I/O

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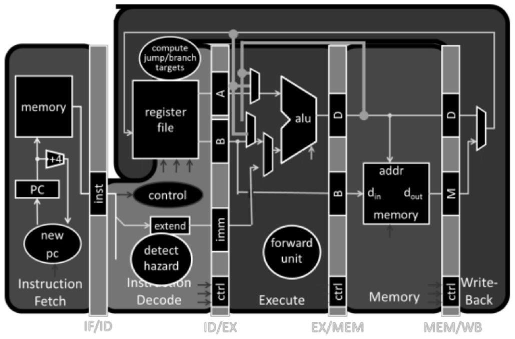
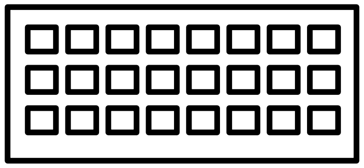
Big Picture: Input/Output (I/O)

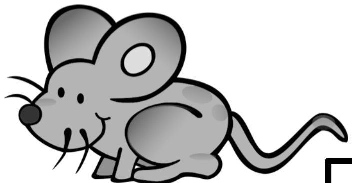
How does a processor interact with its environment?

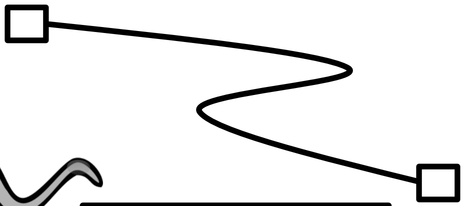
Computer System =

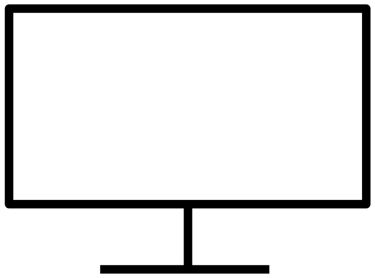
Memory + Datapath + Control + Input + Output

