# CS 3502
# Operating Systems

## Miscellaneous

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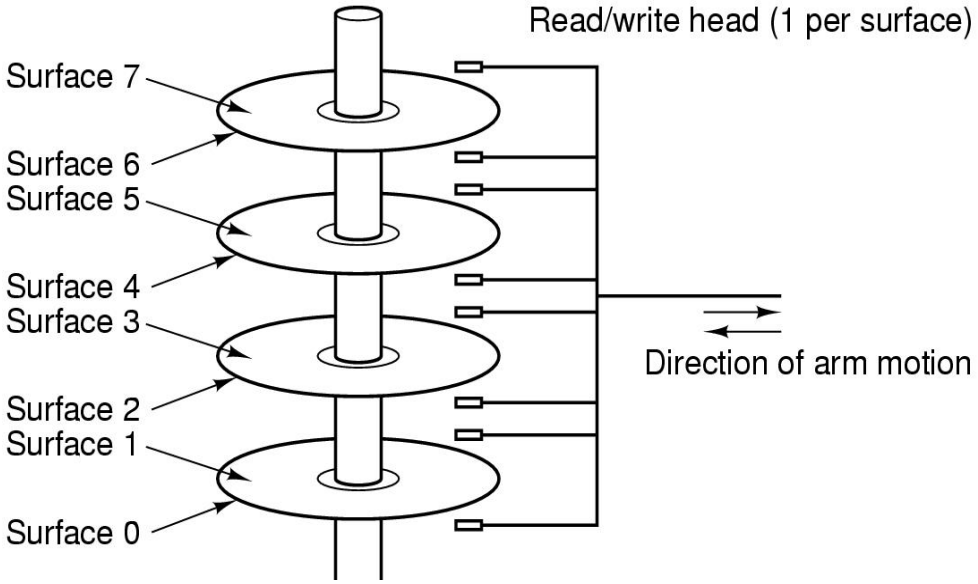
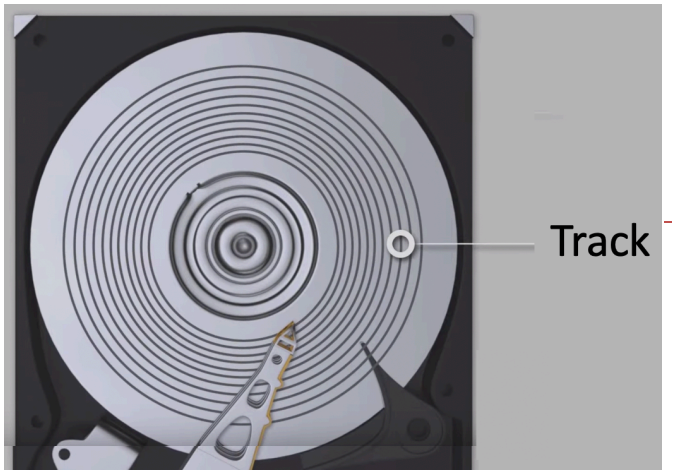
https://kevinsuo.github.io/

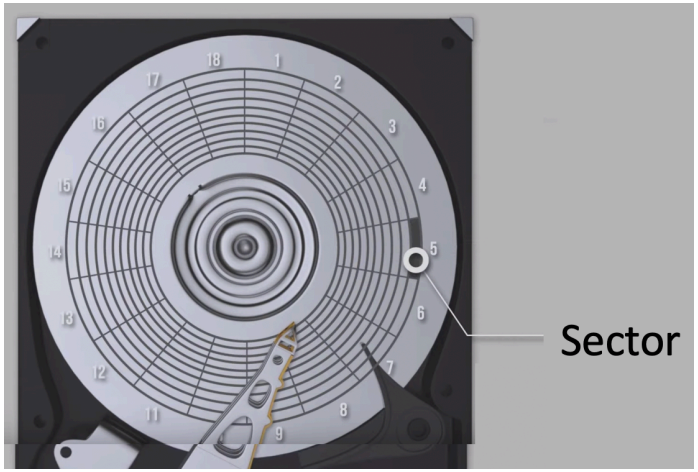
# Outline

- Disk scheduling algorithm
- Time in OS and Networking
- Power management in OS
- Virtualization and cloud

# Hard Disks

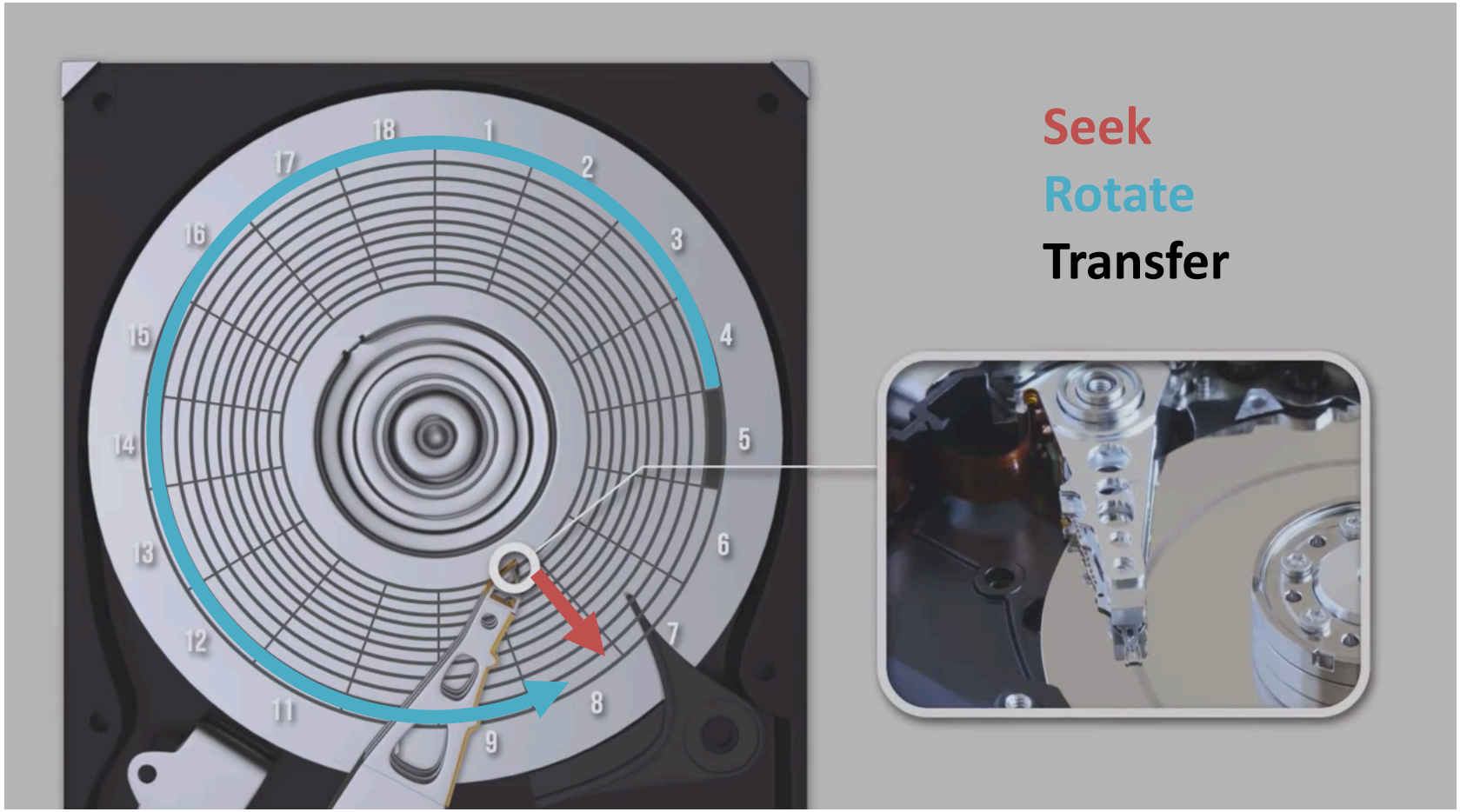



- The conventional *sector-track-cylinder* model
  - A stack of platters, a surface with a magnetic coating
  - Magnetic disks are organized into cylinders, for R/W

# Three-Stage Disk R/W Process



# Three-Stage Disk R/W Process

- Three-stage Disk R/W process: time required to read or write a disk block determined mainly by 3 factors
  1. Seek time (Dominates), 10-100ms
  2. Rotational delay, 1-10ms
  3. Actual transfer time

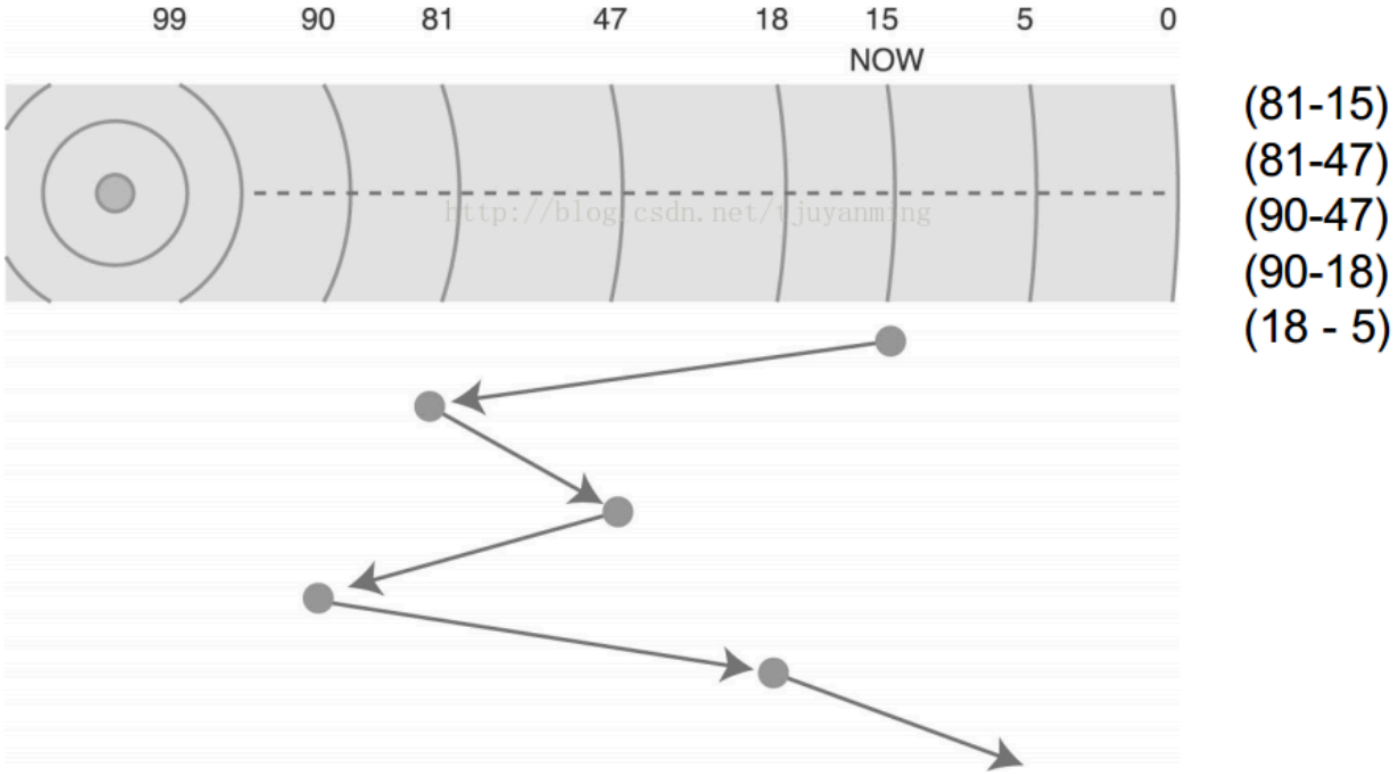
**Disk Access Time = Seek time + Rotational Latency + Transfer time + others**

**How to optimize seek time?**

**Disk arm scheduling algorithms**

# Disk scheduling algorithm: FCFS

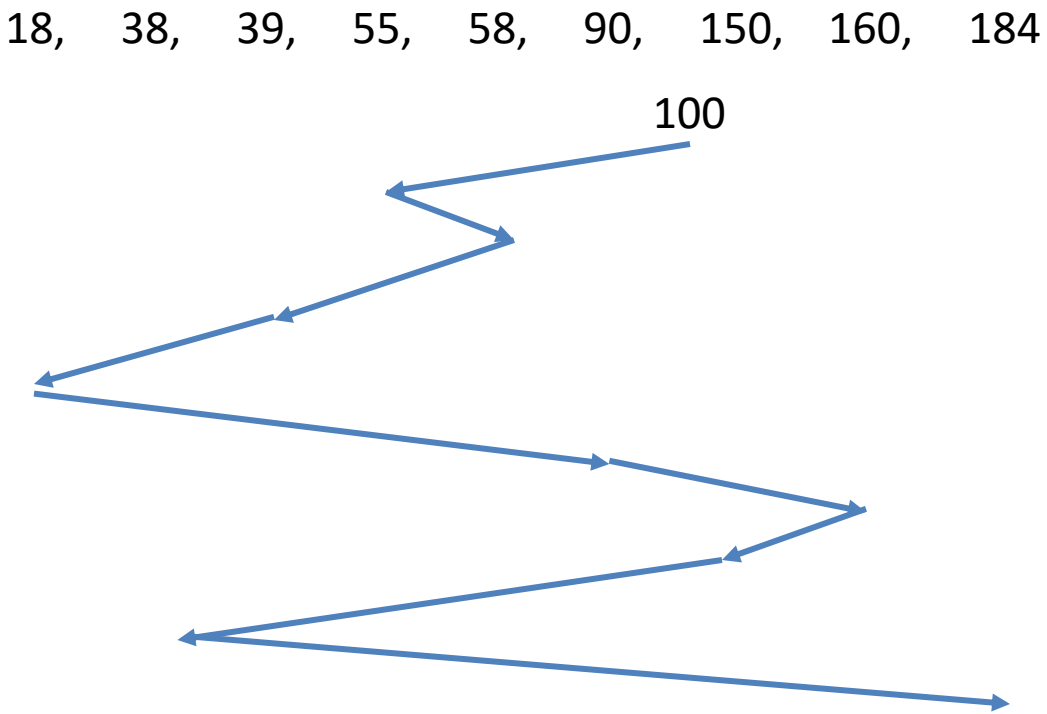
- FCFS: scheduling in order
- 81, 47, 90, 18, 5;  NOW at 15



# Disk scheduling algorithm: FCFS

- Example: header start from 100 and the track sequence is 55, 58, 39, 18, 90, 160, 150, 38, 184

| Start from 100 | |
|---|---|
| The next track | Distance |
| 55 | 45 |
| 58 | 3 |
| 39 | 19 |
| 18 | 21 |
| 90 | 72 |
| 160 | 70 |
| 150 | 10 |
| 38 | 112 |
| 184 | 146 |
| Average: 55.3 | |

