What is an Operating System!?

- What does an OS do?
- What is the purpose of an OS?

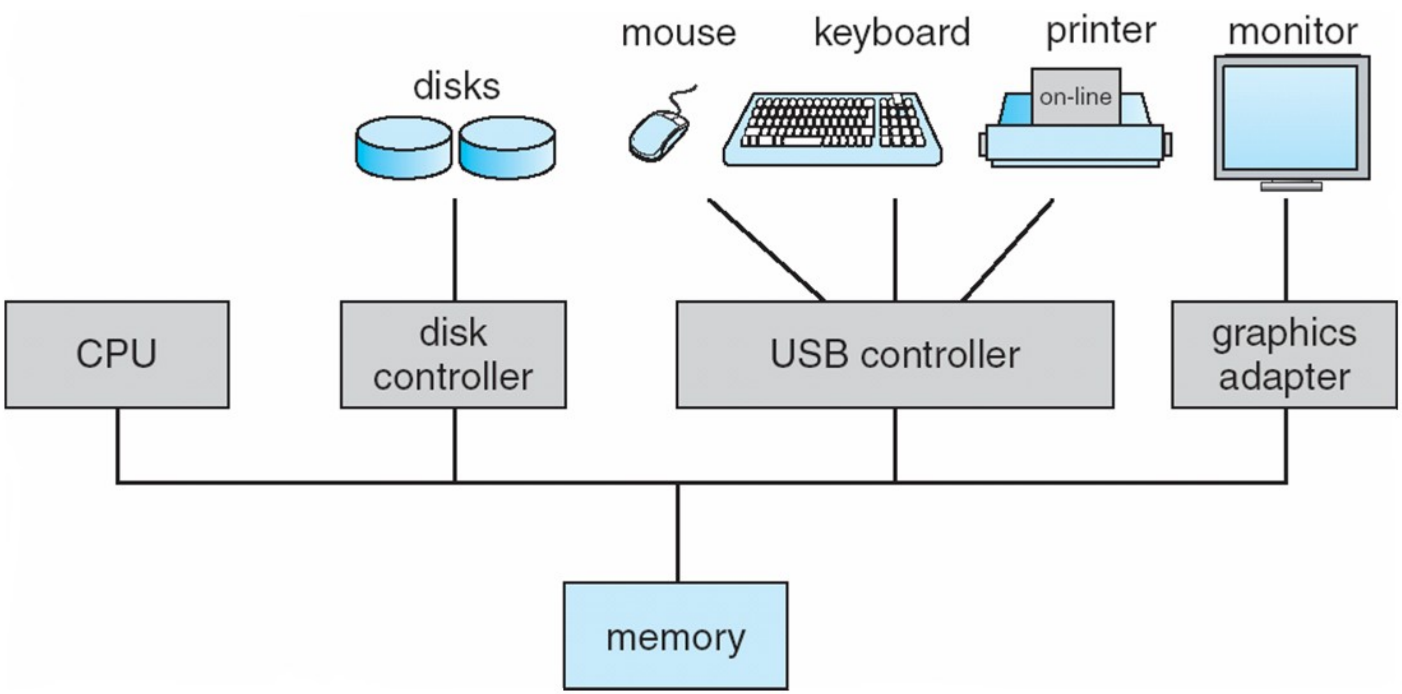
Operating System as Abstraction

- "The effective exploitation of his powers of abstraction must be regarded as one of the most vital activities of a competent programmer." - Edsger W. Dijkstra

- Allow users to translate intentions into actions
- Provide environment in which applications can execute
  - Each application believes it is sole user of HW

Computers as Distributed Systems

"Hardware: The parts of a computer system that can be kicked."
- Jeff Pesis



OS as Hardware Manager

- Control a diverse set of hardware
  - Processors
  - Memory
  - Disks
  - Networking cards
  - Video cards
- Coordinates these hardware resources amongst user programs

Policy/Mechanism Separation in Hydra

- Mechanism: a utility or resource that can be used in a specific manner
- Policy: the algorithm or logic that determines how to use a mechanism
- A policy at one level might be a mechanism for a higher level of *abstraction*
  - Disk → blocks in mem → files → database → …
  - Sequential exec → threads → scheduling → ...

