Intro to Operating Systems
Virtual Memory
Naming

COS 316: Principles of Computer System Design

Lecture 3

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Operating Systems by Example

- Mobile OSes:
  - iOS, Android
- Laptop/Desktop OSes:
  - Windows, macOS, Linux, ChromeOS
- Server OSes
  - Linux, Windows
- Embedded OSes:
  - Pi OS, Tock OS

Operating Systems by Counterexample

- Running Firefox on a laptop without an OS

- Need to rewrite Firefox to replace all its syscalls
  - recvmsg/sendmsg – talk to the NIC to recv / send messages over the network
    - This is specific to the particular type of NIC in your laptop!
  - mmap – allocate memory in a virtual address space

Operating Systems by Counterexample

- Running Firefox and Zoom on a laptop without an OS

- Need to rewrite Firefox to replace all its syscalls
- Need to rewrite Zoom to replace all its syscalls
- Need to join Firefox and Zoom together into one binary that does both
  - When does Firefox functionality run vs Zoom?
  - How do we keep Firefox from goofing up Zoom's memory?
  - What happens when there is a buffer overflow in Zoom and then you access your bank account via Firefox?

Operating Systems to the Rescue 1

- Abstract underlying resources
  - CPU, Memory, Network, Disk
- Much easier to use: implement 1x well, use 10^6 times
- Portable: run on different CPUs, different NICs, different Disks

Operating Systems to the Rescue 2

- Share underlying resources
- Firefox and Zoom and Slack and Terminal can all use the CPU, memory, network, and disk
- With **isolation:** Zoom can have a buffer overflow, but even when compromised can’t read Firefox’s memory
  - And Slack can’t make your terminal crash

Operating Systems in this Class

- Virtual Memory
  - How can we isolate the memory of different applications?
  - How can we have applications think they have more memory than actually exists on the machine?
  - Introduce **Naming** an important general systems concept
- Unix File System
  - How to build a hierarchical file system over a disk
  - Introduce **Layering** an important general systems concept
- Reasoning about Performance, OS style

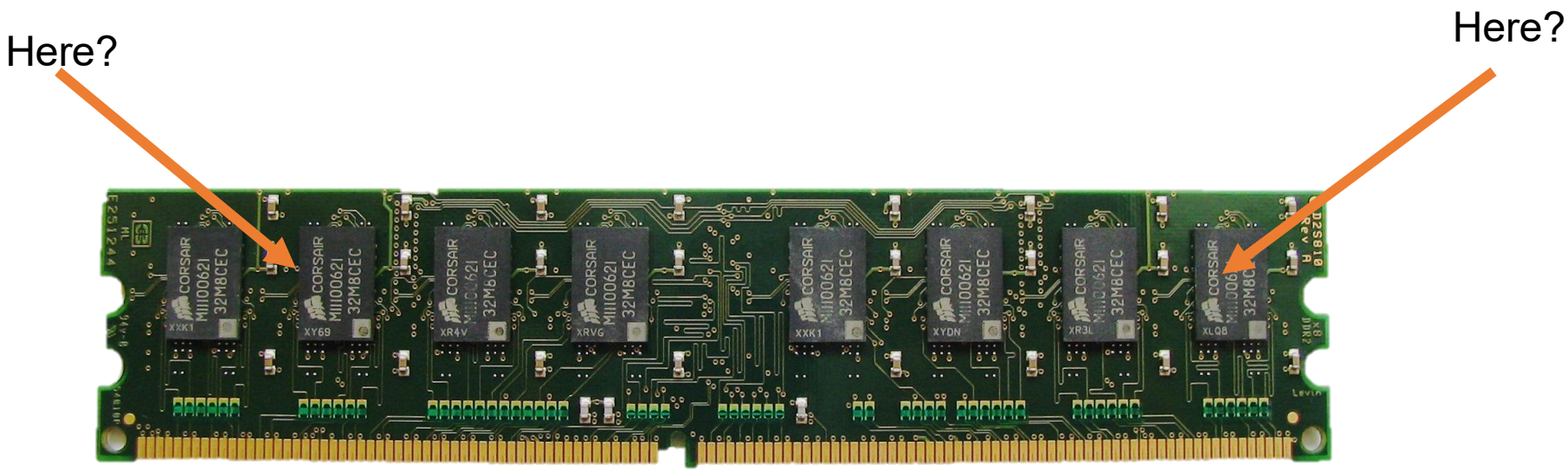
Virtual Memory

Let’s Have Applications Use Memory

Image from: https://commons.wikimedia.org/wiki/File:DRAM_DDR2_512.jpg

Applications need a way to **name** memory

- Where are reads and writes going?!



