
THE UNIVERSITY *of* EDINBURGH
informatics

# Operating Systems (INFR10079)

2023/2024 Semester 2

# IO Subsystems

abarbala@inf.ed.ac.uk

Chapter 12.1, 12.2, 12.3, 12.4, 12.5

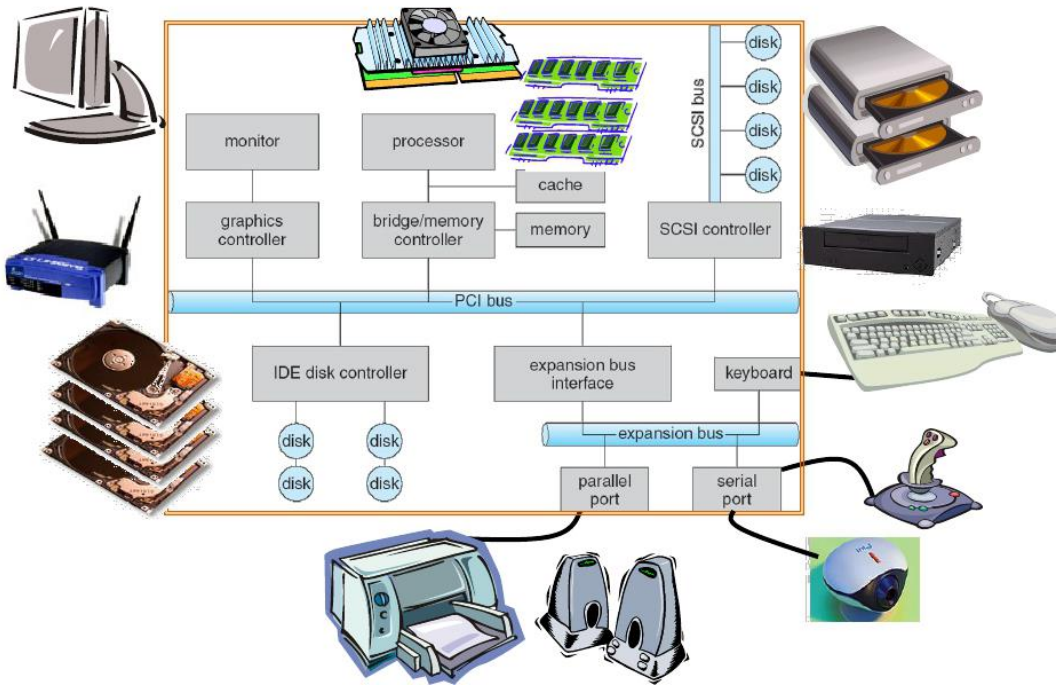
# IO Subsystems: Overview

- Applications do **IO and compute**
  - OS manages and controls IO for applications
    - Common interfaces to IO devices
    - IO Services

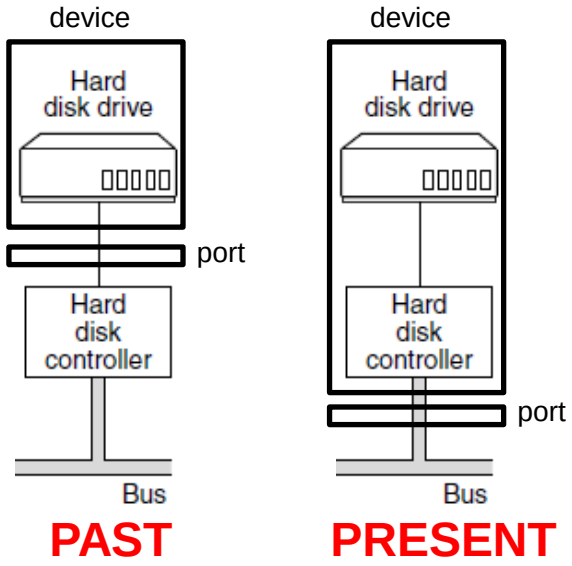
- IO Hardware
- CPU to device communication
  - PIO (Programmed input–output)
  - DMA (Direct memory access)
- Device Drivers
- IO Subsystem
- An IO Syscall Example

# Devices

- Storage devices
  - Disk
  - Tape
- Transmission devices
  - Network connections
  - Bluetooth
- Human-interface devices
  - Screen
  - Keyboard
  - Mouse
  - Audio in
  - Audio out
- Specialized devices
  - E.g., to control a machine/equipment (aircraft)



