# CS202 (003): Operating Systems
# I/O

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Most of the materials covered in this slide come from the lecture notes of Mike Walfish's CS202

# Last Time

# I/O Architecture at a high-level

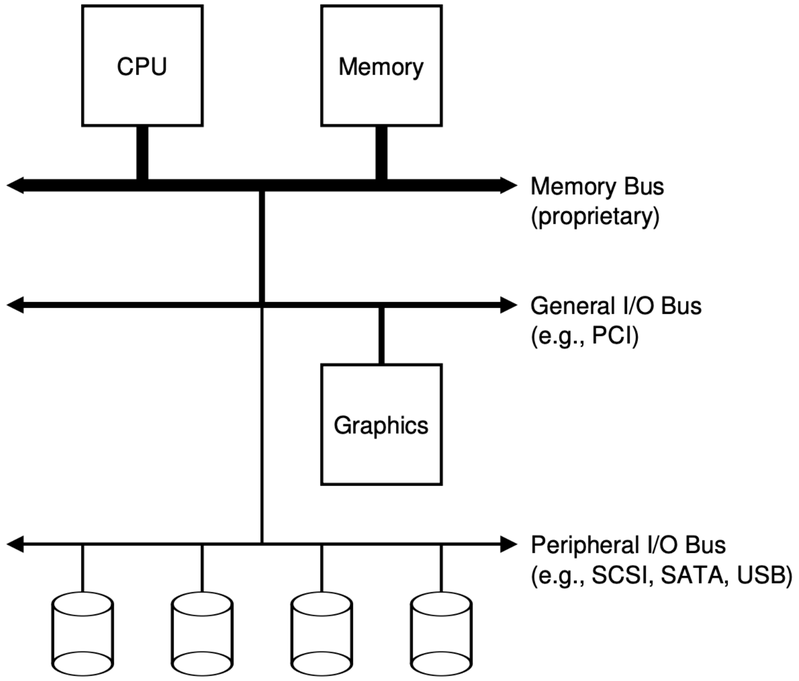
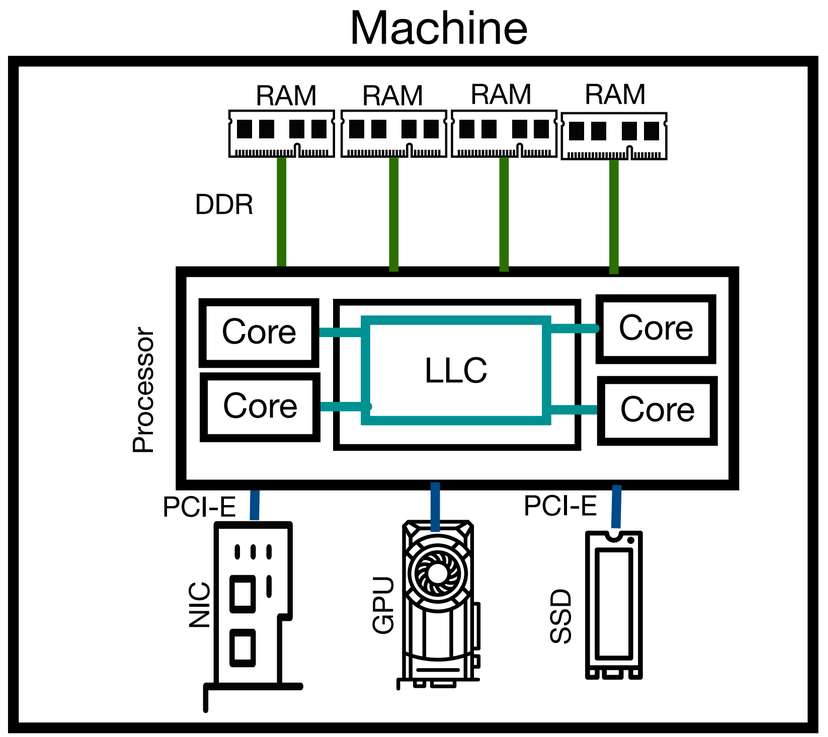



