# Principles of Operating Systems

CS 446/646

## 5. Input/Output

a. Overview of the O/S Role in I/O

b. Principles of I/O Hardware

**c. I/O Software Layers**

- ✓ Overview of the I/O software
- ✓ Interrupt handlers
- ✓ Device drivers
- ✓ Device-independent I/O software
- ✓ User-level I/O system calls

**d. Disk Management**

# 5.c I/O Software Layers

## Overview of the I/O software

- Goals and services of the I/O software
  - ✓ device independence
    - write programs that can access I/O devices without specifying them or knowing them in advance
    - ex: reading a file from a disk, whether floppy, magnetic, CD-ROM, etc.
    - no need to modify the program if a new device comes in
  - ✓ uniform naming (“mounting”)
    - abstract naming space independent from physical device
    - naming should be a string and/or integer ID, again without device awareness

# 5.c I/O Software Layers

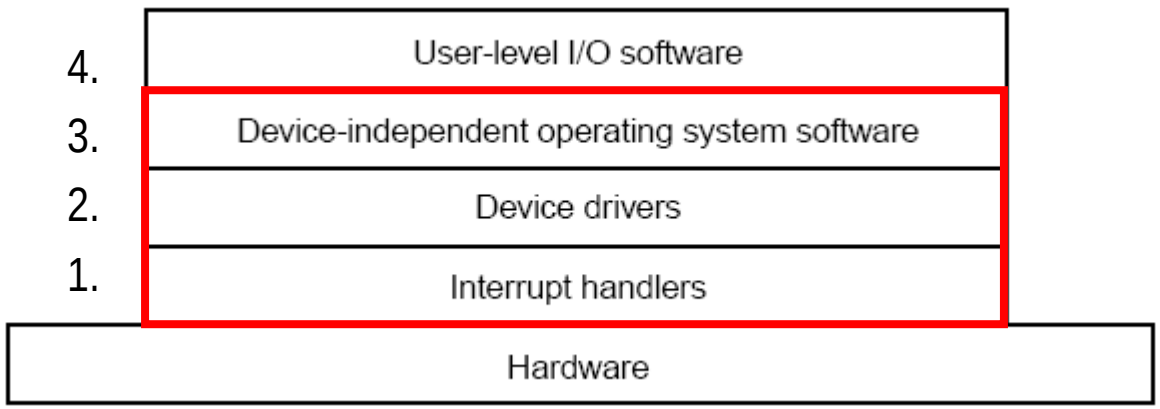
## Overview of the I/O software

- Goals and services of the I/O software
  - ✓ error handling
    - lower layers try to handle the error before upper levels
    - controller hardware should correct error first; if it cannot, then driver software (for ex. by reissuing the command), etc.
    - upper levels can remain unaware of “bumps” at lower levels
  - ✓ synchronous vs. asynchronous transfers
    - most physical I/O is asynchronous (interrupt-driven)
    - O/S should make it look synchronous (blocking) to processes
  - ✓ buffering
    - decouple transfer rates and insulate data from swapping

# 5.c I/O Software Layers

## Overview of the I/O software

- The I/O component of the O/S is organized in layers
  1. interrupt handlers
  2. device drivers
  3. device-independent I/O
  4. user-level I/O system calls



