PERSISTENCE: RAID

Shivaram Venkataraman

CS 537, Spring 2020

ADMINISTRIVIA

Midterm grades

Project 4a: Spec updates, test cases

Project 4a: New due date April 3rd

AGENDA / LEARNING OUTCOMES

Why do we need more than one disk in a system?

How do we achieve resilience against disk errors?

RECAP

SEEK, ROTATE, TRANSFER

Seek cost: Function of cylinder distance

- Not purely linear cost
- Must accelerate, coast, decelerate, settle
- Settling alone can take 0.5 - 2 ms

Entire seeks often takes 4 - 10 ms

Average seek = 1/3 of max seek

Depends on rotations per minute (RPM)

- 7200 RPM is common, 15000 RPM is high end

Average rotation – half of a rotation

Pretty fast: depends on RPM and sector density.

100+ MB/s is typical for maximum transfer rate

I/O SCHEDULERS

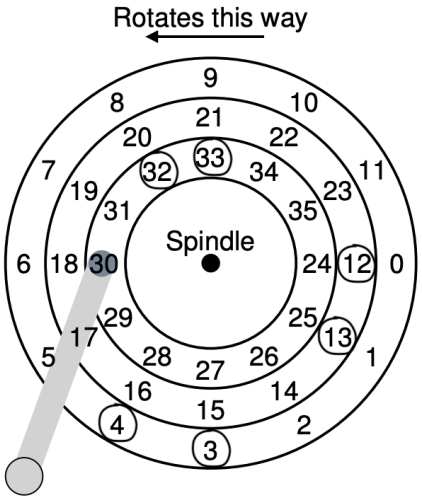
Given a stream of I/O requests, in what order should they be served?

Much different than CPU scheduling

Position of disk head relative to request position matters more than length of job

QUIZ 22

https://tinyurl.com/cs537-sp20-quiz22



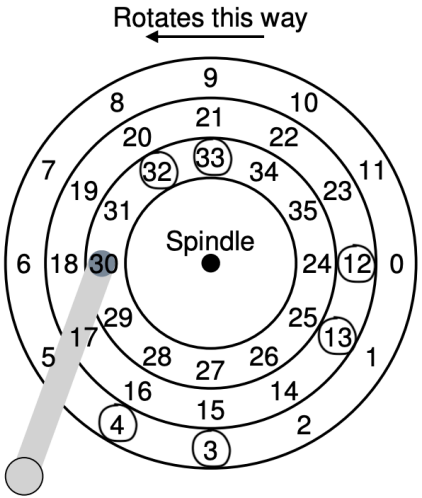
Disk accesses: 32, 12, 33, 3, 13, 4
Rotation Time = 2ms (non-adjacent reads)
Seek Time (for adjacent track) = 2ms.

What is the time taken to using (FCFS) scheduling?

Order in which requests will be serviced for Shortest Seek Time First (SSTF)?

QUIZ 22

https://tinyurl.com/cs537-sp20-quiz22

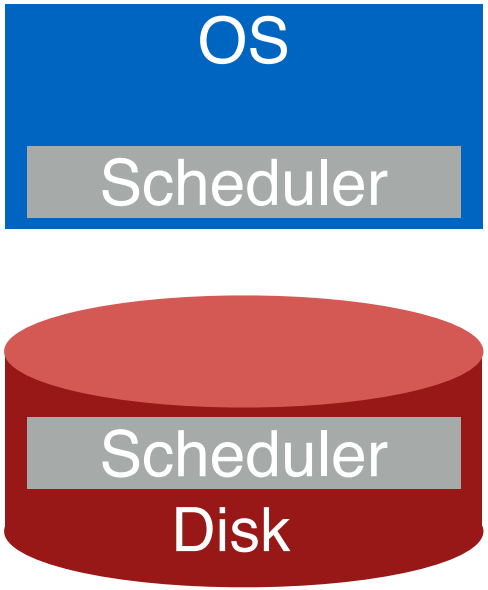


Disk accesses: 32, 12, 33, 3, 13, 4
Rotation Time = 2ms (non-adjacent reads)
Seek Time (for adjacent track) = 2ms.

Order in which requests will be serviced for Shortest Seek Time First (SSTF)?

Time Taken

SCHEDULERS



Where should the scheduler go?

WHAT HAPPENS?

