Operating Systems

HDD + RAID

Nipun Batra

Device Protocol Variants

Status checks: polling *vs.* interrupts

Data: PIO *vs.* DMA

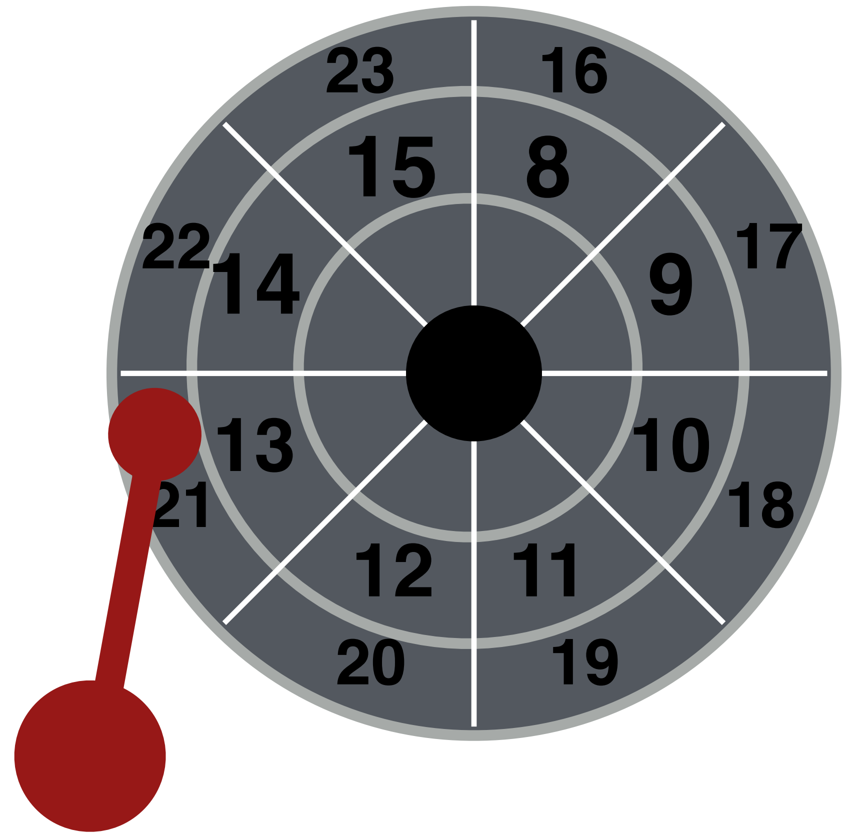
Control: special instructions *vs.* memory-mapped I/O

Disks

Doing an I/O requires:
- seek
- rotate
- transfer

What is expensive?

Track Skew



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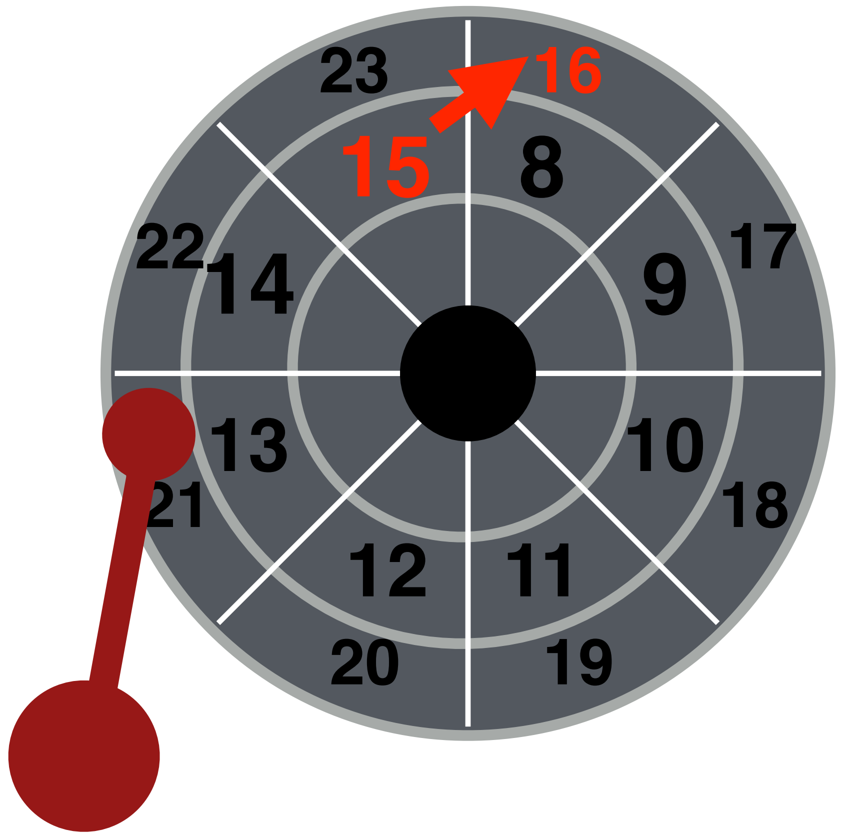
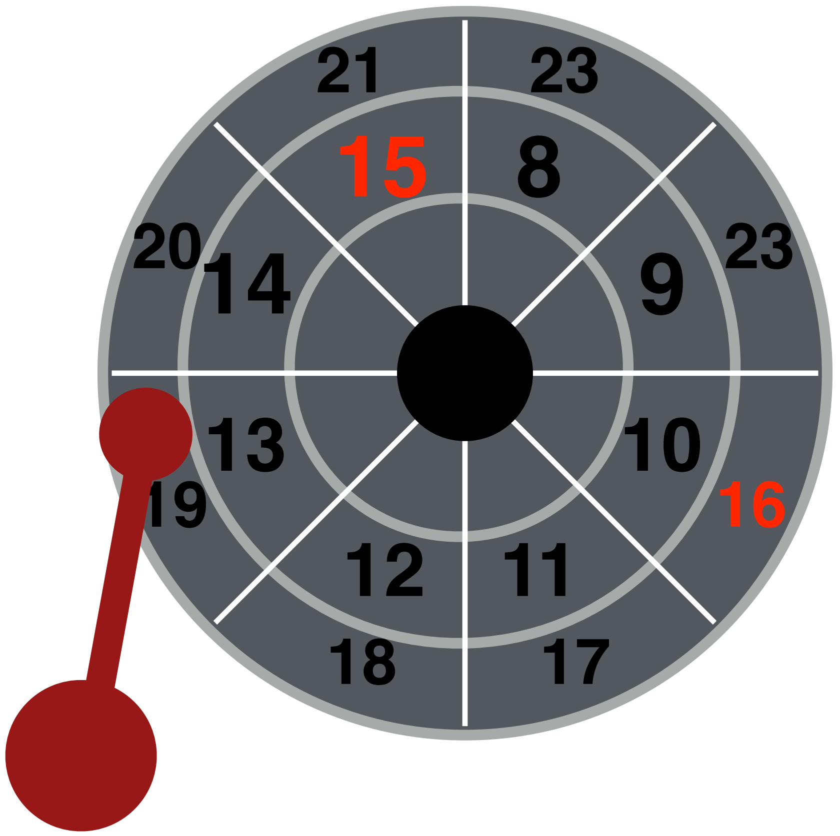


