I/O Management

Operating system

- Has protocols
  - Interfaces for device I/O
- Has dedicated handlers
  - Device drivers, interrupt handlers
- Decouple I/O details from core processing
  - abstract I/O device detail from applications

I/O Device Features

- Control registers (accessed by CPU)
  - Command
  - Data Transfers
  - Status
- Microcontroller : device's CPU
- On device memory
- Other logic
  - e.g. analog to digital

Device drivers

- per each device type
- responsible for device access management and control

- provided by device manufacturers per OS /version
- each OS standardizes interfaces
  - device independence
  - device diversity

Types of devices

- Block
  - e.g. disk
  - read/write blocks of data
  - direct access to arbitrary block
- Character
  - e.g. keyboard
  - get/put character
- Network devices

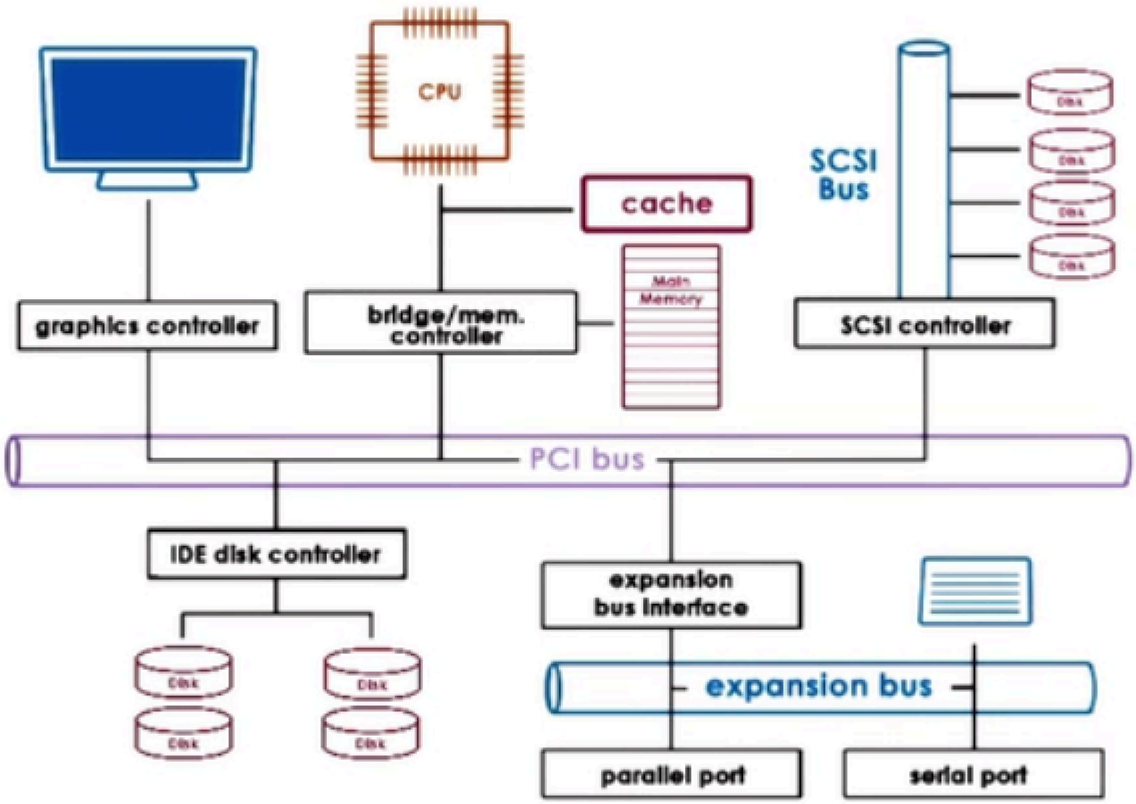
OS representation of a device : special device file

UNIX like systems:

- /dev
- tmpfs
- devfs

Linux supports a number of pseudo "virtual" devices that provide special functionality to a system.