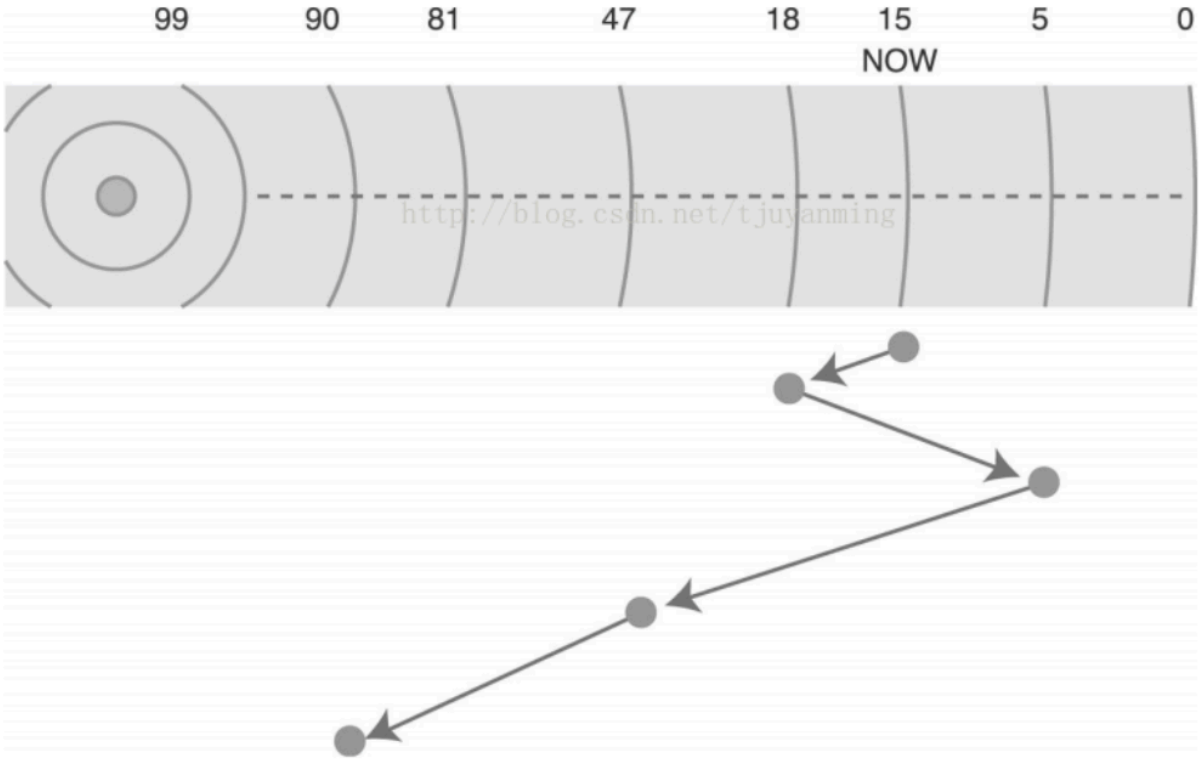


# Disk scheduling algorithm: FCFS

- Pros:
  - Fair and simple
  - each process request can be processed in turn
- Cons:
  - The average seek time is long
  - suitable for occasions where the number of disk I/O processes is small

# Disk scheduling algorithm: Shortest Seek First (SSF)

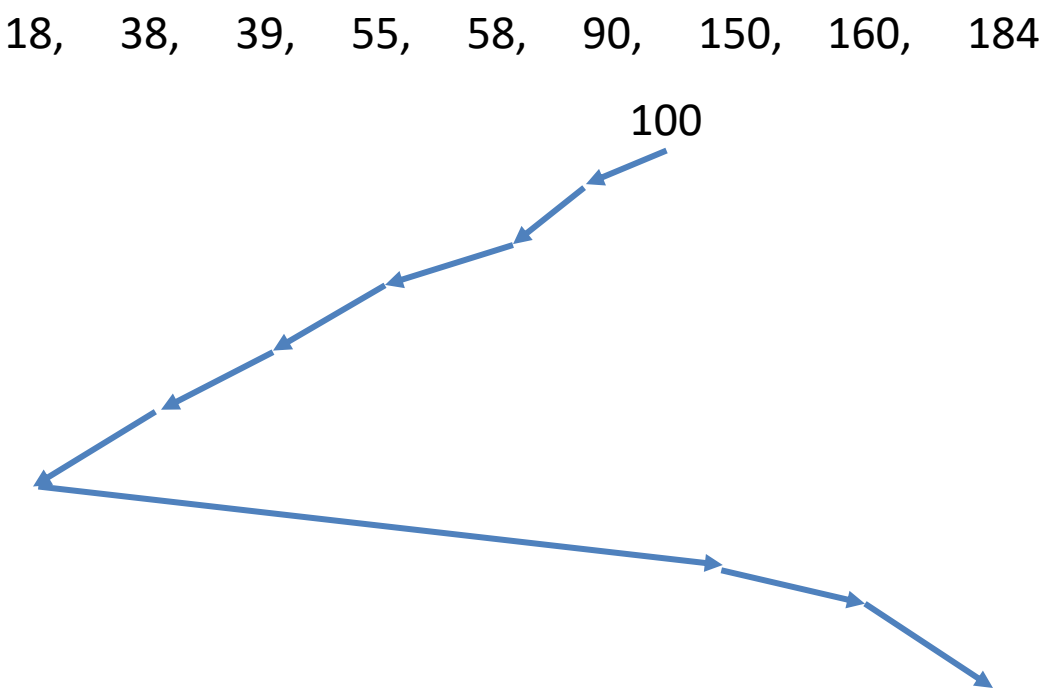
- SSF: scheduling to the track which is the closest
- 81, 47, 90, 18, 5;  NOW at 15



# Disk scheduling algorithm: Shortest Seek First (SSF)

- Example: header start from 100 and the track sequence is 55, 58, 39, 18, 90, 160, 150, 38, 184

| Start from 100 | |
|---|---|
| The next track | Distance |
| 90 | 10 |
| 58 | 32 |
| 55 | 3 |
| 39 | 16 |
| 38 | 1 |
| 18 | 20 |
| 150 | 132 |
| 160 | 10 |
| 184 | 24 |
| Average: 27.5 | |

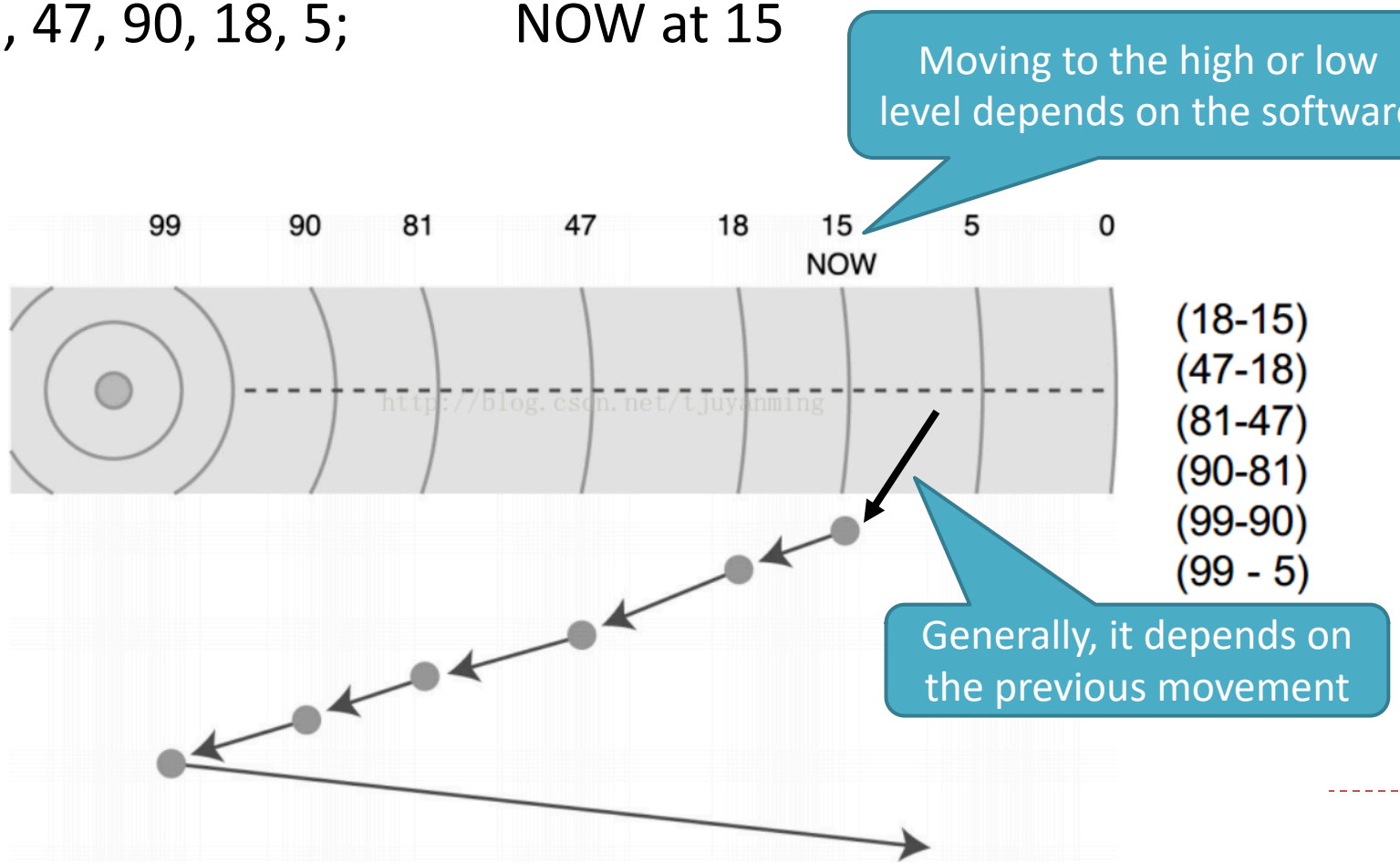


# Disk scheduling algorithm: Shortest Seek First (SSF)

- Pros:
  - Schedule the track closest to the header
- Cons:
  - Starvation occurs in low priority processes

# Disk scheduling algorithm: elevator algorithm

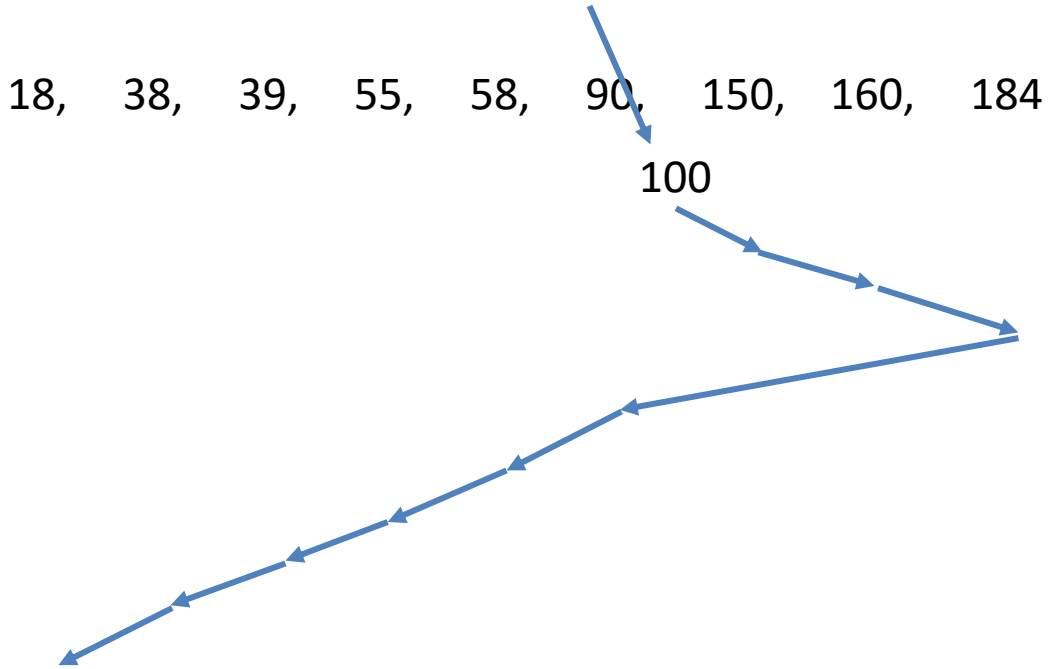
- Scheduling: keep moving in the same direction until there are no more outstanding requests in that direction
- 81, 47, 90, 18, 5;  NOW at 15



# Disk scheduling algorithm: elevator algorithm

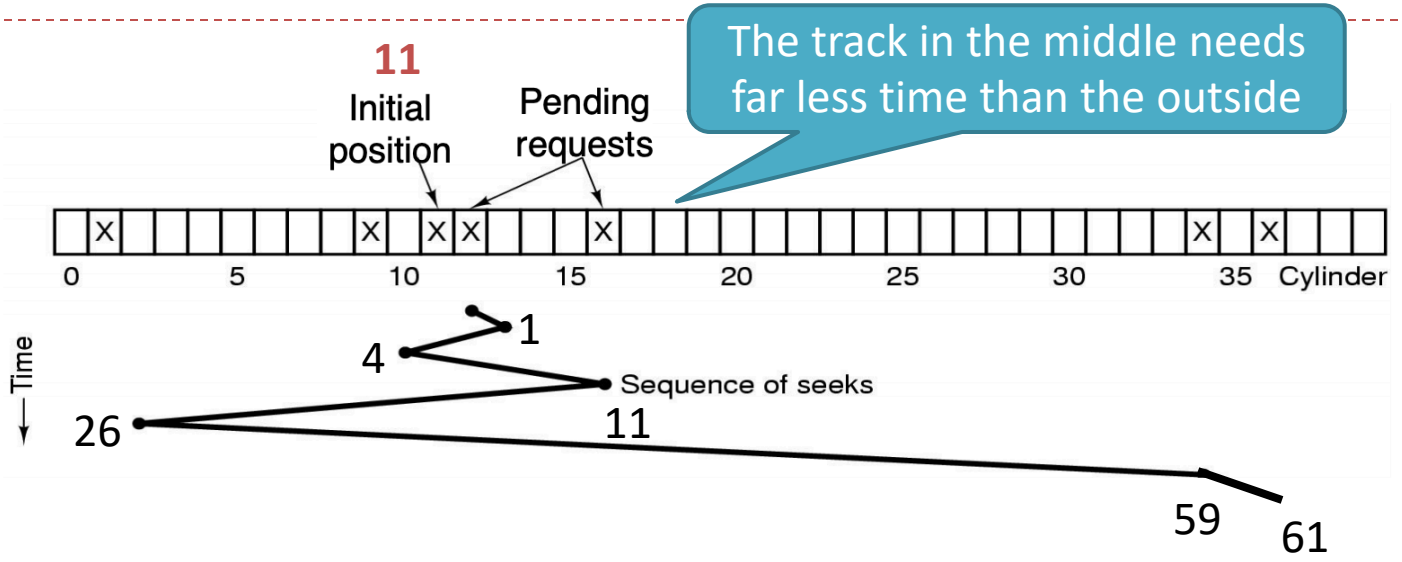
- Example: header start from 100 and the track sequence is 55, 58, 39, 18, 90, 160, 150, 38, 184

| Start from 100 | |
|---|---|
| The next track | Distance |
| 150 | 50 |
| 160 | 10 |
| 184 | 24 |
| 90 | 94 |
| 58 | 32 |
| 55 | 3 |
| 39 | 16 |
| 38 | 1 |
| 18 | 20 |
| Average: 27.8 | |

