What is an OS?

Science Computer Science

CS 450: Operating Systems

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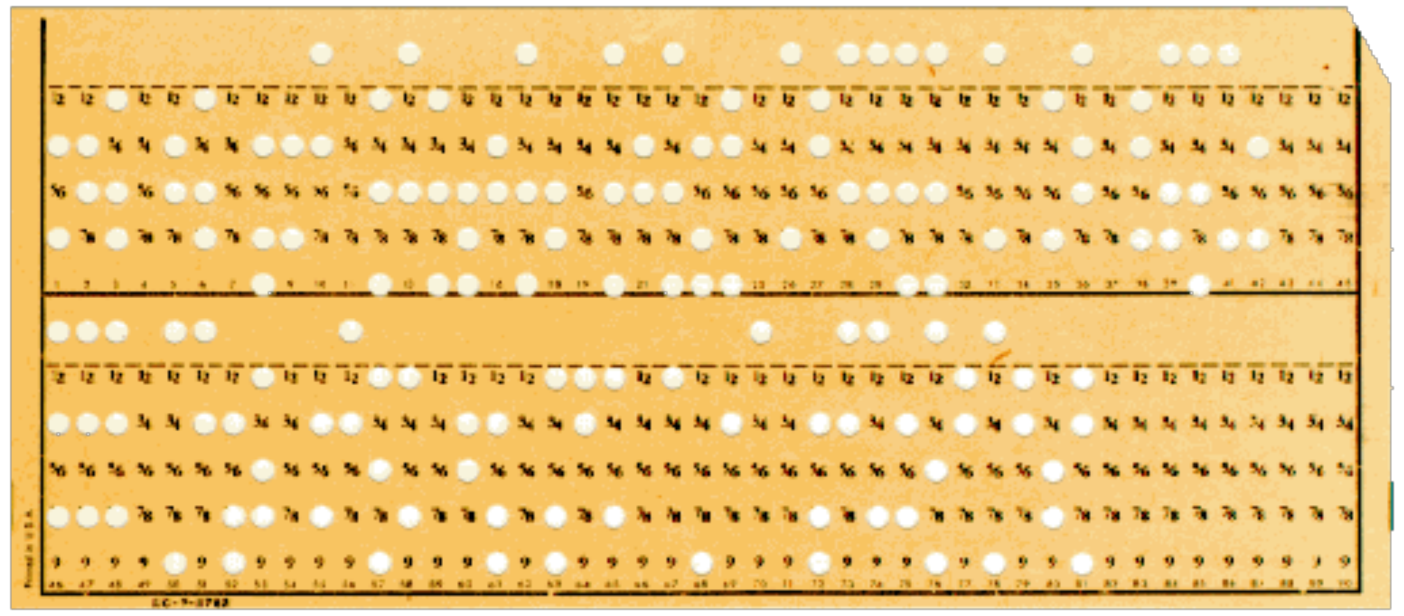
Agenda

- Road to the modern OS
- OS responsibilities
- OS privileges
- OS organization
- Summary

§ Road to the modern OS

1950s: Batch processing



- A program is completely defined by a “batch” of punchcards
- Batches are manually fed into mainframes, which execute *a single batch at a time* (a “job”)
- Programmer defines *any and all routines* needed for the job
  - E.g., for controlling and accessing specific I/O devices

1950s-1960s: Support libraries

- Useful, reusable routines (e.g., for math, I/O) distributed as collections of punchcards
- These routines can be “linked” (manually) into programs without much modification
- First support libraries = the original OSes
  - No standardization!