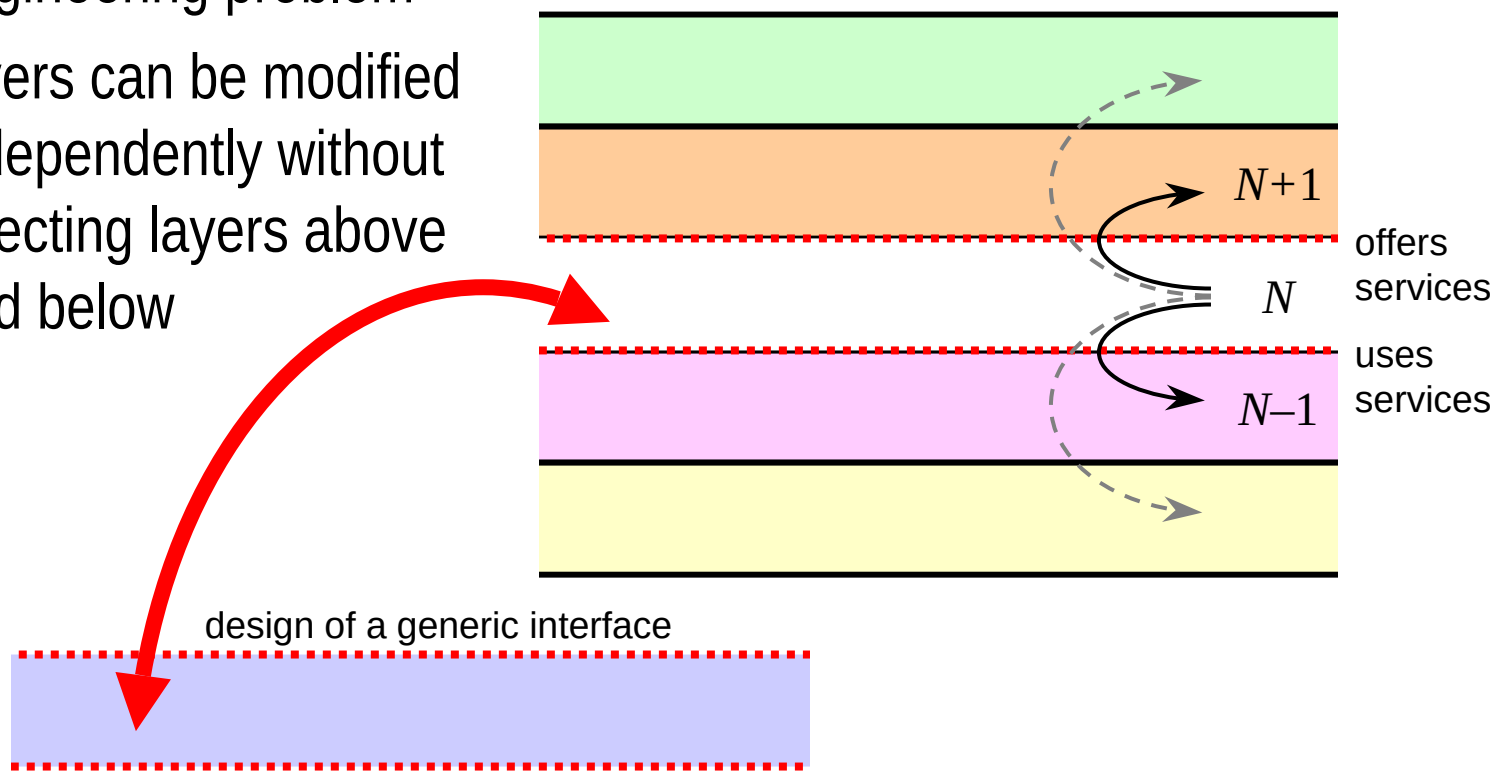

Tanenbaum, A. S. (2001)
*Modern Operating Systems (2nd Edition).*

Typical layers of the I/O software subsystem

# 5.c I/O Software Layers

## Overview of the I/O software

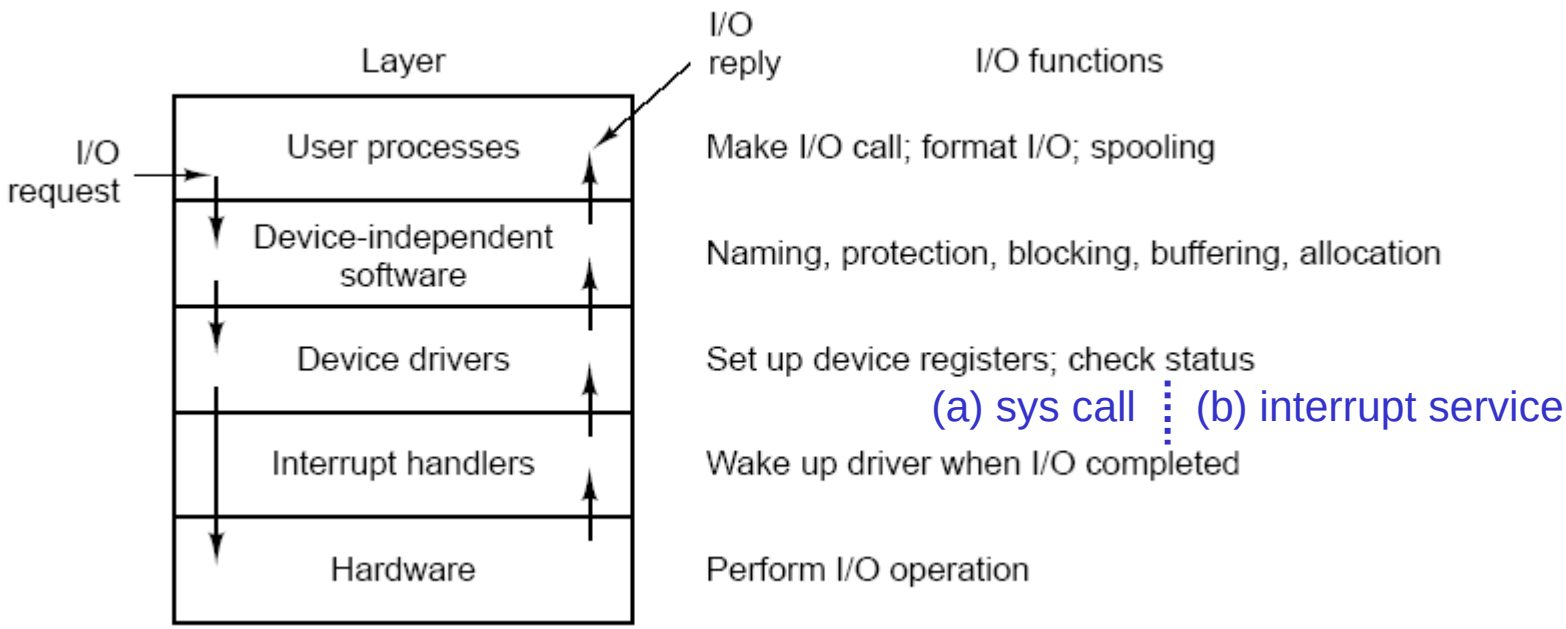
- Abstraction, encapsulation and layering
  - ✓ any complex software engineering problem
  - ✓ layers can be modified independently without affecting layers above and below