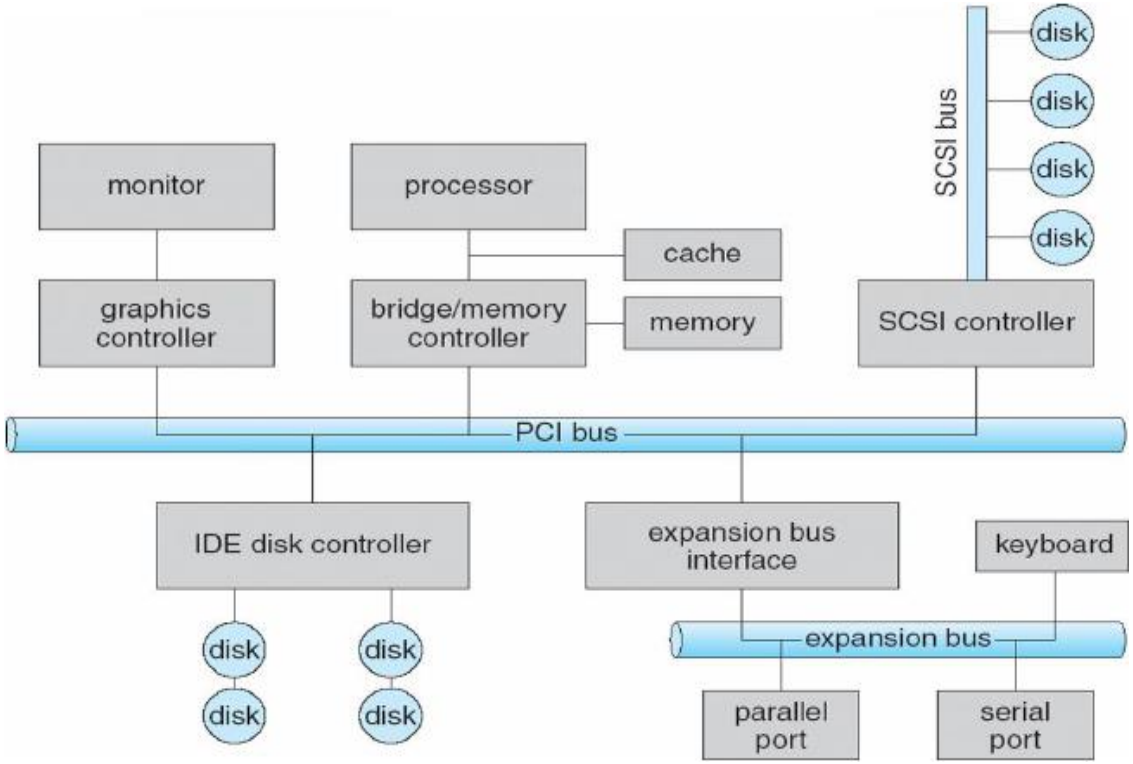
# I/O Hardware #1




- Variety of I/O devices
- Common concepts
  - **Port**
    - Connection point for device (e.g., USB, parallel, serial, Ethernet)
  - **Bus**
    - **Peripheral** buses (e.g., PCI/PCIe)
    - **Expansion bus** connects relatively slow devices
  - **Device**
  - **Controller** (**host adapter**)
    - Electronics that operate port, bus, device
      - Sometimes integrated
      - Sometimes separate circuit board (host adapter)
    - Contains processor, microcode, private memory, bus controller, etc.

# I/O Hardware #2

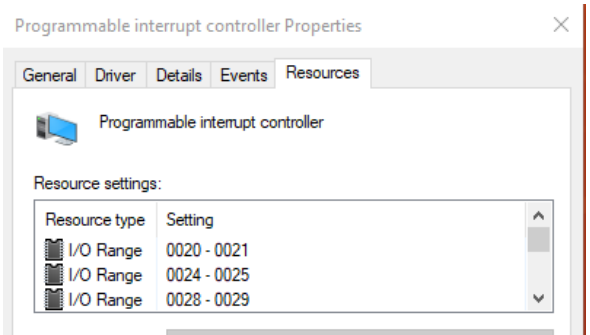
- Buses (cyan)
  - Handle the traffic between I/O devices and processor
- Examples
  - PCI/PCIe
    - Connects with high speed graphics, networking, etc.
    - Connects to low speed buses
  - SCSI
    - Used to be for fast devices with large bandwidth (disks, scanners, etc.)



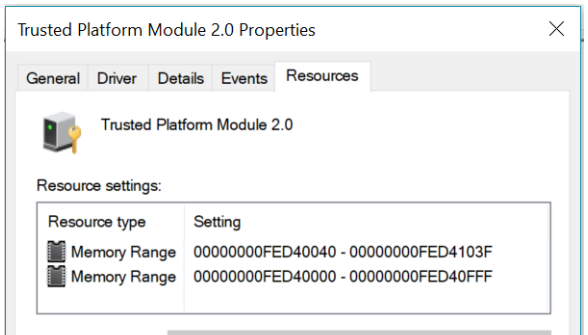
# CPU to Device Communication

- Controllers have
  - **Registers** for data and control
  - **Buffers** (memory-like areas) mostly for data
- CPU **communicates** with devices by reading and writing in registers and buffers
- Communication methods
  - **IO Ports**
  - **Memory-mapped IO**
  - **Hybrid**