1960s: Automatic batch processing

- To keep up with faster processors, reading and starting/transitioning between jobs require automation
- “Monitor” programs also keep track of usage, resources expended, etc.
  - Grew to become *runtime libraries* that automatically manage the execution of multiple batches of jobs (in sequence)

Pros/Cons of Batch processing

- Pros
  - Full use of hardware
  - No worrying about other jobs during execution

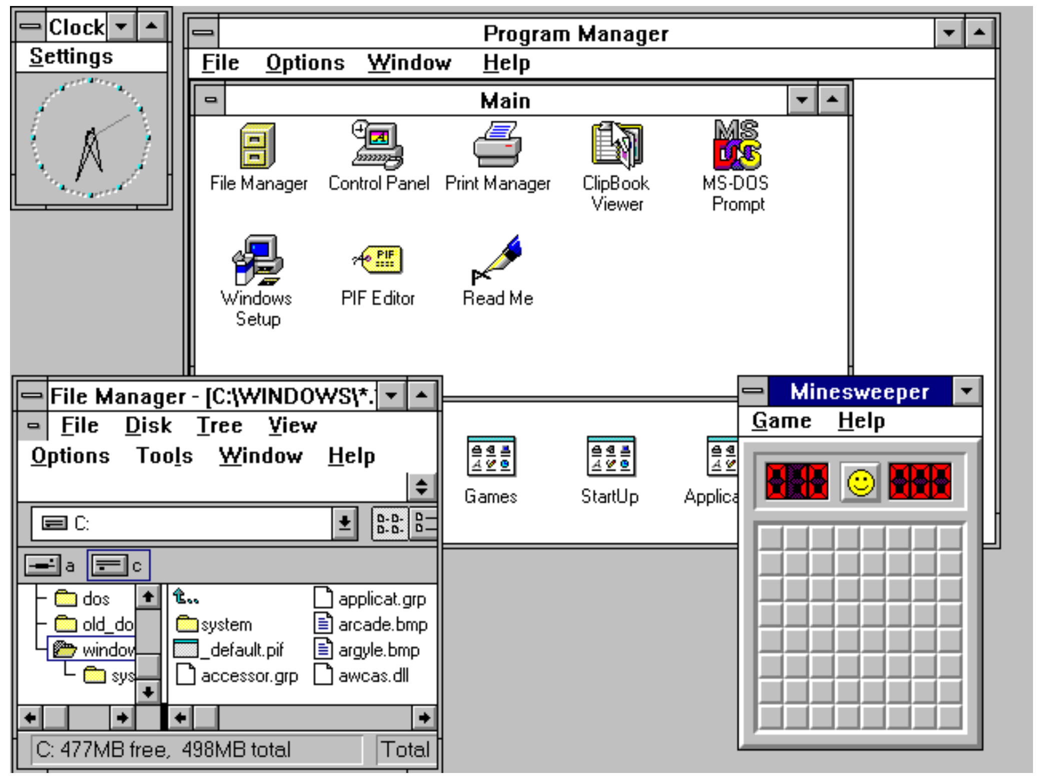
- Cons
  - No interactivity
  - No live debugging
  - No feedback loop
  - Poor hardware utilization
  - Do everything yourself!

1970s: Rise of Timesharing

- To let many users share a computer *concurrently*, software is needed to *automatically save/restore context* between jobs
  - Resources (e.g., CPU & memory) are *virtualized*
  - Jobs are *isolated* and *protected* from each other
  - Resulted in a lot of system overhead, but offset by interactivity and improved hardware utilization
- Development and availability of UNIX on mainframes and "minicomputers"

