Principles of Operating Systems

Lecture 1 - Introduction and overview, operating system structure

Ardalan Amiri Sani (ardalan@uci.edu)

[*lecture slides contains some content adapted from : Silberschatz textbook authors, Anderson textbook authors, John Kubiatowicz (Berkeley), John Ousterhout(Stanford), previous slides by Prof. Nalini Venkatasubramanian,* http://www-inst.eecs.berkeley.edu/~cs162/ *and others*]

Staff

- Instructor
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Staff

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- Pavel Frolikov <pavel@uci.edu>
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Course logistics and details

- Course web page -
  - https://www.ics.uci.edu/~ardalan/courses/os/index.html
- Discussions (starts in week 1)
  - Fridays 3:00-3:50pm (ALP 2300)

Course logistics and details

- Textbook:

  Operating System Concepts -- Ninth Edition
  A. Silberschatz, P.B. Galvin, and G. Gagne
  (Tenth, Eighth, Seventh, Sixth, and Fifth editions are fine as well).

- Other suggested Books
  - Operating Systems: Principles and Practice, by T. Anderson and M. Dahlin (second edition)
  - Modern Operating Systems, by Tanenbaum (Third edition)
  - Principles of Operating Systems, by L.F. Bic and A.C. Shaw, 2003.
  - Operating Systems: Three Easy Pieces, by Remzi H. Arpaci-Dusseau and Andrea C. Arpaci-Dusseau

Course logistics and details

- Homeworks and Assignments
  - 8 written homeworks
  - 1 **optional** programming assignment (knowledge of C).
    - Multistep assignment – don't start in last week of classes!!!
  - Late homework policy.
    - Lose 10% of grade for every late hour.
  - All submissions will be made using Gradescope (find entry code on Canvas)
- Tests
  - 4 in-class quizzes – Thursday, Weeks 3, 5, 7, 9
  - Final Exam – per UCI course catalog (Thu, 3/20, 1:30pm-3:30pm)

Grading Policy

Will pick the best of the following two:

- Grade 1:
  - Written Homeworks - 40%
    - 8 written homeworks each worth 5% of the final grade.
  - Project - 20% of the final grade (4% for lab0, 16% for lab1)
  - In-class quizzes - 20% of the final grade
    - 4 quizzes each worth 5% of the final grade
  - Final exam - 20% of the final grade

Grading Policy (cont.)

- Grade 2:
  - Written Homeworks - 40%
    - 8 written homeworks each worth 5% of the final grade.
  - In-class quizzes - 30% of the final grade
    - 4 quizzes each worth 7.5% of the final grade
  - Final exam - 30% of the final grade
- Curve will be used if needed.

Lecture Schedule

- Week 1
  - Introduction to Operating Systems, Computer System Structures, Operating System Structures
- Week 2
  - Processes and Threads
- Week 3
  - Processes and Threads, and CPU Scheduling
- Week 4
  - Scheduling
- Week 5
  - Process Synchronization

Lecture Schedule

- Week 6
  - Process synchronization
- Week 7
  - Deadlocks
- Week 8
  - Memory Management
- Week 9
  - Memory Management, Virtual Memory
- Week 10
  - File Systems Interface and Implementation

Classes I will miss:

- None that I know of at the moment
- I will announce it ASAP if any comes up

Office hours

- Instructor
  - Tuesdays 4 pm - 5 pm (My office)
- TA
  - Thursdays 9:30 am - 10:30 am (ICS 458A)

Office hours will start on the second week of classes

For questions?

- Ed discussion (Edstem) on Canvas

Slides

- Will upload first draft of the slides for all of the week on Tuesday
- Might (and most likely will) update slides for each class before the class
  - Will mention on the website which slides have been updated

Overview

- What is an operating system?
- Computer system and operating system structure

What is an Operating System?

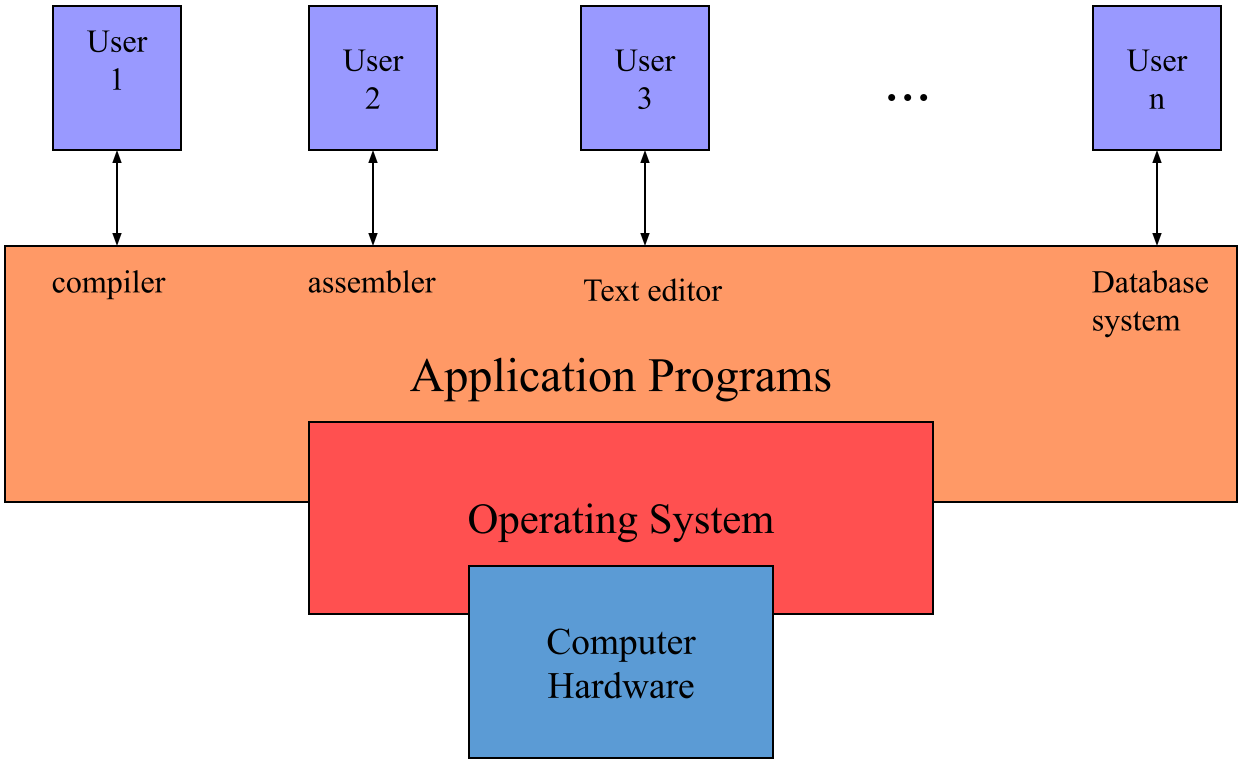
What is an Operating System?

- OS is the software that acts an intermediary between the applications and computer hardware.

Computer System Components

- Hardware
  - Provides basic computing resources (CPU, memory, I/O devices).
- Operating System
  - Controls and coordinates the use of hardware among application programs.
- Application Programs
  - Solve computing problems of users (compilers, database systems, video games, business programs).
- Users
  - People, other computers

Abstract View of System



Operating system roles

Operating system roles

- Referee
  - Resource allocation among users, applications
  - Isolation of different users, applications from each other
  - Communication between users, applications

Operating system roles

- Illusionist
  - Each application appears to have the entire machine to itself
    - Infinite number of processors, (near) infinite amount of memory, reliable storage, reliable network transport

Operating system roles

- Glue
  - Libraries, user interface widgets, …
  - Reduces cost of developing software

OS challenges

OS challenges

- Reliability
  - Does the system do what it was designed to do?

OS challenges

- Availability
  - What portion of the time is the system working?
  - Mean Time To Failure (MTTF), Mean Time to Repair

OS challenges

- Security
  - Can the system be compromised by an attacker?

OS challenges

- Privacy
  - Data is accessible only to authorized users

OS challenges

- Performance
  - Latency/response time
    - How long does an operation take to complete?
  - Throughput
    - How many operations can be done per unit of time?
  - Overhead
    - How much extra work is done by the OS?
  - Fairness
    - How equal is the performance received by different users?
  - Predictability
    - How consistent is the performance over time?

OS challenges

- Portability
  - For programs:
    - Application programming interface (API)
  - For the kernel
    - Hardware abstraction layer

OS needs to keep pace with hardware improvements

- Faster CPU
- More CPUs
- More memory (different types of memory, e.g., persistent)
- More storage
- Faster network
- Different usage model (e.g., ratio of users to computers)

Why should I study Operating Systems?

Why should I study Operating Systems?

- Need to understand interaction between the hardware and software
- Need to understand basic principles in the design of computer systems
  - efficient resource management, security, etc.

Why should I study Operating Systems?

- Because it enables you to do things that are difficult/impossible otherwise.

