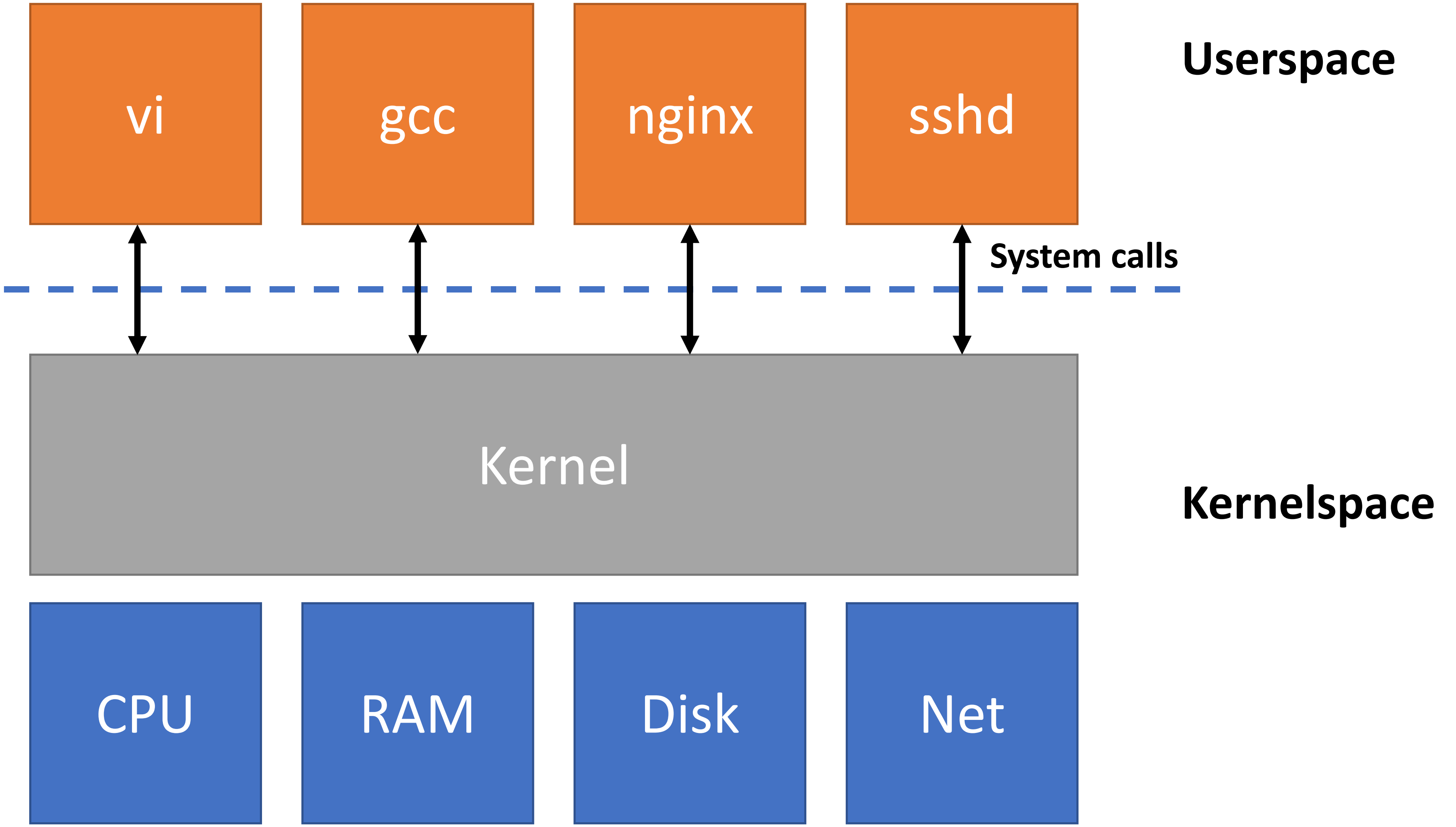
6.S081: OS Organization

Adam Belay <abelay@mit.edu>

Lecture topics

- OS design
  - System calls
  - Hardware isolation
  - Micro kernels vs. monolithic kernels
- System calls in xv6

OS Organization (from last time)