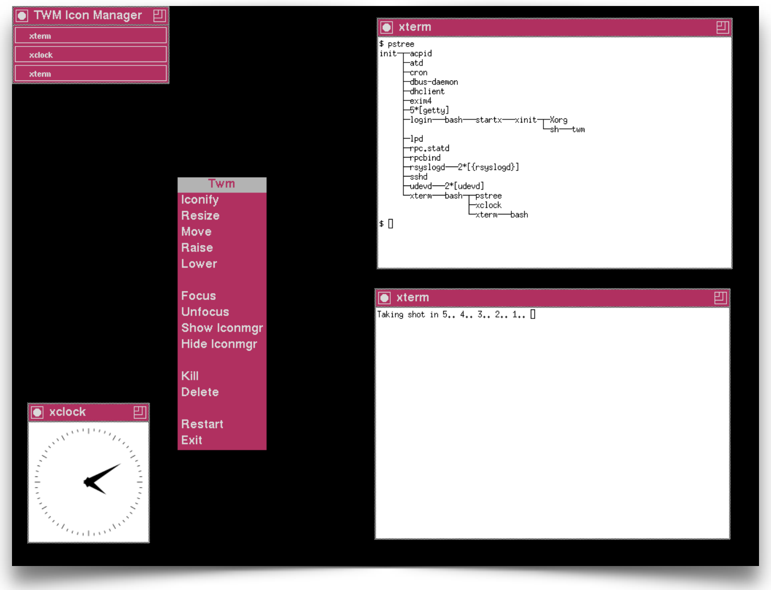
1980s: Era of (some) bad ideas

- Personal computers (microcomputers) become widely available
  - Underpowered compared to systems that ran contemporary timesharing OSes such as UNIX
- PC OSes (e.g., MS-DOS, Mac OS) were dumbed down in many ways
  - Lack of memory protection
  - Cooperative multitasking vs. preemptive multitasking
  - Poor system stability, and chaos for developers!



1990s-Present: Modern OSes

- More powerful PCs make *preemptively multitasked* OSes generally viable
- High degrees of *virtualization*, *isolation*, and *concurrency*
- Exploding market for varied I/O devices and peripherals
  - OS support for “plug and play” third-party device drivers
- Large, sophisticated system call interfaces
  - Standards are created for portability across OSes (e.g., POSIX)



```
$ pstree
init─┬─acpid
     ├─atd
     ├─cron
     ├─dbus-daemon
     ├─dhclient
     ├─exim4
     ├─5*[getty]
     ├─login───bash───startx───xinit─┬─Xorg
     │                               └─sh───twm
     ├─lpd
     ├─rpc.statd
     ├─rpcbind
     ├─rsyslogd───2*[{rsyslogd}]
     ├─sshd
     ├─udevd───2*[udevd]
     └─xterm───bash─┬─pstree
                    ├─xclock
                    └─xterm───bash
$ 
```

```
Taking shot in 5.. 4.. 3.. 2.. 1.. 
```

Welcome to Windows 95

Did you know...

To open a program, you just click the Start button, and then click the program's icon.

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§ OS responsibilities

operating system

noun

the software that supports a computer's basic functions, such as scheduling *tasks*, executing *applications*, and controlling *peripherals*.

New Oxford American Dictionary

Breaking down the definition

- “tasks and applications” = running programs
= **processes**
  - instructions & data stored in memory; executed and fetched on the CPU
- “peripherals” = **I/O devices** (hardware)
- OS raison d’être: facilitate process execution and access to hardware