When reading 16 after 15, the head won’t settle quick enough, so we need to do a rotation.

Track Skew



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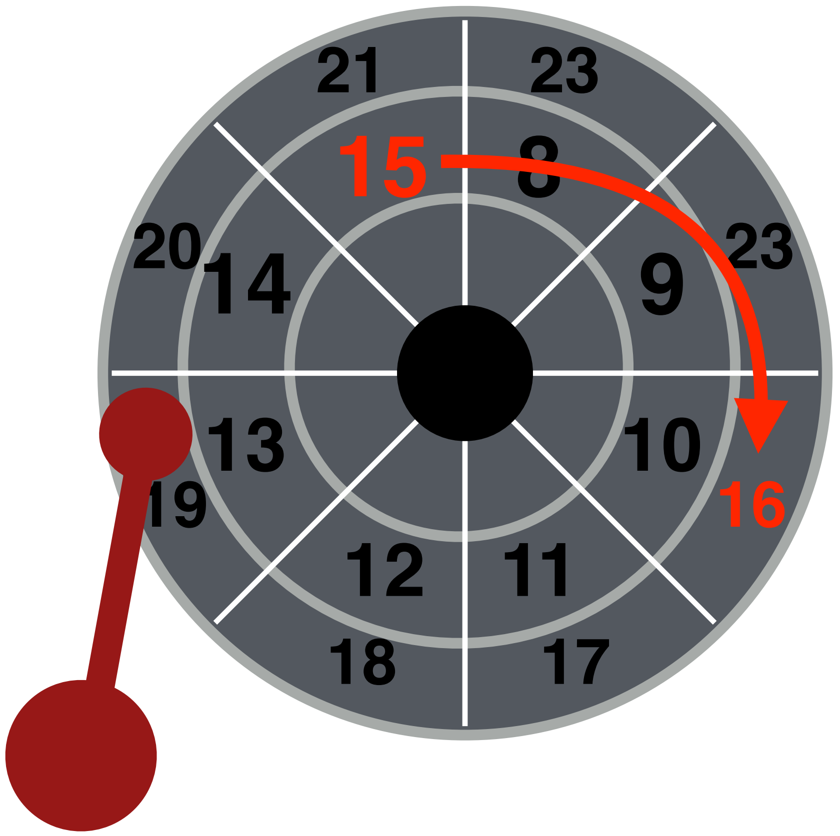