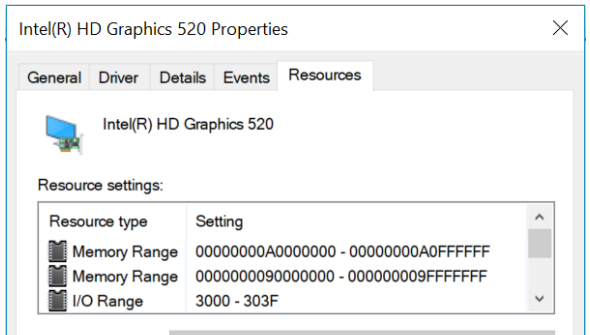
I/O Ports



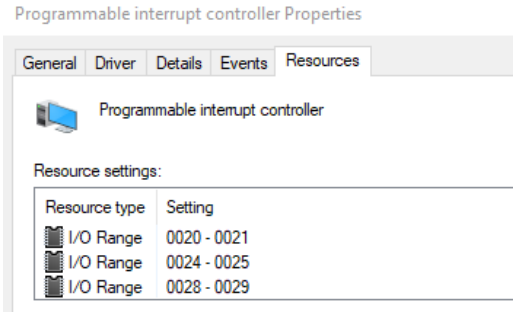

Memory Mapped I/O




Hybrid

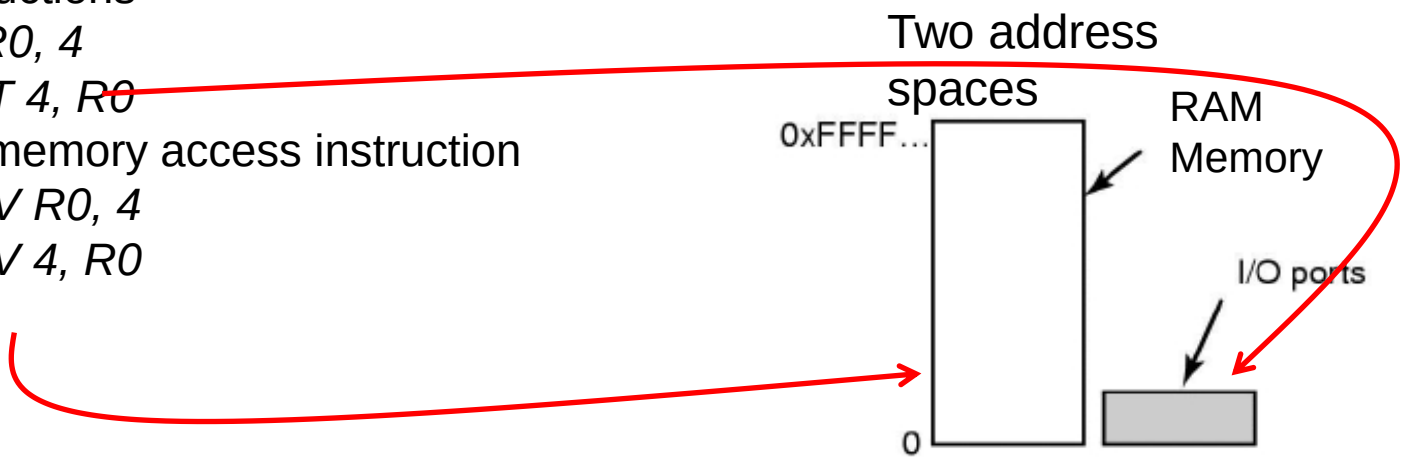


# I/O Ports #1

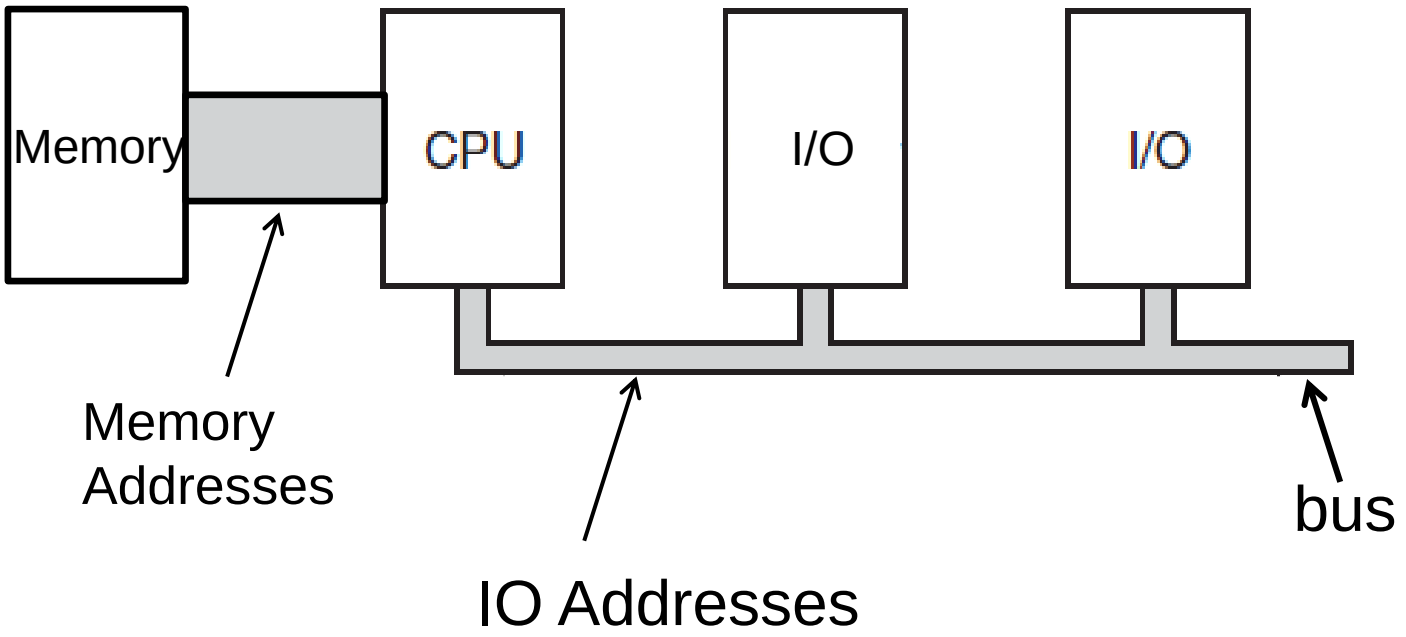



- Each control register an I/O port number
- Special instructions to access the I/O port space
  - CPU reads in from device I/O PORT to CPU register
    - IN REG, PORT
  - CPU writes to device I/O PORT from CPU register
    - OUT PORT, REG
- Instruction are privileged (OS kernel only)

- Separate **I/O port space** and **memory space**
  - I/O instructions
    - *IN R0, 4*
    - *OUT 4, R0*
  - Similar memory access instruction
    - *MOV R0, 4*
    - *MOV 4, R0*



# I/O Ports #2




| I/O address range (hexadecimal) | device |
|---|---|
| 000–00F | DMA controller |
| 020–021 | interrupt controller |
| 040–043 | timer |
| 200–20F | game controller |
| 2F8–2FF | serial port (secondary) |
| 320–32F | hard-disk controller |

# I/O Ports #3

**You must be root!**

antonio@antonio-VirtualBox: ~

File Edit View Search Terminal Help

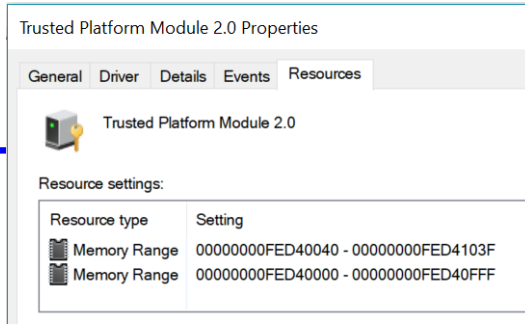
```
antonio@antonio-VirtualBox:~$ cat /proc/ioports