# 5.c I/O Software Layers

## Overview of the I/O software

- Typical flow of control through the I/O layers upon an I/O request

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# 5.c I/O Software Layers

## Interrupt handlers

## 1. Interrupt handler routines

- ✓ interrupts (asynchronous, external to process) basically use the same mechanism as exceptions and traps (synchronous, internal to process)
- ✓ when an interrupts happen, the CPU saves a small amount of state and jumps to an interrupt-handler routine at a fixed address in memory
- ✓ the interrupt routine's location is determined by an interrupt vector

# 5.c I/O Software Layers

## Interrupt handlers

## 1. Interrupt handler routines (cont'd)

nonmaskable, used for various error conditions

maskable, used for device-generated interrupts

| vector number | description |
|---|---|
| 0 | divide error |
| 1 | debug exception |
| 2 | null interrupt |
| 3 | breakpoint |
| 4 | INTO-detected overflow |
| 5 | bound range exception |
| 6 | invalid opcode |
| 7 | device not available |
| 8 | double fault |
| 9 | coprocessor segment overrun (reserved) |
| 10 | invalid task state segment |
| 11 | segment not present |
| 12 | stack fault |
| 13 | general protection |
| 14 | page fault |
| 15 | (Intel reserved, do not use) |
| 16 | floating-point error |
| 17 | alignment check |
| 18 | machine check |
| 19Ð31 | (Intel reserved, do not use) |
| 32Ð255 | maskable interrupts |

Intel Pentium processor event-vector table

Silberschatz, A., Galvin, P. B. and Gagne. G. (2003) *Operating Systems Concepts with Java (6th Edition).*