Why does naming matter?

- Naming is a central design choice in the interface of a system

- Recall: Systems provide an interface to underlying resources
  - Mediate access to shared resources
  - Isolate applications
  - Abstract complexity
  - Abstract differences in implementation

- We always need some way for applications (or other clients) to name those resources

Why does naming matter?

- The names systems use to expose underlying resources affects every other aspect of the system:
  - Performance of the system implementation
  - Application performance and flexibility
  - Security & Isolation
  - Portability
  - Resource sharing and concurrency

Naming Memory #1: Geometric memory (strawman)

- **Values**: Words of memory

- **Names**: `DIMM 1; BANK 3; ROW 1200; COLUMN 4;`
  - Specifies the precise location of the word(s)

- **Lookup** mechanism: direct in simple hardware

Naming Memory #2: Physical memory

- **Values**: Words of memory
- **Names**: `0xDEADBEEF`
  - Integer up to the maximum size of memory in words
- **Lookup** mechanism: direct in simple hardware

Comparing Geometric and Physical

- Performance of the system implementation
- Application performance and flexibility
- Security & Isolation
- Portability
- Resource sharing and concurrency

- All essentially the same
- But physical is more **portable** than geometric
  - (Geometric is not real for memory, dominated by physical)

Issues with Physical Memory

- How can I isolate one application from another?
  - Slack can directly access memory used by Firefox
- How can I run an application that wants more memory than a machine physically has?
  - How can I run a collection of applications that want more memory than a machine physically has?
- **Hide the physical names and instead use virtual names!**

Naming Memory #3: Virtual memory

- **Values**: (type, address)
  - Type is a type of storage; address is storage specific
    - (Memory, memory address)
    - (File, file name and offset in file)
    - (Remote memory, remote node and memory address)
    - …

- **Names**: 64 bit address & process ID
  - E.g., `(0xDEADBEEF, 1337)`
  - process ID is typically implicit

- **Allocation**: mmap

mmap system call

- void *mmap(void *addr, size_t length) (simplified)

- Application chooses an unused name: an address not yet allocated for it
  - (Or can pass in NULL if it doesn't care)

- OS Kernel (the system!)
  - keeps a list of unused physical 4KB memory pages
  - allocates "value" by removing a physical page from the list
  - adds mapping between virtual address and physical to the application's "page table"
    - in-memory data structure understood by virtual memory hardware that maps virtual addresses to physical addresses

Virtual memory lookup

- Lookup virtual address in “page table”
  - Stored in memory (where it is “pinned”)
  - OS maintains one page table per process
  - Page table maps virtual address to physical memory address OR file and location OR remote machine and memory address
- Performance implications?

Naming Memory #3: Virtual memory

- **Values**: (type, address)
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    - …
- **Names**: 64 bit address & process ID
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  - process ID is typically implicit
- **Allocation**: mmap
- **Lookup**: TLB, page table, disk, …

Virtual memory lookup

- Lookup virtual address in TLB (Translation lookaside buffer)
  - Small hardware implemented cache
  - Hit → translates to physical address
- TLB miss goes to “page table”
  - Stored in memory (where it is “pinned”)
  - OS maintains one page table per process
  - Page table maps virtual address to physical memory address OR file and location OR remote machine and memory address

Comparing Physical and Virtual

	Winner?
• Performance of the system implementation	• Physical
• Application performance	• Physical
• Application flexibility	• Virtual
• Security (Isolation)	• Virtual
• Effectiveness of caching	• Physical
• Resource sharing and concurrency	• ~Same
• Portability	• ~Same

What type of memory naming to use?

1. On your laptop
2. For a tiny power constrained microcontroller
3. For a supercomputer that runs one massive simulation at a time
4. On your phone

Virtual Memory and Naming Summary

- Names are the way systems expose resources to applications
- Central to designing and understanding systems
  - Performance
  - Security
  - Caching
  - Resource sharing
- Virtual Memory
  - Names are unique to each process → isolation
  - Names are translated to physical addresses → can have larger address space than physical memory
  - Hardware support (TLB) makes the implementation efficient