0000-0000 : PCI Bus 0000:00
  0000-0000 : dma1
  0000-0000 : pic1
  0000-0000 : timer0
  0000-0000 : timer1
  0000-0000 : keyboard
  0000-0000 : keyboard
  0000-0000 : rtc_cmos
    0000-0000 : rtc0
  0000-0000 : dma page reg
  0000-0000 : pic2
  0000-0000 : dma2
  0000-0000 : fpu
  0000-0000 : 0000:00:01.1
    0000-0000 : ata_piix
  0000-0000 : 0000:00:01.1
    0000-0000 : ata_piix
  0000-0000 : 0000:00:01.1
    0000-0000 : ata_piix
  0000-0000 : vga+
  0000-0000 : 0000:00:01.1
    0000-0000 : ata_piix
0000-0000 : PCI conf1
0000-0000 : PCI Bus 0000:00
  0000-0000 : 0000:00:07.0
    0000-0000 : ACPI PM1a_EVT_BLK
    0000-0000 : ACPI PM1a_CNT_BLK
    0000-0000 : ACPI PM_TMR
    0000-0000 : ACPI GPE0_BLK
  0000-0000 : 0000:00:07.0
    0000-0000 : piix4_smbus
  0000-0000 : 0000:00:01.1
    0000-0000 : ata_piix
  0000-0000 : 0000:00:03.0
    0000-0000 : e1000
  0000-0000 : 0000:00:04.0
  0000-0000 : 0000:00:05.0
    0000-0000 : Intel 82801AA-ICH
  0000-0000 : 0000:00:05.0
    0000-0000 : Intel 82801AA-ICH
  0000-0000 : 0000:00:0d.0
    0000-0000 : ahci
  0000-0000 : 0000:00:0d.0
    0000-0000 : ahci
0000-0000 : 0000:00:0d.0
```