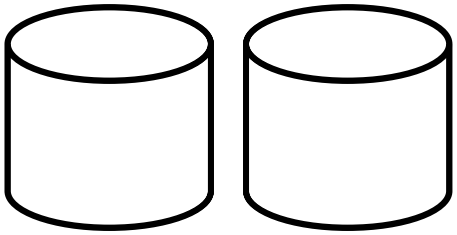



Keyboard




Network

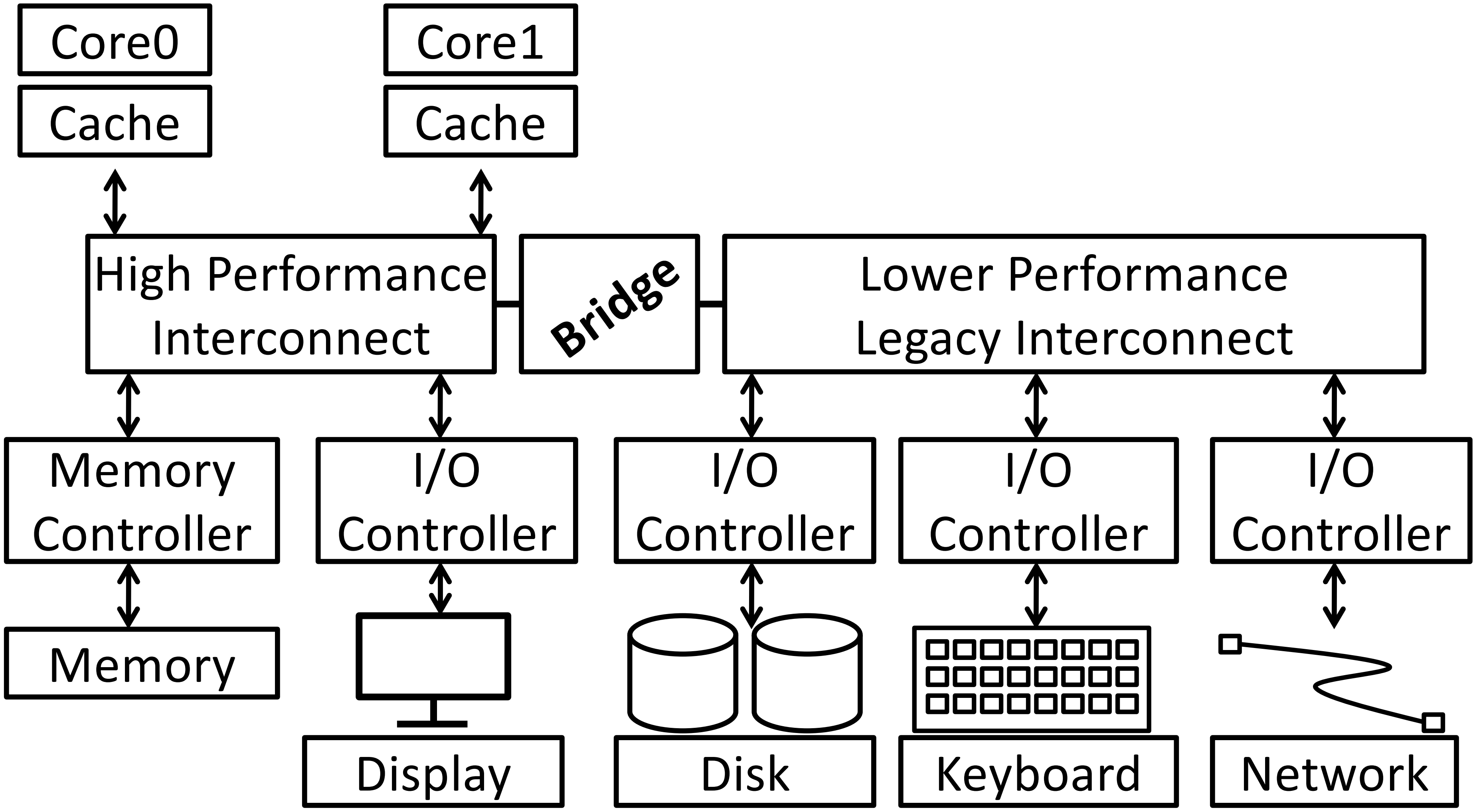

Display


Disk

Putting it all together

I/O connected with I/O Controllers

high-performance interconnect: processor, memory, display
lower-performance interconnect: disk, keyboard, network



Bus Types

Processor – Memory (“Front Side Bus”)

- Short, fast, & wide
- Mostly fixed topology, designed as a “chipset”
  - CPU + Caches + Interconnect + Memory Controller

I/O and Peripheral busses (PCI, SCSI, …)

- Longer, slower, & narrower
- Flexible topology, multiple/varied connections
- Interoperability standards for devices
- Connect to processor-memory bus through a bridge

I/O Device API

Typical I/O Device API

- a set of read-only or read/write registers

Command registers

- writing causes device to do something

Status registers

- reading indicates what device is doing, error codes, …

Data registers

- Write: transfer data to a device
- Read: transfer data from a device

Every device uses this API

How to talk to a device?