# 5.c I/O Software Layers

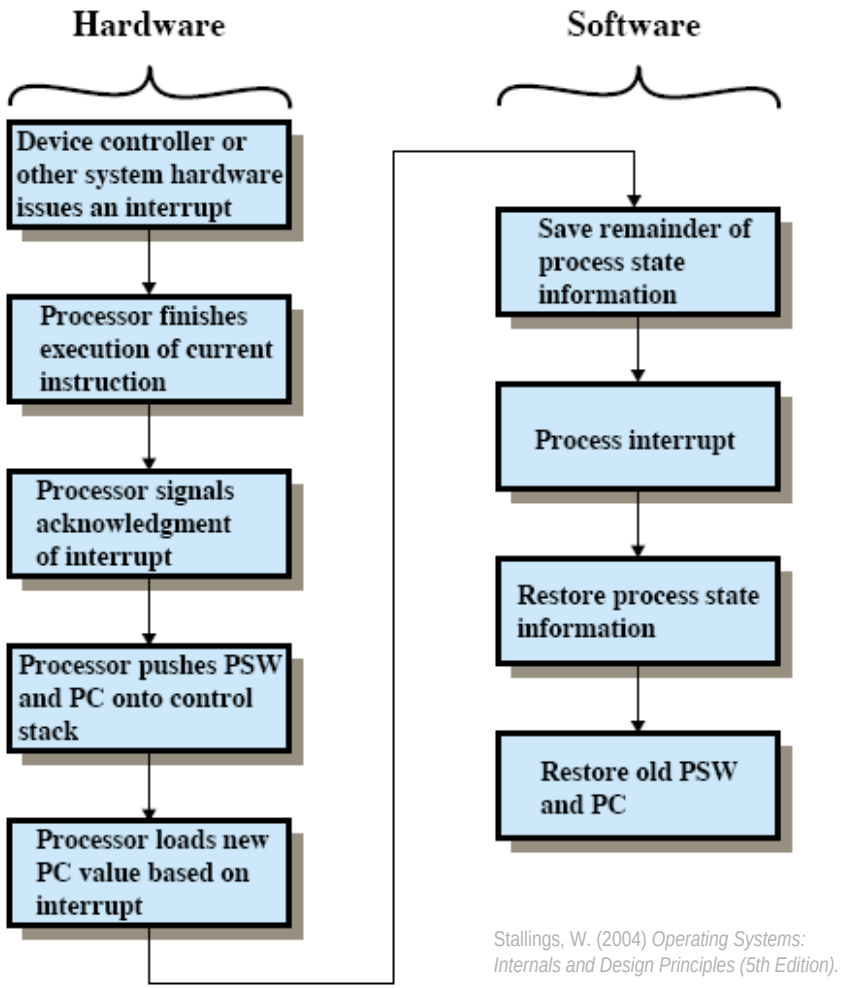
## Interrupt handlers

### 1. Interrupt handler routines

- ✓ typical steps followed by an interrupt routine:
  a. save any registers not saved by the interrupt hardware
  b. set up a context (TLB, MMU, page table) for the routine
  c. set up a stack for the routine
  d. acknowledge the interrupt controller
  e. extract information from the I/O device controller's registers
  f. etc.
- ✓ interrupt processing is a complex operation that takes a great number of CPU cycles, especially with virtual memory

# 5.c I/O Software Layers

## Interrupt handlers

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Simple interrupt processing

# 5.c I/O Software Layers

Device drivers

## 2. Device drivers

- ✓ each I/O device needs a **device-specific code** to control it
- ✓ device manufacturers supply drivers for several popular O/S
- ✓ a driver handles one type of device or one class (ex: SCSI)
- ✓ the driver logic is generally executed in kernel space (although microkernel architectures might push it in user space)
- ✓ drivers should "snap into place" in the kernel through device-independent interfaces (see next section)
- ✓ two main categories of drivers (two higher-level interfaces)
  - block-device drivers: disks, etc.
  - character-device drivers: keyboards, printers, etc.

# 5.c I/O Software Layers

## Device drivers

## 2. Device drivers (cont'd)

- ✓ a driver has several functions
  - accept abstract read/write requests from the device-independent software above and translate them into concrete I/O-module-specific commands
  - schedule requests: optimize queued request order for best device utilization (ex: disk arm)
  - initialize the device, if needed
  - manage power requirements
  - log device events

# 5.c I/O Software Layers

## Device drivers

## 2. Device drivers (cont'd)

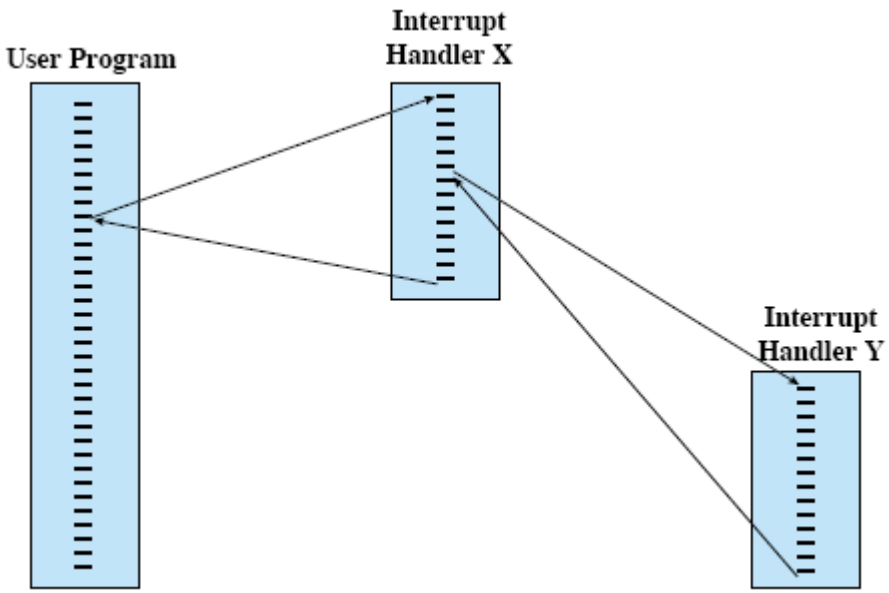
- ✓ typical code organization of a device driver:
  a. check validity of input parameters coming from above
  b. if valid, translate to concrete commands, e.g., convert block number to head, track & sector in a disk's geometry
  c. check if device currently in use; if yes, queue request; if not, possibly switch device on, warm up, initialize, etc.
  d. issue appropriate sequence of commands to controller
  e. if needs to wait, block
  f. upon interrupted from blocking, check for errors and pass data back
  g. process next queued request