CPU device interactions



access device registers : memory load/store

1. Memory mapped I/0
   - part of 'host' physical memory dedicated for device interactions
   - Base Address Registers (BAR)
2. I/O Port
   - dedicated in low instructions for device access
   - target device (I/0 port) and value in register

Path from Device to CPU

1. Interrupt
   - Overhead: Interrupt handling steps
   - +: Can be generated as soon as possible
2. Polling
   - Overhead: Delay or CPU overhead
   - when convenient for OS

Device access : Programmed I/O (PIO)

- No additional hardware support
- CPU "programs" the device
  - via command registers
  - data movement
- E.g. NIC(Network Interface Card)
  - data = network packet
- Write command to request packet information
- Copy packet to data registers
- Repeat until packet sent

E.g. 1500B packet; 8 byte registers or bus => 1(for bus command) + 188(for data) = 189 CPU store instructions

Direct Memory Access (DMA)

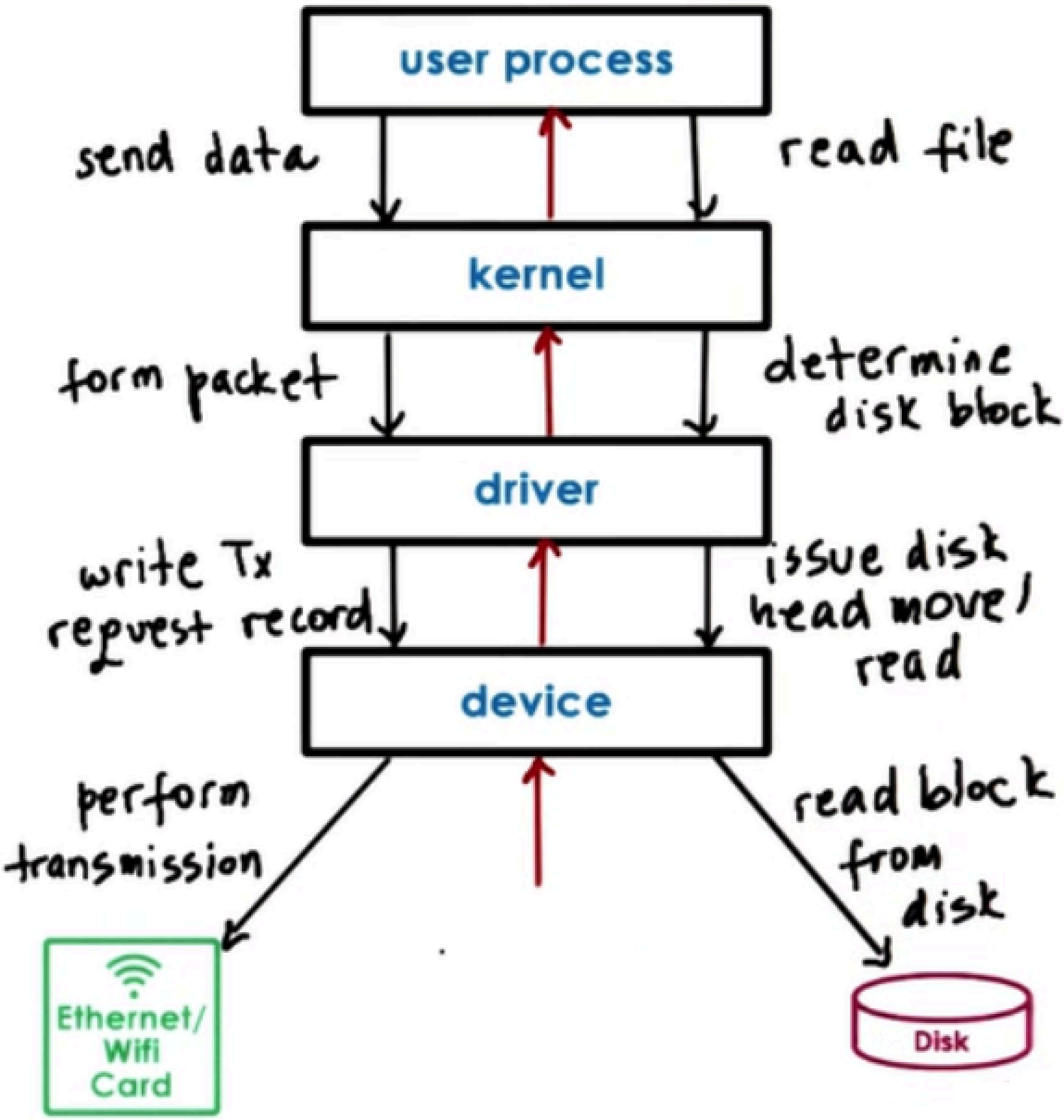
- Relies on DMA controller
- CPU "programs" the device
  - via command registers
  - via DMA controls
- E.g. NIC (data = network packet)
- Write command to request packet information
- Configure DMA controller with in memory address and size of packet buffer

E.g. 1500B packet; 8 byte registers or bus => 1(for bus command) + 1(for DMA configuration) = total 2 CPU store instructions. Less steps, but DMA configuration is more complex.