root@antonio-VirtualBox: /home/antonio

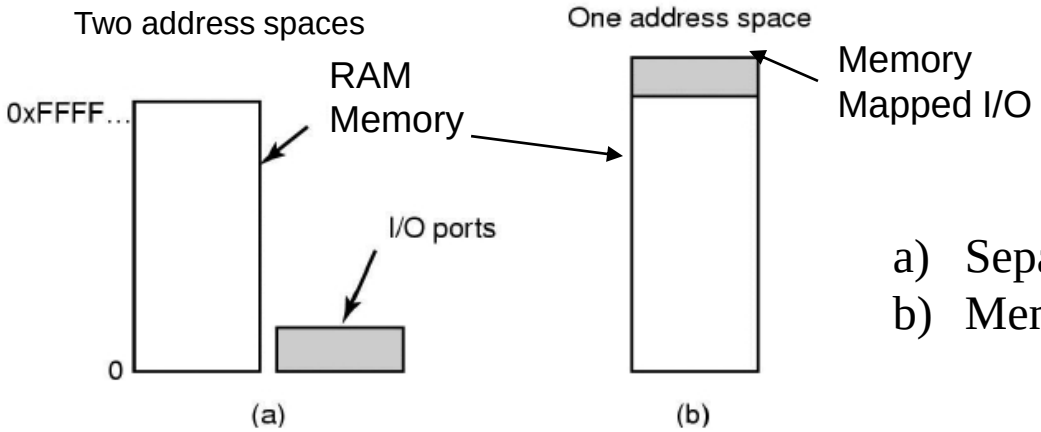
File Edit View Search Terminal Help

```
root@antonio-VirtualBox:/home/antonio# cat /proc/ioports
0000-0cf7 : PCI Bus 0000:00
  0000-001f : dma1
  0020-0021 : pic1
  0040-0043 : timer0
  0050-0053 : timer1
  0060-0060 : keyboard
  0064-0064 : keyboard
  0070-0071 : rtc_cmos
    0070-0071 : rtc0
  0080-008f : dma page reg
  00a0-00a1 : pic2
  00c0-00df : dma2
  00f0-00ff : fpu
  0170-0177 : 0000:00:01.1
    0170-0177 : ata_piix
  01f0-01f7 : 0000:00:01.1
    01f0-01f7 : ata_piix
  0376-0376 : 0000:00:01.1
    0376-0376 : ata_piix
  03c0-03df : vga+
  03f6-03f6 : 0000:00:01.1
    03f6-03f6 : ata_piix
0cf8-0cff : PCI conf1
0d00-ffff : PCI Bus 0000:00
  4000-403f : 0000:00:07.0
    4000-4003 : ACPI PM1a_EVT_BLK
    4004-4005 : ACPI PM1a_CNT_BLK
    4008-400b : ACPI PM_TMR
    4020-4021 : ACPI GPE0_BLK
  4100-410f : 0000:00:07.0
    4100-4108 : piix4_smbus
  d000-d00f : 0000:00:01.1
    d000-d00f : ata_piix
  d010-d017 : 0000:00:03.0
    d010-d017 : e1000
  d020-d03f : 0000:00:04.0
  d100-d1ff : 0000:00:05.0
    d100-d1ff : Intel 82801AA-ICH
  d200-d23f : 0000:00:05.0
    d200-d23f : Intel 82801AA-ICH
  d240-d247 : 0000:00:0d.0
    d240-d247 : ahci
  d248-d24b : 0000:00:0d.0
    d248-d24b : ahci
  d250-d257 : 0000:00:0d.0
```

# Memory-mapped I/O #1

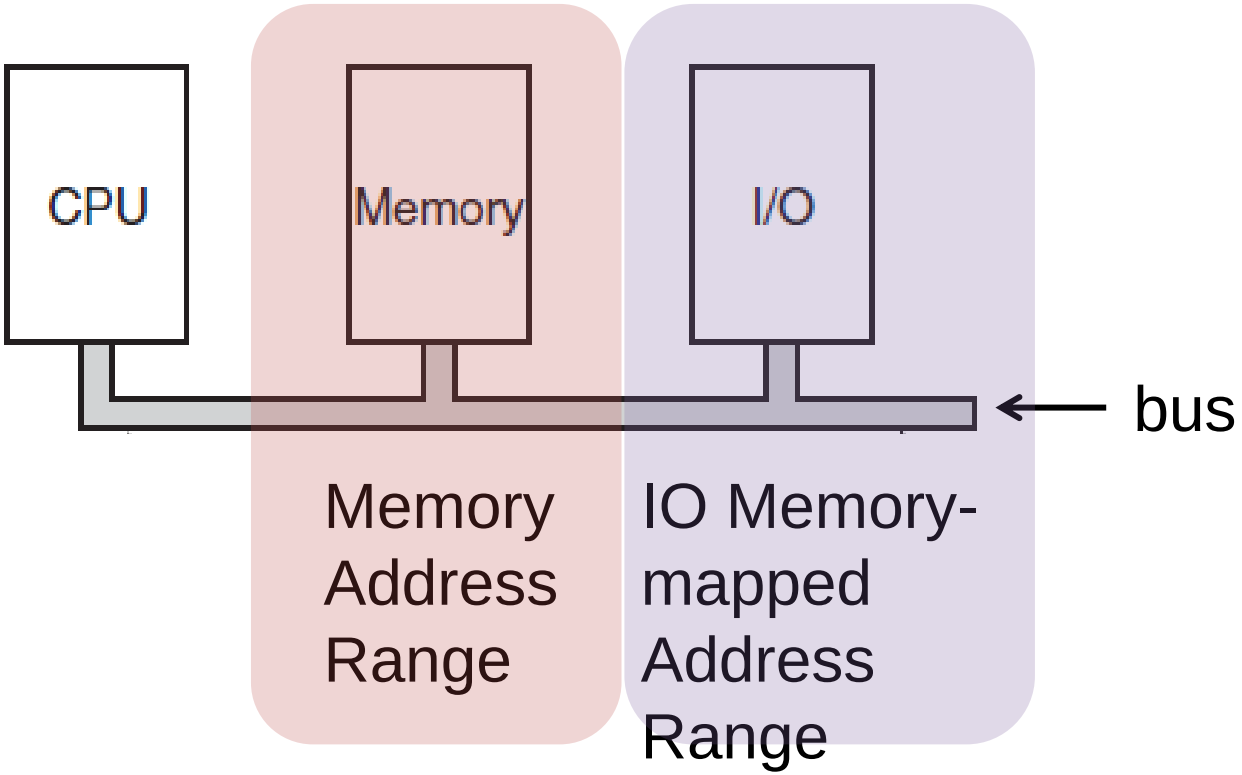



- All control registers and buffers into the memory space
- Each control register is assigned a unique memory address
  - There is no actual RAM memory for this address
- Such addresses may be at the top of the physical address space