# 5.c I/O Software Layers

## Device drivers

## 2. Device drivers (cont'd)

- ✓ a driver code must be reentrant to allow for nested interrupts
- ✓ a driver must expect to be called a 2nd time before the 1st call is finished

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Nested interrupt processing

# 5.c I/O Software Layers

## Device-independent I/O software

## 3. Device-independent I/O software

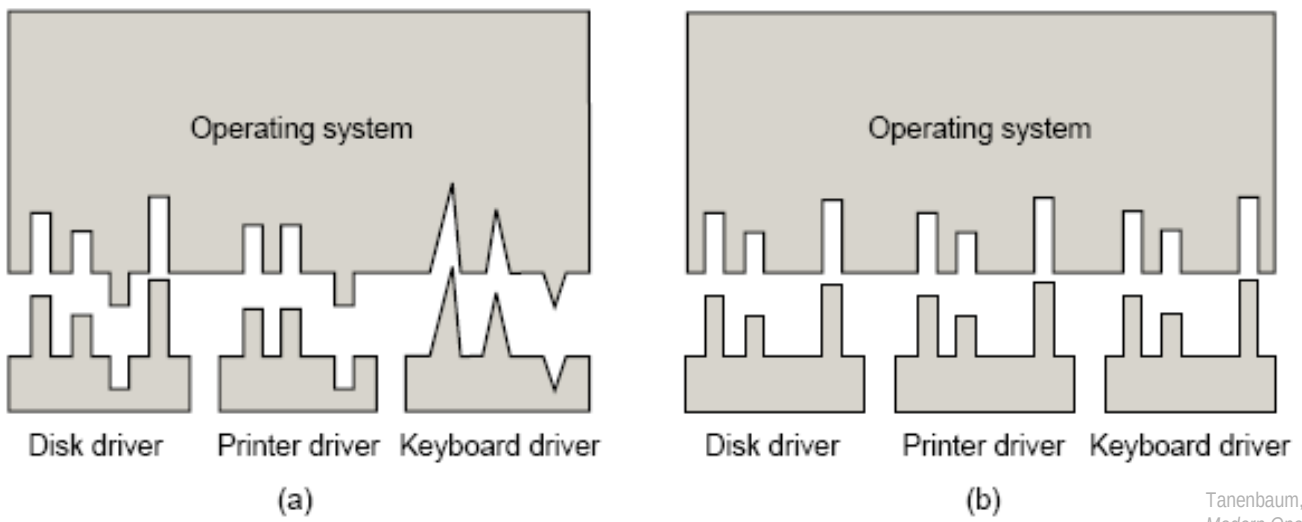
- ✓ generic functions provided by the kernel I/O subsystem:
  - uniform interfacing for device drivers
  - buffering
  - error reporting
  - providing a device-independent block size

# 5.c I/O Software Layers

## Device-independent I/O software

### 3. Device-independent I/O software (cont'd)

- ✓ uniform interfacing
  - make all I/O devices look more or less the same, so that the O/S doesn't need to be hacked every time a new device comes along

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(a) Without and (b) with a standard driver interface

# 5.c I/O Software Layers

Device-independent I/O software

## 3. Device-independent I/O software (cont'd)

- ✓ uniform interfacing
  - therefore, generally one unified interface
  - possibly additional specialized extensions for the main device categories
    - block devices: **`read()`**, **`write()`**
    - random-access block devices: **`seek()`**
    - character-stream devices: **`get()`**, **`put()`**
    - network devices: network socket interface similar to file system