1. Programmed I/O:

   special instructions talk over special busses

   Specify: device, data, direction

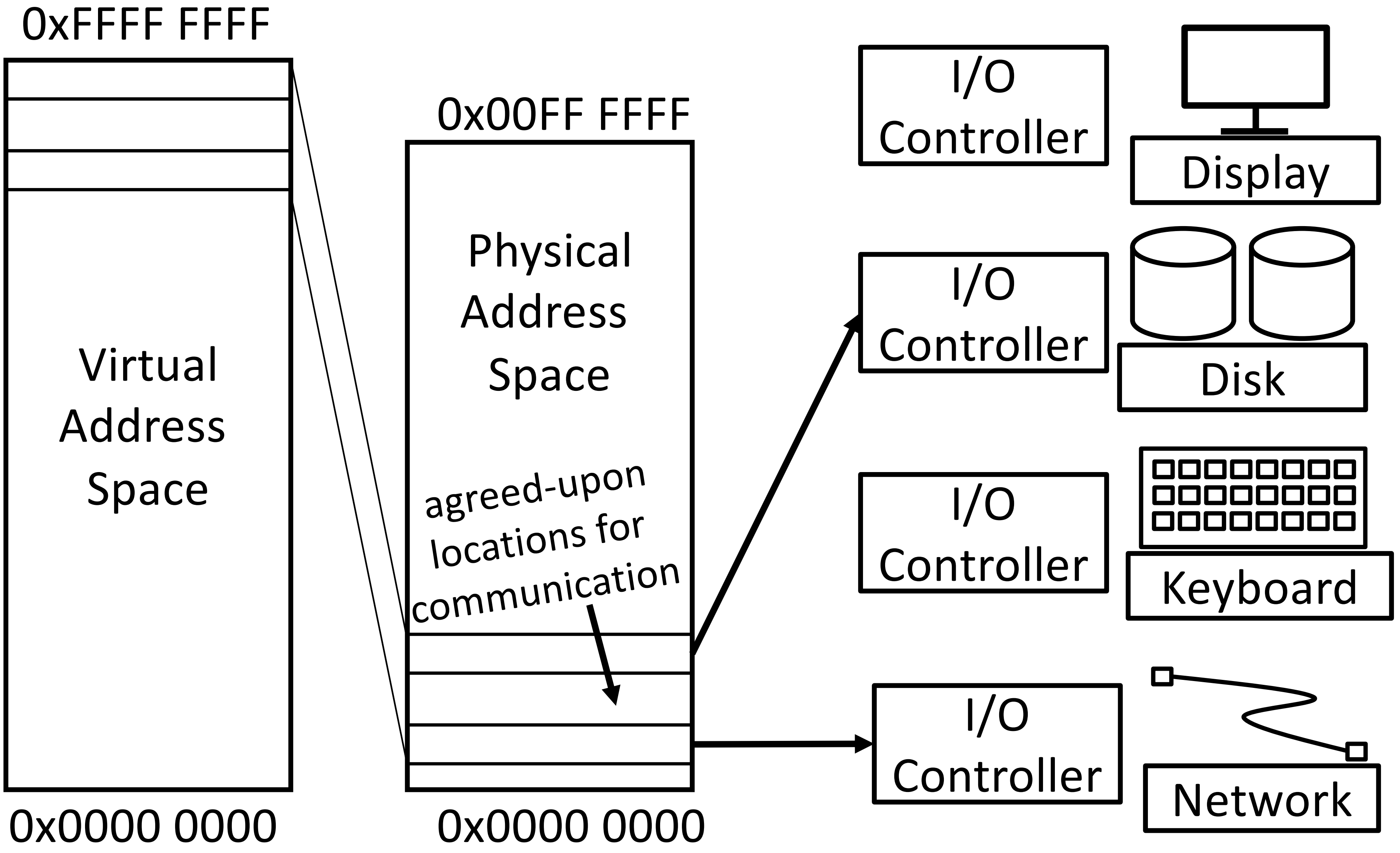
   - inb $a, 0x64 (keyboard status register)
   - outb $a, 0x60 (keyboard data register)
   - Protection: only allowed in kernel mode (expensive)

2. Memory-Mapped I/O:

   map registers into virtual address space

   - Accesses to certain addresses redirected to I/O devices
   - Data goes over the memory bus (faster!)
   - Protection: via bits in pagetable entries
   - OS+MMU+devices configure mappings

Memory-Mapped I/O



vs. less-favored alternative = Programmed I/O:

- Syscall instructions that communicate with I/O
- Communicate via special device registers

Device Drivers

Programmed I/O

```
char read_kbd()
{
do {
    sleep();
    status = inb(0x64);
  } while(!(status & 1));

  return inb(0x60);
}
```

syscalls

Memory Mapped I/O

```
struct kbd {
  char status, pad[3];
  char data, pad[3];
};
kbd *k = mmap(...);

char read_kbd()
{
  do {
    sleep();
    status = k->status;
  } while(!(status & 1));
  return k->data;
}
```

syscall

Clicker Question: Which is better?