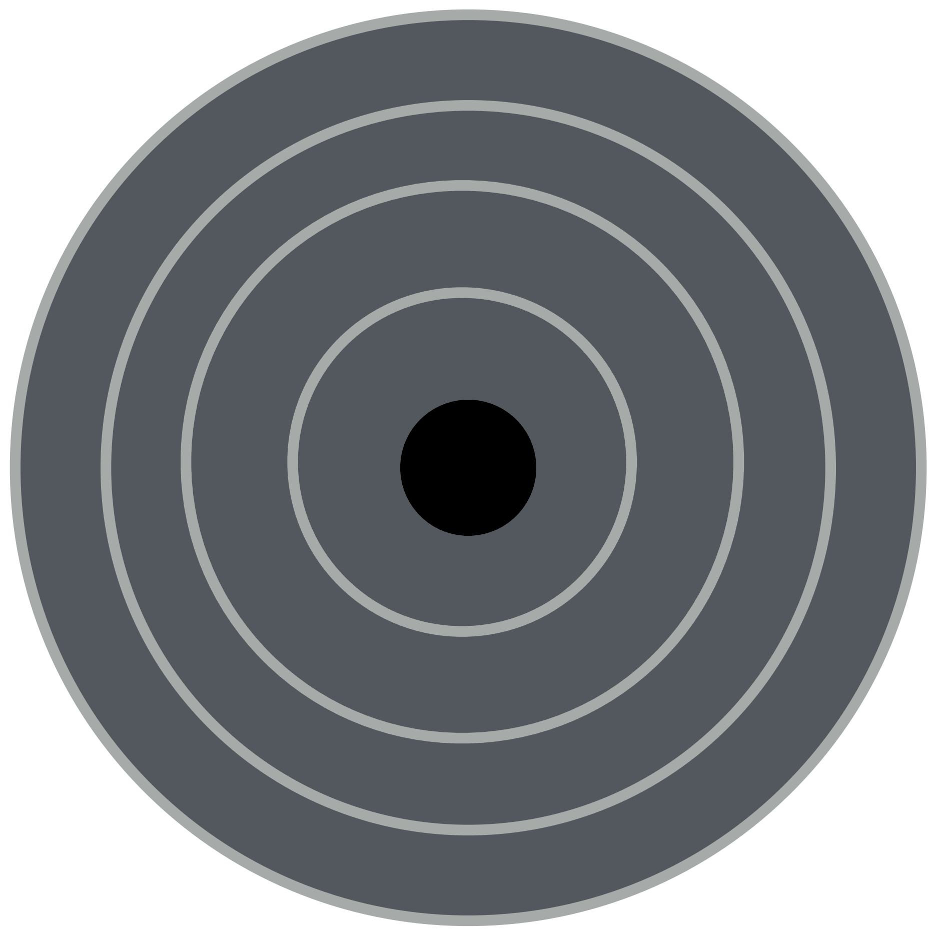
Other Improvements

Track Skew

Zones

Cache

Zones



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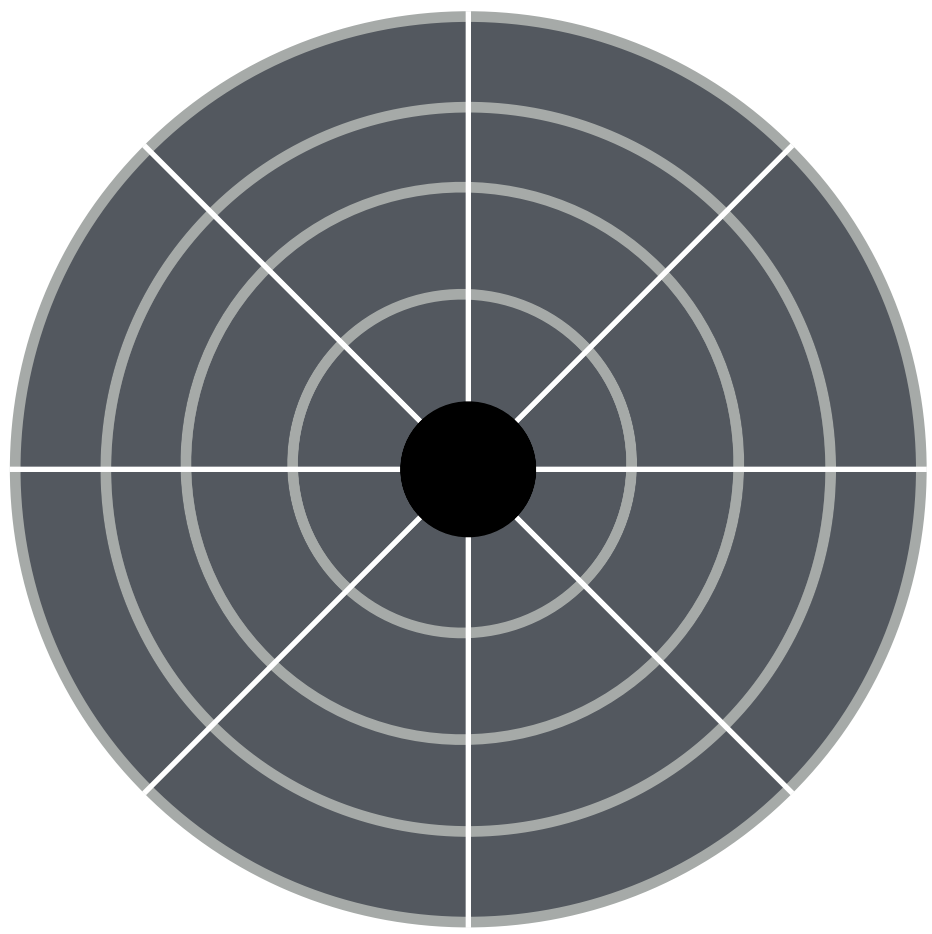

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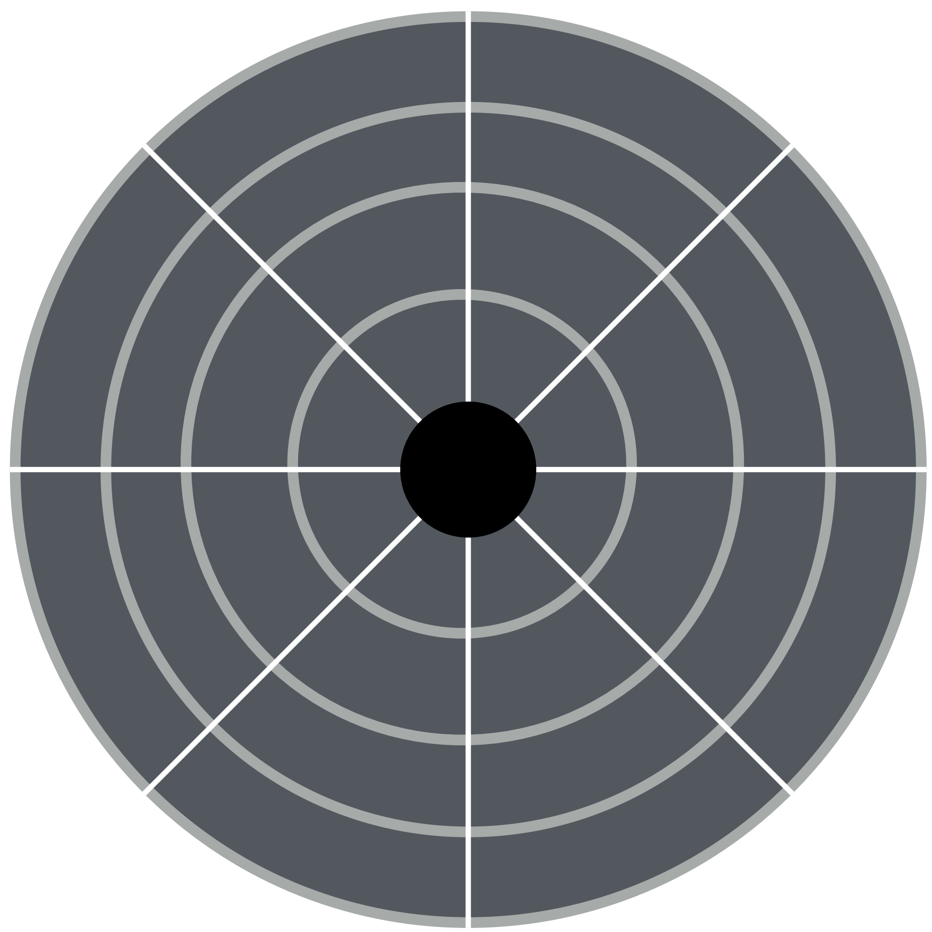
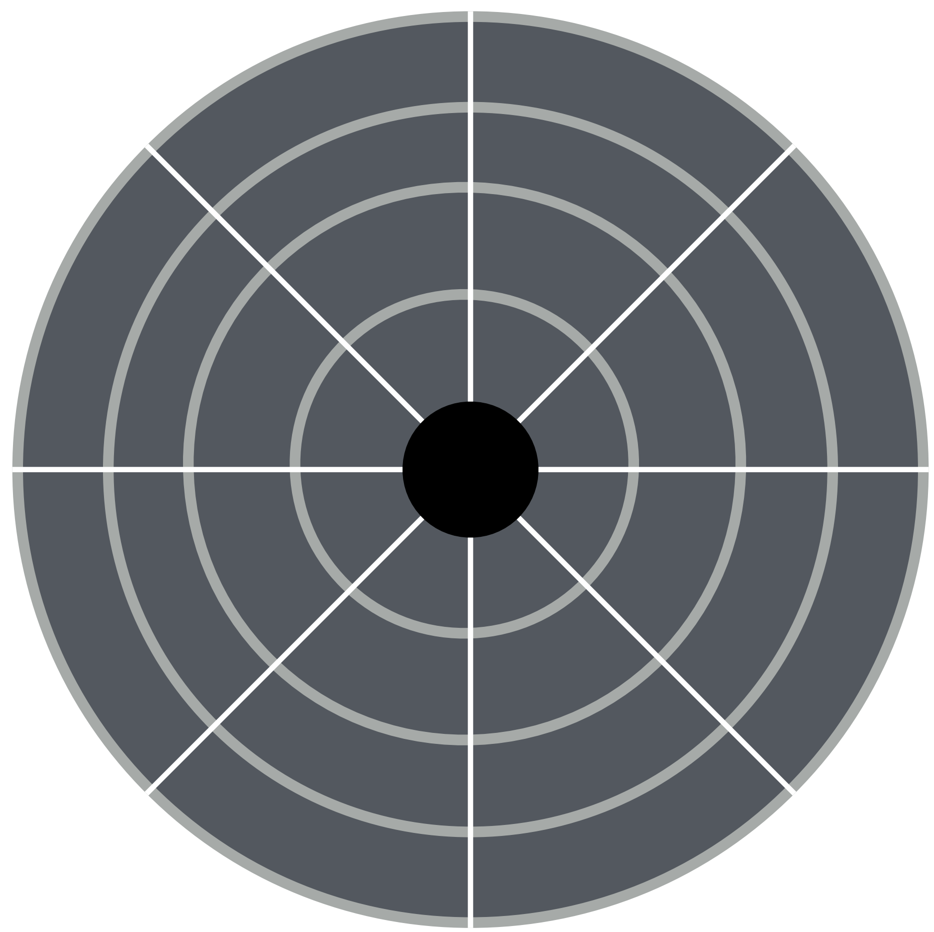