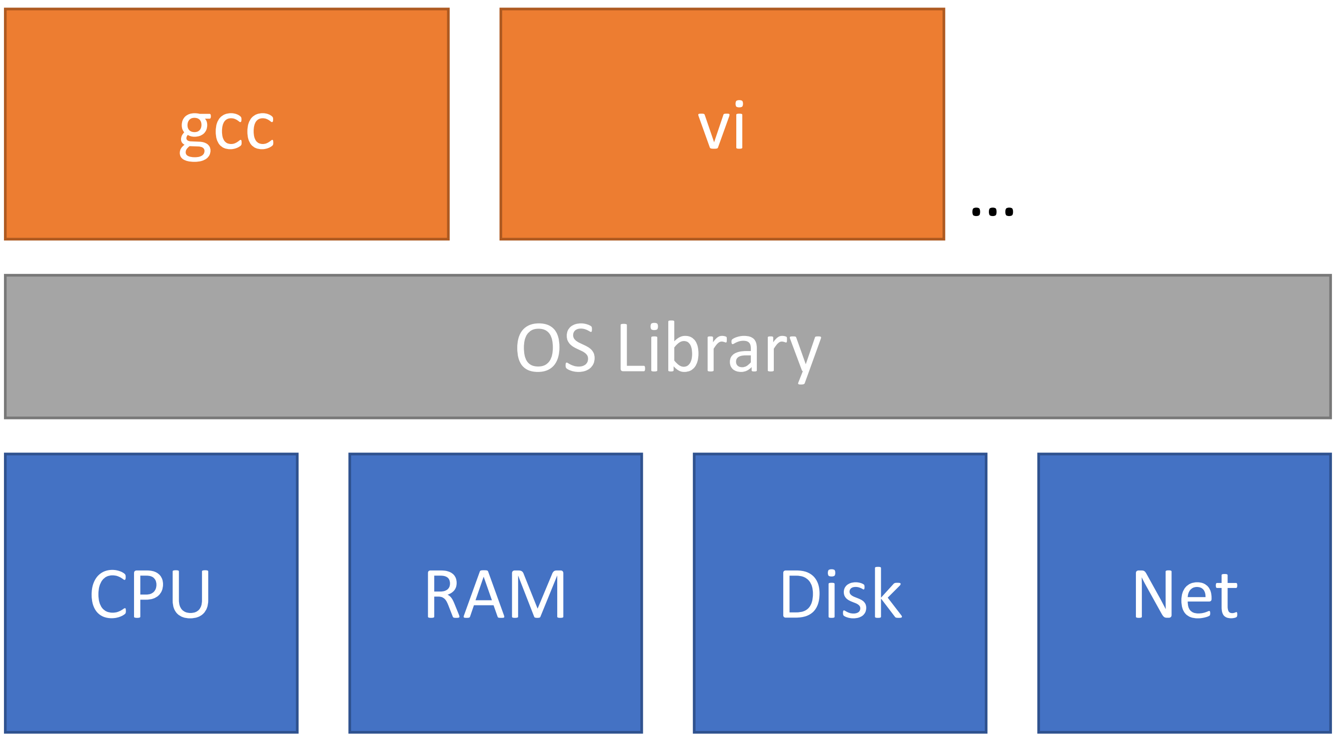


Multiplexing

- Must handle multiple applications
- Need isolation between them
- But must share resources too

Strawman solution

- Applications use hardware directly
- OS acts as a library



Problem: Can’t multiplex

- Each app must periodically give up hardware
- But weak isolation
  - App forgets to give up -> nothing else runs
  - Apps has end-less loop -> nothing else runs
  - Can’t even kill the misbehaving app from another app
- This scheme is sometimes used in practice
  - Called *cooperative scheduling*

Bigger problem: Memory isolation

- All apps share physical memory
  - One app can overwrite another app’s memory
  - One app can overwrite the OS library
- No security!

UNIX interface

- Processes (instead of cores): fork()
  - OS transparently allocates cores
    - Save + Restore registers
  - Enforces that processes give them up
    - Periodically re-allocates cores

UNIX interface

- Memory (instead of physical memory): exec(), brk()
  - Each process has its own memory
  - OS decides where to place app in memory
  - OS enforces isolation between apps
  - OS stores image in file system (loaded with exec)

UNIX interface

- Files instead of disk blocks: open(), read(), write()
  - OS provides convenient names
  - OS allows files to be shared by apps and users
- Pipes instead of shared physical memory: pipe()
  - OS buffers data
  - OS stops sender if it transmits too fast

OS must be defensive

- An app shouldn't be able to crash OS
- An app shouldn't be able to break out of isolation
- Need strong isolation between apps and OS

Solution: use CPU hardware support

- User/kernel mode (privilege modes)
- Virtual memory

CPUs provide user/kernel mode

- Kernel mode: can execute “privileged” instructions
  - E.g., changing back to user mode
  - E.g., programming a timer chip
  - E.g., controlling virtual memory
- User mode: can’t execute “privileged” instructions
  - If it tries, faults to kernel