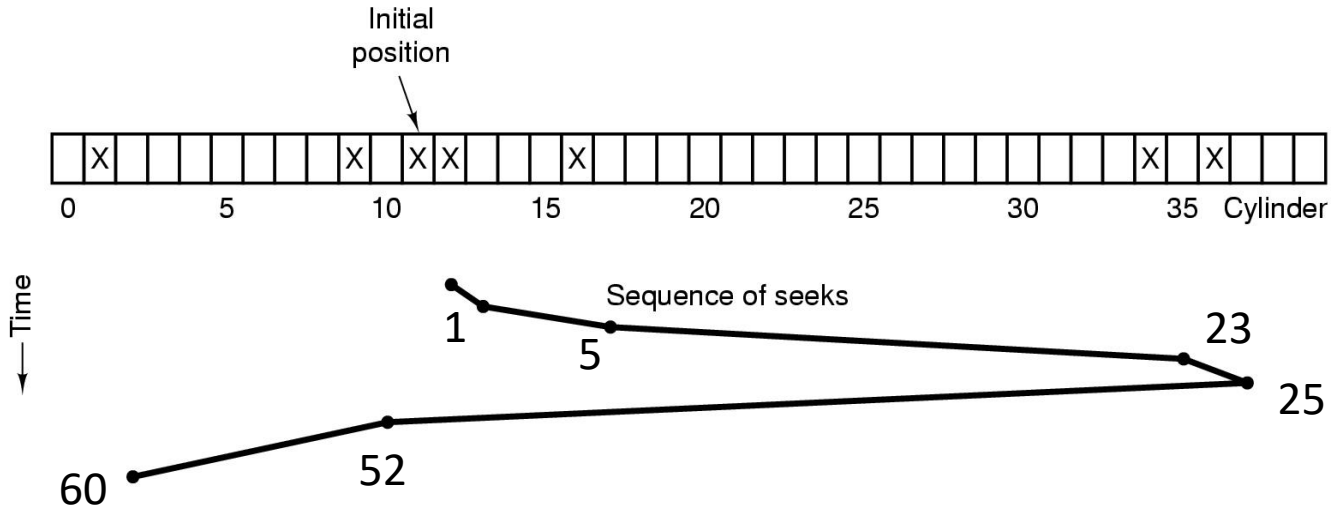


# SSF vs. Elevator algorithm: 1, 36, 16, 34, 9, 12

SSF




Elevator



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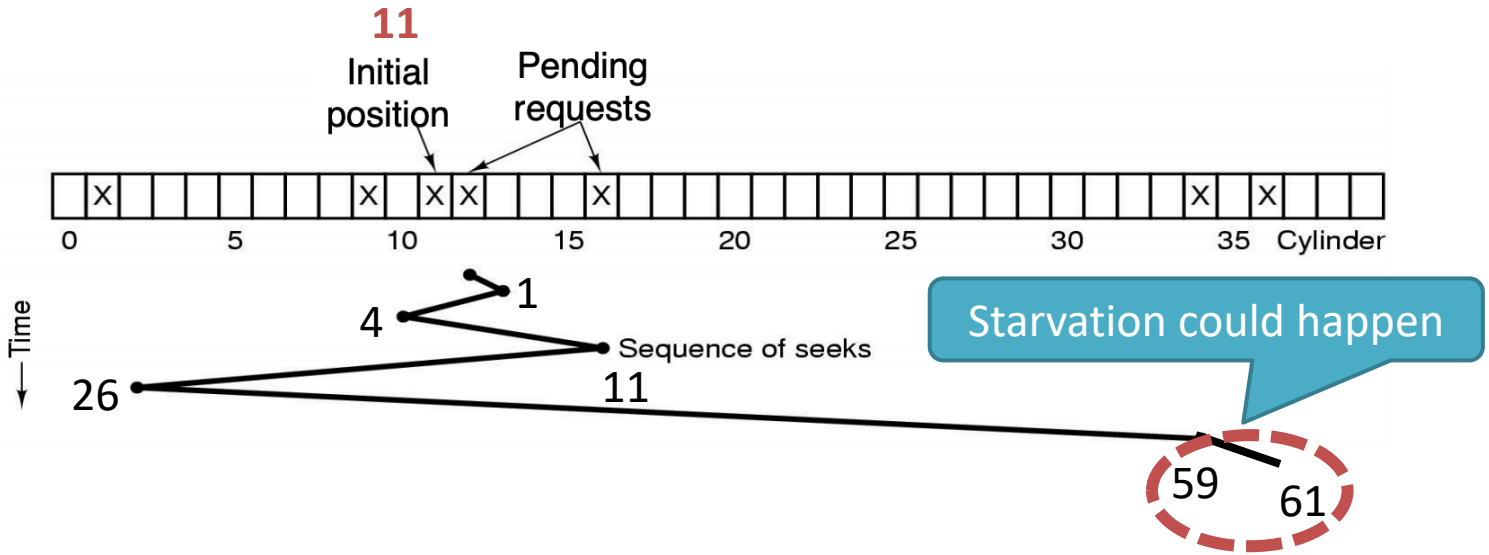
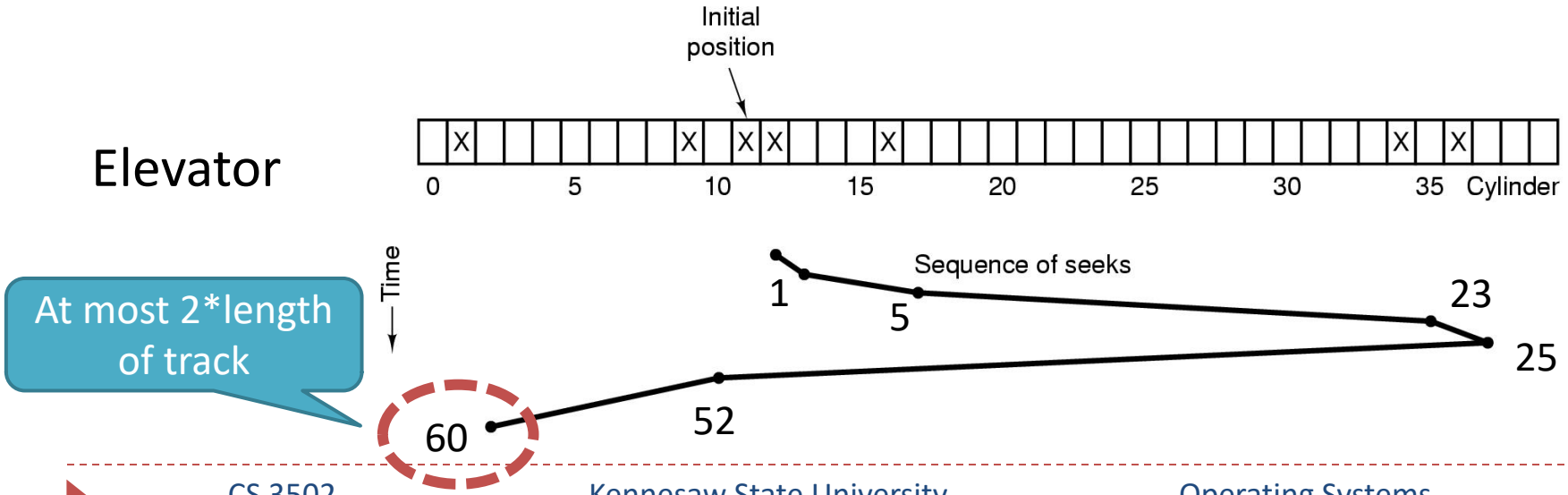
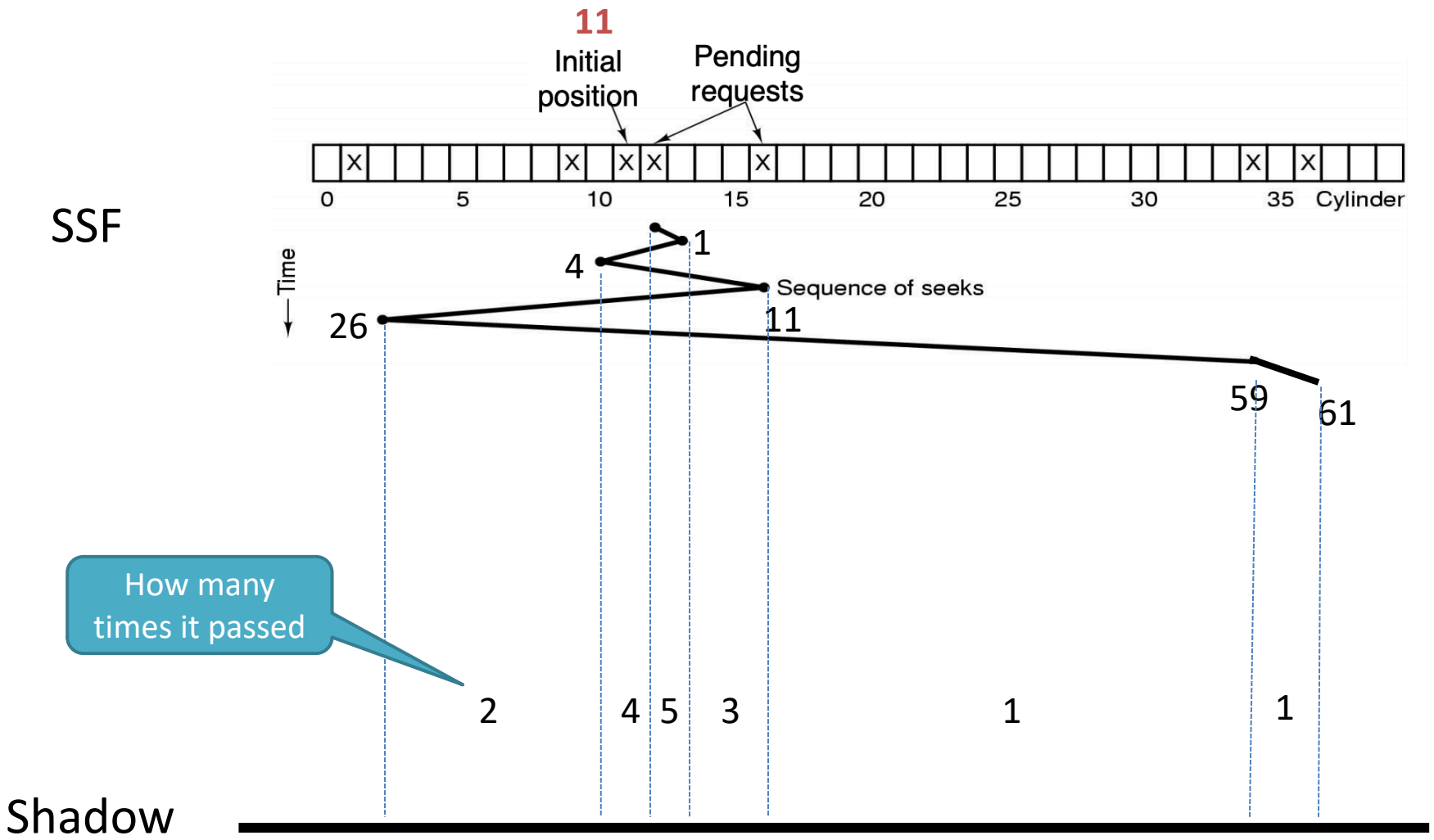
SSF