# 5.c I/O Software Layers

Device-independent I/O software

## 3. Device-independent I/O software (cont'd)

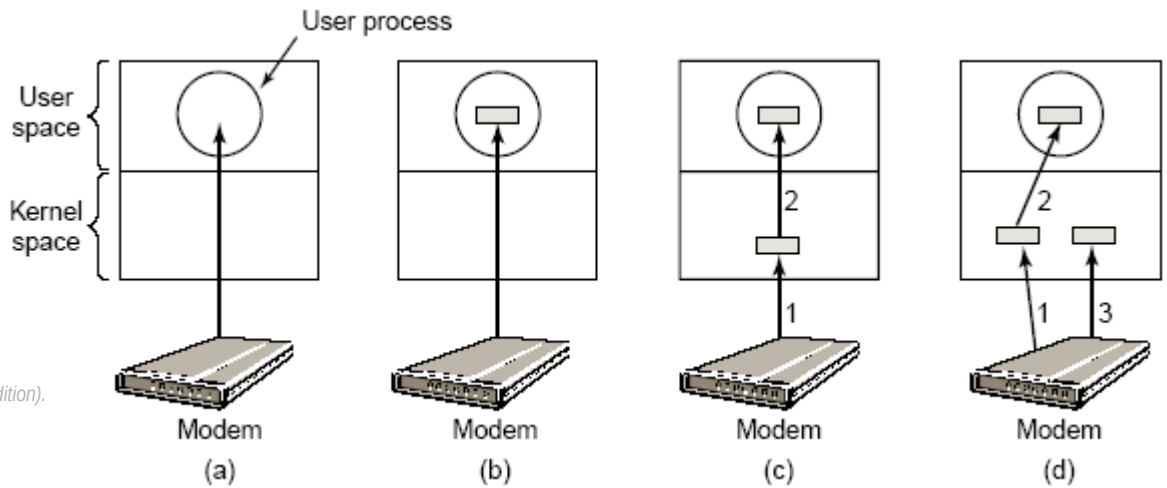
- ✓ buffering = "decoupling"
  - memory area that stores data in kernel space while transferred between device and application
  - cope with a speed mismatch between producer and consumer (ex: modem thousand times slower than disk)
  - adapt between services with different data-transfer sizes (ex: fragmentation and reassembly of network packets)
  - "copy semantics": cache data while transferred so it is not affected by changes from application or swapping
  - read ahead (locality principle)

# 5.c I/O Software Layers

## Device-independent I/O software

## 3. Device-independent I/O software (cont'd)

- ✓ buffering
  - a) unbuffered input → *context switch for each transferred byte*
  - b) buffering in user space → *what happens if paged out?*
  - c) buffering in kernel, copy to user space → *what if buffer full?*
  - d) <u>double-buffering in kernel</u>

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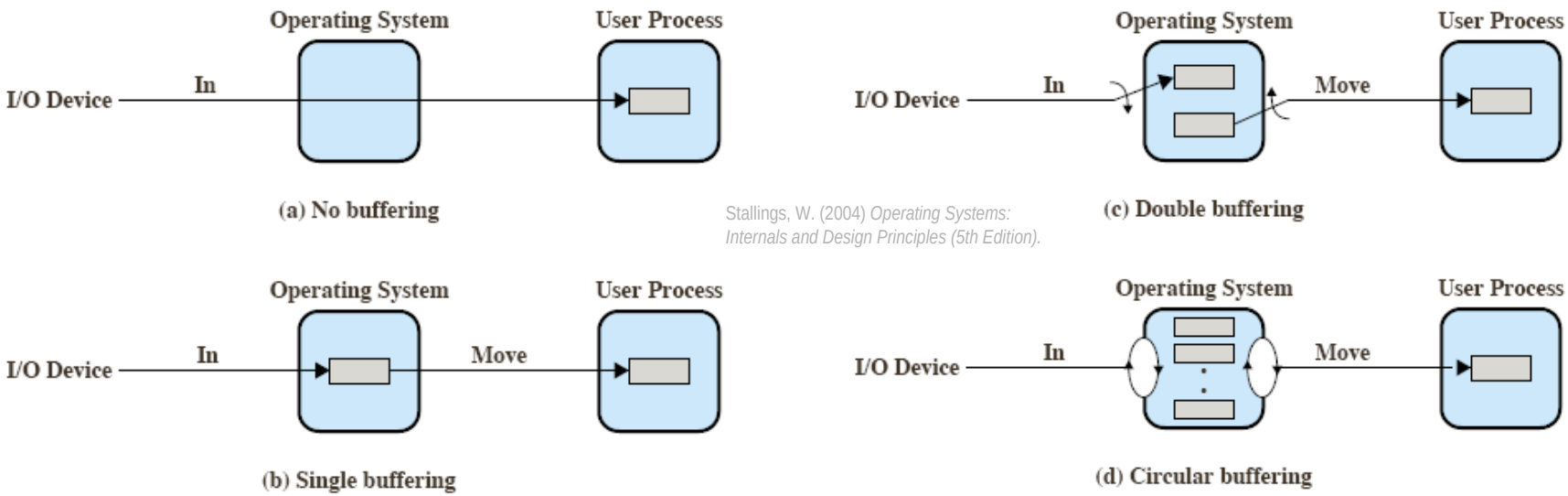
# 5.c I/O Software Layers

## Device-independent I/O software

## 3. Device-independent I/O software (cont'd)

- ✓ buffering
  - double buffering: further decouples producer from consumer (ex: modem fills 2nd buffer while 1st buffer is written to disk)
  - circular buffering: extension suitable for rapid bursts of I/O