Resource management

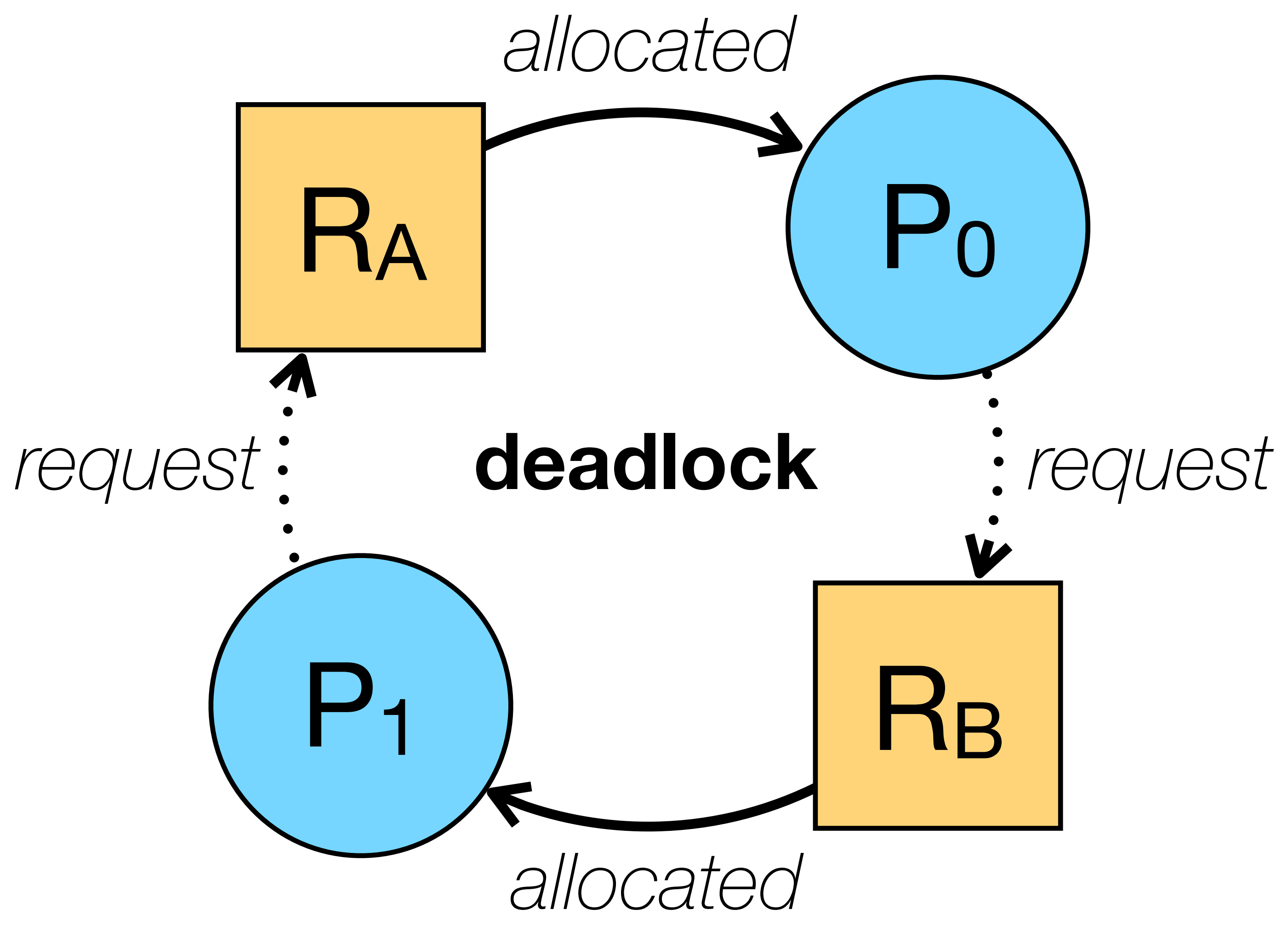
- CPU, Memory, I/O devices are *limited resources*
    - i.e., possible for num processes > num CPU cores,
      total memory required > physical RAM,
      file accesses > disk read/write heads
- OS acts as a high level *resource manager*
    - So processes can focus on their own tasks, the OS ideally manages and allocates resources in an unobtrusive, transparent way

Virtualization

- A powerful model for resource allocation is *virtualization*:
  - Each process behaves as though it is accessing its own private CPU(s), address space, I/O device, etc.
  - Behind the scenes, the OS maintains this illusion by allocating and multiplexing resources across all concurrently executing processes
    - Effectively creates an idealized machine for each process

Concurrency

- Concurrency presents its own hurdles and techniques for dealing with them
- Concurrent processes must by protected/isolated from each other
- Nondeterministic execution and requests/access to resources creates *race conditions* within the OS and between processes
    - Dealing with these issues requires special tools and techniques



Persistence

- CPU and Memory state are volatile
- I/O devices provide support for persistent storage
  - Presents a host of new issues:
    - How to namespace persistent data?
    - What APIs are needed for accessing persistent data?
    - How to efficiently manage and access data on slow HDDs?
    - If processes crash when updating persistent store, how to guarantee consistency?