Example: Rio: I/O sharing implemented in the operating system kernel

(Slides on Rio are not part of the course material)

Observation: I/O devices important for personal computers

A personal computer today

- Super AMOLED display
- Capacitive touchscreen (multitouch)
- Audio (speaker, microphone)
- Vibration
- S pen
- 13 MP front camera
- 2 MP back camera
- Accelerometer
- Gyroscope
- Proximity sensor
- Compass
- Barometer
- Temperature sensor
- Humidity sensor
- Gesture sensor
- GPS
- 4G LTE
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- Infrared
- 64 GB internal storage (extended by microSD)
- Adreno 330 GPU
- Hexagon DSP
- Multimedia processor

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interaction

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sensing

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connectivity, storage

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acceleration

Multiple computers for unique I/O

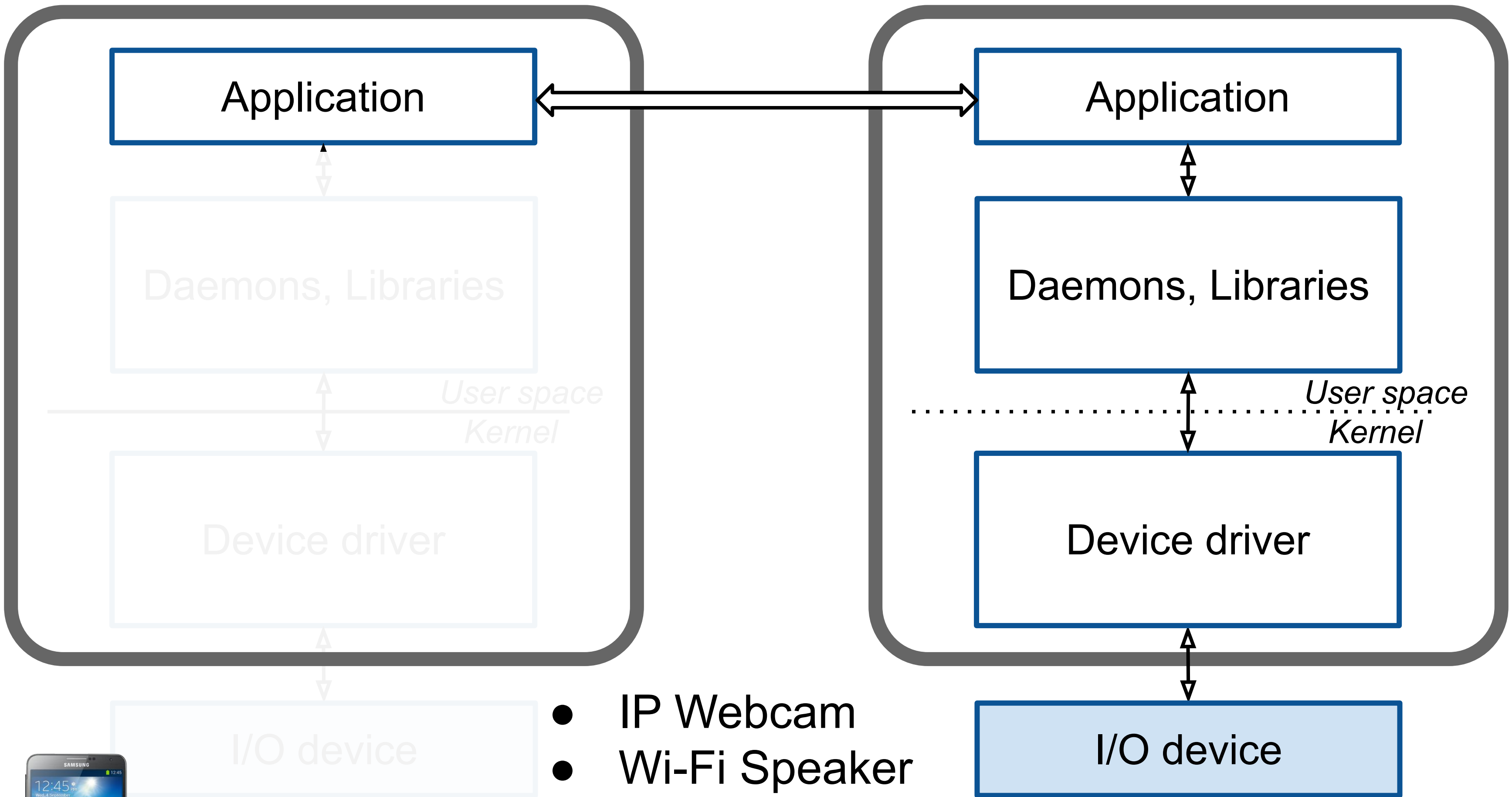
Multiple computers for unique I/O

Multiple computers for unique I/O

I/O sharing

How to build this?

Application layer



- IP Webcam
- Wi-Fi Speaker
- MightyText

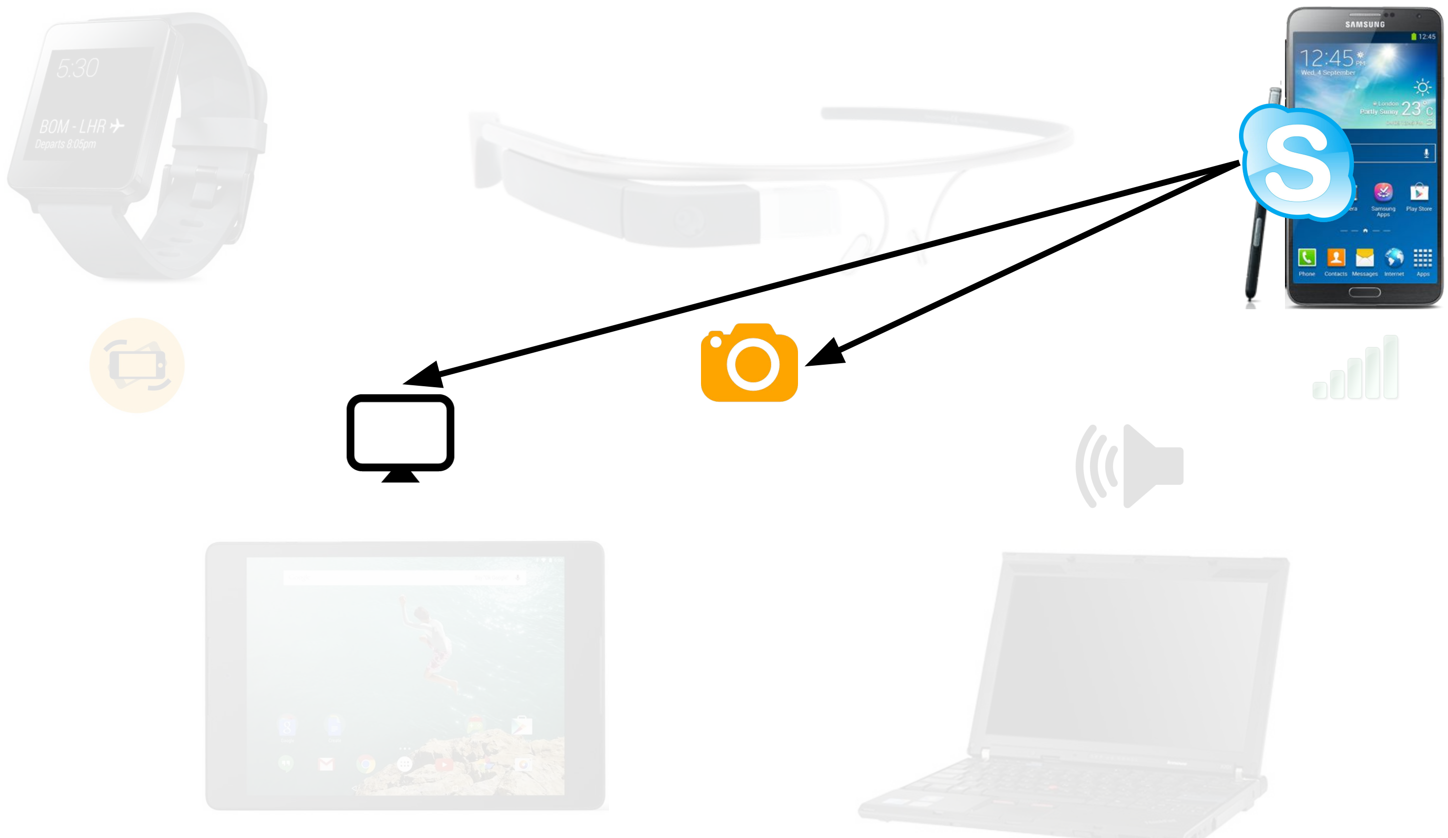
Client

Server

Do not meet our criteria

- High engineering effort
- No support for legacy applications
- No support for all I/O device features

Rio: I/O servers for sharing I/O between mobile systems

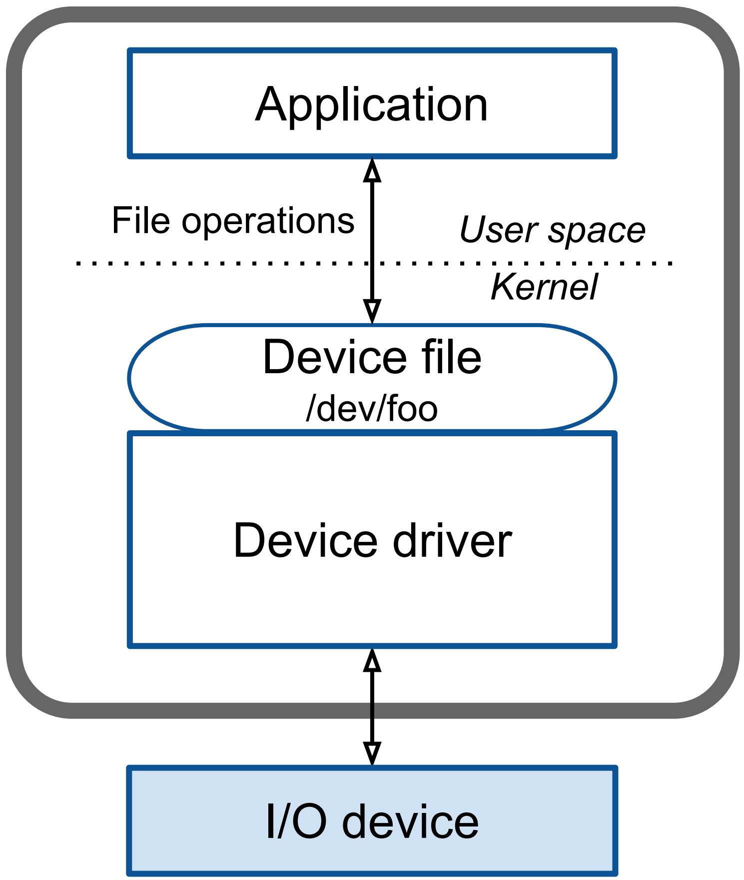


Ardalan Amiri Sani, Kevin Boos, Min Hong Yun, and Lin Zhong, "Rio: A System Solution for Sharing I/O between Mobile Systems," in *Proc.* ***ACM MobiSys***, June 2014. **(Best Paper Award)**