(A) Programmed I/O

(B) Memory Mapped I/O

(C) Both have syscalls, both are bad

I/O Data Transfer

How to talk to device?

- Programmed I/O or Memory-Mapped I/O

How to get events?

- Polling or Interrupts

How to transfer lots of data?

```
disk->cmd = READ_4K_SECTOR;
disk->data = 12;
while (!(disk->status & 1) { }
for (i = 0..4k)
    buf[i] = disk->data;
```

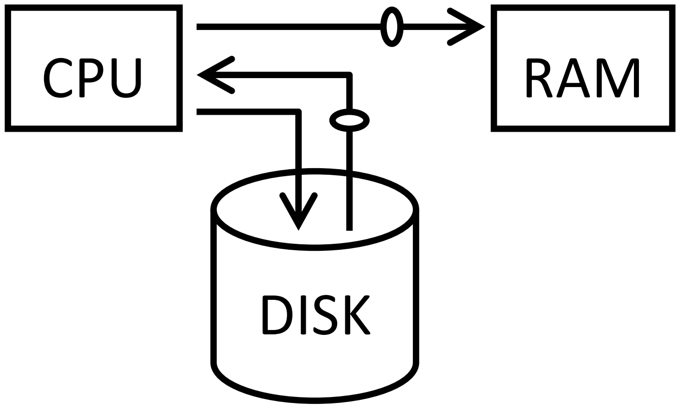
Very,
Very,
Expensive

Data Transfer

1. Programmed: Device ←→ CPU ←→ RAM Transfer

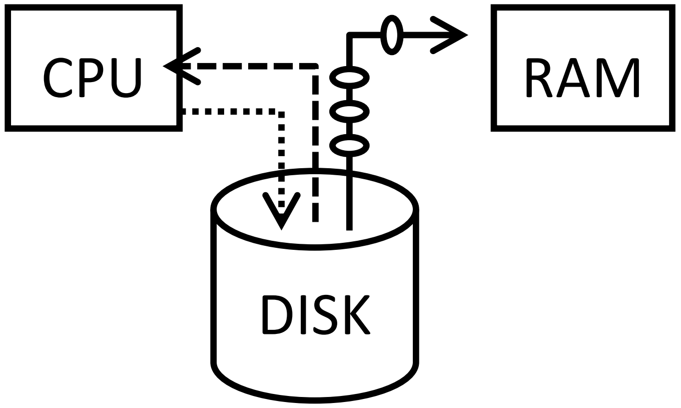
for (i = 1 .. n)

- CPU issues read request
- Device puts data on bus & CPU reads into registers
- CPU writes data to memory



2. Direct Memory Access (DMA): Device ←→ RAM

- CPU sets up DMA request
- for (i = 1 ... n)
  Device puts data on bus
  & RAM accepts it
- Device interrupts CPU after done



Programmed I/O vs Memory Mapped I/O

Programmed I/O

- Requires special instructions
- Can require dedicated hardware interface to devices
- Protection enforced via kernel mode access to instructions
- Virtualization can be difficult

Memory-Mapped I/O

- Re-uses standard load/store instructions
- Re-uses standard memory hardware interface
- Protection enforced with normal memory protection scheme
- Virtualization enabled with normal memory virtualization scheme

Polling vs. Interrupts

How does program learn device is ready/done?

1. Polling: Periodically check I/O status register
   - Common in small, cheap, or real-time embedded systems

   + Predictable timing, inexpensive

   – Wastes CPU cycles

2. Interrupts: Device sends interrupt to CPU
   - Cause register identifies the interrupting device
   - Interrupt handler examines device, decides what to do

   + Only interrupt when device ready/done

   – Forced to save CPU context (PC, SP, registers, *etc.*)

   – Unpredictable, event arrival depends on other devices' activity

Clicker Question: Which is better?

(A) Polling (B) Interrupts (C) Both equally good/bad