Assume 2 processes each calling read() with C-SCAN

```
void reader(int fd) {
    char buf[1024];
    int rv;
    while((rv = read(fd, buf)) != 0) {
        assert(rv);
        // takes short time, e.g., 1ms
        process(buf, rv);
    }
}
```

WORK CONSERVATION

Work conserving schedulers always try to do work if there's work to be done

Sometimes, it's better to wait instead if system anticipates another request will arrive

Possible improvements from I/O Merging

DISKS SUMMARY

Disks: Specific geometry with platters, spindle, tracks, sectors

I/O Time: rotation_time + seek_time + transfer_time

Sequential throughput vs. random throughput

Advanced Techniques: Skewed layout, caching

Scheduling approaches: SSTF, SCAN, C-SCAN
Benefits of violating work conservation

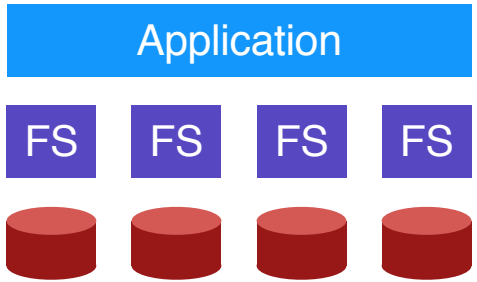
ONLY ONE DISK?

Sometimes we want many disks — why?

- capacity
- reliability
- performance

Challenge: most file systems work on only one disk

SOLUTION 1: JBOD

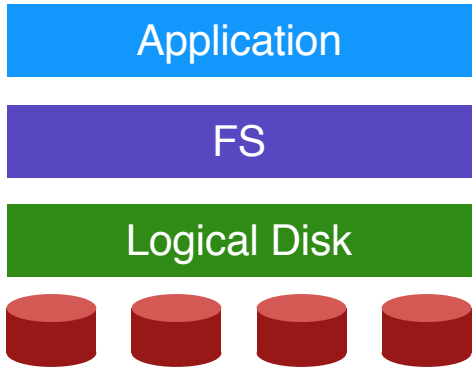


Application is smart, stores different files on different file systems.

JBOD: **J**ust a **B**unch **O**f **D**isks

SOLUTION 2: RAID

Build logical disk from many physical disks.



Logical disk gives

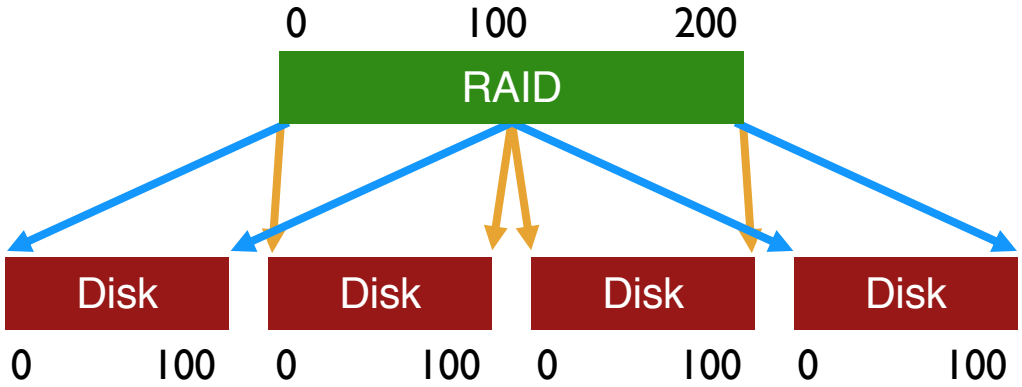
capacity,

performance,

reliability

RAID: **R**edundant **A**rray of **I**nexpensive **D**isks

GENERAL STRATEGY: MAPPING, REDUNDANCY



MAPPING

How should we map logical block addresses to physical block addresses?

1) **Dynamic** mapping: use data structure (hash table, tree)

2) **Static** mapping: use simple math

WORKLOADS

- Reads
  - One operation
  - Steady-state I/O
    - Sequential
    - Random
- Writes
  - One operation
  - Steady-state I/O
    - Sequential
    - Random

METRICS

Capacity: how much space can apps use?