Policy/Mechanism Separation in Hydra

- OSes are concerned with building policy and mechanism
- Create a usable abstraction to achieve a system's goals

Source: xkcd.com

Fundamental OS Concepts

- Abstraction
- Concurrency
- Parallelism
- Resource management
- Protection
- Performance
  - Kernel doesn't *do* useful work, enables it

Course Topics

- System Structure
- Data Movement
- Accounting
- Concurrency
  - Threading models
- Parallelism
- Reliability
- Security

- Keep in mind any preferences you may have between topics

Research Papers

- We will be reading old and new papers...

  ...about systems...

  ...that noone uses.

- If the proposed systems aren't being used, why do we care
  - Competitive environment: that which is best will prevail, right?

The Rise of “Worse is Better”

- Richard Gabriel – lisp researcher
- 1991
- Lisp vs Unix/C

```
    evalquote[fn;x] = apply[fn;x;NIL]

where

    apply[fn;x;a] =
          [atom[fn] → [eq[fn;CAR] → caar[x];
                       eq[fn;CDR] → cdar[x];
                       eq[fn;CONS] → cons[car[x];cadr[x]];
                       eq[fn;ATOM] → atom[car[x]];
                       eq[fn;EQ] → eq[car[x];cadr[x]];
                       T → apply[eval[fn;a];x;a]];
          eq[car[fn];LAMBDA] → eval[caddr[fn];pairlis[cadr[fn];x;a]];
          eq[car[fn];LABEL] → apply[caddr[fn];x;cons[cons[cadr[fn];
                                                   caddr[fn]];a]]]
    eval[e;a] = [atom[e] → cdr[assoc[e;a]];
          atom[car[e]] →
                    [eq[car[e],QUOTE] → cadr[e];
                    eq[car[e];COND] → evcon[cdr[e];a];
                    T → apply[car[e];evlis[cdr[e];a];a]];
          T → apply[car[e];evlis[cdr[e];a];a]]

pairlis and assoc have been previously defined.

    evcon[c;a] = [eval[caar[c];a] → eval[cadar[c];a];
                  T → evcon[cdr[c];a]]
and
    evlis[m;a] = [null[m] → NIL;
                  T → cons[eval[car[m];a];evlis[cdr[m];a]]]
```

vs.

```
char buff[4];
strcpy(buff, “fail”);
```

Source: LISP 1.5 Programmers Manual, 1985

Intertia vs. “The right thing”

- Normal OS class: how systems we use work

- This class:
  - Will include some of how current systems work
  - Focus on non-typical design decisions to explore the possibilities of OSes

Intertia vs. "The right thing" II

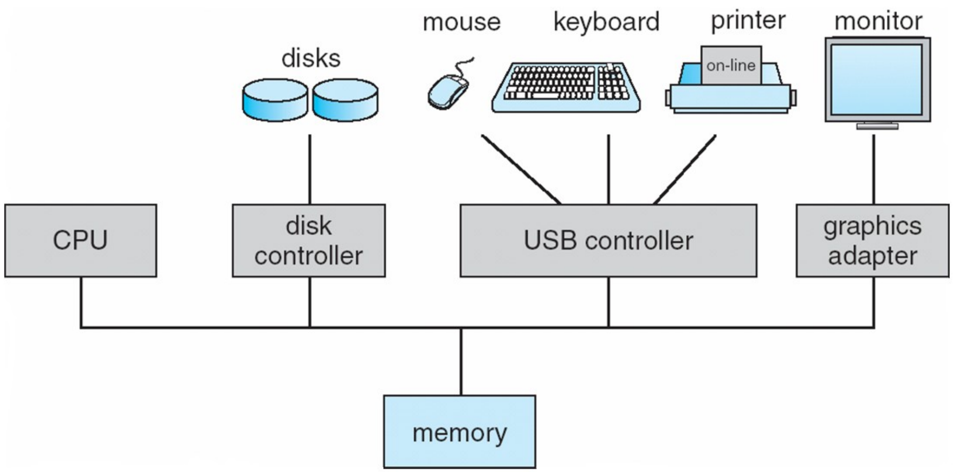
- Why read these papers?
  - Understanding different design's trade-offs makes us better understand the systems we do use
  - The computing environment changes
    - Hardware – multicore
    - Culture/economics – power/cloud
    - Requires "out of the box" thinking

Blank Slate

- Hardware as a blank slate
  - Where do we go from there?
- Each paper in this class approaches this question differently
- Next slides: what does this blank slate look like?