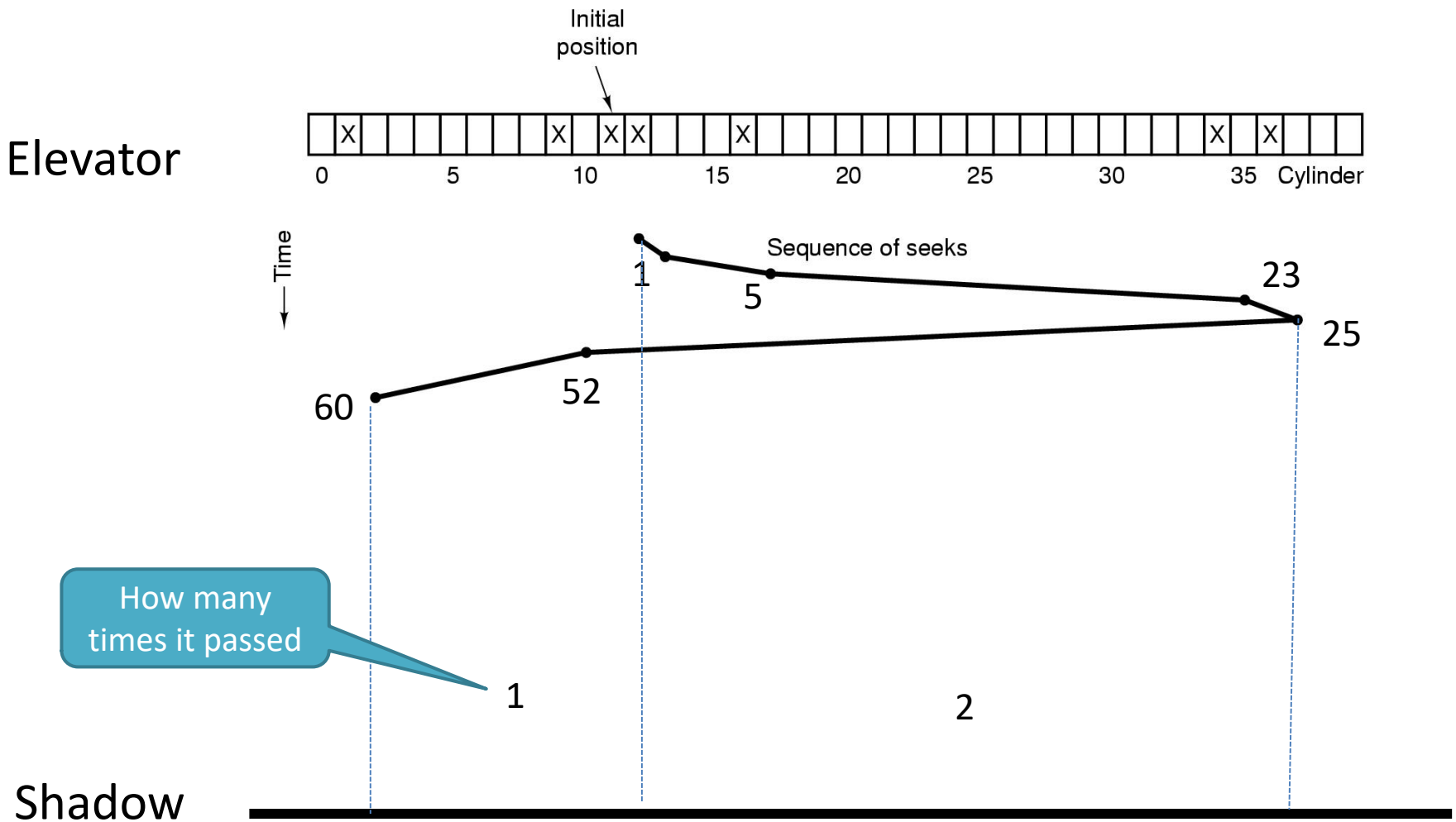

Elevator



# SSF vs. Elevator algorithm: 1, 36, 16, 34, 9, 12



# SSF vs. Elevator algorithm: 1, 36, 16, 34, 9, 12



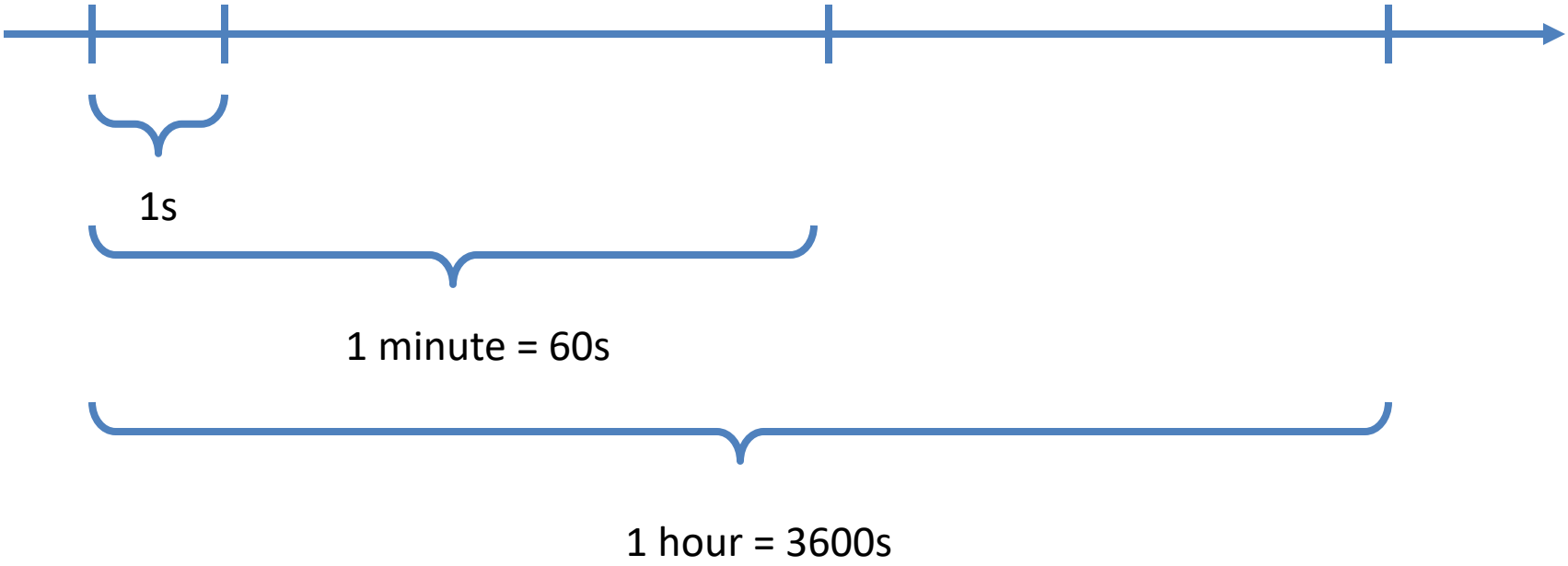
# Disk scheduling algorithm: elevator algorithm

- Pros:
  - Consider both distance and moving direction
  - Avoid starvation (less tracking distance)
- Cons:
  - Certain track might have to wait for long time

# Outline

- Disk scheduling algorithm
- Time in OS and Networking
- Power management in OS
- Virtualization and cloud

# Time in OS

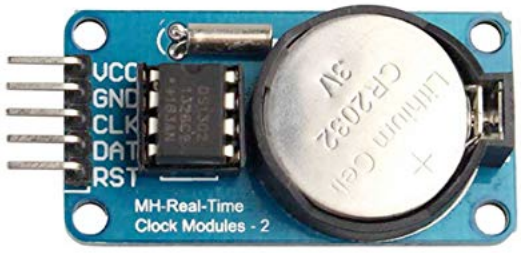



- Time in the OS is a counter number

# Time in OS: Real Time Clock (RTC)

- The RTC continues to tick even when the machine is powered off, because it is energized by a small battery

- Linux uses the RTC only to derive the time and date




# Time in OS: Time Stamp Counter(TSC)

- The counter is accessible through the 64-bit Time Stamp Counter(TSC) register
- Every time the time interrupts come, the TSC counter will be plus by N, (N is related with CPU speed)
- TSC can be read by ***native_read_tsc()*** function
- Example: CPU frequency is 1GHz, every 1ns, the TSC counter is added by 1

# TSC example

```
[root@disco-0006 ~]# ./test
v1: 6101225874679404, v2: 6101227774910159, delta: 1900230755
1900
```

```c
#include <stdio.h>

typedef unsigned long long u64;
#define DECLARE_ARGS(val, low, high)    unsigned low, high
#define EAX_EDX_RET(val, low, high)     "=a" (low), "=d" (high)
#define EAX_EDX_VAL(val, low, high)     ((low) | ((u64)(high) << 32))

static __always_inline unsigned long long __native_read_tsc(void)
{
        DECLARE_ARGS(val, low, high);
        asm volatile("rdtsc": EAX_EDX_RET(val, low, high));
        return EAX_EDX_VAL(val, low, high);
}

unsigned long long native_read_tsc(void)
{
        return __native_read_tsc();
}

int main()
{
        unsigned long long val, val2;
        unsigned long long delta;

        val = native_read_tsc();
        sleep(1);
        val2 = native_read_tsc();
        delta = val2 - val;

        printf ("v1: %llu, v2: %llu, delta: %llu \n", val, val2, delta);
        printf ("%lld\n", delta/1000000);

        return (0);
}
```

My CPU is 1.9GHz

$$Time = \frac{t_2 - t_2}{CPU\ frequency}$$

Read two TSC counters $t_1$, $t_2$

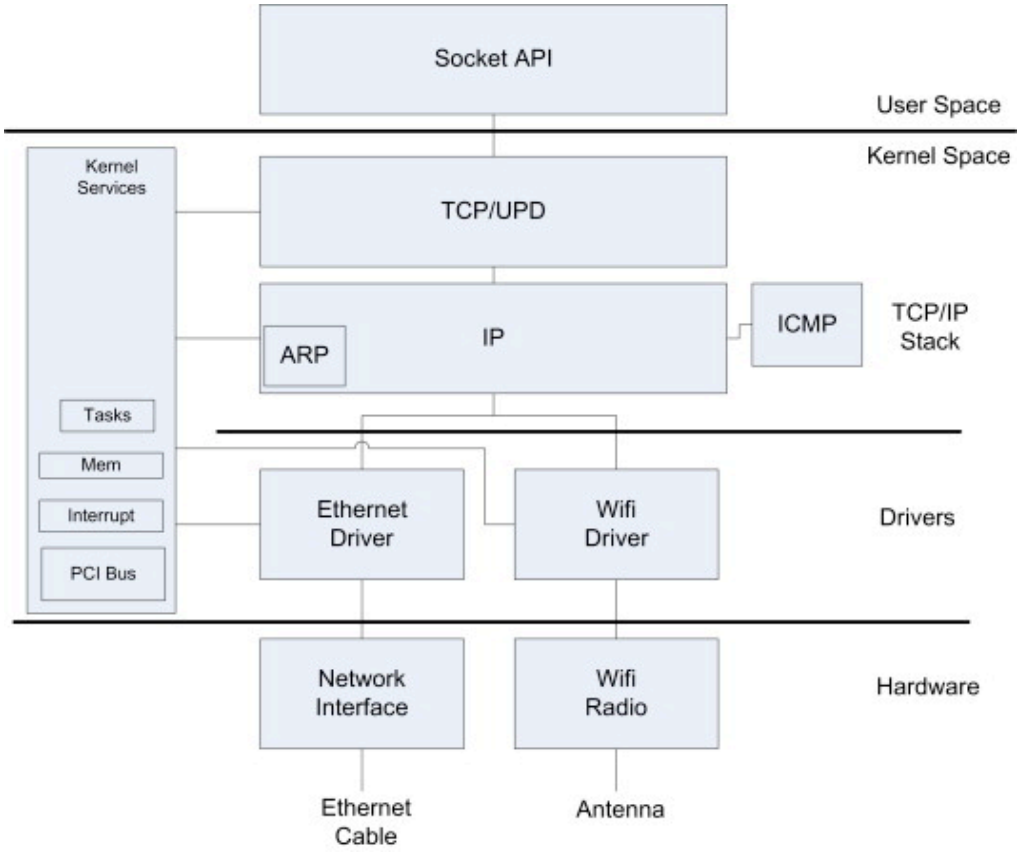
# Other Timers in OS

- Programmable Interval Timer (PIT): raise interrupts in a fixed frequency; used for operating system and application programming

- The High Precision Event Timer (HPET): a hardware timer with high precision (nanosecond)

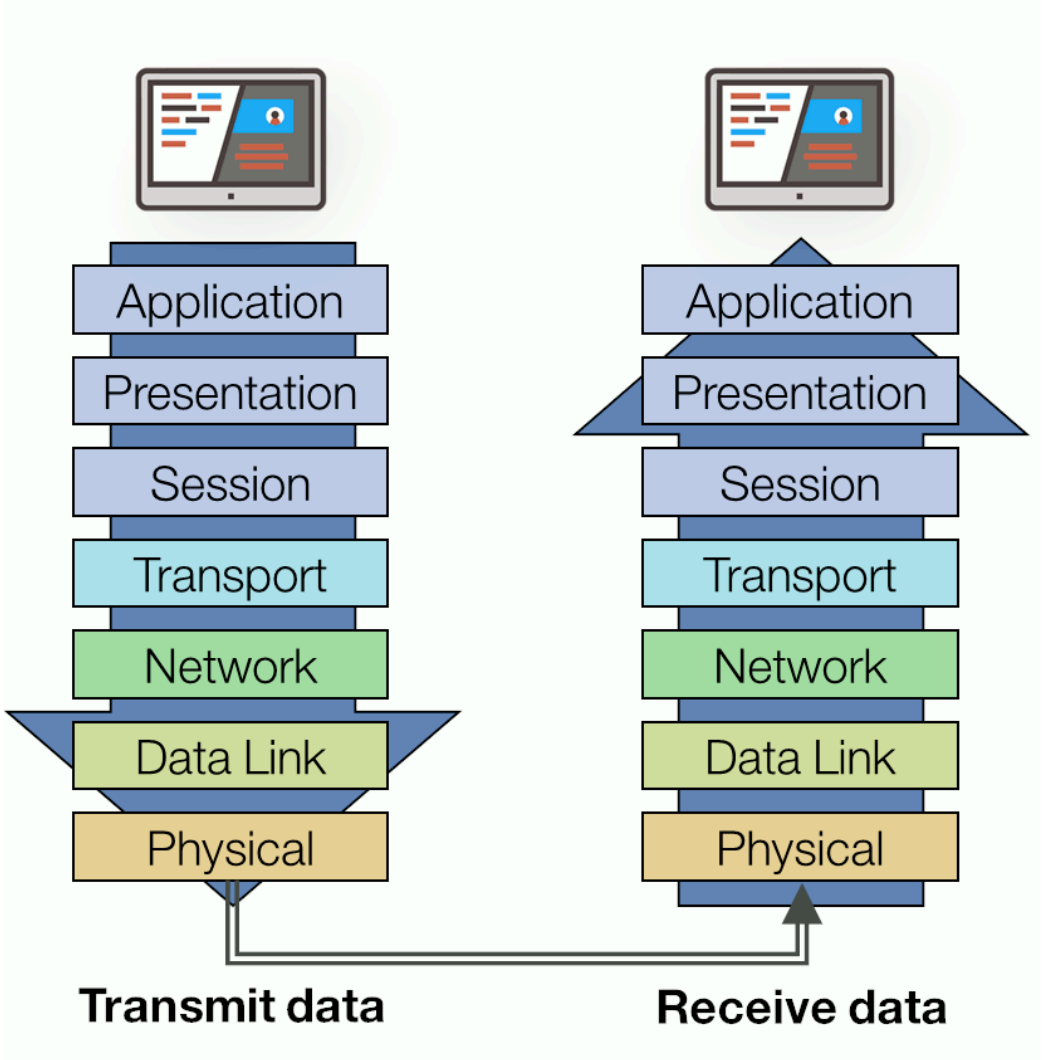
- ACPI power management timer (ACPI PMT): a simple counter that has a fixed frequency clock

# Networking in OS



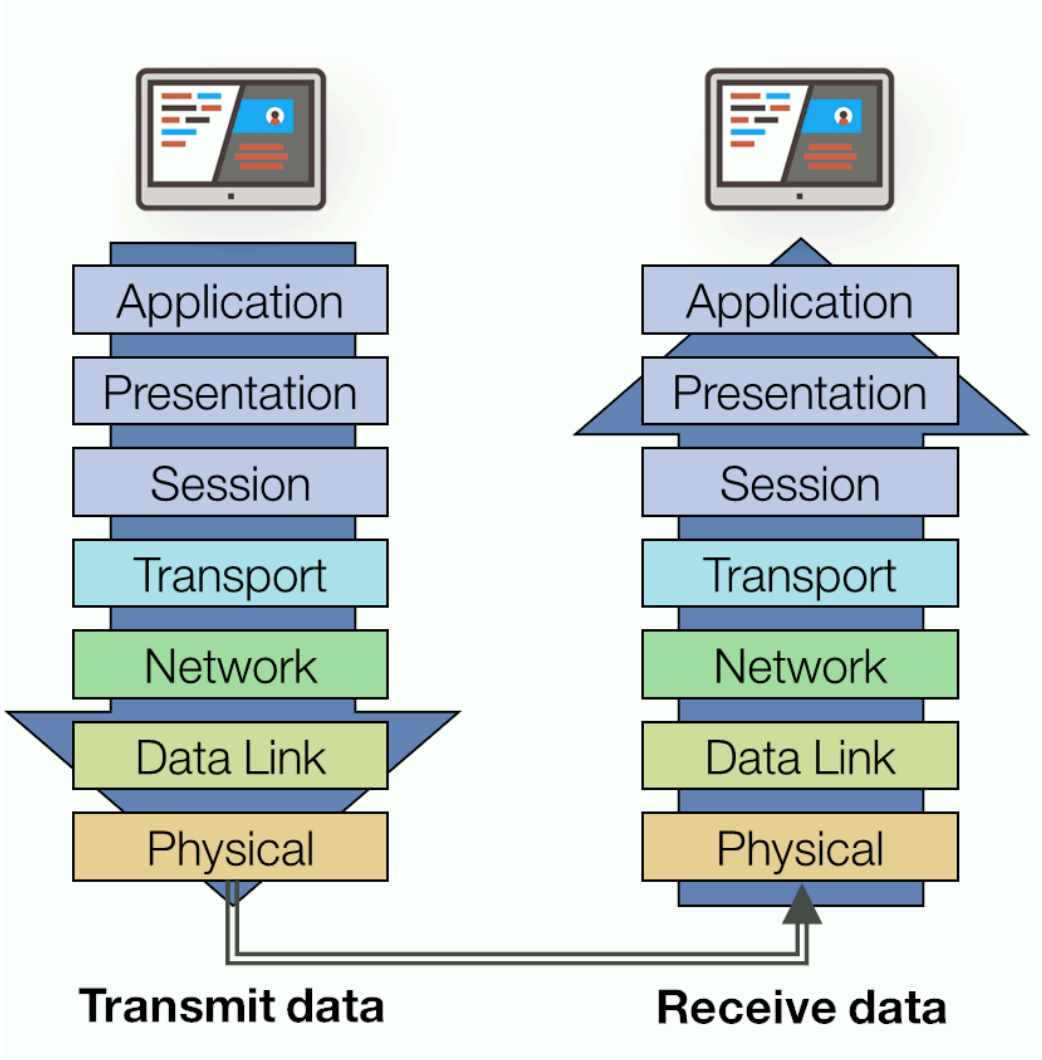

- Network subsystem is part of the I/O system in the OS
- Most operating systems provide a networking stack for the network activities
- Network stack includes IP stack, TCP/UDP protocol, device drivers, socket APIs, etc.