Reliability: how many disks can we safely lose? (assume fail stop)

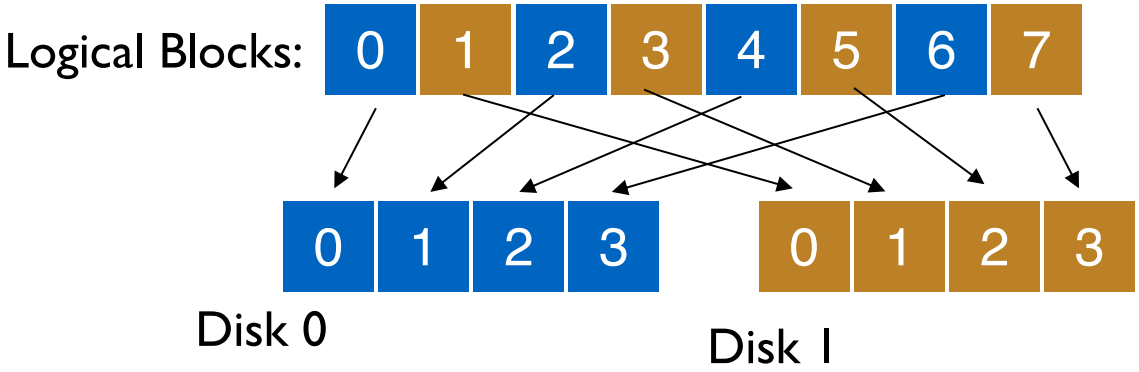
Performance: how long does each workload take? (latency, throughput)

Normalize each to characteristics of one disk

Different **RAID levels** make different trade-offs

RAID-0: STRIPING

Optimize for capacity. No redundancy



Disk 0 Disk 1

RAID 0: STRIPES AND CHUNK SIZE

Chunk size = 1

stripe:

Disk 0	Disk 1	Disk 2	Disk 4
0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

assume chunk size of 1 for this lecture

Chunk size = 2

Disk 0	Disk 1	Disk 2	Disk 4
0 1	2 3	4 5	6 7
8 9	10 11	12 13	14 15

RAID-0: ANALYSIS

What is capacity?

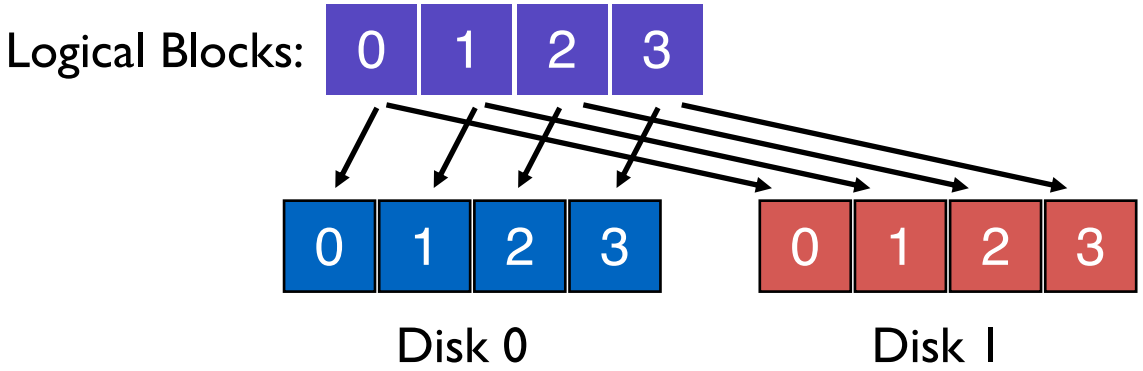
How many disks can we safely lose?

Latency (random)

Throughput (sequential, random)?

N := number of disks
C := capacity of 1 disk
S := sequential throughput of 1 disk
R := random throughput of 1 disk
D := latency of one small I/O operation

RAID-1: MIRRORING



Keep two copies of all data.

RAID-1 LAYOUT: MIRRORING

2 disks

Disk 0	Disk 1
0	0
1	1
2	2
3	3

4 disks

Disk 0	Disk 1	Disk 2	Disk 4
0	0	1	1
2	2	3	3
4	4	5	5
6	6	7	7

RAID-1: ANALYSIS

What is capacity?

How many disks can fail?

Latency (read, write)?

N := number of disks
C := capacity of 1 disk
S := sequential throughput of 1 disk
R := random throughput of 1 disk
D := latency of one small I/O operation

Disk 0	Disk 1
0	0
1	1
2	2
3	3

RAID-1: THROUGHPUT

What is steady-state throughput for

- random reads?

- random writes?

- sequential writes?

- sequential reads?