For DMAs

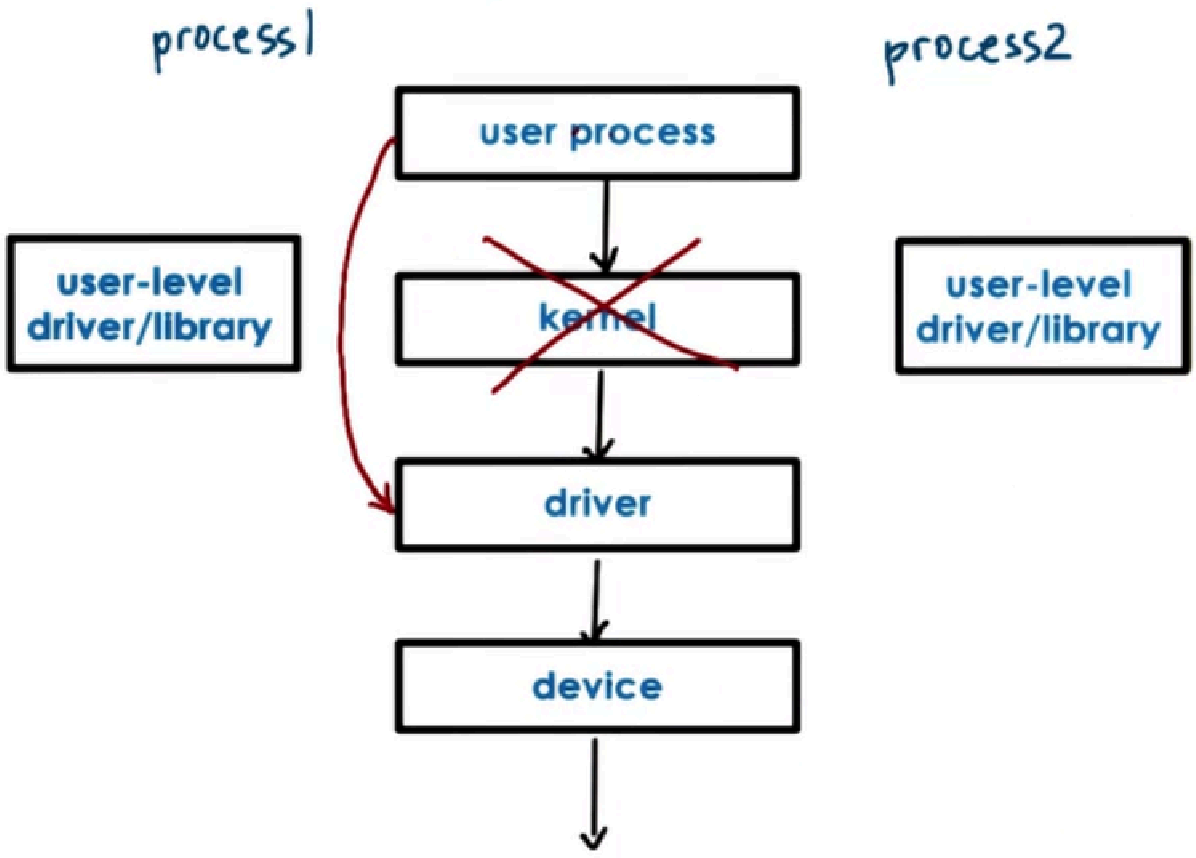
- data buffer must be in physical memory until transfer completes
- pinning regions (non-swappable)