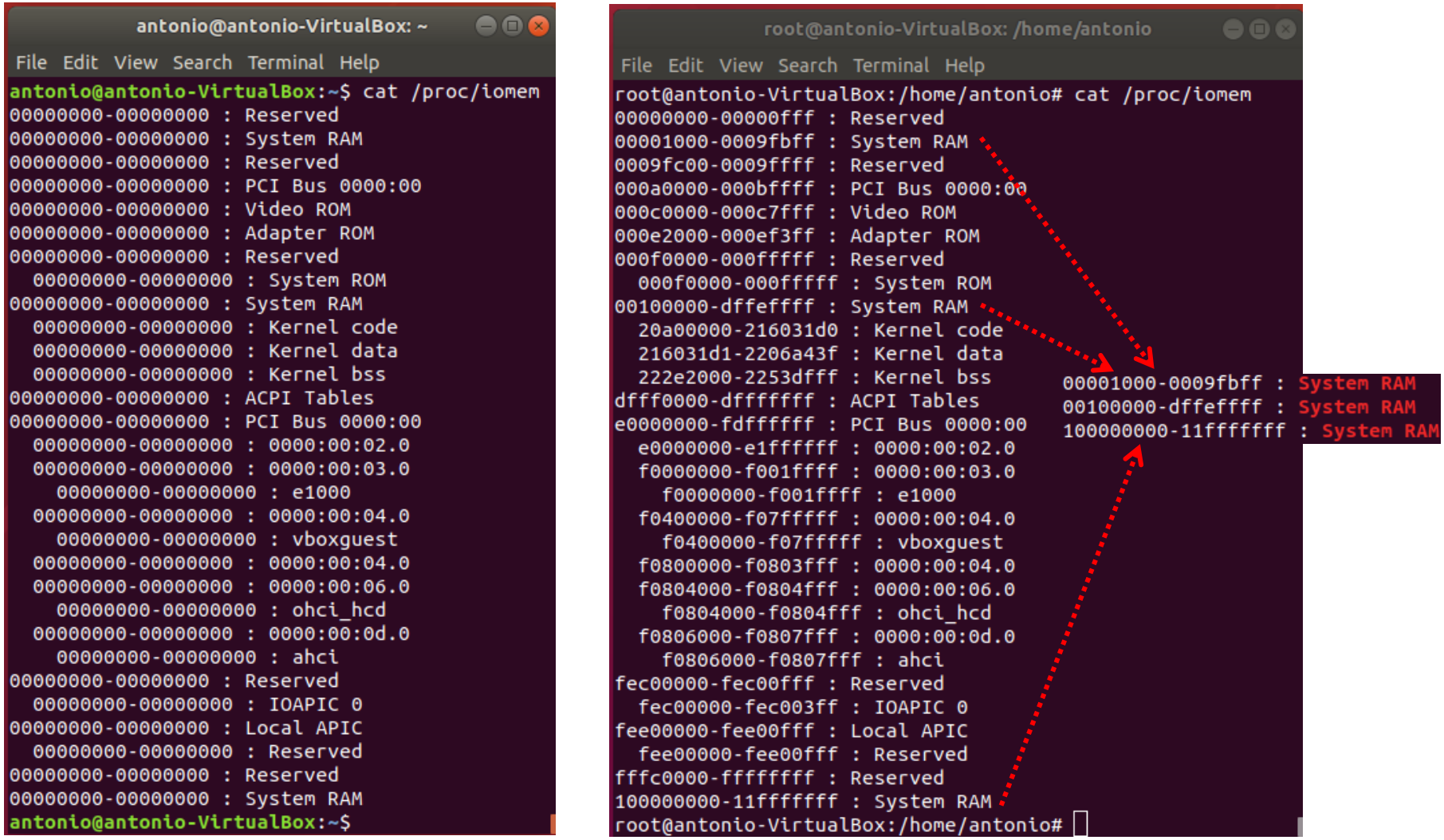

a) Separate I/O and memory space
b) Memory-mapped I/O

# Memory-mapped I/O #2

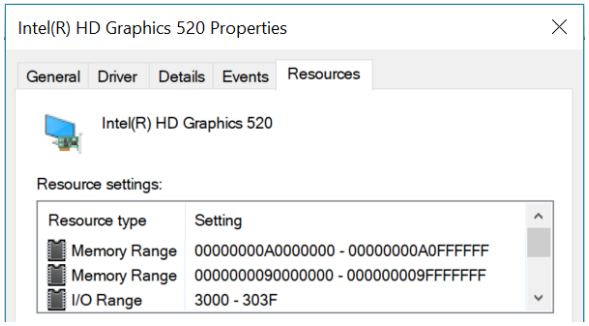



| | | |
|---|---|---|
| Example | 0 … 32GB | 127.999TB … 128TB |

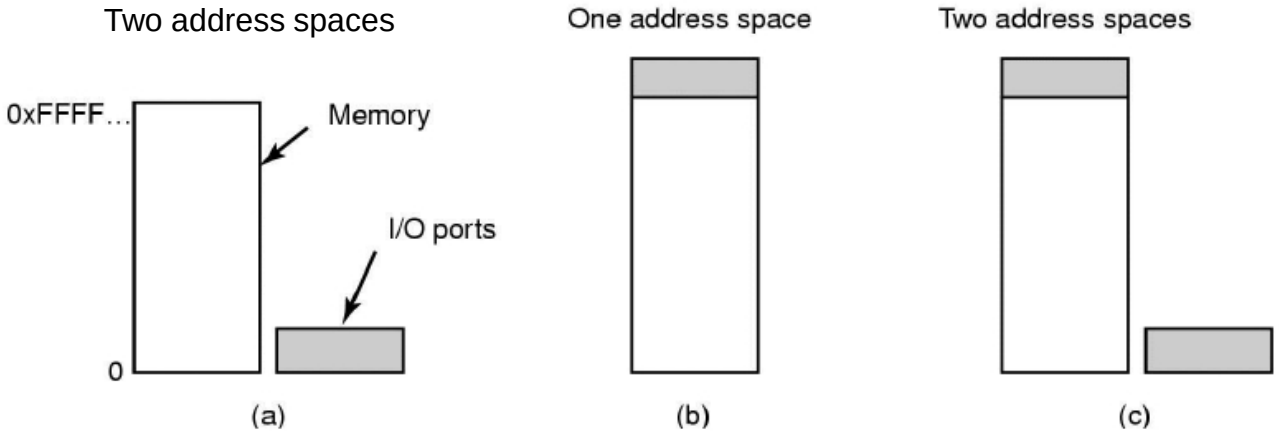