QUIZ 23

https://tinyurl.com/cs537-sp20-quiz23

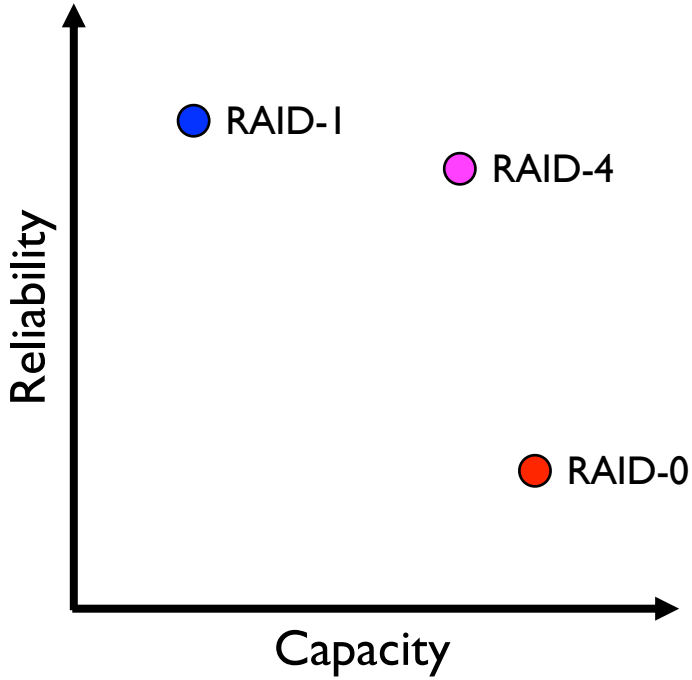
Disk characteristics: Average seek time = 7ms,
Average rotational time = 3ms, transfer rate = 50 MB/s

Sequential transfer of 10MB

Random transfer of 10KB

RAID0, Random Writes

RAID1, Random Writes


RAID-1
RAID-4
RAID-0
Reliability
Capacity

RAID-4 STRATEGY

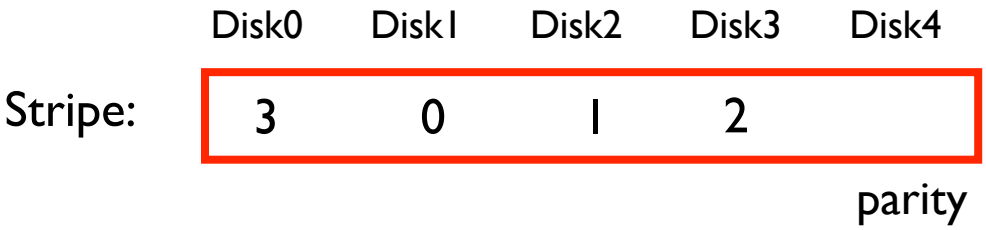
Use **parity** disk

If an equation has N variables, and N-1 are known,
you can solve for the unknown.

Treat sectors across disks in a stripe as an equation.

Data on bad disk is like an unknown in the equation.

RAID 4: EXAMPLE



What functions can we use to compute parity?

RAID-4: ANALYSIS

What is capacity?

How many disks can fail?

Latency (read, write)?

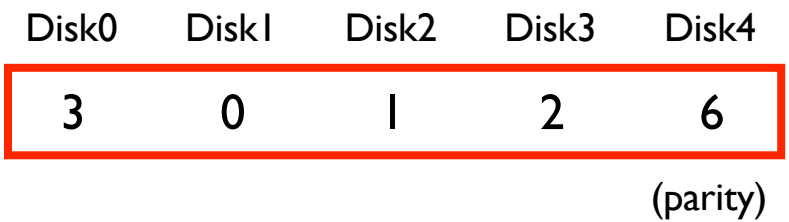
Disk0	Disk1	Disk2	Disk3	Disk4 parity
1	0	1	1	1
0	1	1	0	0
1	1	0	1	1

N := number of disks
C := capacity of 1 disk
S := sequential throughput of 1 disk
R := random throughput of 1 disk
D := latency of one small I/O operation

RAID-4: THROUGHPUT

What is steady-state throughput for

- sequential reads?
- sequential writes?
- random reads?
- random writes? (next page!)