Should we have equal number of sectors for all tracks?

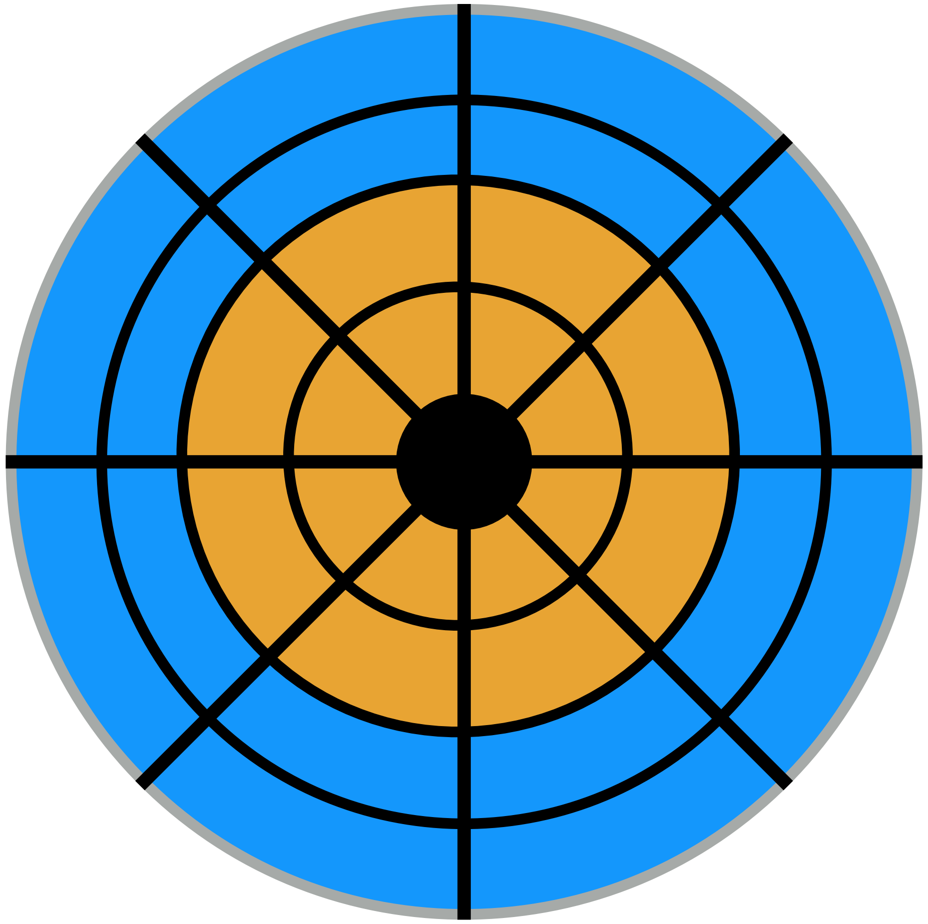
Zones



Should we have equal number of sectors for all tracks?

Sector density decreases with increasing radius?