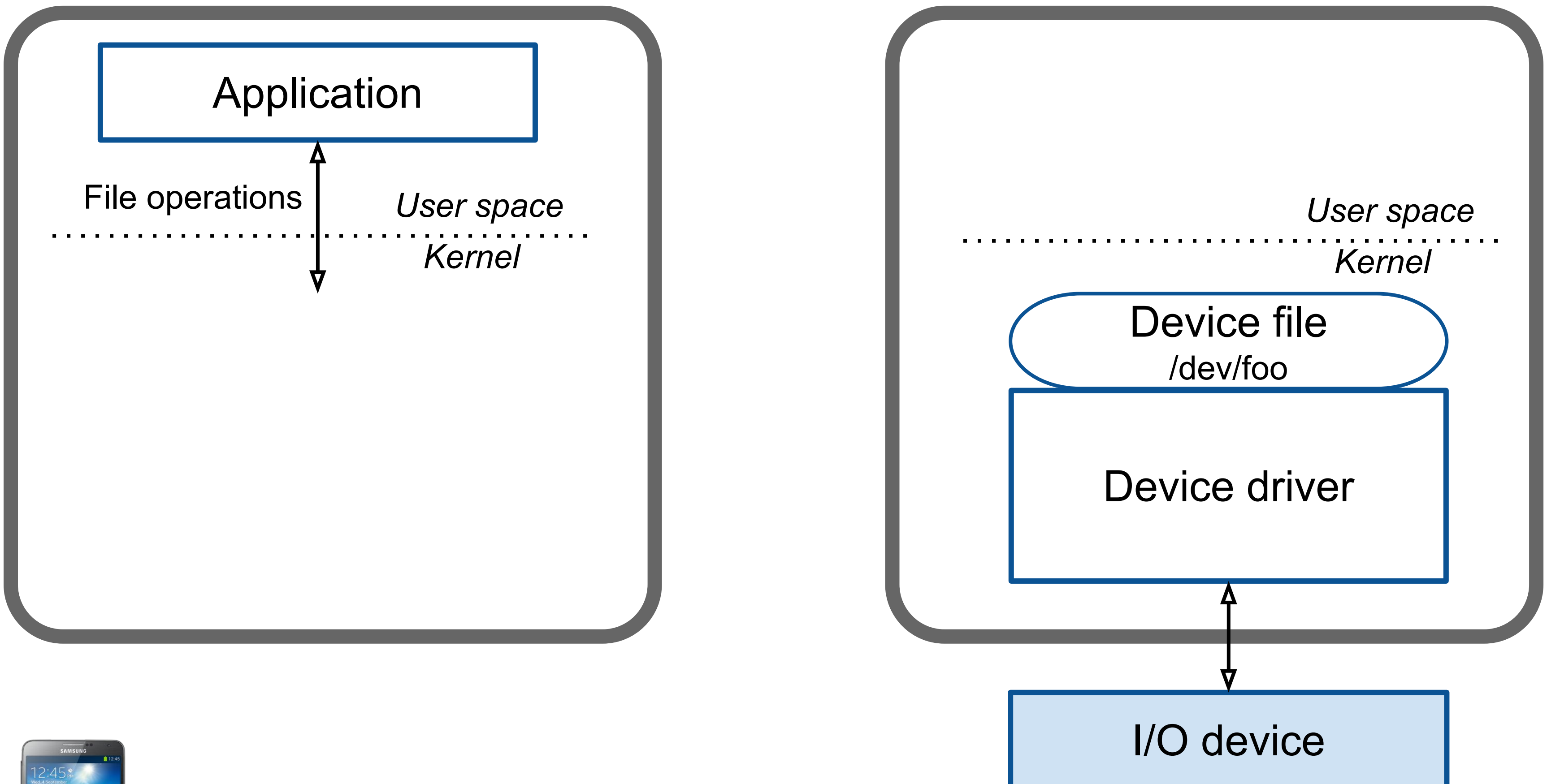
Key idea: device files as the boundary

I/O devices abstracted as
(device) files in Unix-like OSes
e.g., /dev/foo

Key idea: device files as the boundary



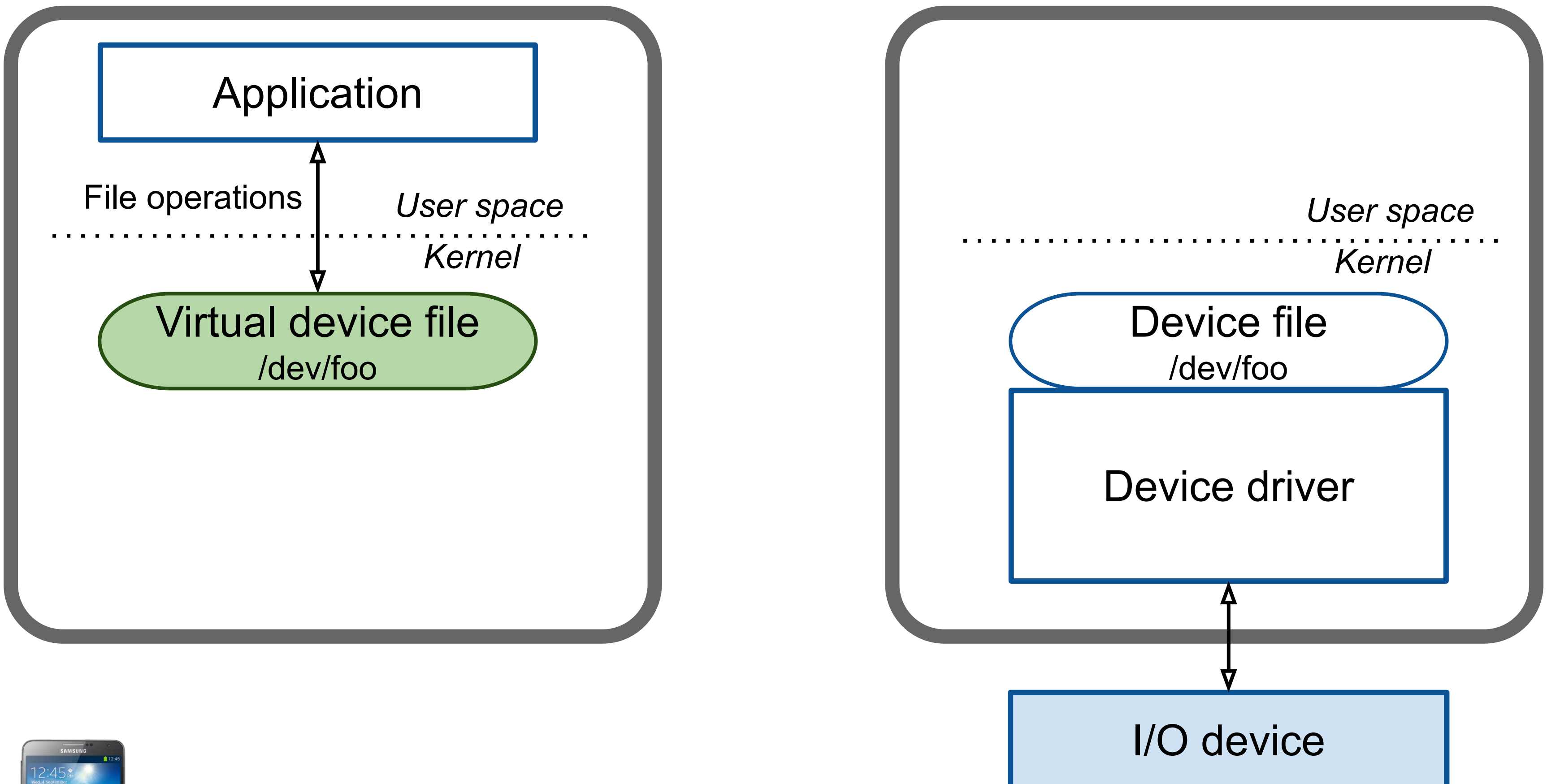
Key idea: device files as the boundary



Client

Server

Key idea: device files as the boundary



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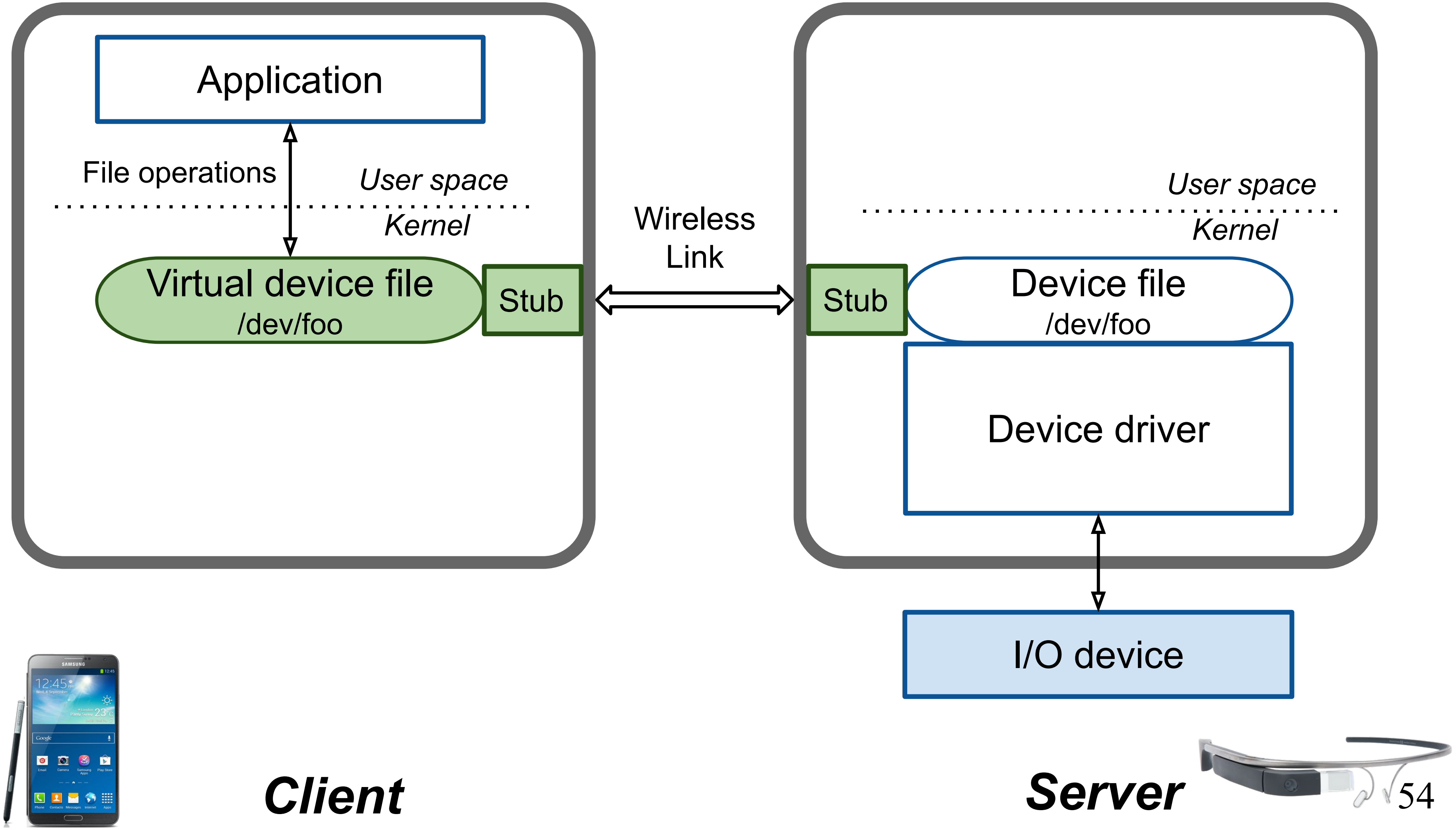