RAID-4: ADDITIVE VS SUBTRACTIVE

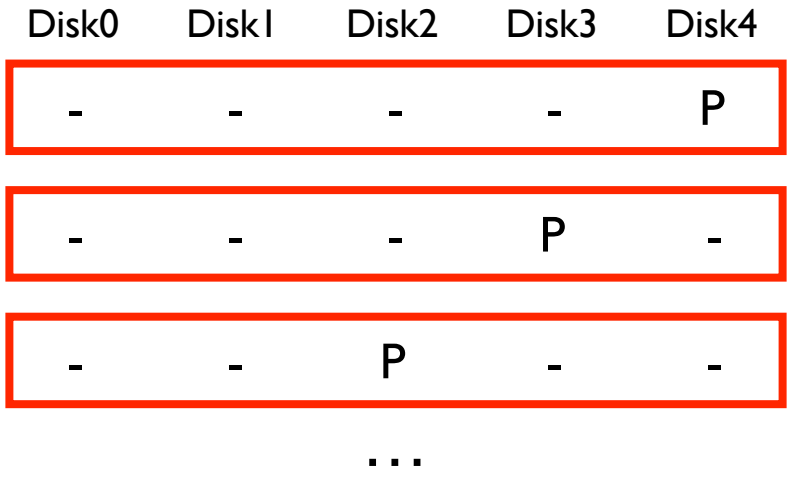
C0	C1	C2	C3	P0
0	0	1	1	XOR(0,0,1,1)

Additive Parity

Subtractive Parity

$$P_{new} = (C_{old} \oplus C_{new}) \oplus P_{old}$$

RAID-5



Rotate parity across different disks

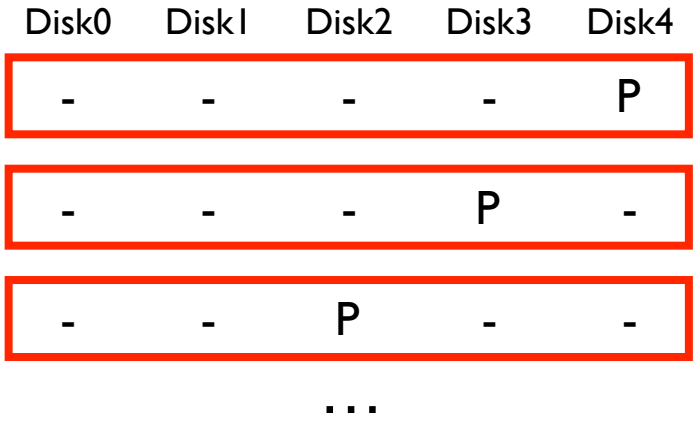
RAID-5: ANALYSIS

What is capacity?

How many disks can fail?

Latency (read, write)?

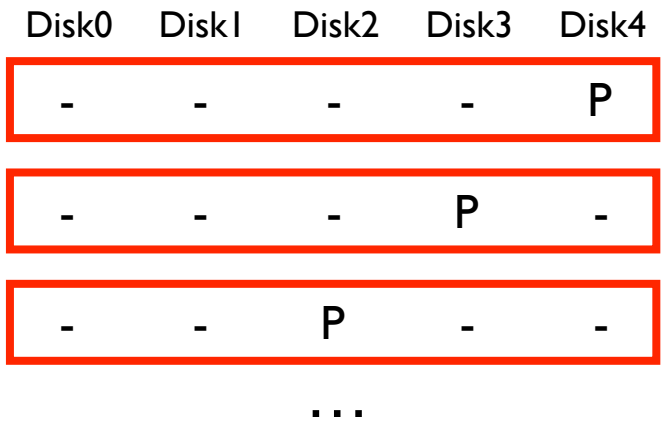
N := number of disks
C := capacity of 1 disk
S := sequential throughput of 1 disk
R := random throughput of 1 disk
D := latency of one small I/O operation



RAID-5: THROUGHPUT

What is steady-state throughput for RAID-5?

- sequential reads?
- sequential writes?
- random reads?
- random writes? (next page!)



RAID-5 RANDOM WRITES

Disk 0	Disk 1	Disk 2	Disk 3	Disk 4
0	1	2	3	P0
5	6	7	P1	4
10	11	P2	8	9
15	P3	12	13	14
P4	16	17	18	19

RAID LEVEL COMPARISONS

	Reliability	Capacity	Read latency	Write Latency	Seq Read	Seq Write	Rand Read	Rand Write
RAID-0	0	C*N	D	D	N * S	N * S	N * R	N * R
RAID-1	1	C*N/2	D	D	N/2 * S	N/2 * S	N * R	N/2 * R
RAID-4	1	(N-1) * C	D	2D	(N-1)*S	(N-1)*S	(N-1)*R	R/2
RAID-5	1	(N-1) * C	D	2D	(N-1)*S	(N-1)*S	N * R	N/4 * R

SUMMARY

RAID: a faster, larger, more reliable disk system

One logical disk built from many physical disk

Different mapping and redundancy schemes

Present different trade-offs

Next steps: Filesystems on Thu

P4a due on Friday!