# Memory-mapped I/O #3



# Hybrid #1

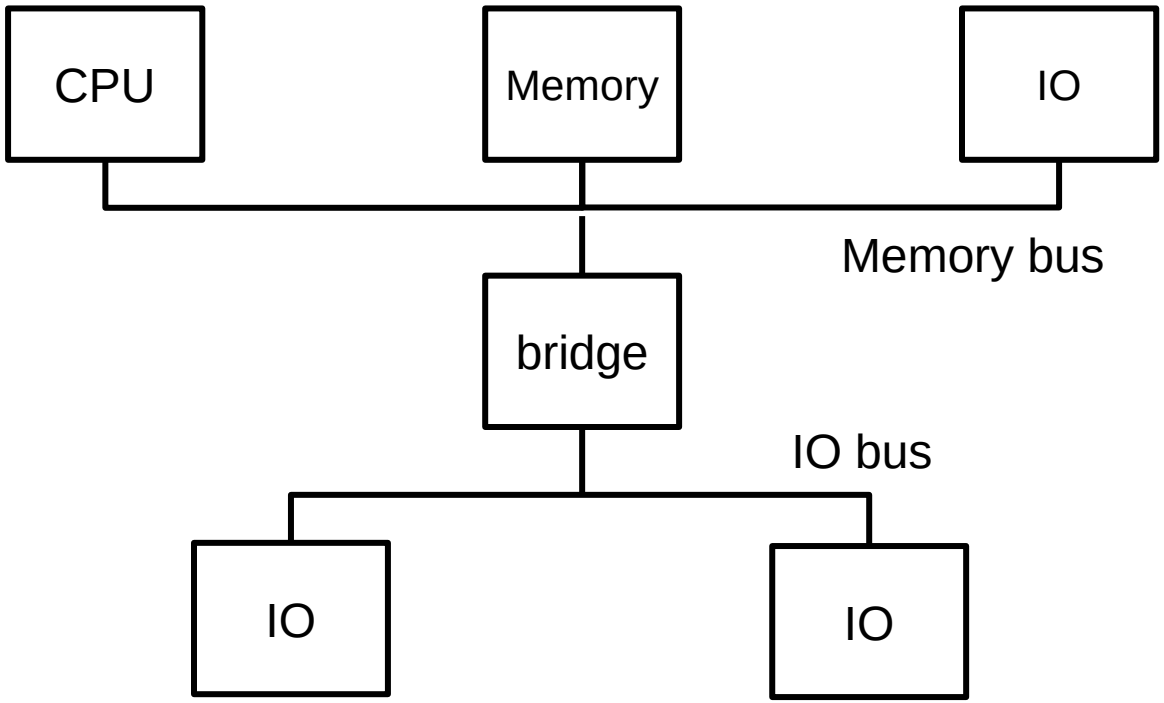



- I/O ports and memory-mapped IO
- Example
  - Memory-mapped I/O data buffers and separate I/O ports for the control registers
  - x86 CPUs, memory addresses 640K to 1M − 1 being reserved for device data buffers, in addition to I/O ports 0 to 64K − 1