Basic Hardware: Mechanism

- CPU – sequential execution
- Memory – large array of *physical* memory
- Devices –
  - Receive instructions from CPU...
  - Over a distributed system...



  - To interact with the outside world

Complicating the CPU

- Sequential execution:
  - Stream of instructions are executed
  - Manipulate *registers* and memory
  - Use *stack* for storage/bookkeeping
- Wish to execute multiple applications

  → multiple sequential streams of instructions
  - Switch between these *threads*: dispatching mechanism

```
struct thread *current, *next;
switch_regs(current, next)
```

```
switch_regs:
        mov %a, current->regs.a
        …
        mov %sp, current->regs.sp
        mov post_switch, current->regs.ip
        mov next->regs.a, %a
        …
        mov next->regs.sp, %sp
        jmp next->regs.ip
post_switch:
        ret
```

Do threads complicate the system as a whole?

Complicating Memory

- Want multiple applications
- Protection – reliability and security
  - Segregate diff system parts from each other: Virtual Mem
  - Memory accesses in virtual address space
- Virtual memory mechanism provided by hardware
  - Paging/segmentation/etc...

Complicating Memory II

- System complications:
  - Page-table maintenance
  - Overhead of switching between address spaces:
    `mov pgtbl_addr, %cr3` = 300-800 cycles on P4
- Hydra – "Given that user-level policy programs must execute in their own protection domains, and that domain switching is costly..., it is impractical to invoke such programs each time a policy decision is required.

  Thus we compromise. We give this compromise a name: the principle of policy/mechanism separation."

Complicating Devices

- General operations (type of data/device differs):
  - CPU → Device: transfer data @ address *x* to the device
  - CPU → Device: when you have data ready (?), transfer it to address *y* in memory
  - Direct Memory Access (DMA)
- How does the CPU know when the device has placed new data at *y*?

Complicating Devices II

- Devices can raise *interrupts* on CPU
  - Halt current stream of instructions
    - Save some register state such as instruction ptr (where?)
  - Begin execution of an interrupt service routine (ISR)
    - Understands how to communicate with device
  - Interrupts can happen at any time
    - Except when they are disabled: cli … sti

How do interrupts complicate the system?

Done?

- With these hardware-provided mechanisms
  - Do we have the necessary building blocks for complex systems?
    - With multiple applications

- What else do we need from hardware? Why?

Separation of Privileges

- Can all applications
  - Switch page tables?
  - Switch between any threads?
  - Send commands to devices?
  - Disable interrupts?

- What keeps them from doing this?

Separation of Privileges II

- Dual-mode execution
  - User-mode
    - Applications execute in user-mode in protection domains
    - Cannot execute sensitive instructions
    - Cannot access kernel memory (memory marked with mode)
  - Kernel-mode
    - *Trusted* code
    - Can execute sensitive instructions (cli, sti, mov cr3, …)
    - Creates and manages protection domains
    - The *kernel*!

System Calls

User-level syscall function:

```
    mov syscall_num, %eax
    /* save normal regs */
    push %ebp
    mov %esp, %ebp
    mov $1f, %ecx
    sysenter
1:
    mov %eax, 0
    pop %ebp
    /* restore normal regs */
```