Server

Key idea: device files as the boundary



Video demo of Rio

https://www.yecl.org/rio.html

(end of slides on Rio)

Operating systems are everywhere

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Overview

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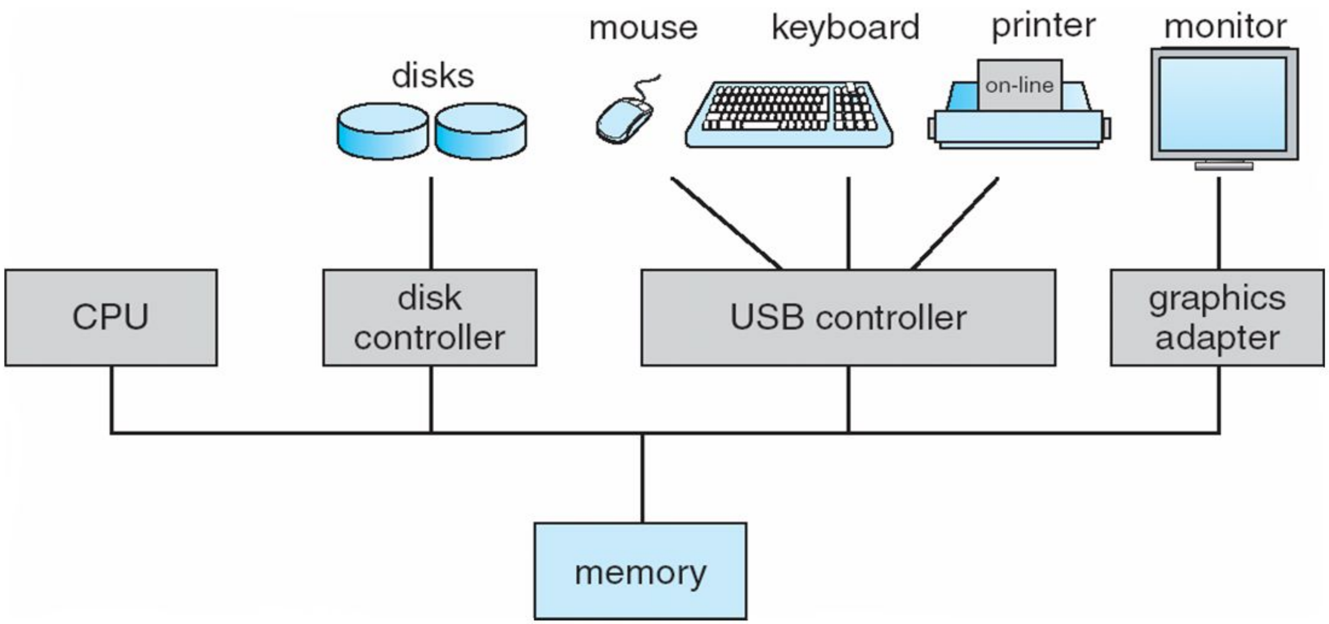
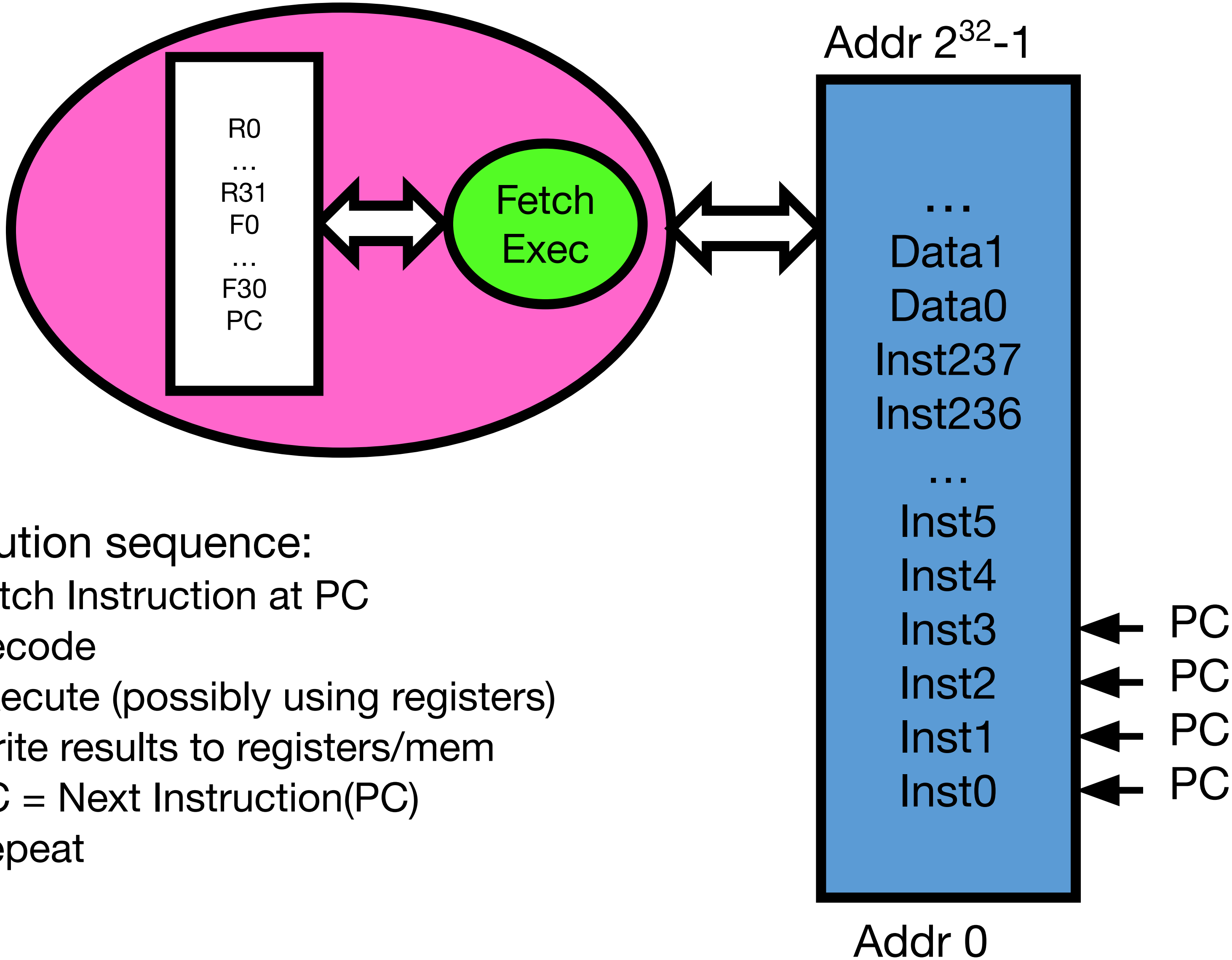
Computer System Organization