Plan: Run kernel is kernel mode, apps in user mode

* (RISC-V M-mode not used in this class)

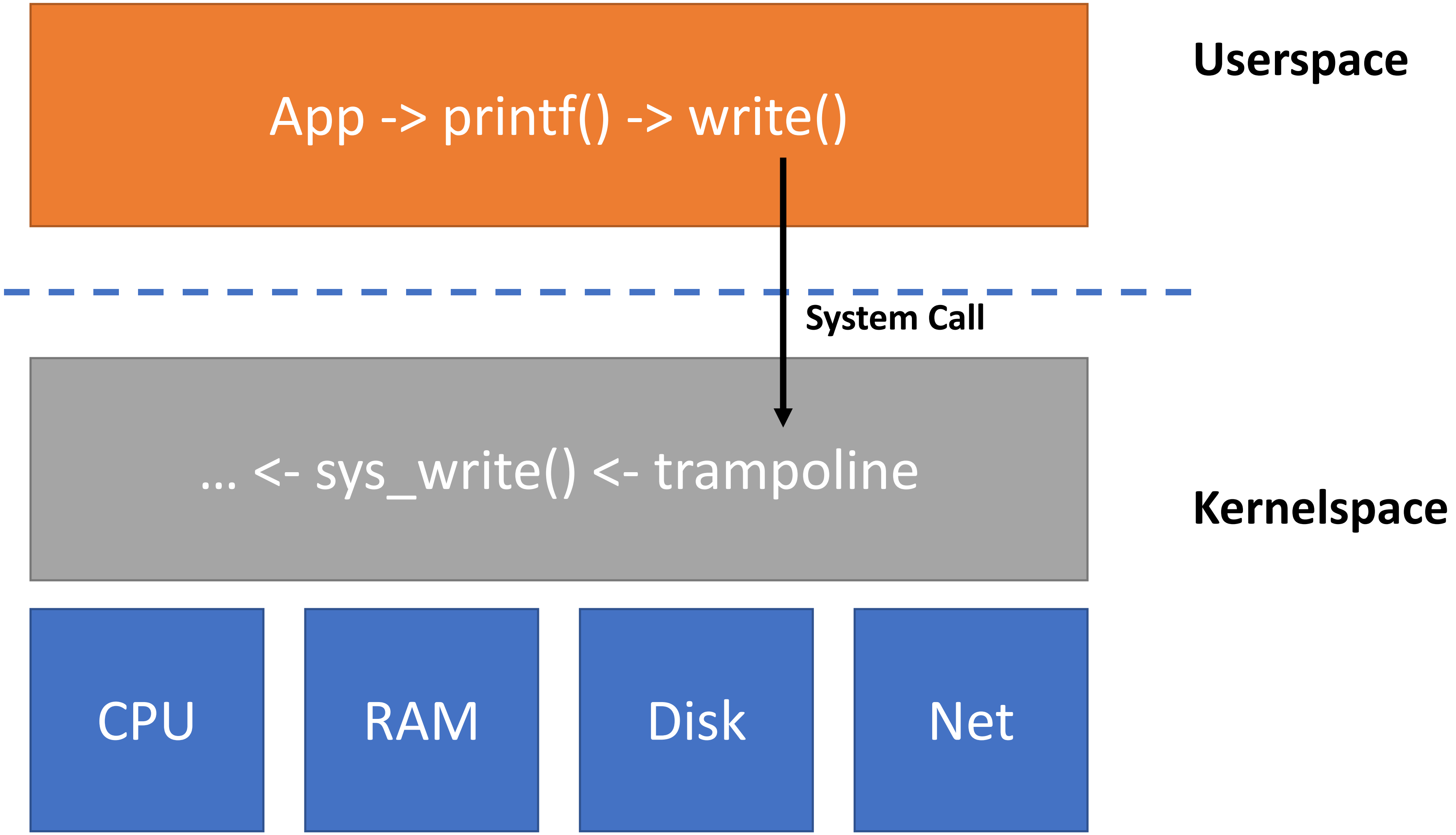
CPUs provide virtual memory

- Page tables translate virtual address to physical
- Defines what physical memory an app can access
- OS sets up page table so each app can only access its memory

System calls

- Apps need to communicate with kernel
- Solution add instruction to change mode in controlled way
  - ecall on Risc-V
  - Enters kernel at pre-agreed instruction address

System calls



Kernel is trusted computing base

- Kernel must be “correct”
  - Bugs could allow user apps to circumvent isolation
- Kernel must treat user apps as suspect
  - Each system call argument must be validated
  - User/kernel mode transitions must be set up correctly
- Requires a security mindset
  - Any bug could be a security exploit!