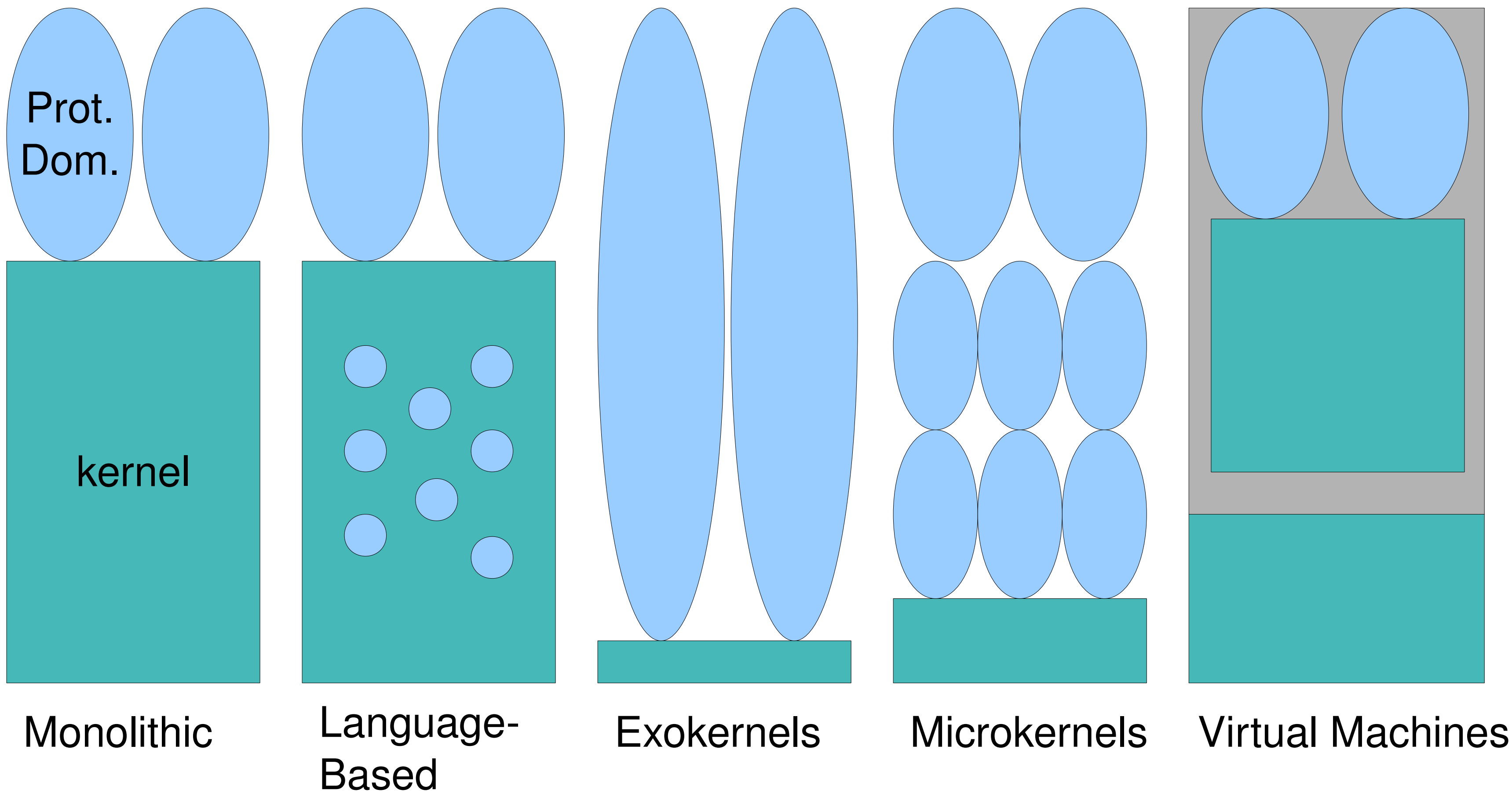
Kernel system call handler:

```
    pushl %ebp /* user-sp */
    pushl %ecx /* user-ip */
    call *cos_syscall_tbl(,%eax,4)
    popl %edx /* user-ip */
    popl %ecx /* and  sp */
    sysexit
```

- Sysenter instruction changes the mode from user → kernel
- Sysexit does opposite

System Structure

- Defines
  - how different *parts* of the system (or *subsystems)* interact
  - the separation of mechanism/policy throughout the system



Bias

- As you read papers, please, choose sides
  - What do you like about specific approaches?
  - And what are the limitations?
  - And always: what is new about the paper (contributions)

- Which systems present the best trade-offs?

Volunteers

- Two system structure papers 2 weeks from today...

- Everyone: Email me with
  - Your interests
  - If you have any projects you're already working on
  - Which topics/titles (on the schedule) are most interesting to you