How to achieve these?

- To implement virtualization, concurrency, persistence (and other goals), the OS relies on hardware assistance
  - All modern ISAs have built-in mechanisms to support OS tasks
- Of paramount importance: hardware features that allow the OS to maintain *exclusive access* to privileged operations and structures
  - To prevent accidental/malicious process behavior from interfering with other processes or the OS itself — i.e., ensuring robustness & isolation

§ OS privileges

Can we do this without HW?

- I.e., can you write a program (the OS) to execute other (user) programs, and guarantee isolation and robustness without hardware support?
- Consider some common (local) security vulnerabilities:
  - address fabrication
  - code injection
  - return-oriented programming

Software mitigation

- Software mechanisms:
  - Static verification (e.g., type-checking)
  - Run-time tools (e.g., garbage collection, exception handling, VM)
- Very hard to guard against all security vulnerabilities in software alone!
  - Basic issue: once untrusted/dangerous code starts running on the processor, how can we prevent it from doing whatever it wants?

Hardware support

- All modern CPUs support, at minimum, two “modes” of operation
  - Privileged/Supervisor mode: all features accessible
    - Including special operations and access to I/O devices, control registers, and all of memory
  - User mode: only “safe” operations and process-local data accessible
- System boots to OS in privileged mode, which runs processes in user mode
  - Mode switches must be rigorously enforced!

Mode transitions

- A common mechanism for switching between privileged & user modes is the *interrupt* (either software or hardware triggered)
  - E.g., system call / trap (starting in user mode):
    1. Process executes special `int` instruction with interrupt # as argument
    2. Hardware looks up associated OS entry point from interrupt table
       - Interrupt table is managed by OS
    3. Hardware switches to privileged mode before running OS handler
  - Implements a hardware-assisted *application binary interface* (ABI)

OS exists to serve

- OS carries out privileged operations on behalf of user processes
  - Also keeps up the illusion of various abstractions that simply process execution (e.g., concurrency and non-overlapping address spaces)
- Important: privileged/supervisor mode is only for the OS!
  - Administrator / “root” user do not run processes in privileged mode
  - *All processes* run in user mode!
    - But does all of the OS?

§ OS organization

What is privileged?

- Which portions/modules of an OS will be run in “privileged” mode?
- “Standard OS modules”:
  - virtual memory
  - scheduler
  - device drivers
  - file system
  - IPC

The “Kernel”

- Privileged modules constitute the “kernel” of the operating system
  - First program loaded into memory, and always memory-resident
  - Handles all privileged operations
    - Hardware access
    - Updating special/control registers
    - Running special instructions
  - Works in close concert with architecture features (e.g., clock interrupt)