Figure 36.1: **Prototypical System Architecture**

**Textbook (older)**




**Newer**

# CPU(kernel)/Device Interaction

Mechanics of Communication

Explicit I/O instructions `outb, inb, outw, inw`

WeesyOS boot.c (handout)

```
Control Register:
  Address 0x3F6 = 0x08 (0000 1RE0): R=reset,
                  E=0 means "enable interrupt"

Command Block Registers:
  Address 0x1F0 = Data Port
  Address 0x1F1 = Error
  Address 0x1F2 = Sector Count
  Address 0x1F3 = LBA low byte
  Address 0x1F4 = LBA mid byte
  Address 0x1F5 = LBA hi  byte
  Address 0x1F6 = 1B1D TOP4LBA: B=LBA, D=drive
  Address 0x1F7 = Command/status

Status Register (Address 0x1F7):
    7      6     5      4     3     2     1     0
   BUSY  READY FAULT SEEK  DRQ  CORR IDDEX ERROR

Error Register (Address 0x1F1): (check when ERROR==1)
    7      6     5      4     3     2     1     0
   BBK    UNC   MC    IDNF  MCR  ABRT T0NF AMNF

   BBK  = Bad Block
   UNC  = Uncorrectable data error
   MC   = Media Changed
   IDNF = ID mark Not Found
   MCR  = Media Change Requested
   ABRT = Command aborted
   T0NF = Track 0 Not Found
   AMNF = Address Mark Not Found
```

each register stores 8-bit data

LBA: Linear block address (28-bit in the handout)

describes storage locations

each sector gets a unique number starting from 0

Status is read-only

Command is used to add instructions to the disk

Figure 36.5: **The IDE Interface**

(Integrated Device Electronics): connection between a bus on the motherboard and disk storage

https://www.rfcandy.biz/communication/ide.html

```
static int ide_wait_ready() {
  while (((int r = inb(0x1f7)) & IDE_BSY) || !(r & IDE_DRDY))
    ;  // loop until drive isn't busy
  // return -1 on error, or 0 otherwise
}

static void ide_start_request(struct buf *b) {
  ide_wait_ready();
  outb(0x3f6, 0);                   // generate interrupt
  outb(0x1f2, 1);                   // how many sectors?
  outb(0x1f3, b->sector & 0xff);    // LBA goes here ...
  outb(0x1f4, (b->sector >> 8) & 0xff);   // ... and here
  outb(0x1f5, (b->sector >> 16) & 0xff);  // ... and here!
  outb(0x1f6, 0xe0 | ((b->dev&1)<<4) | ((b->sector>>24)&0x0f));
  if(b->flags & B_DIRTY){
    outb(0x1f7, IDE_CMD_WRITE);     // this is a WRITE
    outsl(0x1f0, b->data, 512/4);   // transfer data too!
  } else {
    outb(0x1f7, IDE_CMD_READ);      // this is a READ (no data)
  }
}

void ide_rw(struct buf *b) {          handle read/write request
  acquire(&ide_lock);
  for (struct buf **pp = &ide_queue; *pp; pp=&(*pp)->qnext)
    ;                               // walk queue
  *pp = b;                          // add request to end
  if (ide_queue == b)               // if q is empty
    ide_start_request(b);           // send req to disk
  while ((b->flags & (B_VALID|B_DIRTY)) != B_VALID)
    sleep(b, &ide_lock);            // wait for completion
  release(&ide_lock);
}

void ide_intr() {  handle disk interrupt when operation complete
  struct buf *b;
  acquire(&ide_lock);
  if (!(b->flags & B_DIRTY) && ide_wait_ready() >= 0)
    insl(0x1f0, b->data, 512/4);    // if READ: get data
  b->flags |= B_VALID;
  b->flags &= ~B_DIRTY;
  wakeup(b);                        // wake waiting process
  if ((ide_queue = b->qnext) != 0) // start next request
    ide_start_request(ide_queue);  // (if one exists)
  release(&ide_lock);
}
```

read: data is read and valid bit is set
write: data is written and dirty bit is cleaned

Figure 36.6: **The xv6 IDE Disk Driver (Simplified)**

# CPU(kernel)/Device Interaction

Mechanics of Communication

Explicit I/O instructions

`outb, inb, outw, inw` — WeesyOS boot.c (handout)

`keyboard_readc()` — reading keyboard input (handout)

# CPU(kernel)/Device Interaction

Mechanics of Communication

Explicit I/O instructions

`outb, inb, outw, inw` — WeesyOS boot.c (handout)