Zones



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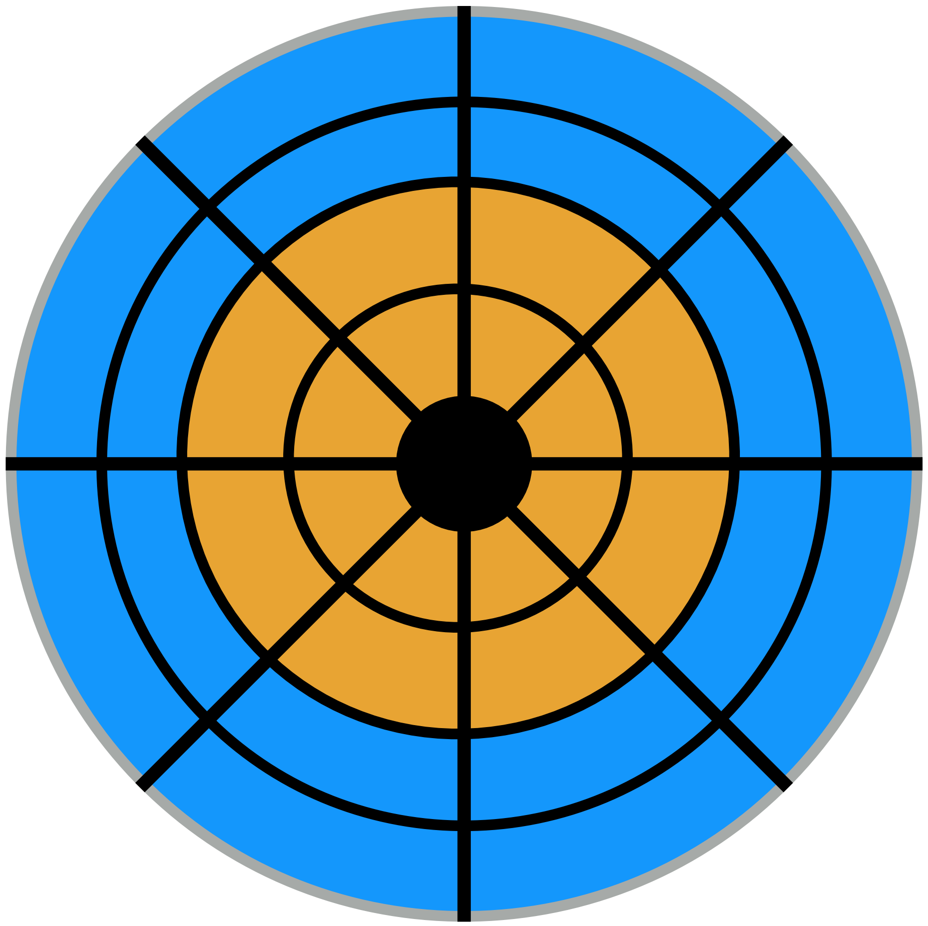

Divide disk into zones — all tracks in a zone have equal number of sectors

Other Improvements

Track Skew

Zones

Cache

Drive Cache

- Drives may cache both reads and writes.

- What advantage does drive have for reads?
  - Anticipate disk reads and put them into cache
  - Return data from cache directly

- What advantage does drive have for writes?
  - Put data in cache —> tell OS that write done (write back caching or immediate reporting)

Schedulers

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

FCFS (First-Come-First-Serve)

Assume seek+rotate = 10 ms on average.
Assume transfer = 100 MB/s.

How long (roughly) does the below workload take?
The integers are sector numbers.

300001, 700001, 300002, 700002, 300003, 700003

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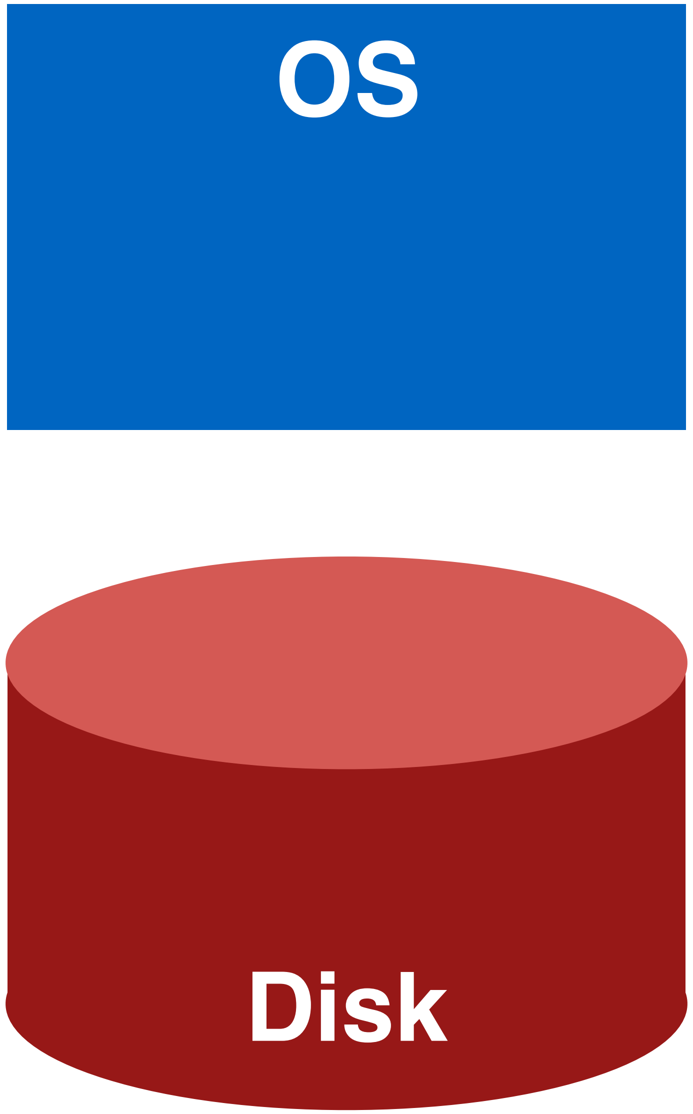
300001, 300002, 300003, 700001, 700002, 700003 (~20ms)

Schedulers



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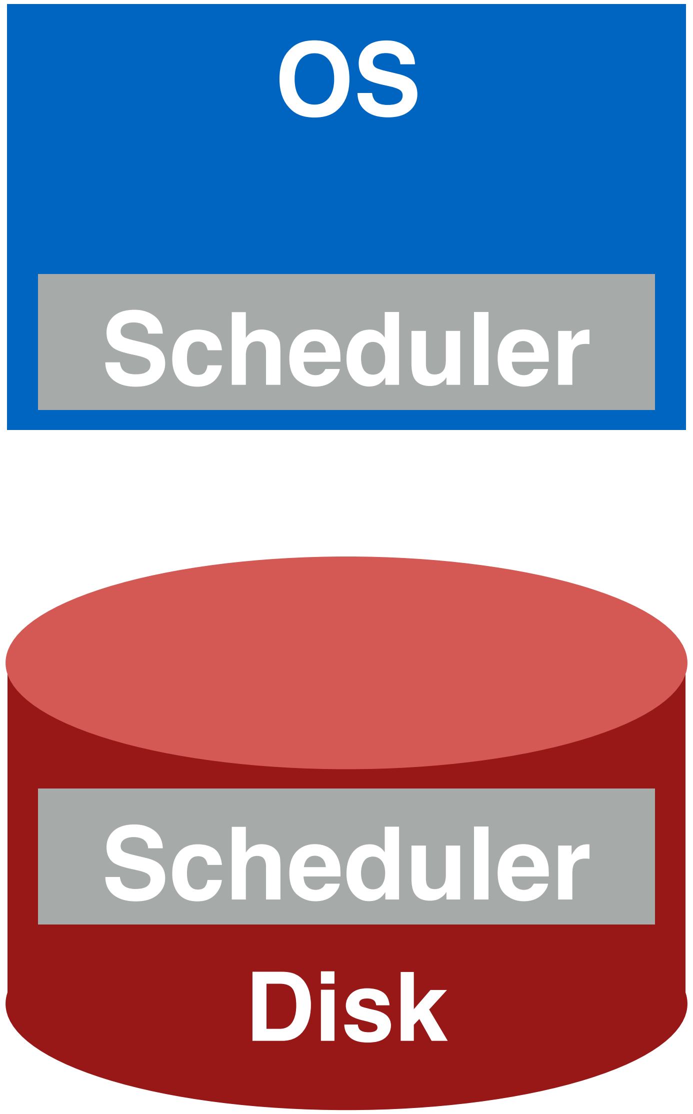