# Networking in OS



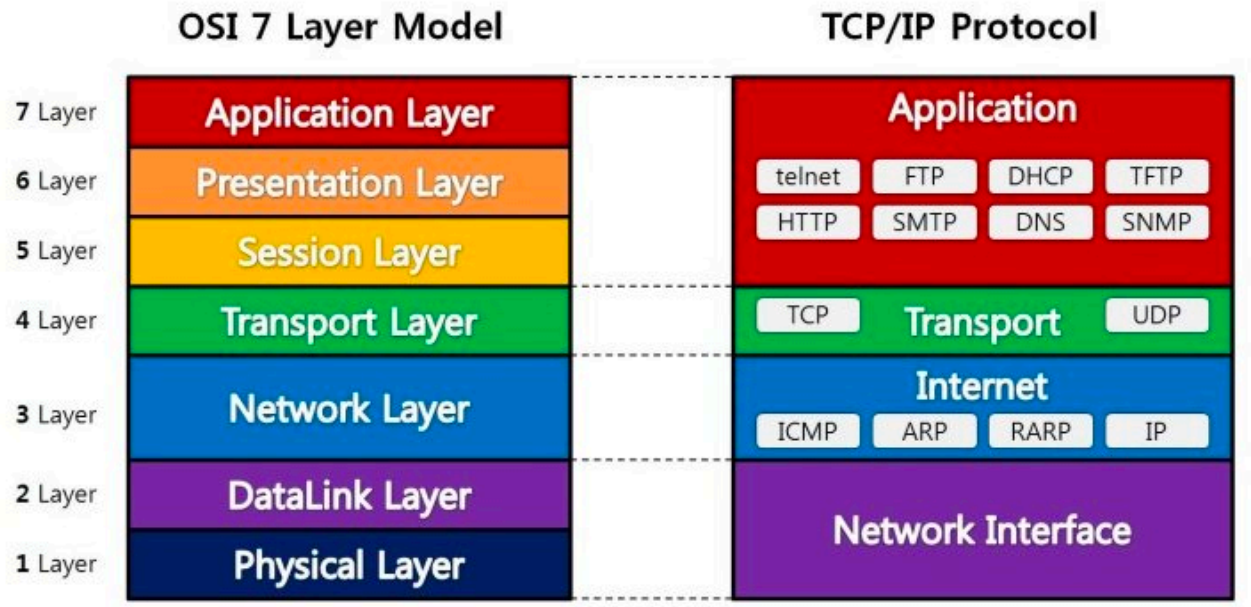

- Physical: represents the electrical and physical representation of the system
- Data link: provides node-to-node data transfer and handles error correction
- Network: router function, packet forwarding, etc.

# Networking in OS




- Transport: coordination of the data transfer between end systems and hosts. How much data to send, at what rate, where it goes, etc.
- Session/Presentation/Application: interaction with the user level application

# Networking in OS




Application data

Segment

Packet

Bits

# Outline

- Disk scheduling algorithm
- Time in OS and Networking
- Power management in OS
- Virtualization and cloud

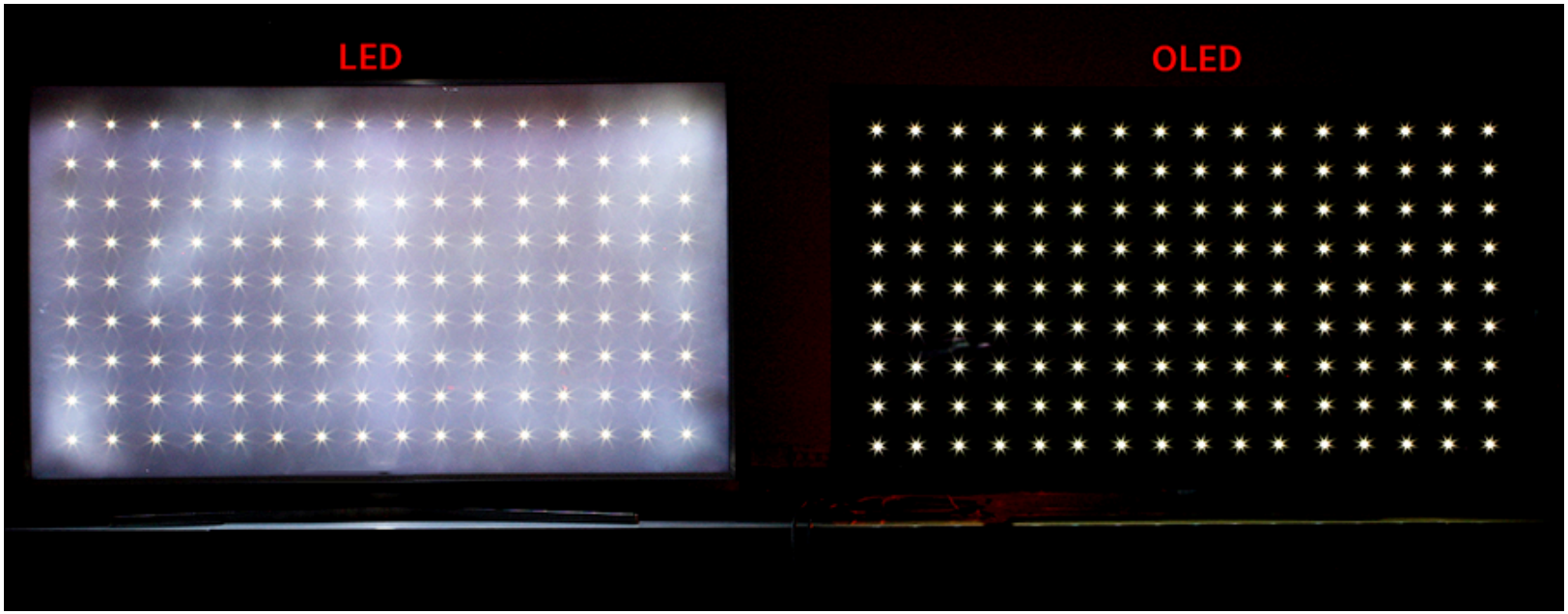
# Power Management

- Power consumption is important to desktops and battery-powered computer
- Two General approaches to battery conservation
  - Turn off (down) some hardware parts, top 3 power eaters: display, hard disk, and CPU
  - Application uses less power, multiple states: on/off, sleep, hibernating

| Device | Li et al. (1994) | Lorch and Smith (1998) |
|---|---|---|
| Display | 68% | 39% |
| CPU | 12% | 18% |
| Hard disk | 20% | 12% |
| Modem | | 6% |
| Sound | | 2% |
| Memory | 0.5% | 1% |
| Other | | 22% |

Power consumption of various parts of a laptop computer

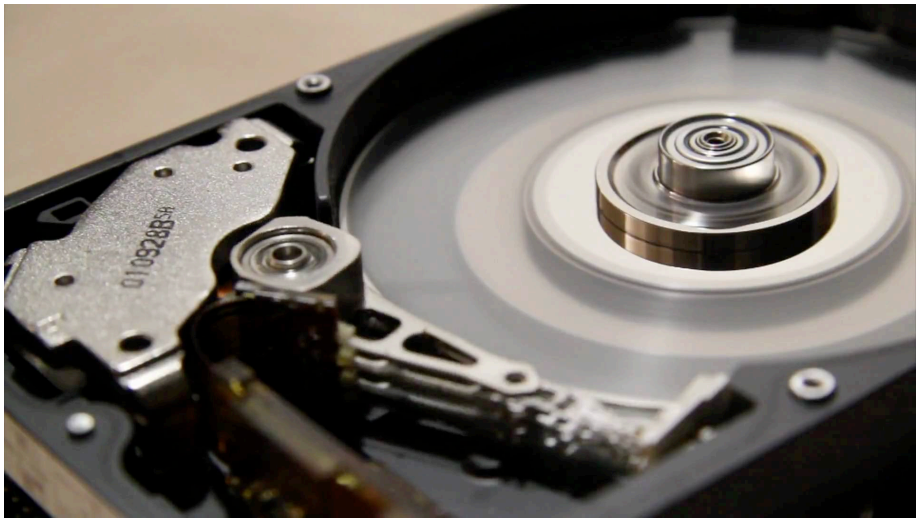
# Power Management: The Display



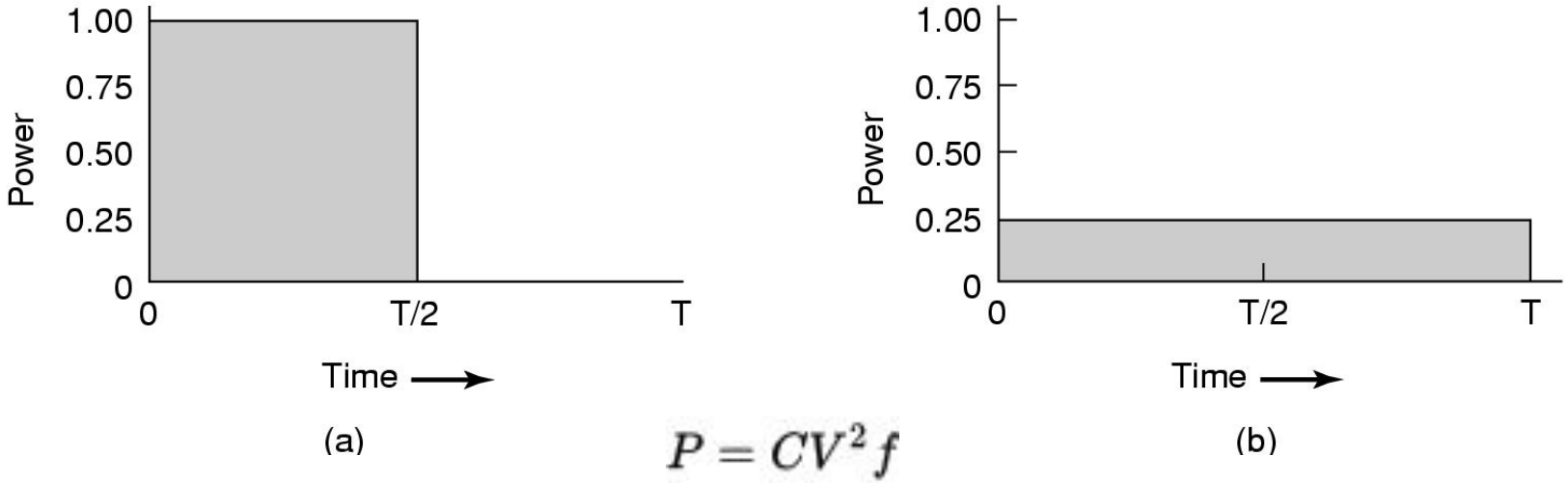

- On-off switching
  - Display consist of some zones that can be independently powered up or down

# Power Management: The Hard Disk

- It takes substantial energy to keep it spinning at high speed, even if there are no disk accesses
- Restarting a hard disk also consumes considerable energy
- Solution:
  - have a substantial disk cache in RAM



# Power Management: The CPU

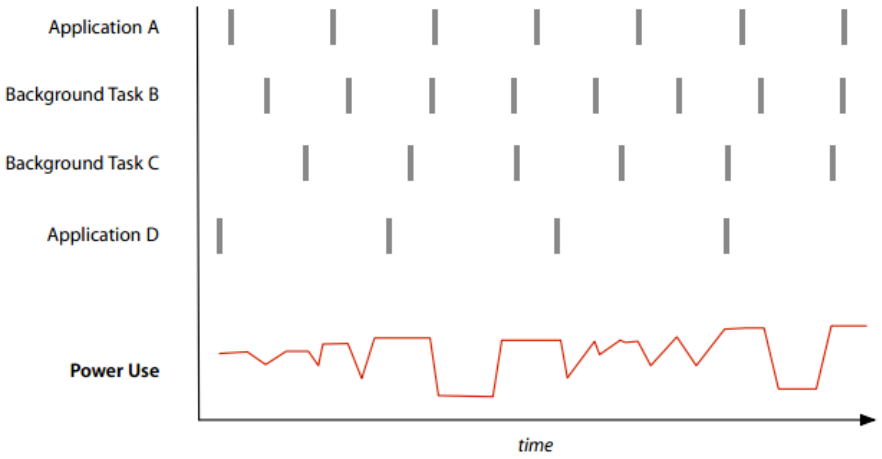



$$P = CV^2 f$$

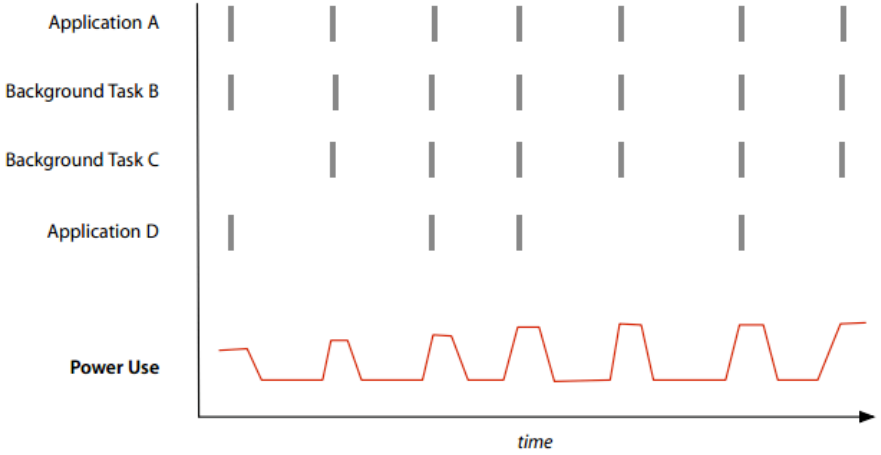
- Cut the CPU frequency
- Cut the voltage
- Dynamic voltage and frequency scaling (DVFS): increased or decreased, depending upon circumstances

# Power Management: OS and software techniques

- Timer Coalescing:
- https://youtu.be/ZIQ5zGOo6qE?t=1652



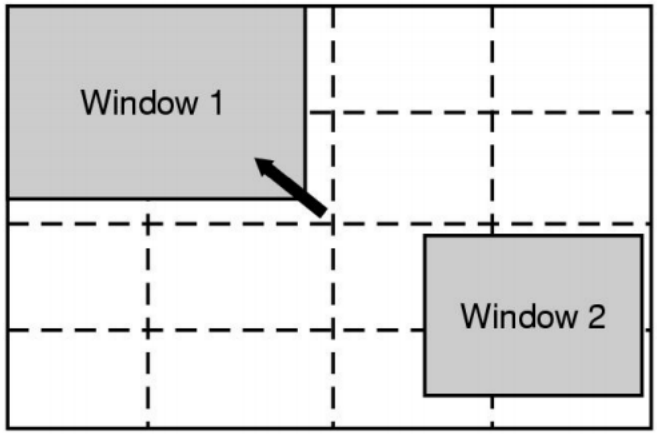

Typically, numerous applications and background processes use timers with different intervals.