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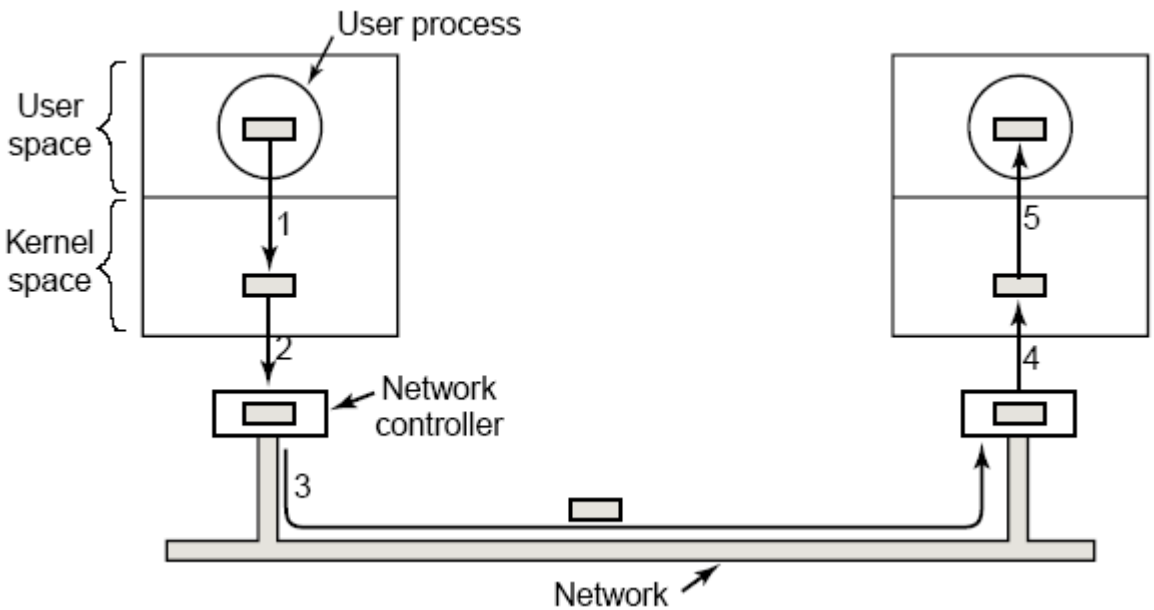
# 5.c I/O Software Layers

## Device-independent I/O software

### 3. Device-independent I/O software (cont'd)

- ✓ buffering in networking

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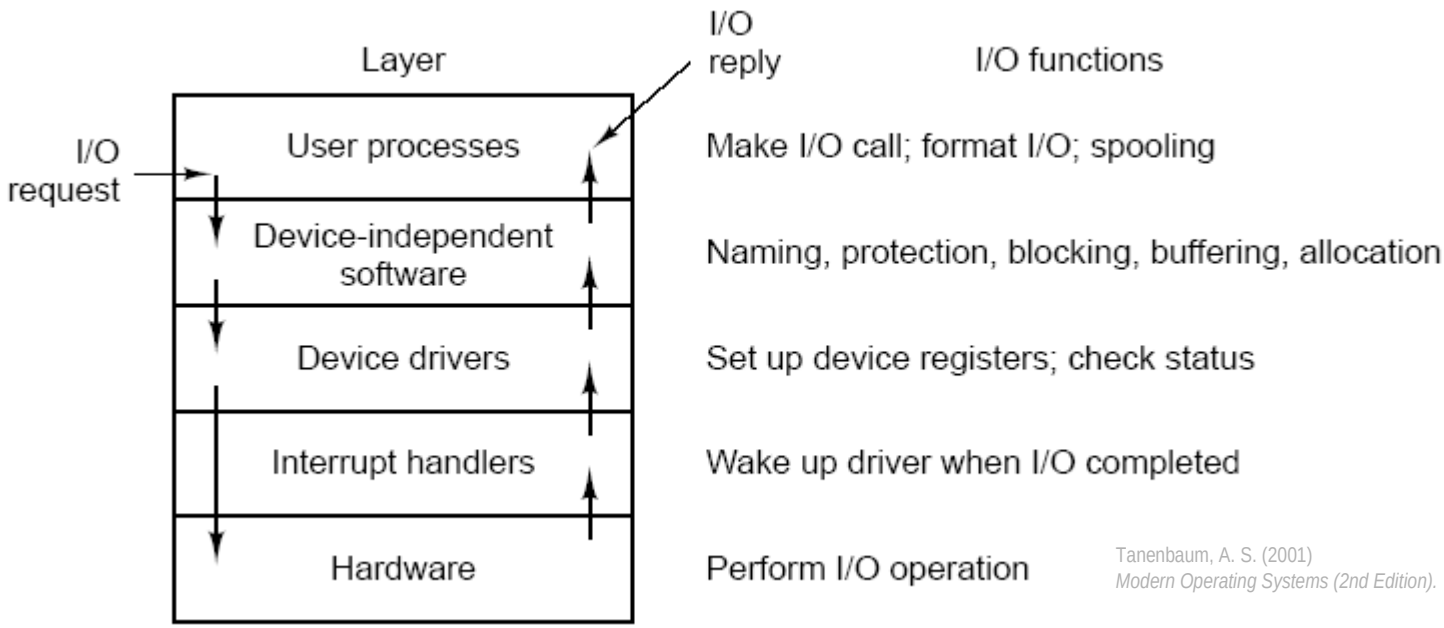
# 5.c I/O Software Layers