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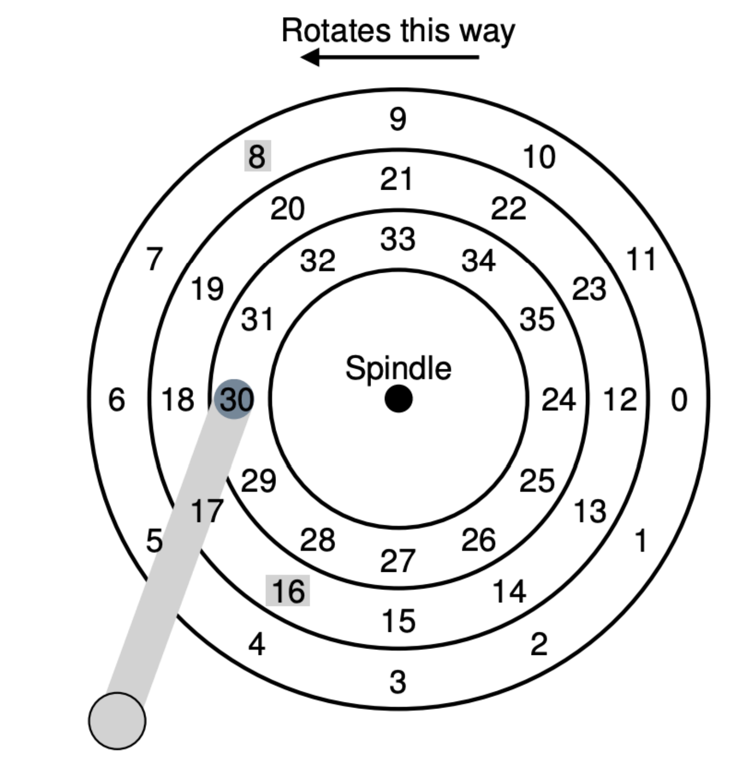

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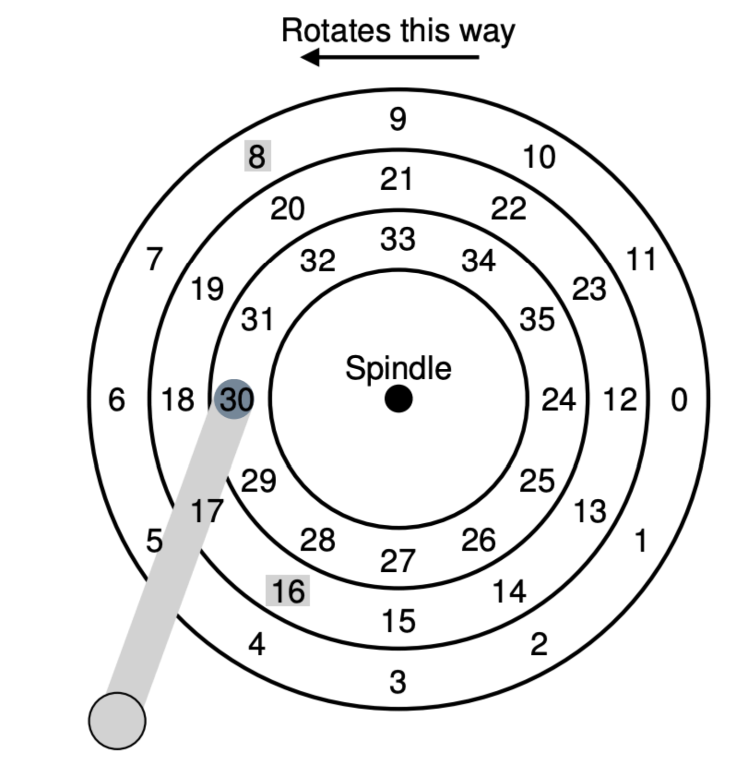

- Currently head is at 30, should next be 19 or 7?

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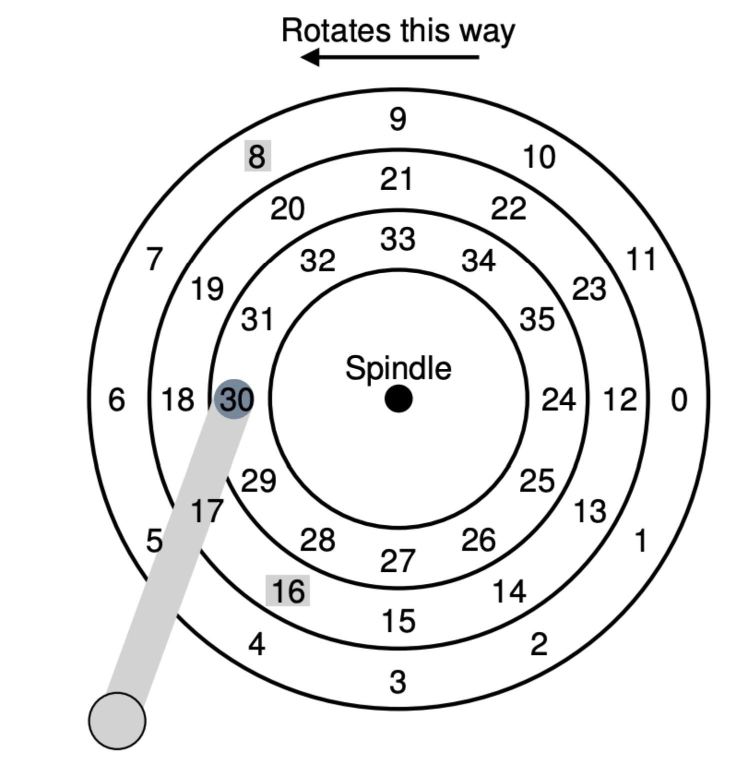