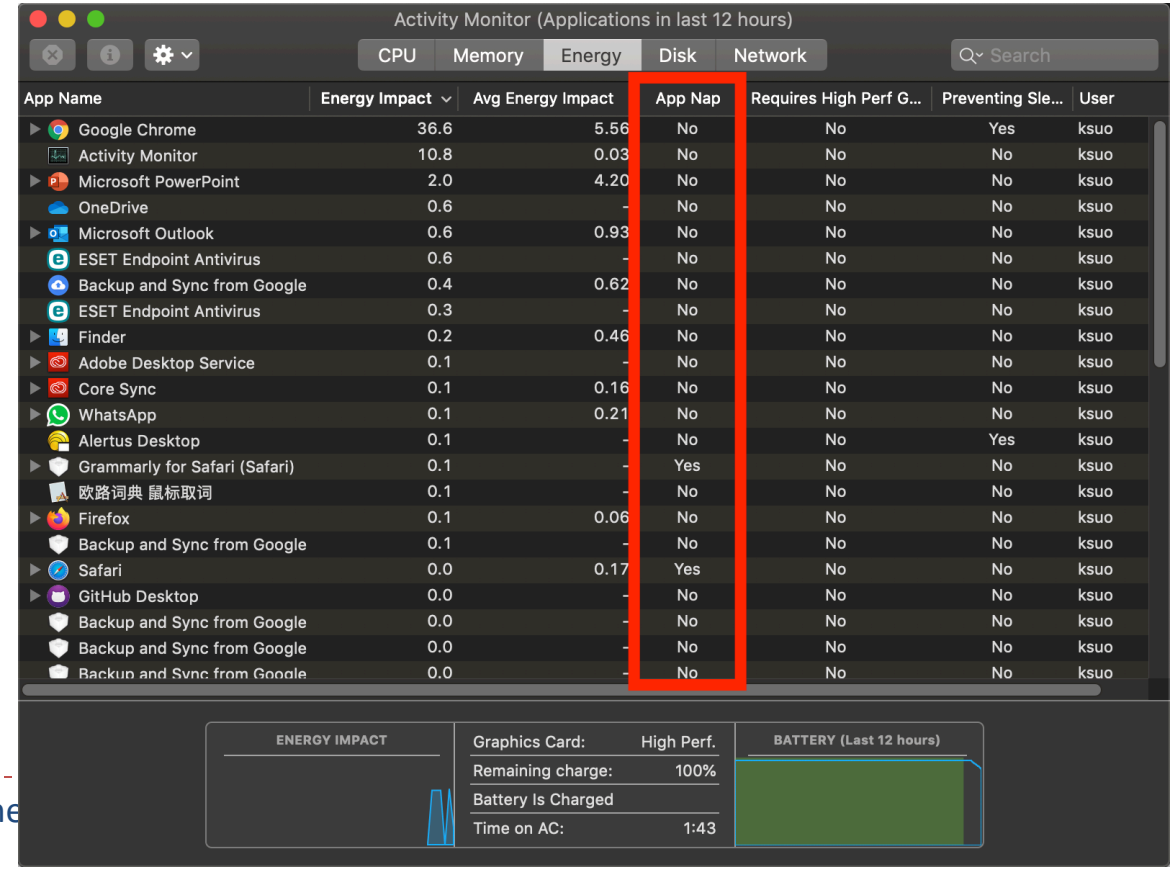



Timer Coalescing shifts timers of multiple applications to execute at the same time.

# Power Management: OS and software techniques

- Application nap:
- https://youtu.be/ZIQ5zGOo6qE?t=1998



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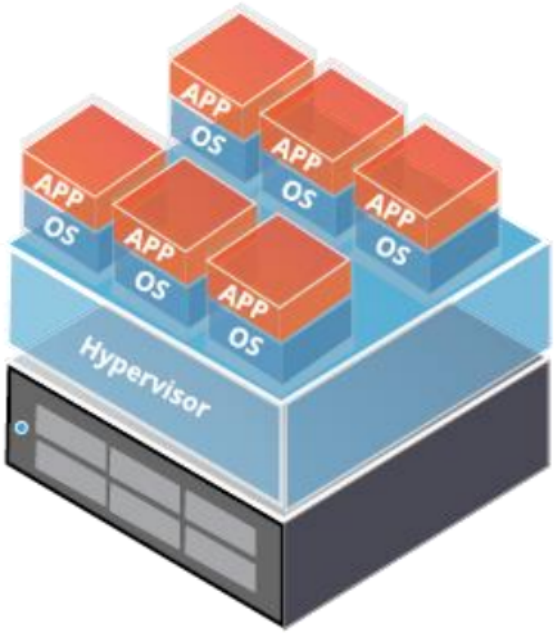
# How to share a physical computer

- Operating systems allows multiple processes/applications to run simultaneously
- Via process/memory management, CPU scheduler, multithreading, concurrency control
- Allow multiple users to access the same machines

# Virtual Machines

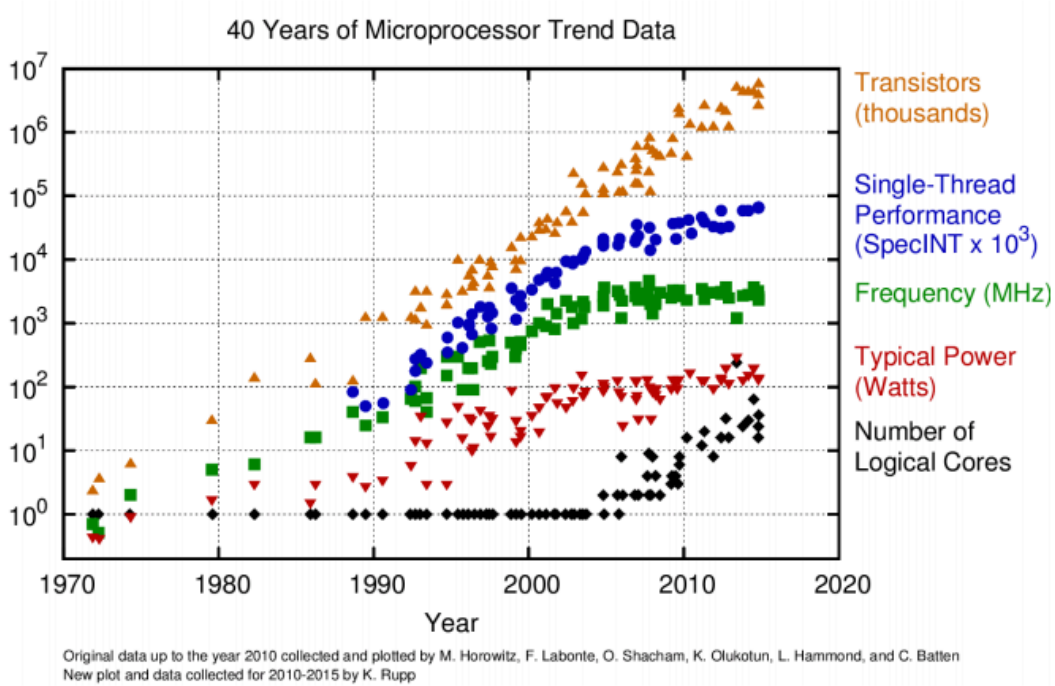
- Run multiple (virtual) machines on the same server to share the same physical resources, including CPU, memory, storage, etc.

- Provide the illusion to the virtual machines that they exclusively occupy the physical resources



# Why VM?

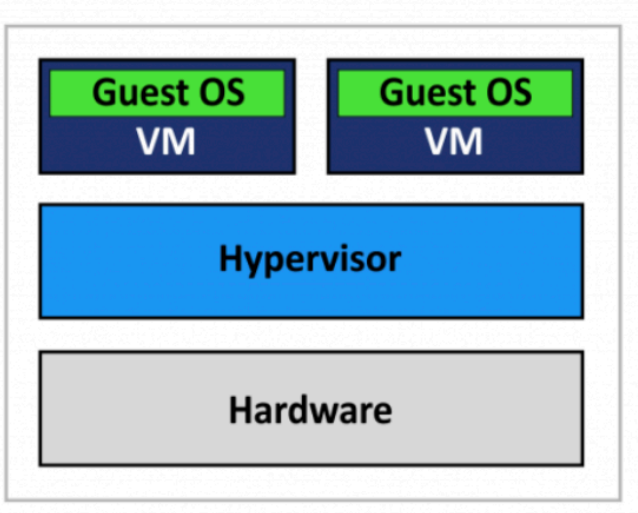
- Single core becomes more powerful
- More and more cores per CPU
- Overall CPU% is low (in data centers) – 15% ~ 18%
- How to efficiently use them? -- Sharing



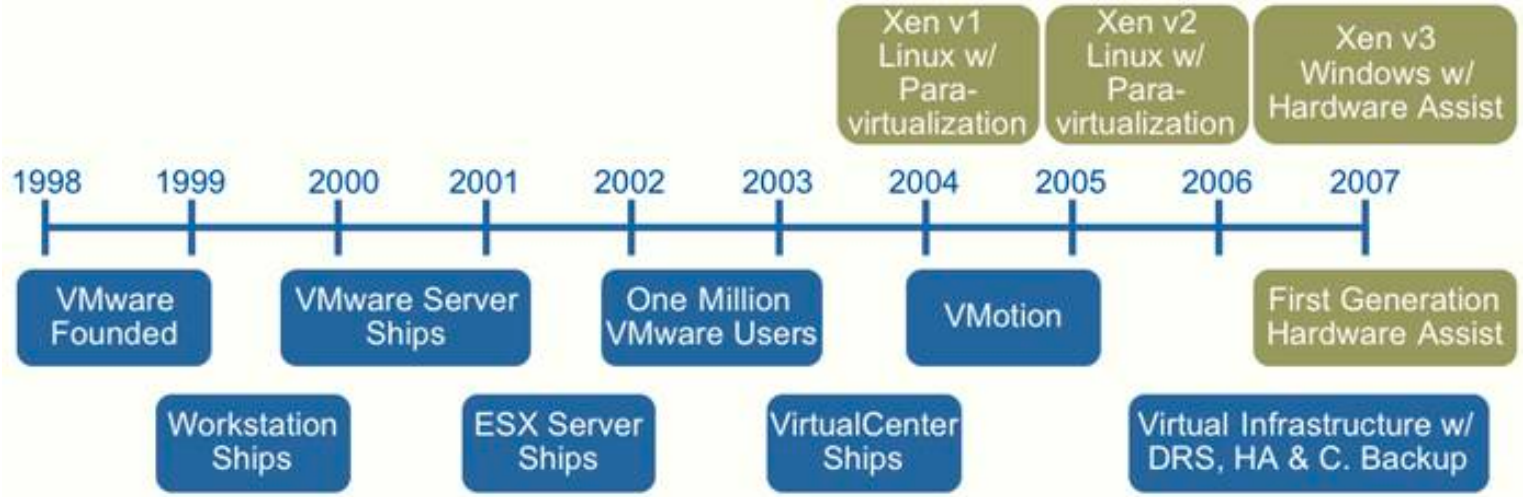
# Solutions for hypervisor

- Commercial virtual machines for x86 architecture
  - VMware (1999-)
  - Connectix Virtual PC (now Microsoft)
  - KVM for Linux