a) Separate I/O and memory space
b) Memory-mapped I/O
c) Hybrid

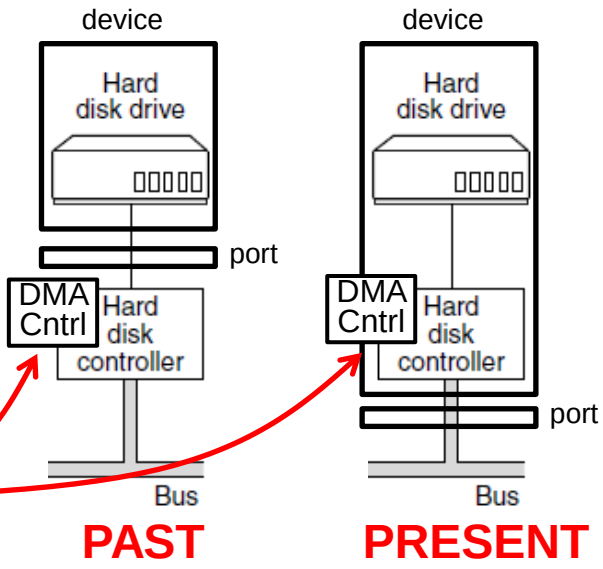
# Hybrid #2



# Offloaded Communication

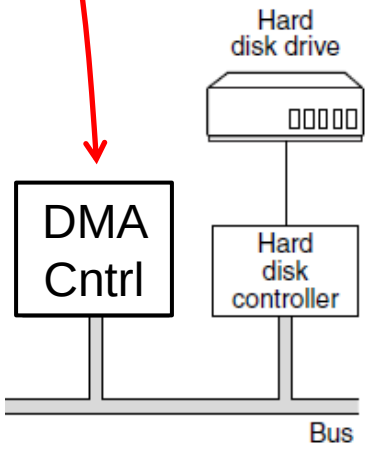
- The CPU can request data from an I/O controller **one byte at a time**
  - Programmed IO (PIO)
    - (Previous slides)
  - This wastes CPU's time for large data transfers
    - Small data transfers are OK
- CPU offloads data transfers
- **DMA (Direct Memory Access) controller** transfers data for the CPU
  - From/to an IO Device
  - Between IO Devices

# Direct Memory Access



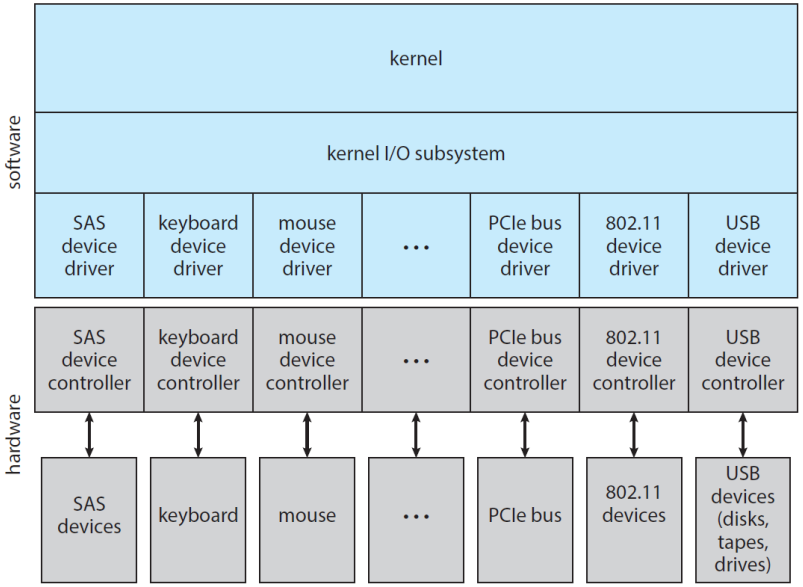

- Requires a **DMA controller**
  - On the device host controller
  - On the motherboard

- **DMA controller** contains registers to be read/written by the software
  - Memory address register
  - Byte count register
  - Control registers to
    - Direction of the transfer
    - Transfer unit
    - Byte burst size
    - …



# OS Device Drivers

- Great variety of devices
  - Each device vendor/model its specs
- OS deals with IO devices in a **standard** and **uniform way**
  - Abstraction
  - Encapsulation
  - Software layering
- Use specific interface (file)
- Encapsulate the differences in devices by **device drivers' classes**
  - Each OS its own standard
- Example
  - An application can open a file without knowing what kind of disk it is
  - Independently of the disk technology



# Characterizing IO Devices

| aspect | variation | example |
|---|---|---|
| data-transfer mode | character<br>block | terminal<br>disk |
| access method | sequential<br>random | modem<br>CD-ROM |
| transfer schedule | synchronous<br>asynchronous | tape<br>keyboard |
| sharing | dedicated<br>sharable | tape<br>keyboard |
| device speed | latency<br>seek time<br>transfer rate<br>delay between operations | |
| I/O direction | read only<br>write only<br>read–write | CD-ROM<br>graphics controller<br>disk |

# IO Services Provided by the OS

- Kernel **IO subsystem** services
  - Available to applications and to other parts of the OS

- Management of the name space for files and devices
- Access control to files and devices
- Operation control (for example, a modem cannot seek())
- File-system space allocation
- Device allocation
- Buffering, caching, and spooling
- I/O scheduling
- Device-status monitoring, error handling, and failure recovery
- Device-driver configuration and initialization
- Power management of I/O devices

# Putting Everything Together: Life Cycle of an IO Request