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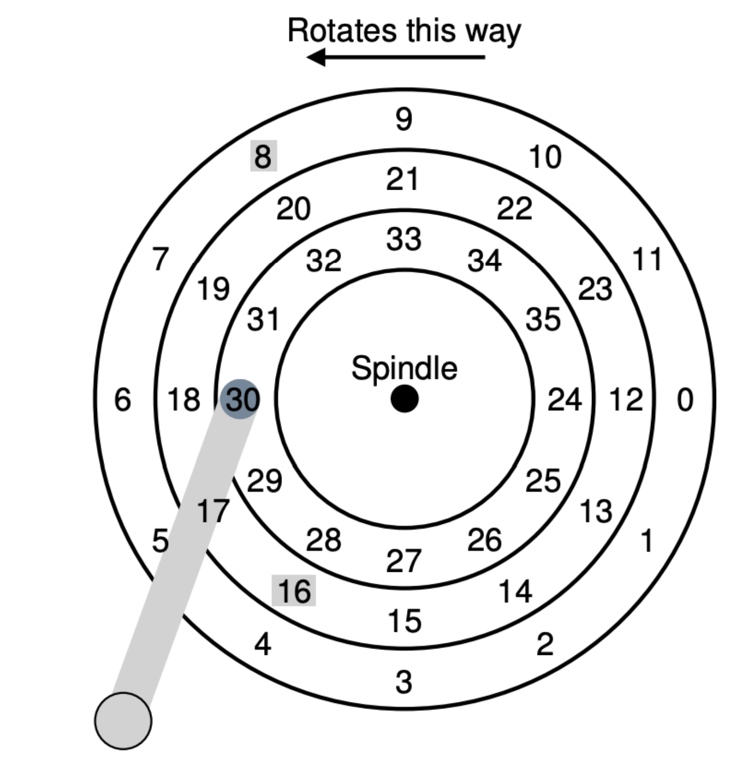

- Currently head is at 30, should next be 19 or 7?
- 19 would have lesser seek time
- Cons?
  - Starvation — if enough requests from close by sectors, then requests from far by sectors will be largely ignored

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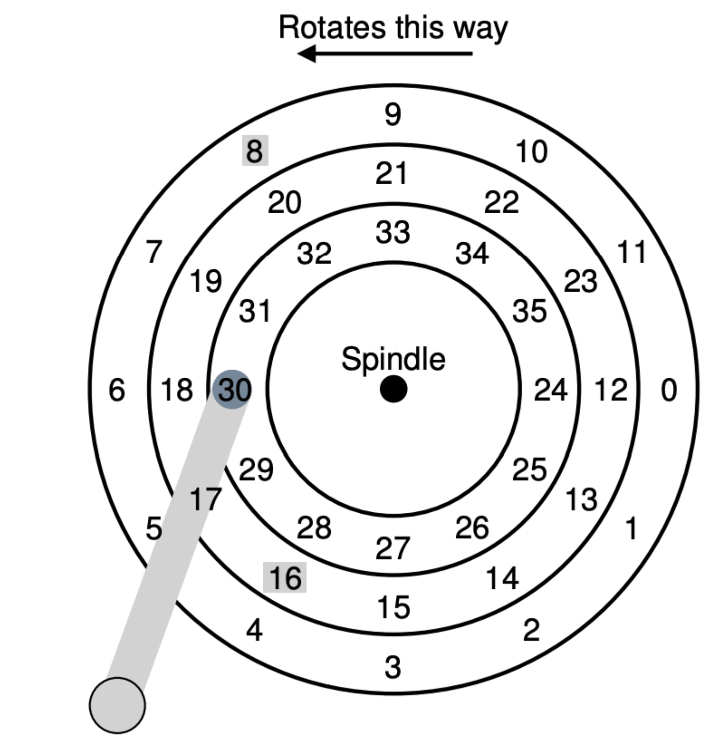

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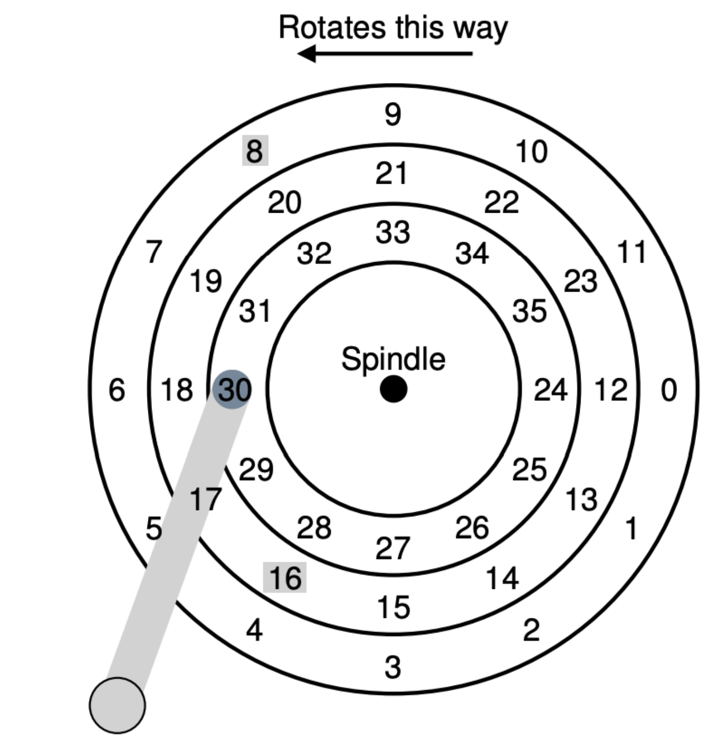