Aside: is isolation possible without HW support?

- Imagine no kernel/user mode or virtual memory
- Yes! Use a strongly-typed programming language
  - E.g., singularity OS
- The compiler is then the TCB
- But HW support is the most common plan

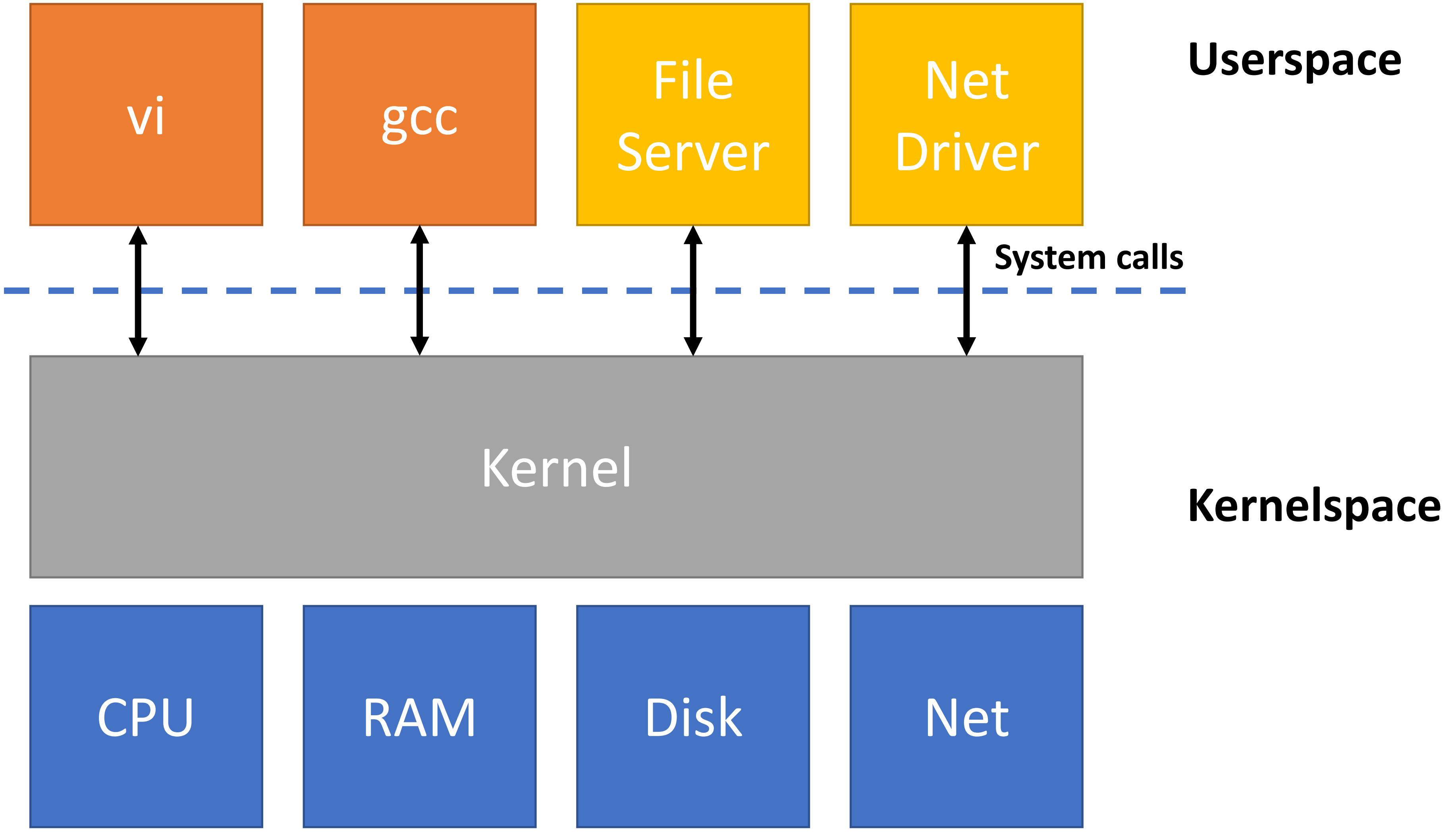
Monolithic kernels

- OS runs in kernel space
- xv6 does this, so does Linux
- Kernel interface == system call interface
- Kernel is one big program with everything (filesystem, drivers, memory management, etc.)
- Pros:
  - Easy for subsystems to cooperate
    - E.g., one cache for file system and virtual memory
  - Good performance
- Cons:
  - Interactions are complex, leads to bugs
  - No isolation within