- Research virtual machines for x86 architecture
  - Xen (SOSP '03)
  - plex86



# Virtualization history

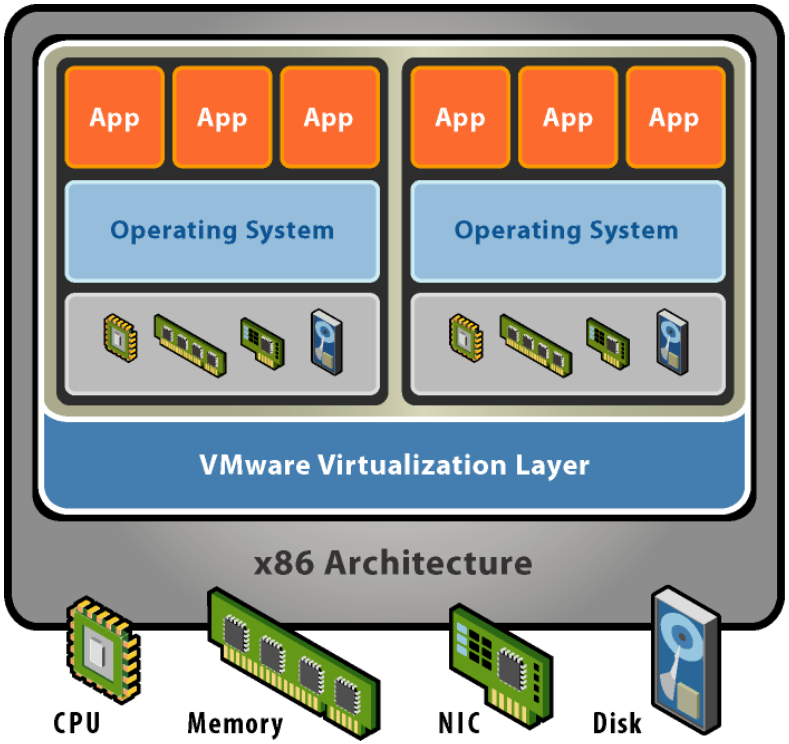






# Resource Virtualization

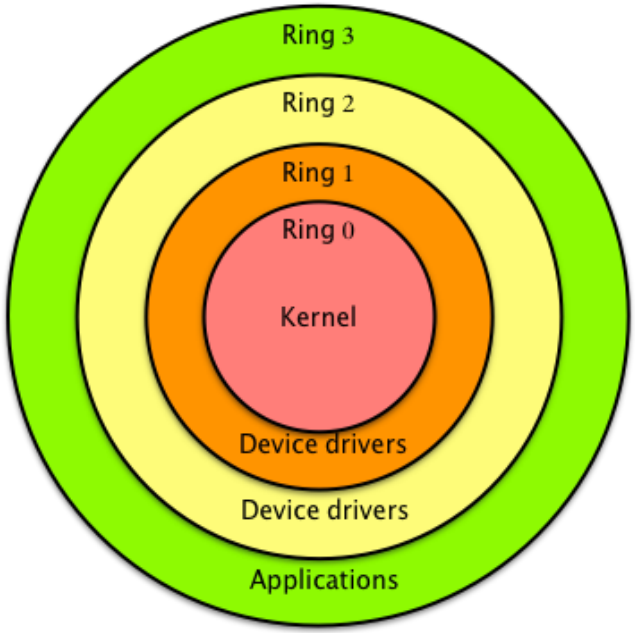
- Processor
- Memory
- Device and I/O



# CPU Rings

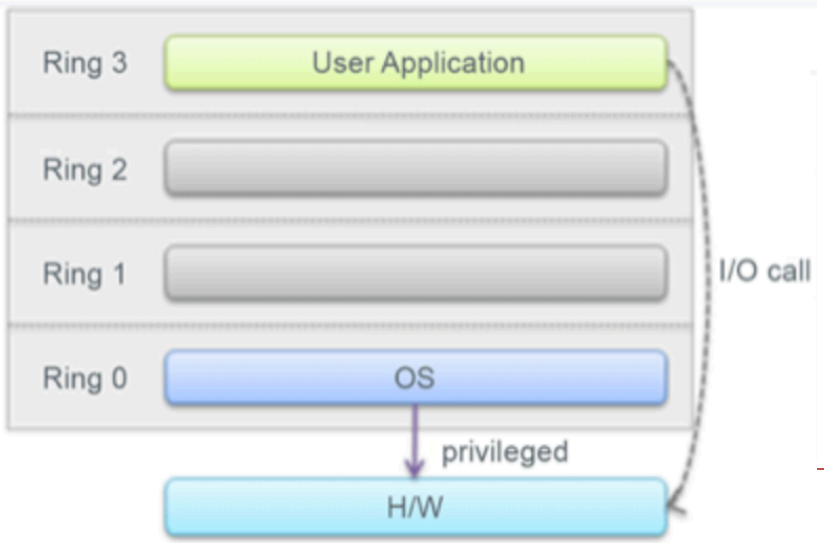
- User and kernel mode are controlled by CPU

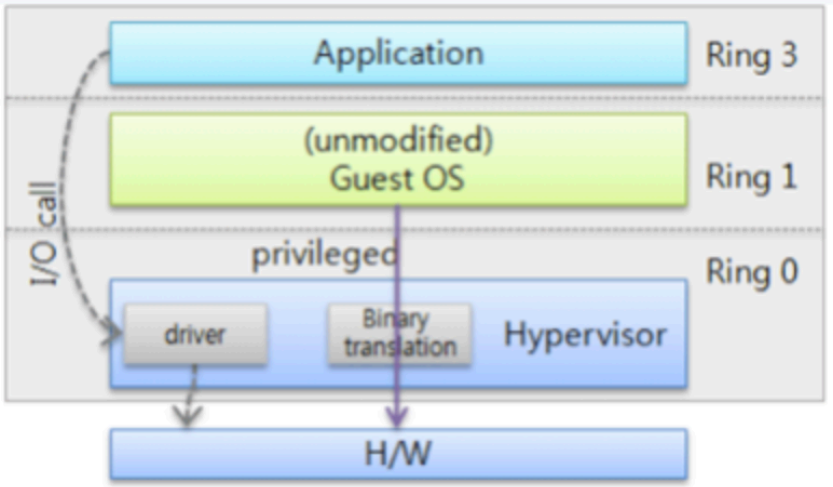
- Multiple CPU protection rings
  - traditional OS runs in ring 0
  - Application runs in ring 3
  - must handle ring 3 to ring 0 transition



# CPU Virtualization

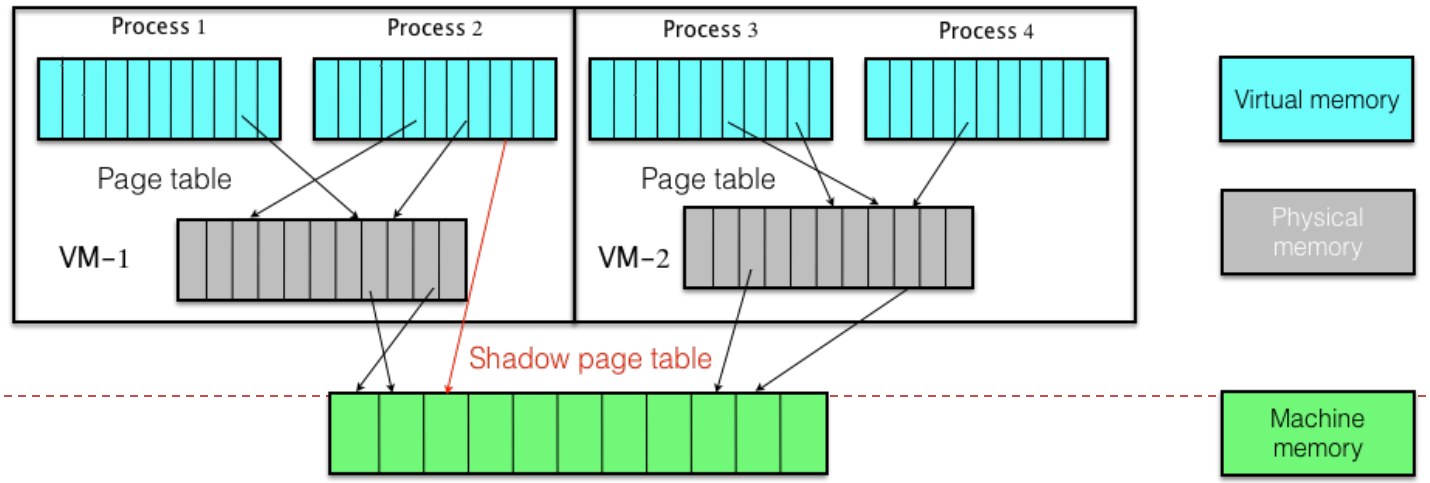
- Place Guest OS in Ring 1, and VMM in Ring 0 (with the highest privilege)
- if Guest OS executes privilege instructions:
  - Cause a trap if executed in privilege level other than Ring 0
  - VMM/hypervisor interprets such instructions and do something



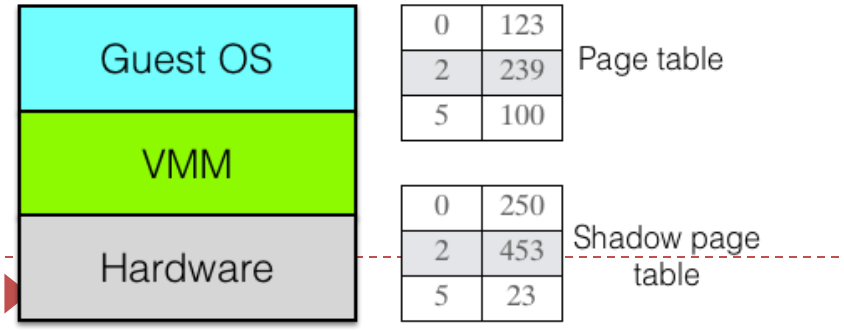
# Memory Virtualization

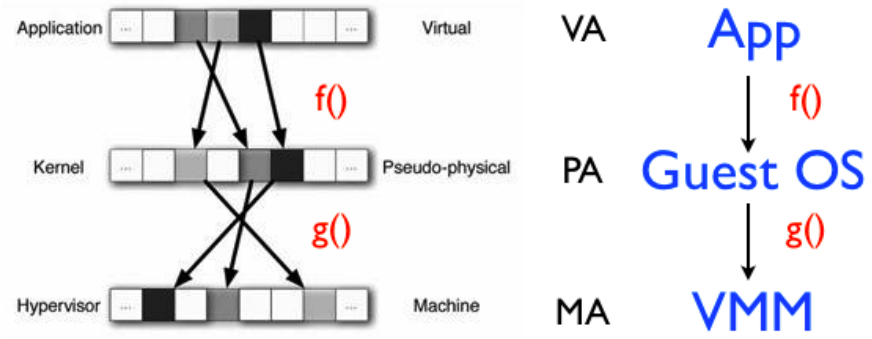
- Three memory addresses
  - virtual memory (process), physical memory (OS), machine memory (VMM)
  - VMM maintains a shadow mapping from VA to MA



# Software MMU

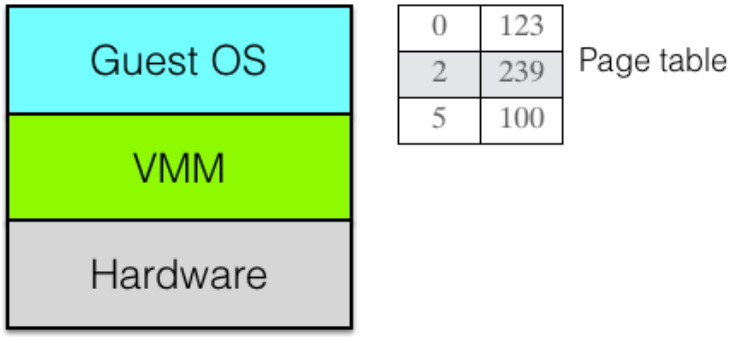
- High virtualization overhead with shadow page table
  - frequent guest OS to VMM transition and TLB flush
  - Xen's optimization
    - directly register guest PG to MMU
    - Read to PG bypass VMM
    - VMM traps updates to VMM
    - Batch updates
    - Reserve top 64MB for VMM to avoid TLB flush due to guest/VMM switch

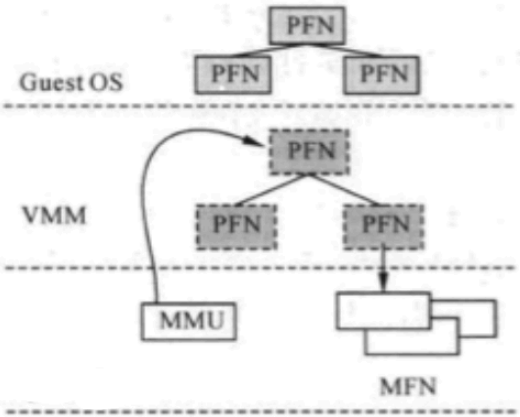


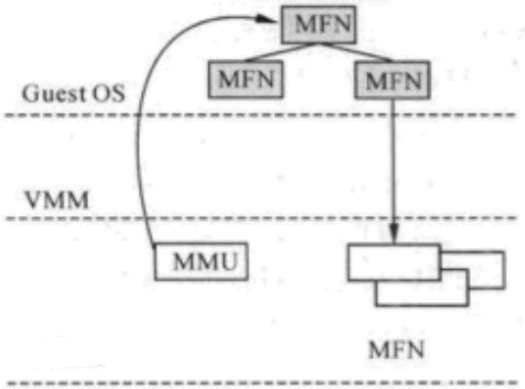
# Hardware assist MMU

- Extended/Nested page tables
  - Intel VT-x and AMD-V
  - no shadow page table is needed
  - Two hardware PGs
    - VA->PA and PA->MA
  - Tagged TLB entry
  - costly page walk