## User-level I/O system calls

## 4. User-level I/O system calls

- ✓ **utility library** procedures wrapping system calls; for example, formatting: printf(), scanf()
- ✓ **spooling**: a daemon centralizes access requests to printer and other devices

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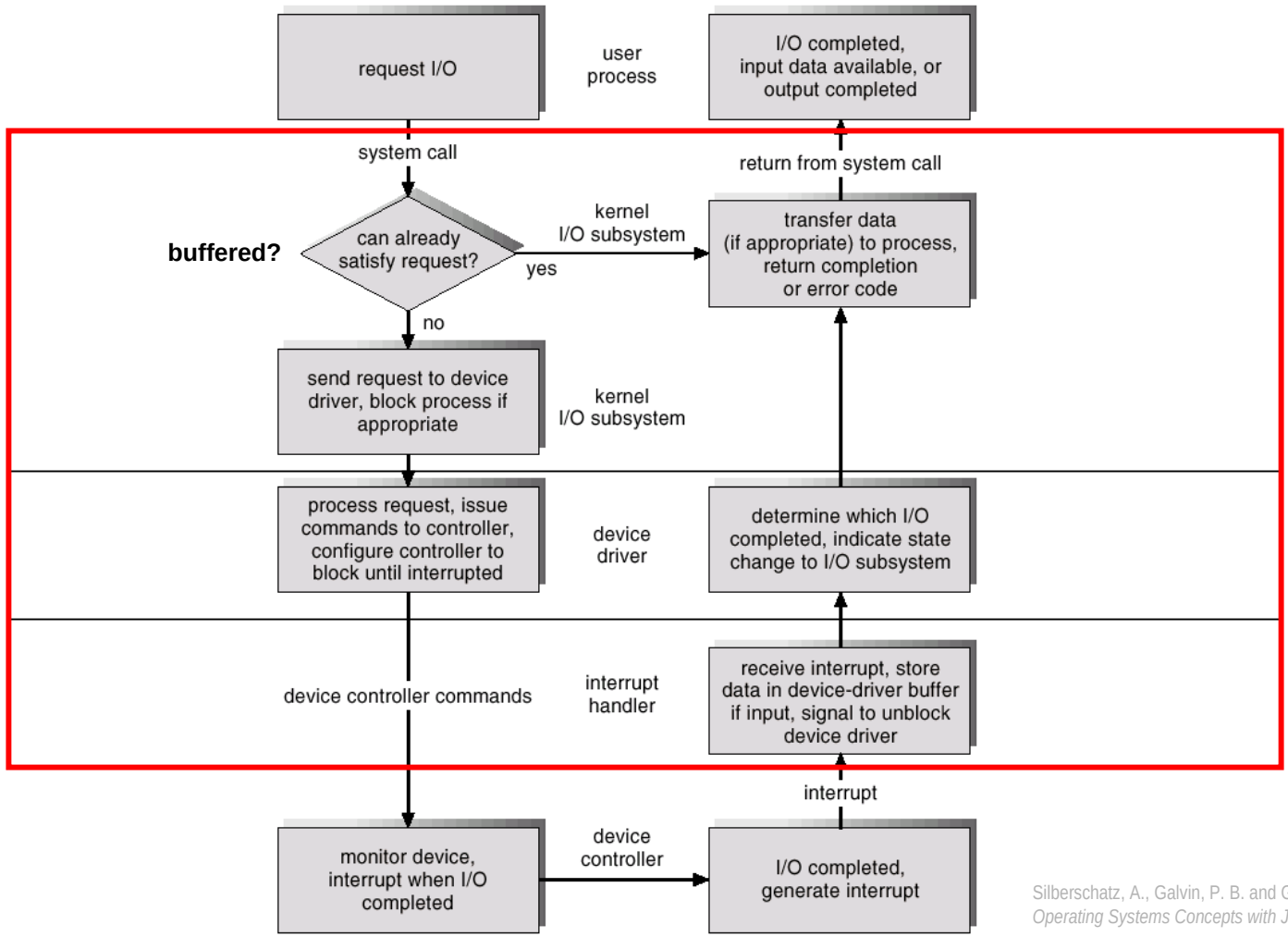
# 5.c I/O Software Layers

## User-level I/O system calls

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The life-cycle of an I/O request

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### d. Disk Management