Microkernels

- Runs OS services as ordinary user programs
  - E.g., a server provides the file system
- kernel implements minimal mechanism to run services in user space
  - Processes with memory
  - Interprocess communication
- Kernel interface != system call interface
- Pro: More isolation, more fault tolorance
- Con: Hard to get good performance, complexity

Microkernels

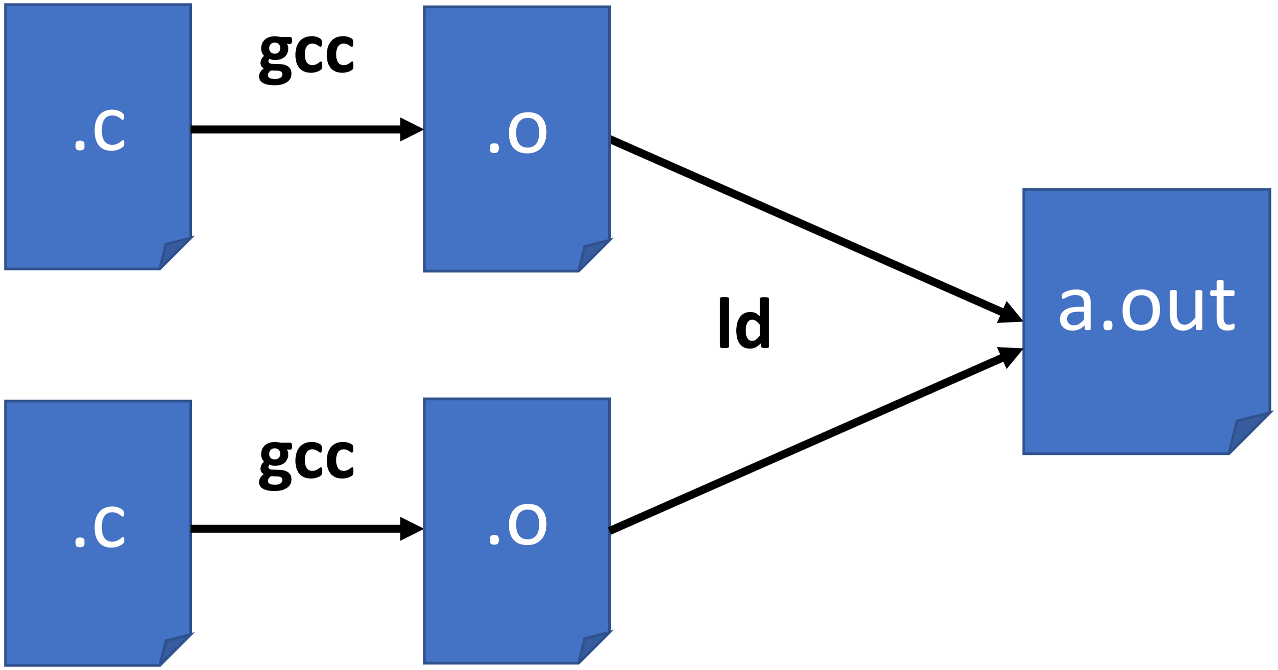


Xv6 case study

- Monolithic kernel
  - UNIX system calls are the kernel interface
- Source code reflects OS organization
  - user/ apps in user mode
  - kernel/ kernel's implementation
- Kernel has several parts
  - kernel/defs.h, kernel/proc.c, kernel/fs.c, etc.

Goal: simple, easily readable/understandable

Building xv6 (e.g., make)



Risc-V's (emulated) computer

- A very simple board, e.g., no display
- Risc-V processor with N cores
- RAM (128 MB)
- Supports interrupts (PLIC, CLINT)
- Supports UART (serial port)
  - Xv6 uses this to provide a console (out)
  - Xv6 uses this to get keyboard input (in)
- Supports E1000 network card (over PCIe)

Why develop with qemu?

- More convenient than using real hardware
- Qemu emulates several types of computers
  - we use the "virt" one https://github.com/riscv/riscv-qemu/wiki
  - close to the SiFive board (https://www.sifive.com/boards) but with virtio for disk

CPU emulation

- What is it to "emulate"?
- qemu is a C program that faithfully implements a RISC-V processor

```
for (;;) {
  read next instructions
  decode instruction
  execute instruction (updating processor state)
}
```