Monolithic architecture

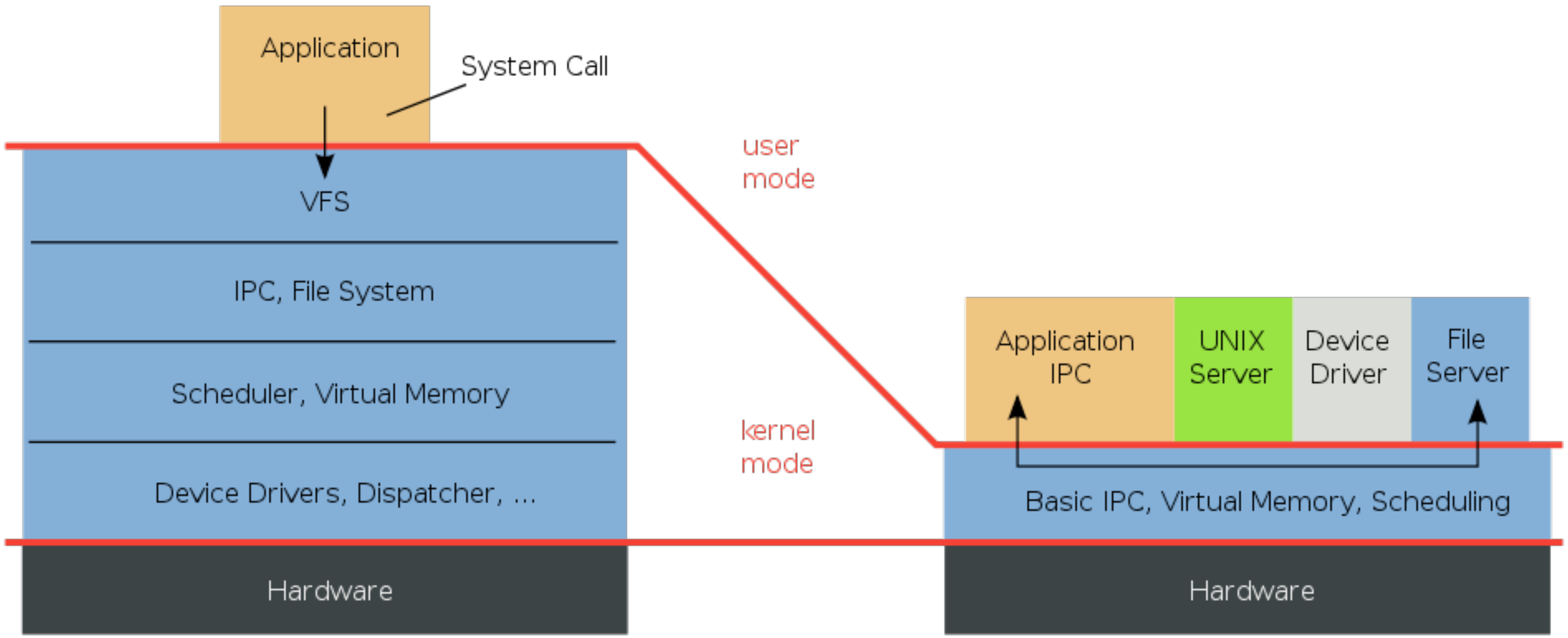
- *All primary modules and I/O device drivers* run in privileged mode
- Relatively large, permanent memory footprint
- No mode transitions when jumping between different pieces of the OS
  - Very little system overhead
- Because the privileged codebase is very large, harder to verify and guarantee system robustness!
  - If one piece of the OS crashes, all of it does

Microkernel architecture

- Only essential services are privileged; everything else runs in user mode
- Relatively small memory footprint
- Microkernel functions in part as a messenger between different modules running in user mode
  - Jumping between different OS modules may require mode switch
  - Higher system overhead (though clever optimizations exist)
- Easier to verify and guarantee robustness
  - If a user-level OS module crashes, just restart it

Monolithic Kernel
based Operating System

Microkernel
based Operating System



courtesy of Wikimedia Commons

… suffice it to say that among the people who actually design operating systems, the debate is essentially over. **Microkernels have won**

- Andrew Tanenbaum
  (noted OS researcher)

The whole “microkernels are simpler” argument is just **bull**, and it is clearly shown to be bull by the fact that whenever you compare the speed of development of a microkernel and a traditional kernel, **the traditional kernel wins**. By a huge amount, too.

- Linus Torvalds
  (chief architect, Linux)

Beyond the debate

- Yet another route: why not just implement OS as a low-level library?
  - Loss of isolation, but big efficiency gain
  - Used by many embedded systems
- And what about hosting multiple OSes on a single machine?
  - Useful/feasible on modern multi-core machines
  - Hypervisors provide low-level virtual machines to guest OSes
    - Yet another layer of isolation!

Summary

- Why do we need an OS?
  - To facilitate process execution and simplify/control access to hardware
- What does an OS do?
  - Provide virtualization, concurrency, and persistence
- How is an OS organized?
  - Separation of kernel (privileged) and user modules — architecture of kernel is an exercise in tradeoffs!