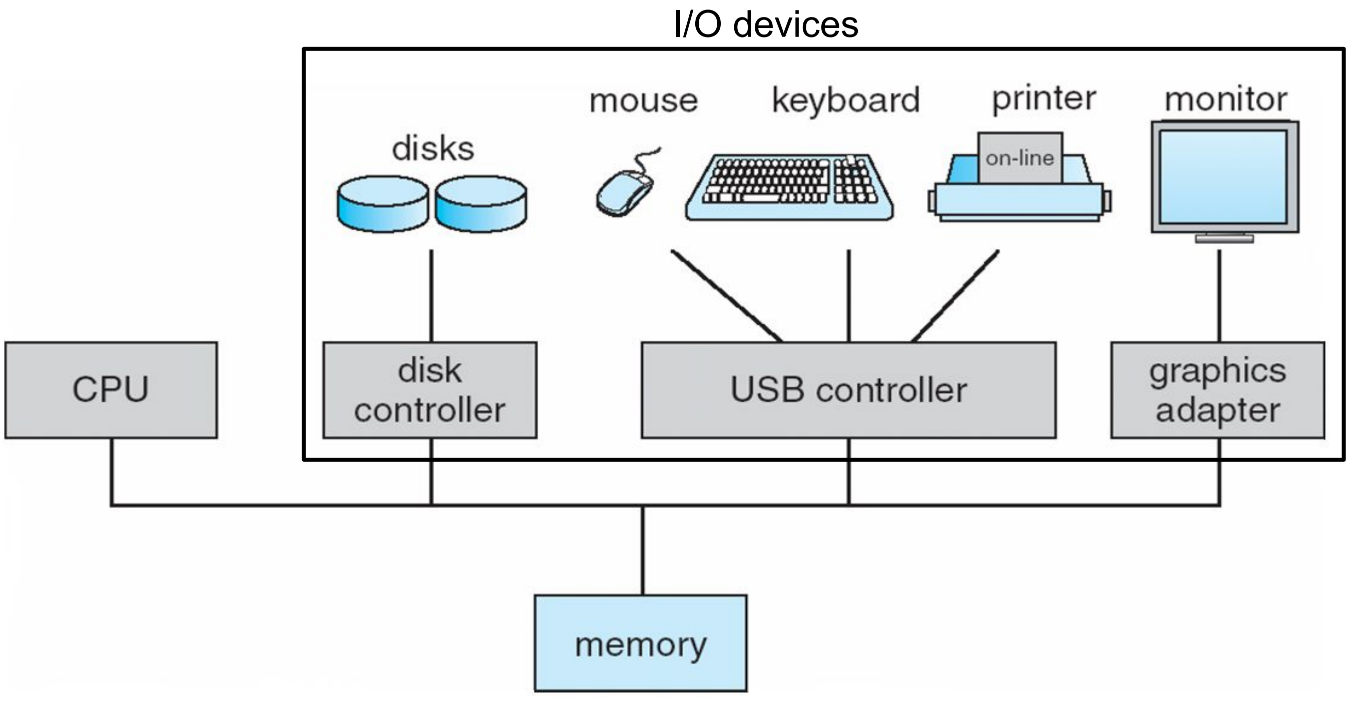
CPU execution



- Execution sequence:
  - Fetch Instruction at PC
  - Decode
  - Execute (possibly using registers)
  - Write results to registers/mem
  - PC = Next Instruction(PC)
  - Repeat

From Berkeley OS course

Computer System Organization

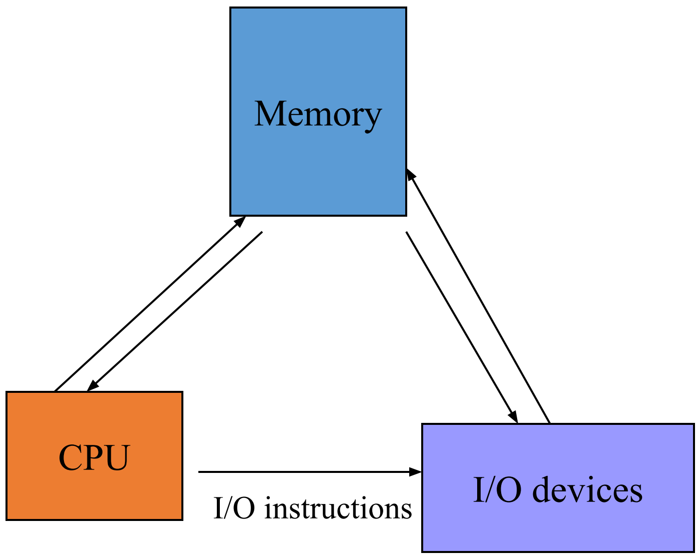


I/O devices

- I/O devices and the CPU execute concurrently.
- Each device controller is in charge of a particular device type
  - Each device controller has a local buffer. I/O is from the device to local buffer of controller
- CPU moves data from/to main memory to/from the local buffers

Direct Memory Access (DMA)

- Typically used for I/O devices with a lot of data to transfer (in order to reduce load on CPU).
- Device controller transfers blocks of data to/from local buffer directly to main memory without CPU intervention.



I/O completion

- How do we know that I/O is complete (e.g., data is ready in local buffer or DMA is complete)?

I/O completion

- How do we know that I/O is complete (e.g., data is ready in local buffer or DMA is complete)?
  - Polling:
    - Device controller sets a flag when it is busy.
    - Program tests the flag in a loop waiting for completion of I/O.
  - Interrupts:
    - On completion of I/O, device controller interrupts CPU.

Interrupts

- Interrupt transfers control to the interrupt service routine
  - Interrupt Service Routine: Segments of code that determine action to be taken for interrupt.

- Determining the type of interrupt
  - Polling: same interrupt handler called for all interrupts, which then polls all devices to figure out the reason for the interrupt
  - Interrupt Vector Table: different interrupt handlers will be executed for different interrupts

Interrupt Number	Address
0	0003h
1	000Bh
2	0013h
3	001Bh
4	0023h
5	002Bh
6	0033h
7	003Bh
8	0043h
9	004Bh
10	0053h
11	005Bh
12	0063h
13	006Bh
14	0073h
15	007Bh

Interrupt Number	Address
16	0083h
17	008Bh
18	0093h
19	009Bh
20	00A3h
21	00ABh
22	00B3h
23	00BBh
24	00C3h
25	00CBh
26	00D3h
27	00DBh
28	00E3h
29	00EBh
30	00F3h
31	00FBh

Interrupt handling

- OS preserves the state of the CPU

Interrupt handling

- OS preserves the state of the CPU
  - stores registers and the program counter (address of interrupted instruction).
- What happens to a new interrupt when the CPU is handling one interrupt?

Interrupt handling

- OS preserves the state of the CPU
  - stores registers and the program counter (address of interrupted instruction).
- What happens to a new interrupt when the CPU is handling one interrupt?
  - Incoming interrupts can be disabled (masked) while another interrupt is being processed. In this case, incoming interrupts may be lost or may be buffered until they can be delivered.
  - Incoming interrupts are delivered, i.e., nested interrupts.

Process Abstraction

Process Abstraction

- Process: an *instance* of a program, running with limited rights

Process Abstraction

- Process: an *instance* of a program, running with limited rights
  - Thread: a sequence of instructions within a process
    - Potentially many threads per process (for now 1:1)
  - Each process has a set of rights
    - Memory that the process can access (address space)
    - Other permissions the process has (e.g., which system calls it can make, what files it can access)

How to limit process rights?

Hardware Protection

- CPU Protection:
  - Dual Mode Operation
  - Timer interrupts
- Memory Protection
- I/O Protection

Should a process be able to execute any instructions?

Should a process be able to execute any instructions?

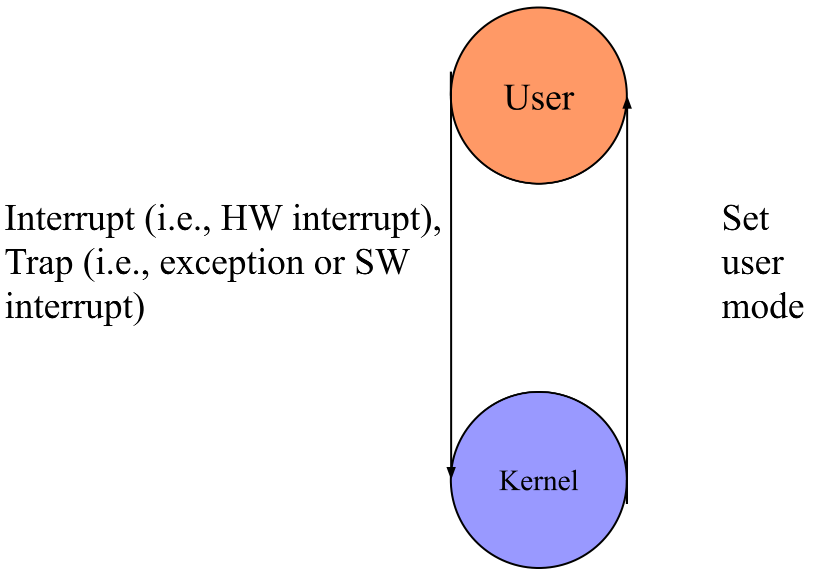
- No
  - Can alter critical system configurations and violate permissions
    - e.g., instructions to alter memory address spaces
    - e.g., instructions to program I/O devices
- How to prevent?

Dual-mode operation

- Provide hardware support to differentiate between at least two modes of operation:
  1. User mode -- execution done on behalf of a user.
  2. Kernel mode (monitor/supervisor/system mode) -- execution done on behalf of operating system.
- “Privileged” instructions are only executable in the kernel mode
- Executing privileged instructions in the user mode “traps” into the kernel mode

Dual-mode operation(cont.)

- Mode bit added to computer hardware to indicate the current mode: kernel(0) or user(1).
- When an interrupt or trap occurs, hardware switches to kernel mode.



CPU Protection

- How to prevent a process from executing indefinitely?

CPU Protection

- Timer - interrupts computer after specified period to ensure that OS maintains control.
  - Timer is decremented every clock tick.
  - When timer reaches a value of 0, an interrupt occurs.
- Timer is commonly used to implement time sharing.
- Timer is also used to compute the current time.
- Should programming the timer require privileged instructions?