Typical Device Access



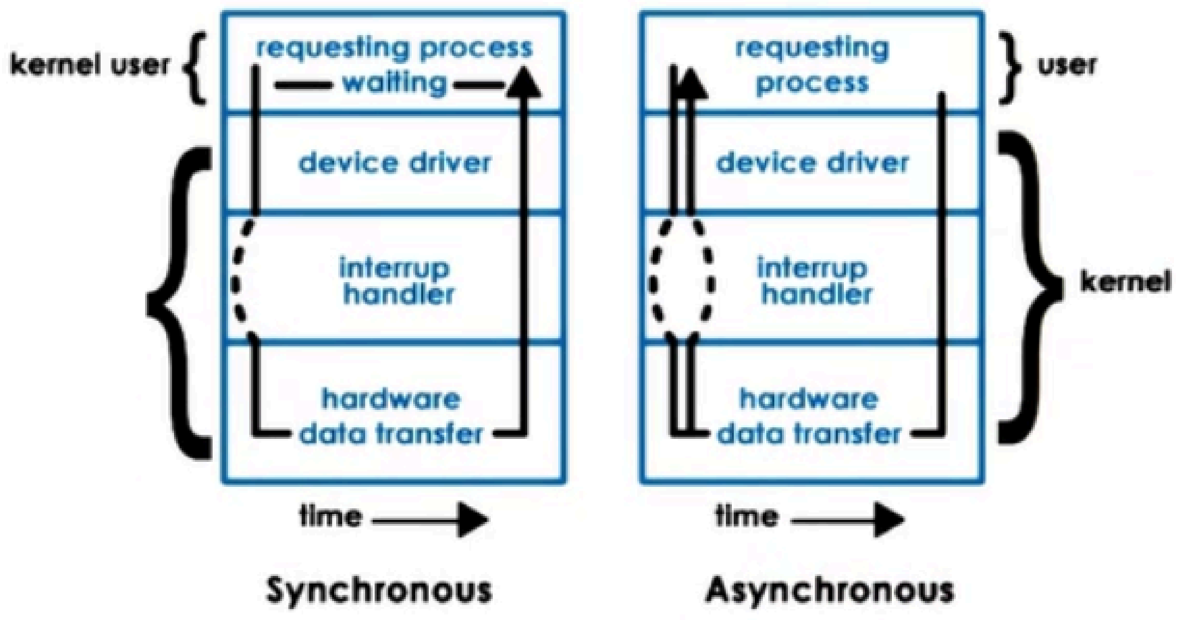
- System call
- In-kernel stack
- Driver Invocation
- Device request configuration
- Device performs request

OS bypass



- device registers/data
  - directly available
- OS configures
  - then gets out of the way
- "user level driver"
  - in library
- OS retains coarse-grain control
- relies on device features
  - sufficient registers
  - demux capability

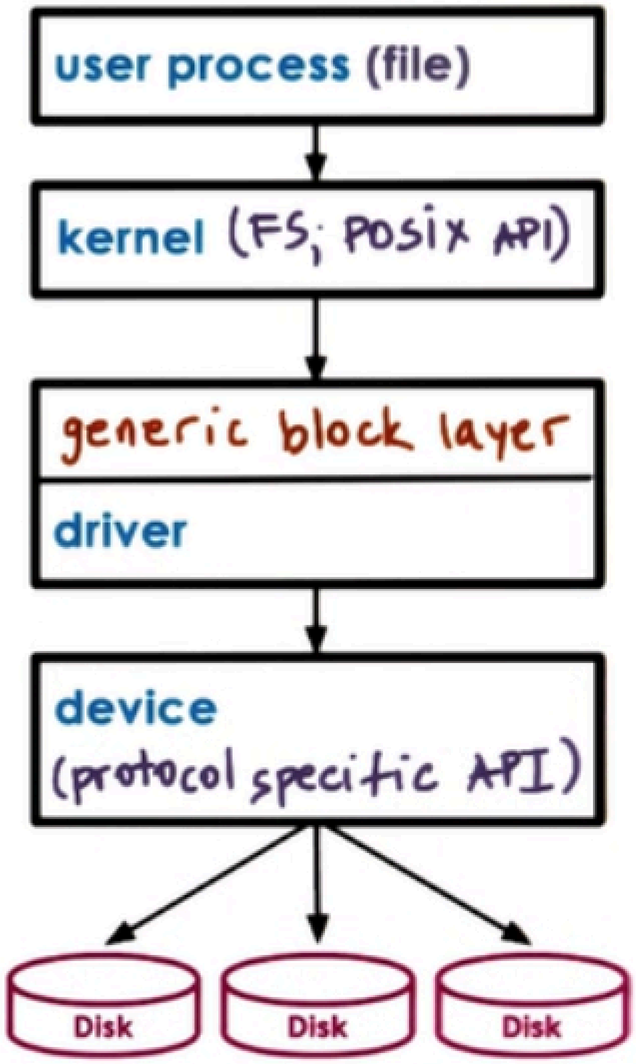
What happens to a calling thread?