`keyboard_readc()` — reading keyboard input (handout)

`console_show_cursor()` — setting blinking cursor (handout)

# CPU(kernel)/Device Interaction

Mechanics of Communication

Memory-mapped I/O

Most of the physical address space contains regular RAM
However, the lower memory addresses (650K-1MB) are special - they don't refer to actual RAM

WeesyOS console printing (handout)

# CPU(kernel)/Device Interaction

Mechanics of Communication

Explicit I/O instructions

Memory-mapped I/O

Interrupts

# CPU(kernel)/Device Interaction

Mechanics of Communication

Explicit I/O instructions

Memory-mapped I/O

Interrupts

Through memory

Both CPU and the device see the same memory, so they can use shared memory to communicate. (eg. DMA)

# Polling vs. Interrupt (vs. busy waiting)

Busy Waiting

```
while (!device_is_ready()) {
  // CPU is stuck here,
repeatedly checking
  // Consuming CPU cycles doing
nothing useful
}
```

Simple but inefficient
CPU stuck here running at full speed

# Polling vs. Interrupt (vs. busy waiting)

Busy Waiting

```
while (!device_is_ready()) {
  // CPU is stuck here,
repeatedly checking
  // Consuming CPU cycles doing
nothing useful
}
```

Polling

```
void poll_device() {
  while (1) {
      if (device_is_ready())
          { process_device_data(); }

        // Sleep/delay for a set
        interval
        sleep_ms(100); // Check every
        100ms
    }
  }
```

System checks device status at regular intervals
Lower CPU usage

# Polling vs. Interrupt (vs. busy waiting)

## Busy Waiting

```
while (!device_is_ready()) {
  // CPU is stuck here,
repeatedly checking
  // Consuming CPU cycles doing
nothing useful
}
```

## Interrupts

```
// CPU sets up interrupt handler
set_interrupt_handler
   (device_interrupt_handler);

// CPU goes on to do other useful work
do_other_work();

// When device needs attention,
it triggers interrupt
// and the handler runs automatically
void device_interrupt_handler() {
   // Handle the device's needs
   process_device_data();
}
```

Most sophisticated approach

If interrupt rate is high, we can get **livelock**

## Polling

```
void poll_device() {
  while (1) {
      if (device_is_ready())
          { process_device_data(); }

        // Sleep/delay for a set
        interval
        sleep_ms(100); // Check every
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    }
  }
```

# Programmed I/O vs. DMA (Direct memory access)

Programmed I/O

CPU writes data directly to device, and reads data directly from device.

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## Programmed I/O

CPU writes data directly to device, and reads data directly from device.

## DMA

CPU places some buffers in main memory.

Tells device where the buffers are
Then "pokes" the device by writing to register
Then device uses DMA to read or write the
The CPU can poll to see if the DMA completed (or the device can interrupt the CPU when done).

CPU don’t have to constantly deal with small amount of data transfer, the device can write the contents straight into memory

# Software architecture: device drivers

Device drivers act as a bridge between hardware devices and the operating system kernel

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```
reset(): Initializes or resets the device
ioctl(): Provides device-specific controls
read()/write(): Standard data transfer operations
handle_interrupt(): Manages hardware interrupts
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# Software architecture: device drivers

Device drivers act as a bridge between hardware devices and the operating system kernel

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```

Example interface

Advantages: don’t have to worry about the specific hardware implementation

Issues:

1. Device drivers is per-OS and per-device  (hard part cannot be reused)
2. Bugs in device drivers often bring down the entire machine

# Synchronous vs. Asynchronous I/O

Synchronous I/O

When a process makes a system call (like read() or write()),
it blocks (suspends) until the operation completes

The process enters a sleep state and cannot
execute other codes

Control returns to process after operation finishes

Code is often more readable, but it is slow

# Synchronous vs. Asynchronous I/O

## Synchronous I/O

When a process makes a system call (like read() or write()), it blocks (suspends) until the operation completes

The process enters a sleep state and cannot execute other codes

Control returns to process after operation finishes

## Async I/O

System calls return immediately, even if the operation isn't completed

Instead of blocking, the call returns a status indicating what would have happened

Check through polling or interrupt

Need to use platform-specific extensions to POSIX to do async I/O for files

Enjoy the spring break!
(no class next week)