CPU Protection

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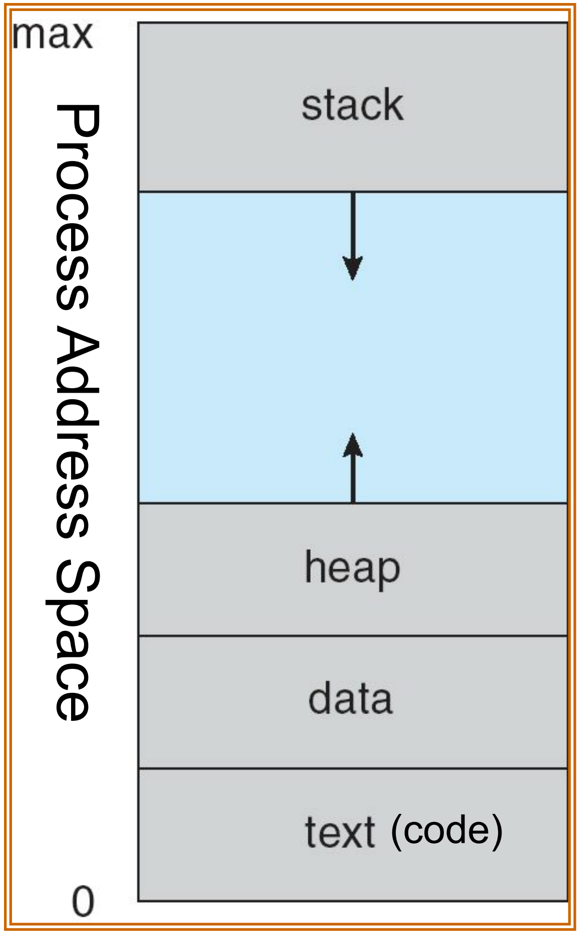
  - Timer is decremented every clock tick.
  - When timer reaches a value of 0, an interrupt occurs.
- Timer is commonly used to implement time sharing.
- Timer is also used to compute the current time.
- Should programming the timer require privileged instructions? Yes!

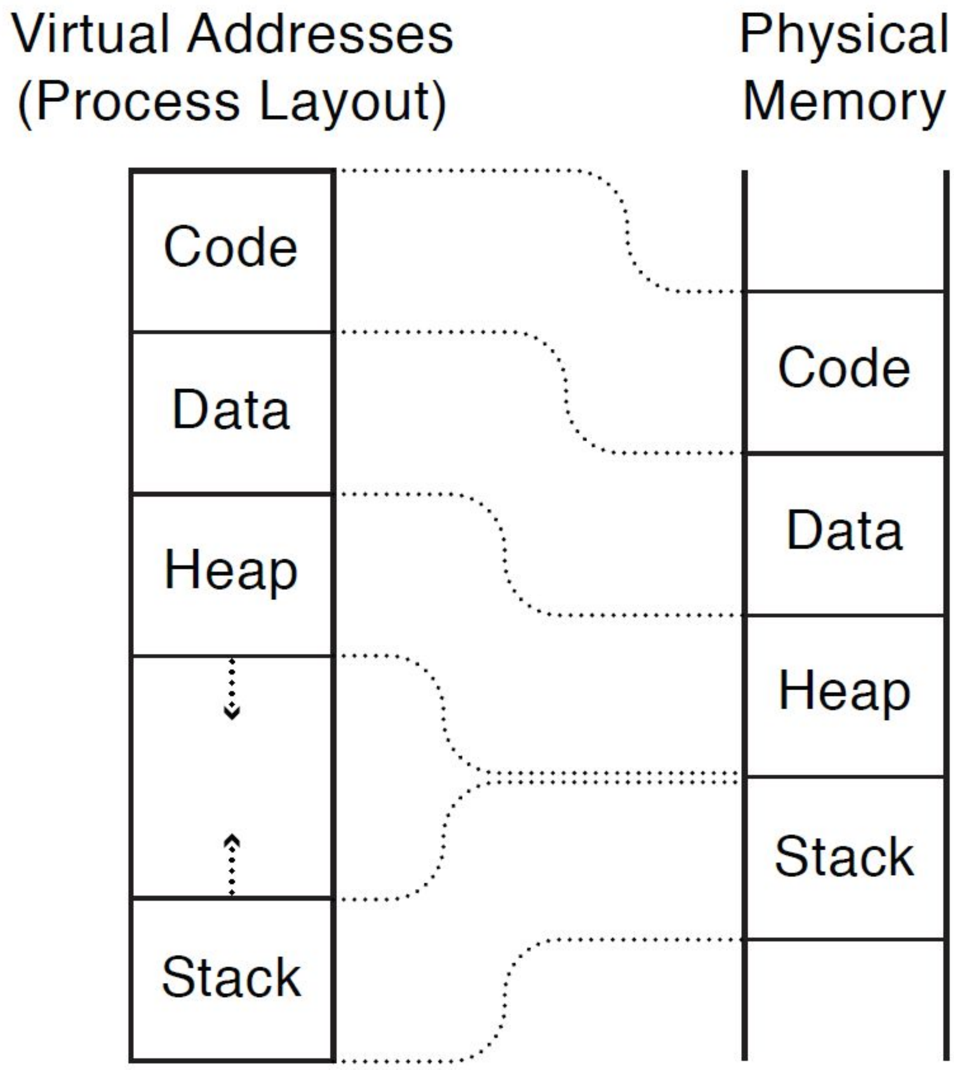
How to isolate memory access?

Process address space

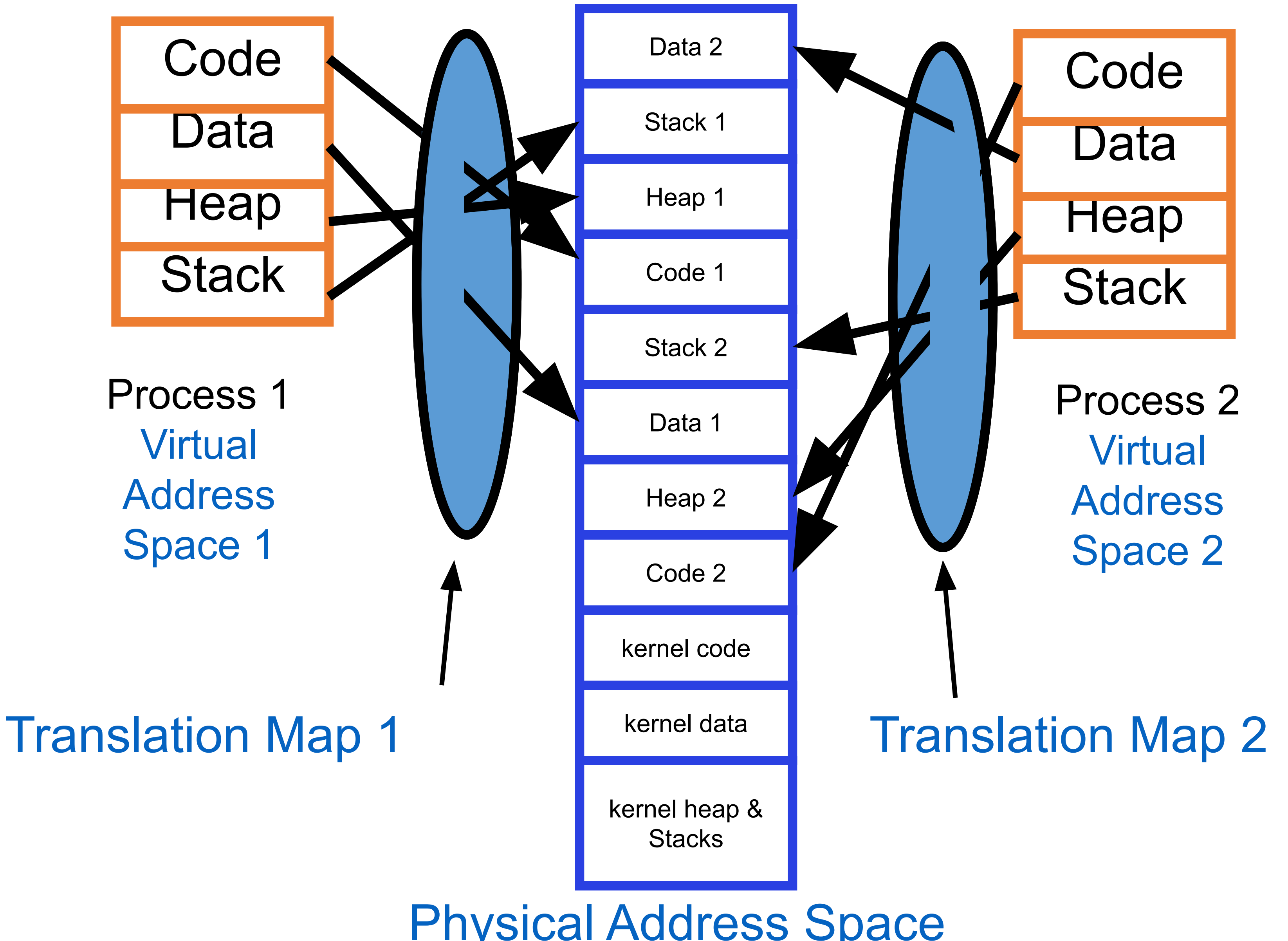
- Address space ⇒ the set of accessible addresses :
  - For a 32-bit processor there are 2^{32} = 4 billion addresses