- Synchronous I/O operations
  - process blocks
- Asynchronous I/O operations
  - process continues
  - Later, process checks and retrieves result
  - OR
  - process is notified that operation is completed and results are ready

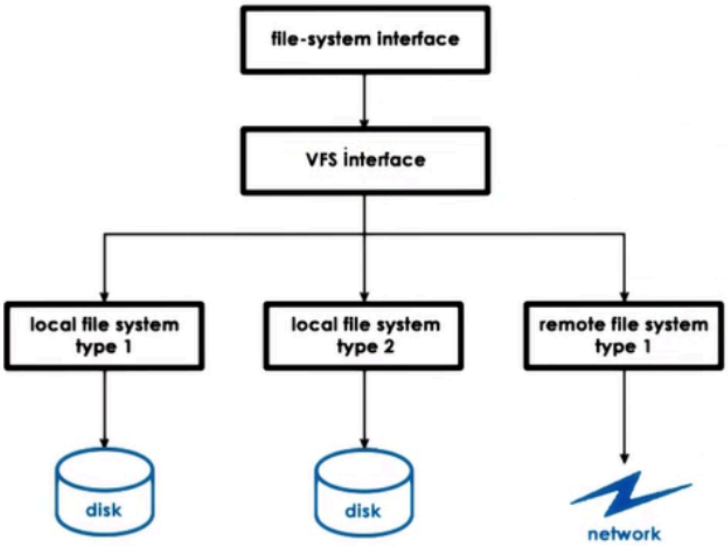
Block Device Stack

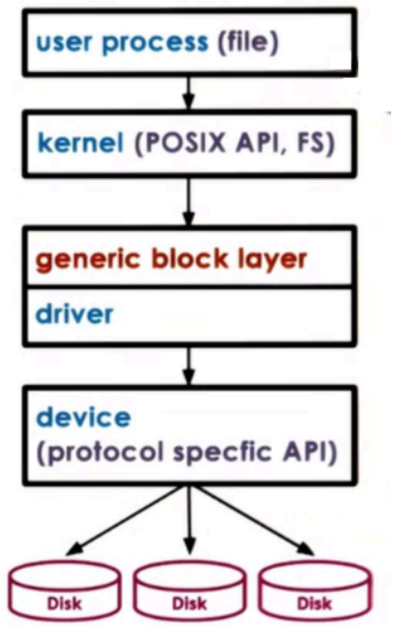
Block device typical storage for files:



- processes use files => logical storage unit
- kernel file system (KFS)
  - where how to find and access file
  - OS specifies interface
- generic block layer
  - OS standardized block interface
- Device driver

Virtual File System





Virtual File System Abstractions

- File : Elements on which the VFS operates
- File Descriptor : OS representation of file
  - open, read, write, send file , lock, close
- inode : Persistent representation of file "index"
  - list of all data blocks
  - device, permissions, size
- dentry : Directory entry, corresponding to the single path component,
  - dentry cache
- super block : file system specific information regarding the File System layout

VFS on disk

- File : data blocks on disk
- inode : track file blocks
  - also resides on disk in some block
- super block : overall map of disk blocks
  - inode blocks
  - data blocks
  - free blocks

Inodes

Index of all disk blocks corresponding to a file

- File : identified by inode
- inode : list of all blocks + other metadata

+: Easy to perform sequential or random access
-: Limit on file size

Inodes with indirect pointers

- Index of all disk blocks corresponding to a file
- Index contain:
  - metadata
  - pointers to blocks
- Direct pointer : Points to data block
  - 1 KB per entry
- Indirect pointer : Points to block of pointers
  - 256 KB per entry
- Double Indirect pointer : Points to block of block of pointers
  - 64 MB per entry

+: Small inode => large file size
-: File access slowdown

Disk access optimizations

Reducing file access overheads

1. Caching/buffering : reducenumber of disk accesses
   - buffer cache in main menu
   - read/write from cache
   - periodically flush to disk - fsync()
2. I/O scheduling : reduce disk head movement
   - maximize sequential vs random access
3. Prefetching : increases cache hits
   - leverages locality
4. Journaling/logging: reduce random access (ext3, ext4)
   - "describe" write in log : block, offset, value..
   - periodically apply updates to proper disk locations