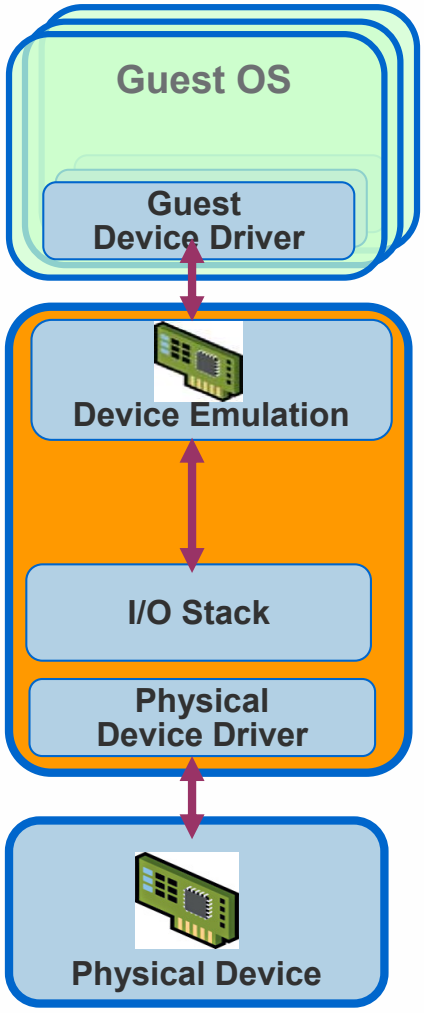

Shadow page table



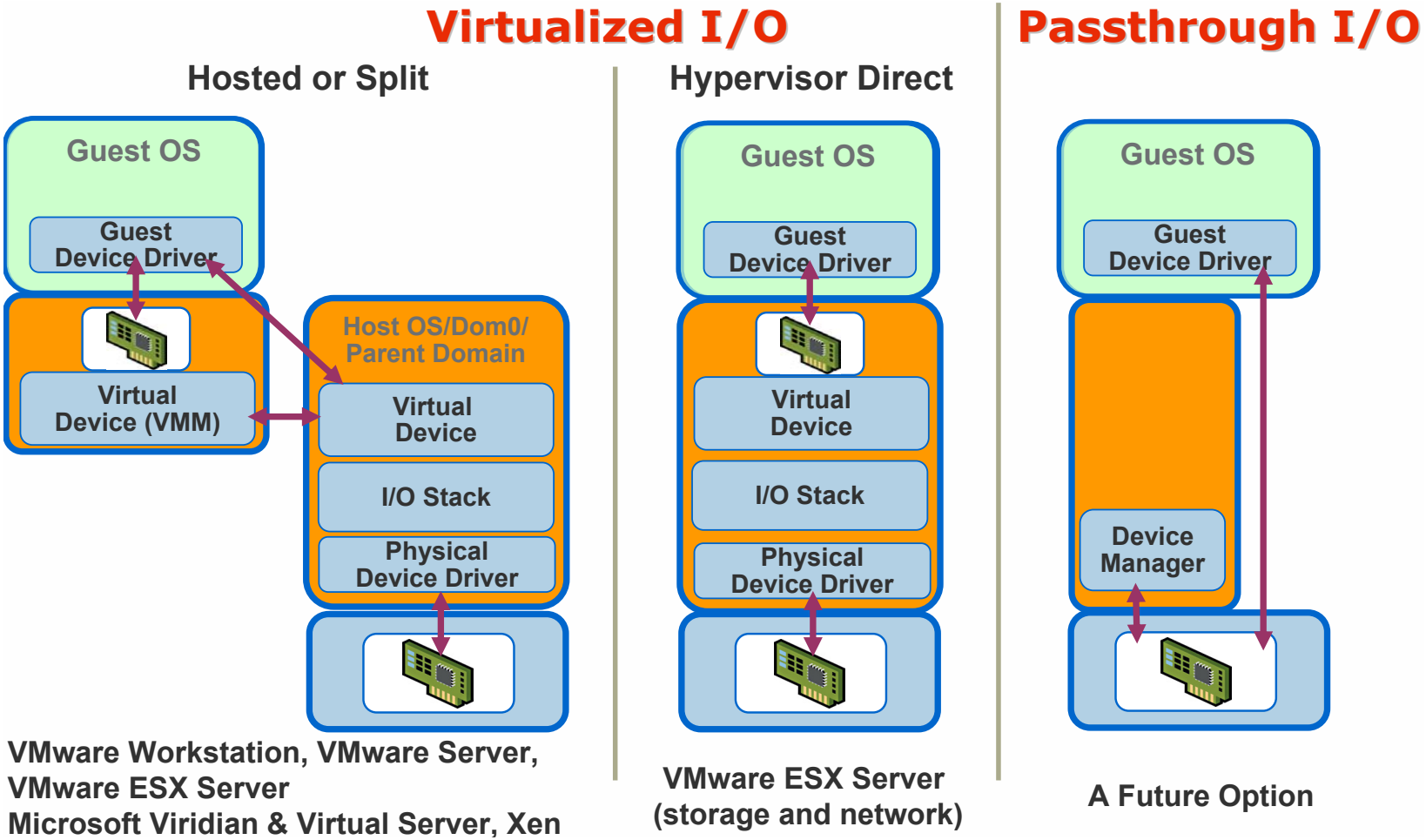

Non-Shadow page table

# I/O Virtualization

- I/O virtualization architecture
  - guest driver
  - generic virtual device, e.g., Intel e1000
  - virtualization I/O stack
  - real device driver
  - hardware device

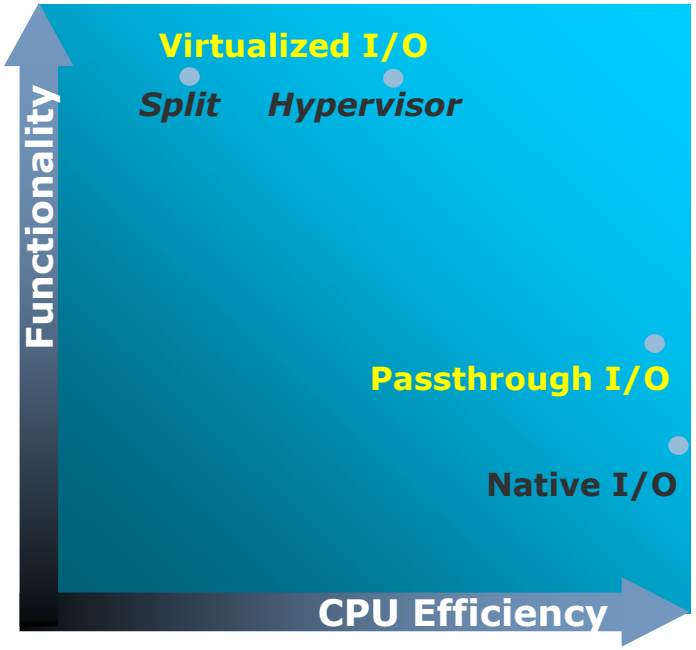


# I/O Virtualization Implementations



# I/O Virtualization Trade-offs

- Virtualized I/O provides rich functionality
- Passthrough I/O reduces CPU utilization and better performance

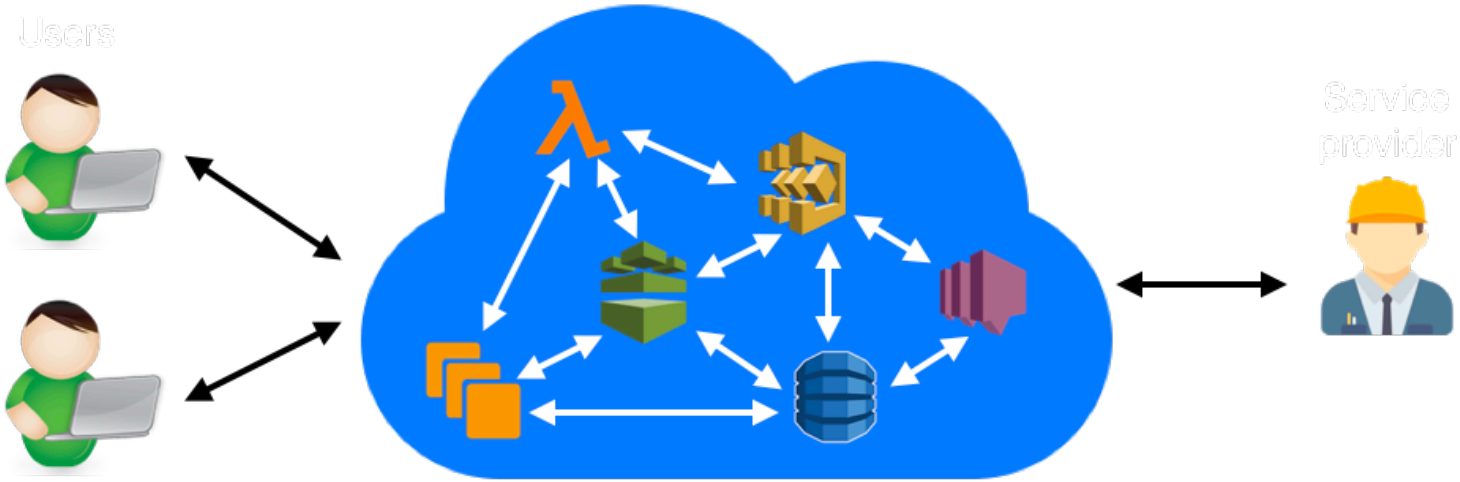


# The Rise of Cloud Computing


The rise of the cloud is more than just another platform shift that gets geeks excited. It will undoubtedly transform the information technology (IT) industry, but it will also profoundly change the way people work and companies operate.

—— A survey of corporate IT – Let it rise
By the Economist
Oct 23rd 2008

# The Benefits of Clouds




Easy to use
High performance
Stable user experience
Automatic software updates
…

Easy to manage
High resource utilization
Low operation cost
Energy efficiency
…

# Virtualization — the Rock of Cloud Computing

App

Library

Container

VM

Hardware

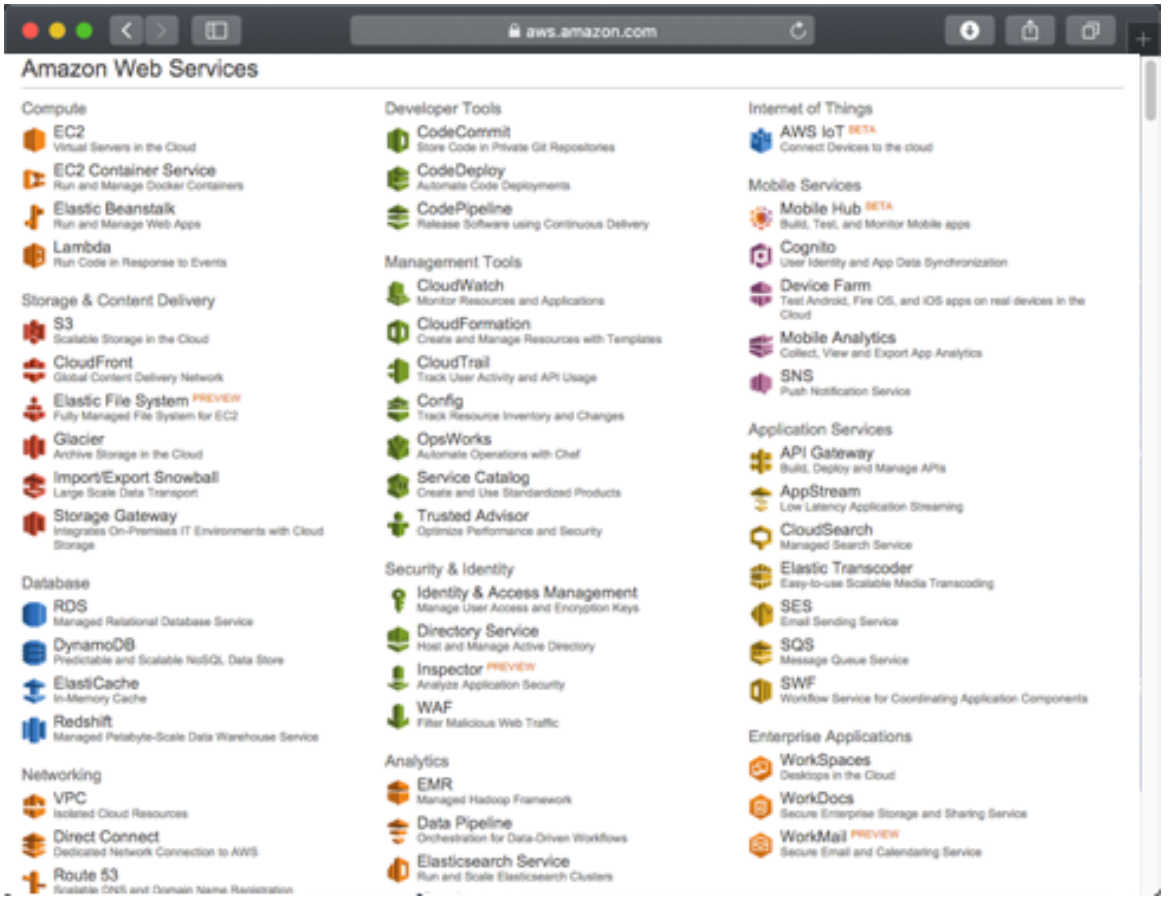
| Level | Example | Performance | Complexity | Isolation |
|---|---|---|---|---|
| Application level | JVM, .Net | xx | xxxxx | xxxxx |
| Library level | WINE, vCUDA | xxx | xx | xx |
| OS level | Docker, LXC | xxxxx | xxx | xx |
| Hardware level | Vmware, Xen, KVM | xxxxx | xxxxx | xxxx |
| Instruction level | QEMU, Bochs | x | xxx | xxx |

# More services on the cloud

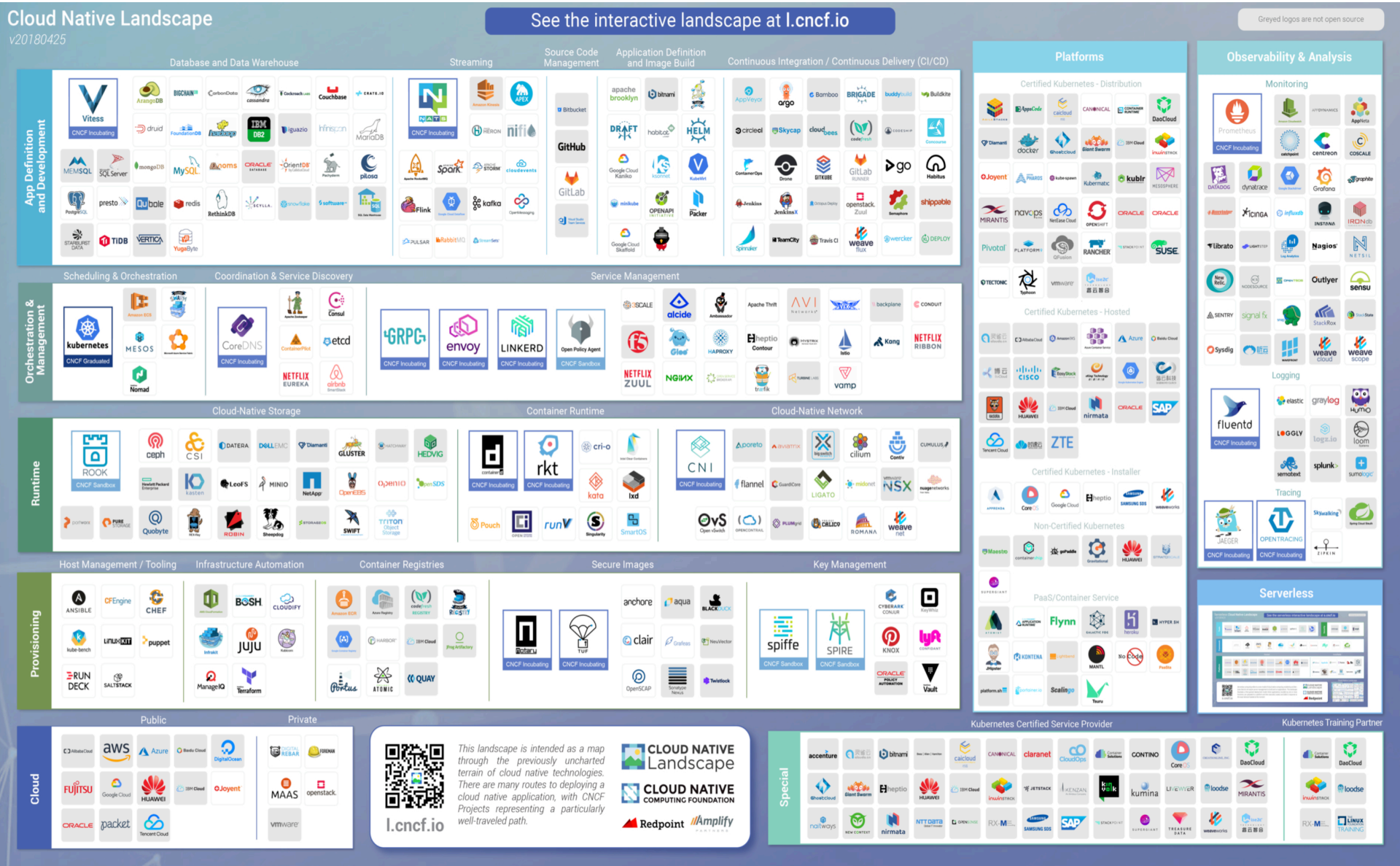
2006

Now: 3149 New & Existing Services

1st AWS Service
S3



# Current cloud ecosystem



# Conclusion

- Disk scheduling algorithm
- Time in OS and Networking
- Power management in OS
- Virtualization and cloud