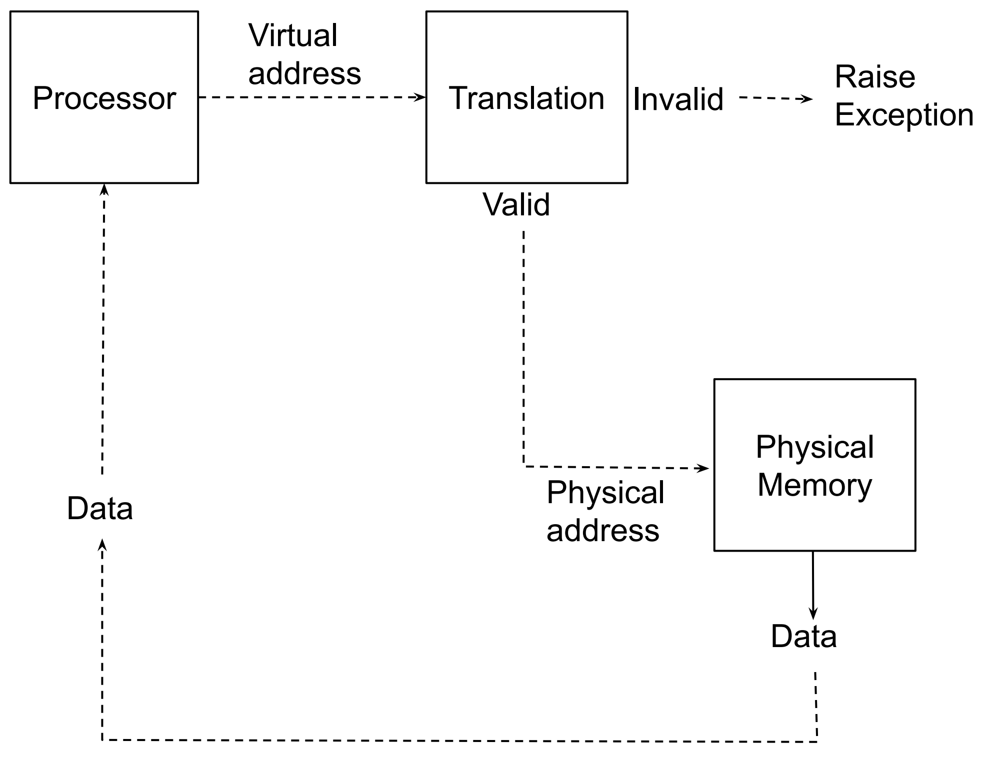
Virtual Address



Providing the Illusion of Separate Address Spaces



Address translation and memory protection

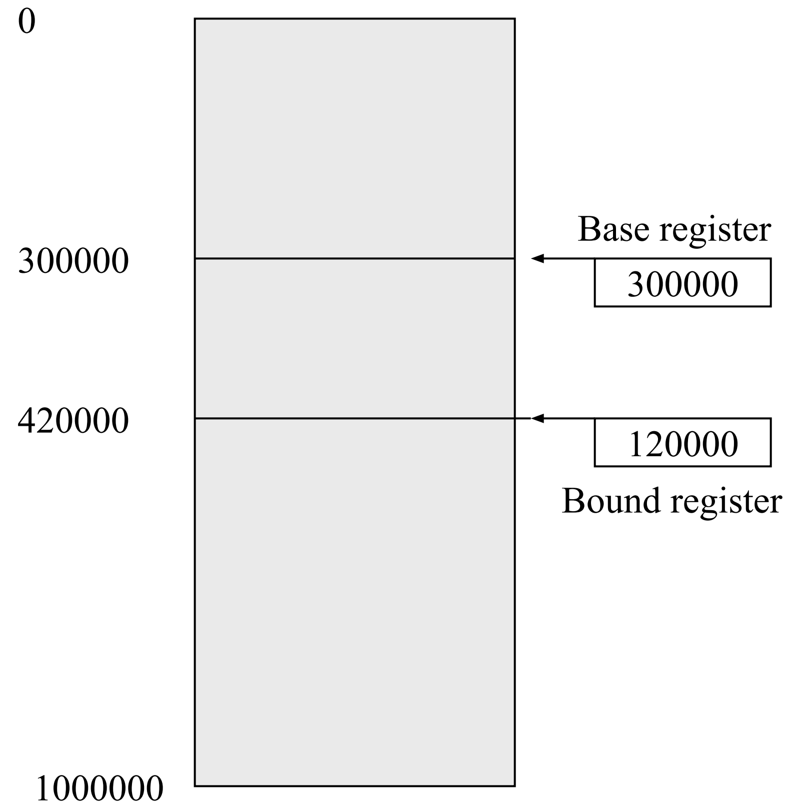


Memory Protection

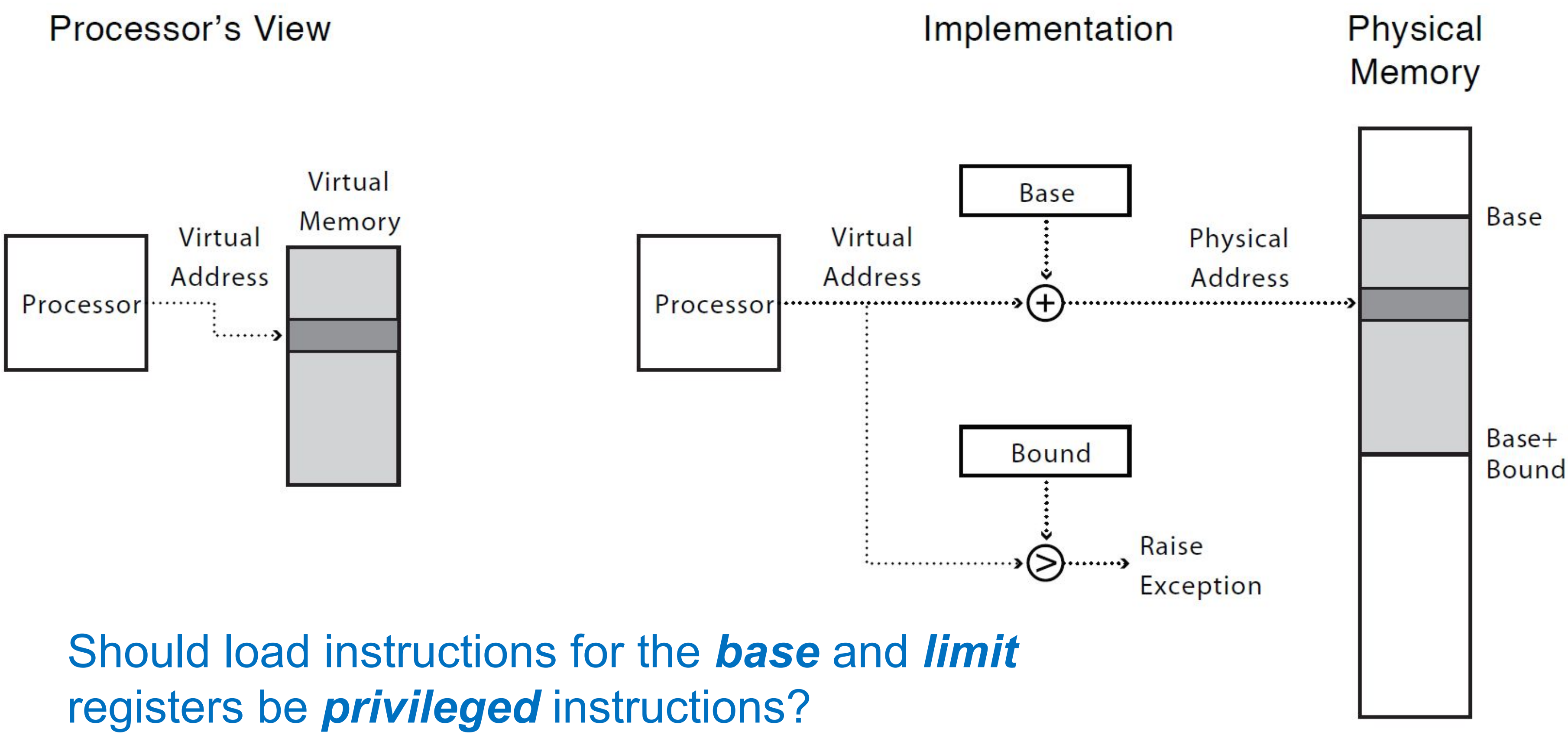
- When a process is running, only memory in that process address space must be accessible.
- When executing in kernel mode, the kernel has unrestricted access to all memory.

Memory Protection: base and bounds

- To provide memory protection, add two registers that determine the range of legal addresses a program may address.
    - Base Register - holds smallest legal physical memory address.
    - Bound register (aka limit register) - contains the size of the range.
- Memory outside the defined range is protected.

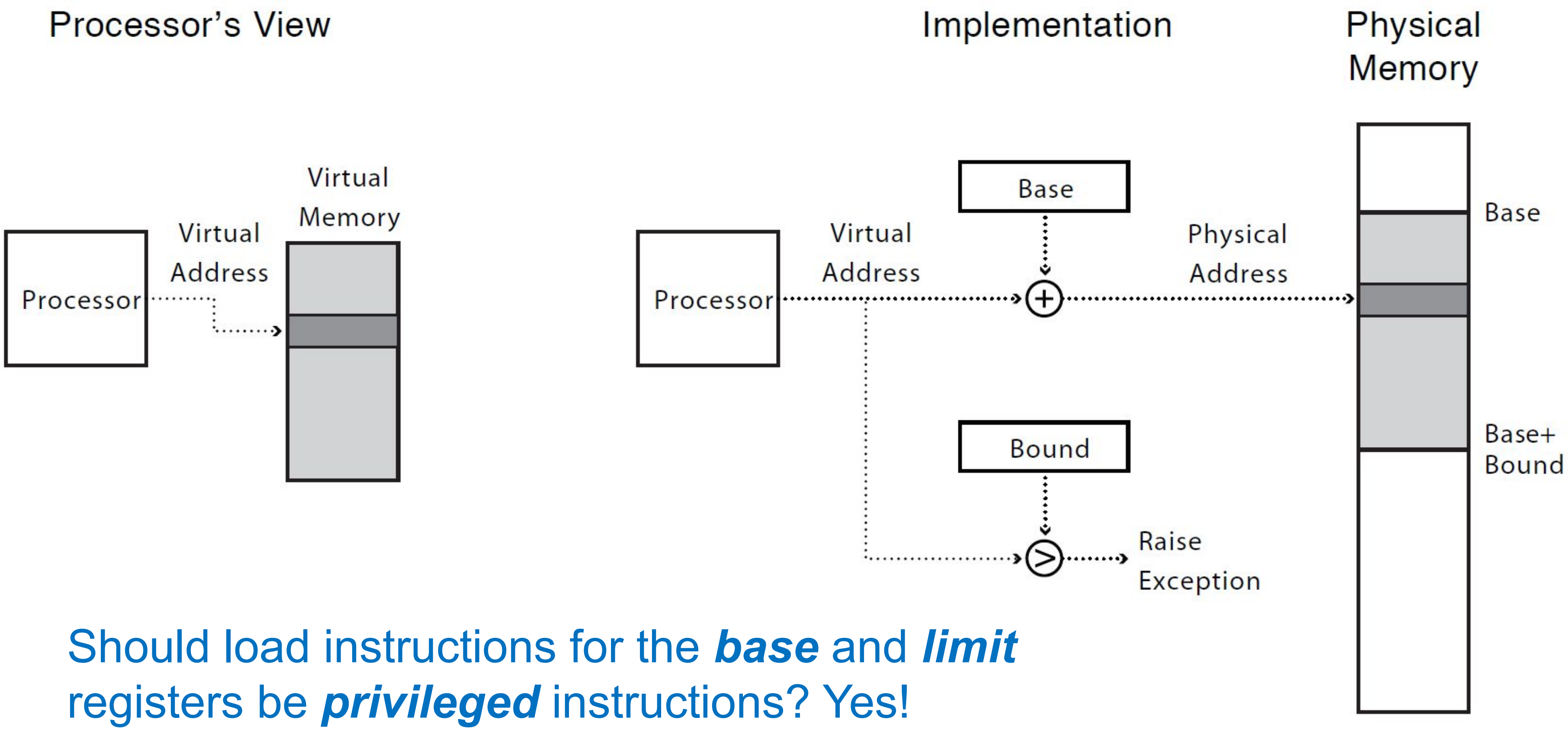


Virtual Address translation using the Base and Bounds method



Should load instructions for the ***base*** and ***limit*** registers be ***privileged*** instructions?

Virtual Address translation using the Base and Bounds method



Should load instructions for the ***base*** and ***limit*** registers be ***privileged*** instructions? Yes!

I/O Protection

- All I/O instructions are privileged instructions.

Question

- Given the I/O instructions are privileged, how do users perform I/O?

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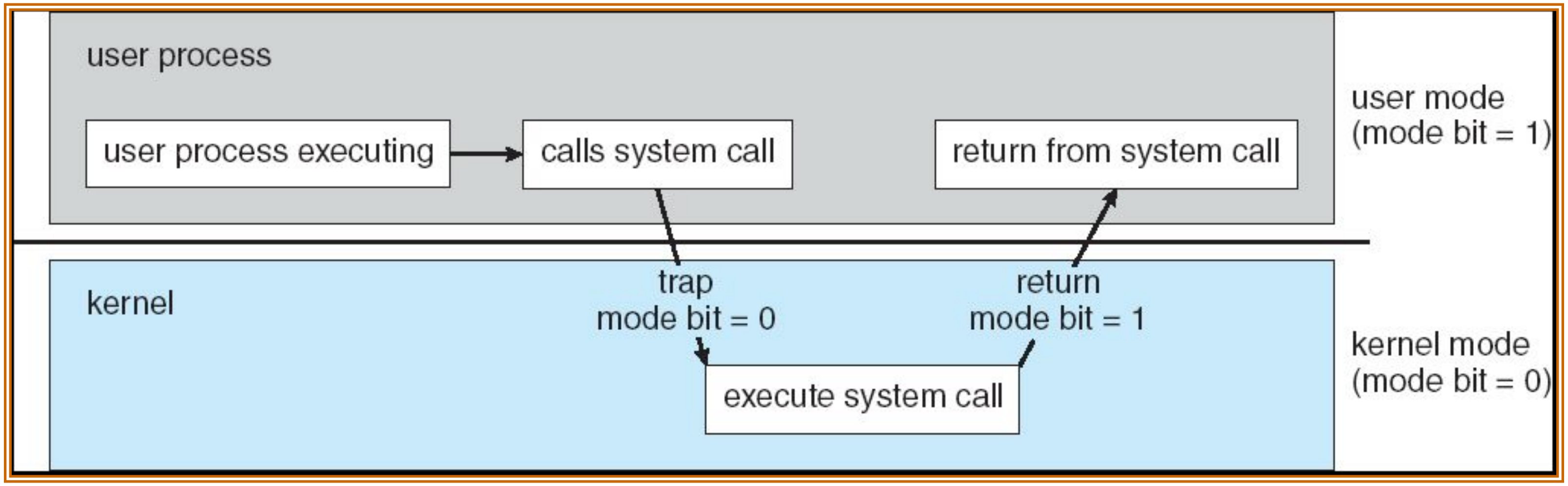
- Given the I/O instructions are privileged, how do users perform I/O?

- Via system calls - the method used by a process to request action by the operating system.

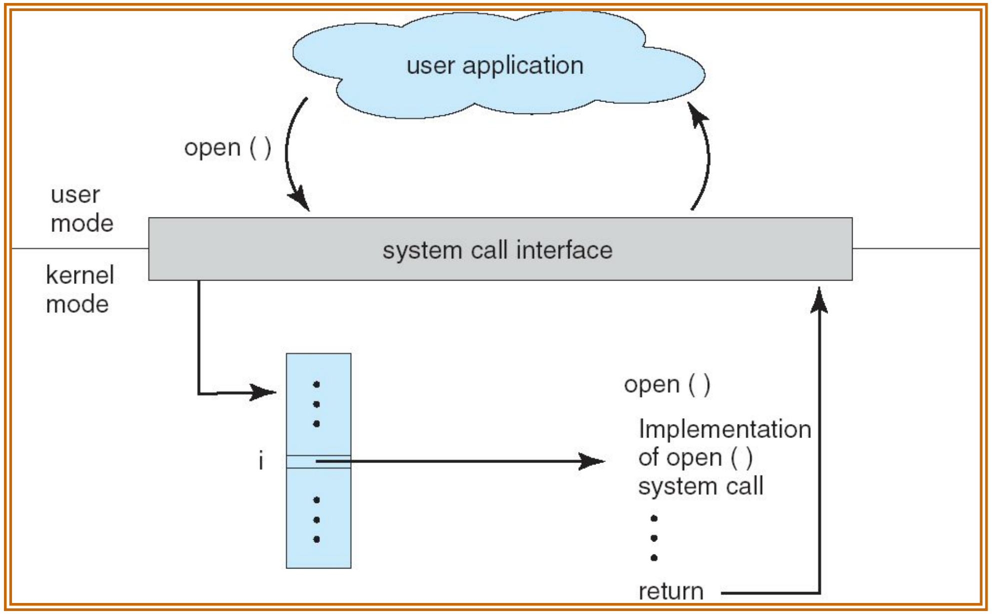
System Calls

- User code can issue a syscall, which causes a trap
- Kernel handles the syscall



System Calls

- Interface between applications and the kernel.
  - Application uses an assembly instruction to trap into the kernel
  - Some higher level languages provide wrappers for system calls (e.g., C)
- System calls pass parameters between an application and OS via registers or memory

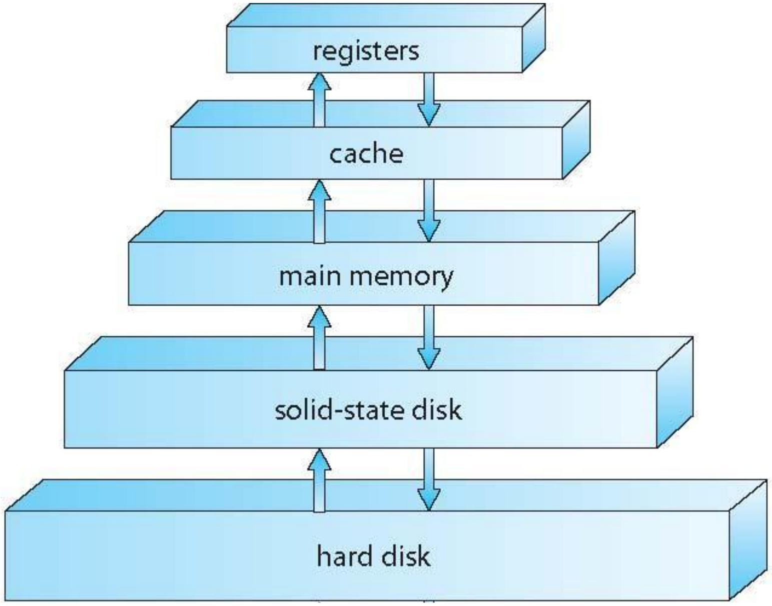


- Linux has about 400 system calls
  - read(), write(), open(), close(), fork(), exec(), ioctl(),…..

System services or system programs

- Components of the OS that provide help for program development and execution.
  - Command Interpreter (i.e., shell) - parses commands and executes other programs
  - Window management
  - System libraries, e.g., libc

Storage Device Hierarchy



Storage Structure

- Main memory - only large storage media that the CPU can access directly.
- Secondary storage - has large nonvolatile storage capacity.
  - Example: Magnetic disks - rigid metal or glass platters covered with magnetic recording material.
    - Disk surface is logically divided into tracks, subdivided into sectors.
    - Disk controller determines logical interaction between device and computer.

Storage Hierarchy

- Storage systems are organized in a hierarchy based on
  - Storage space
  - Access time
  - Cost
  - Volatility

- Caching - process of copying information into faster storage system; main memory can be viewed as fast cache for secondary storage.