- What if currently head is at 30, next choice between 16 & 8

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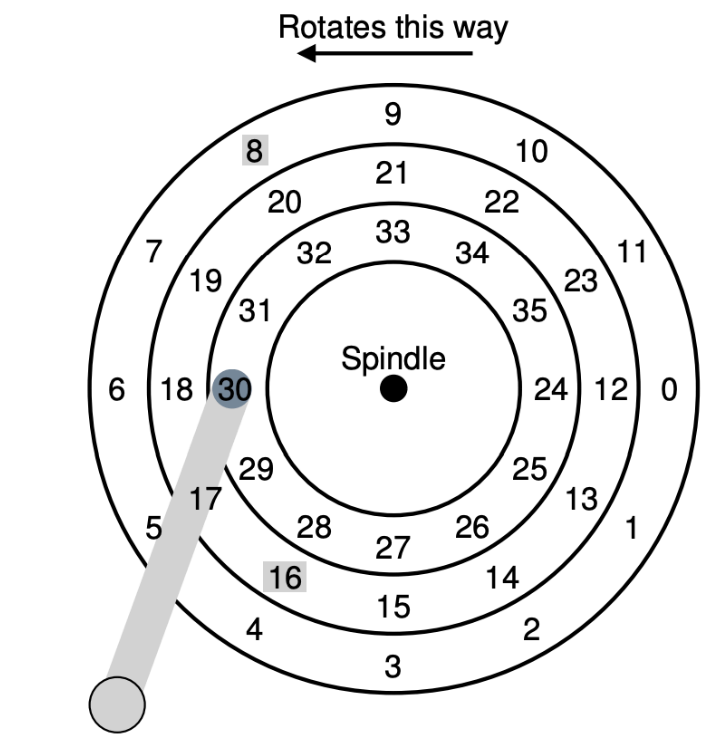


- What if currently head is at 30, next choice between 16 & 8
- 16 would have lesser seek time, but more rotation time. Maybe 8 is a better choice!
  - Called Shortest Positioning Time First

SCAN (or Elevator)

Sweep back and forth, from one end of disk to the other, serving requests as you go.

Pros/Cons?

SCAN

- Sweep back and forth, from one end of disk to the other, serving requests as you go.
- Pros
  - Doesn’t cause starvation
- Cons
  - Favours middle tracks more
- Better: C-SCAN (circular scan)
  - Only sweep in one direction
- Another variant F-Scan (Freeze scan)
  - Freeze the request queue when doing a sweep

Work Conservation

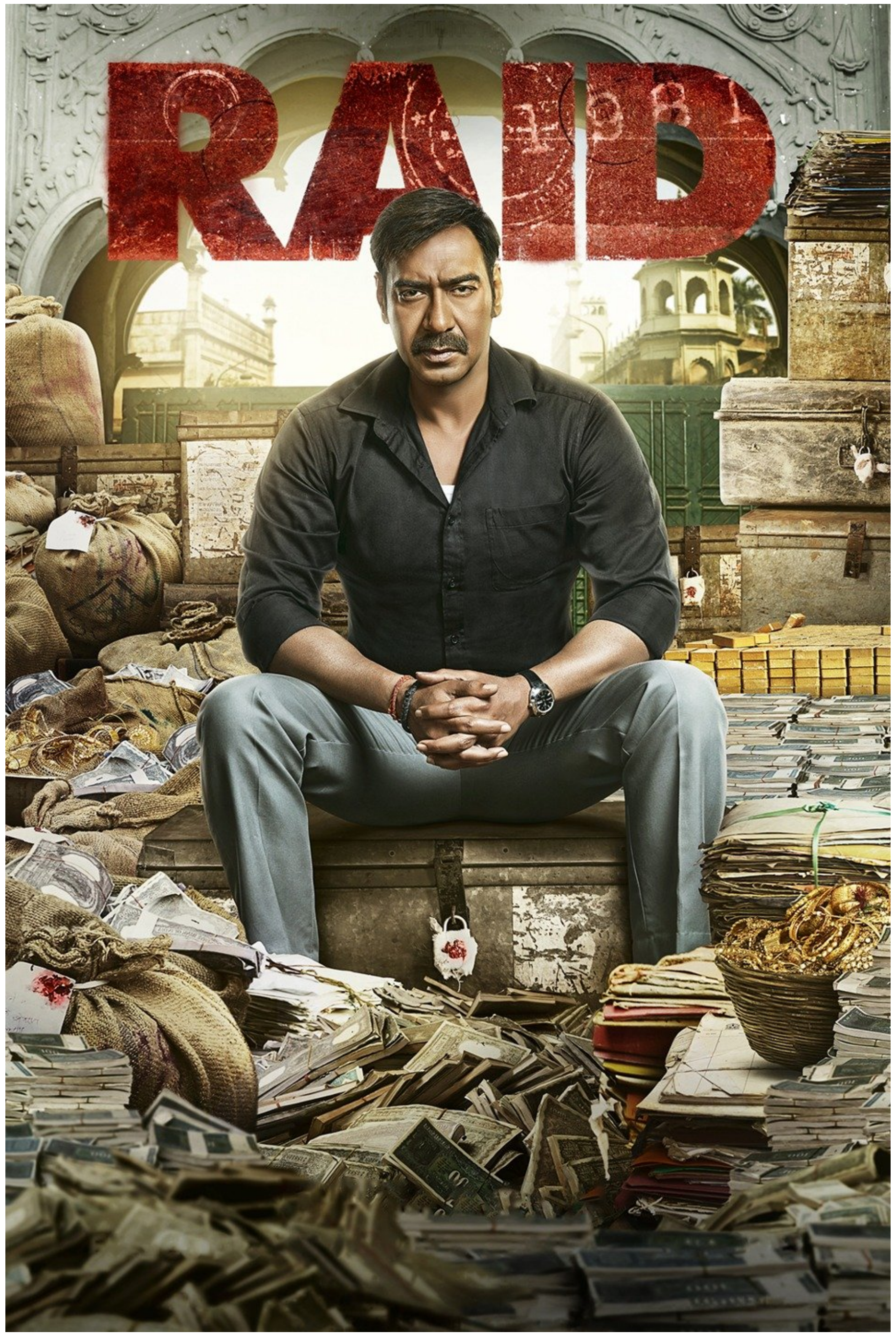
Work conserving schedulers always try to do I/O if there's I/O to be done.

Sometimes, it's better to wait instead if you anticipate another request will appear nearby.

Such non-work-conserving schedulers are called anticipatory schedulers.

RAID

RAID



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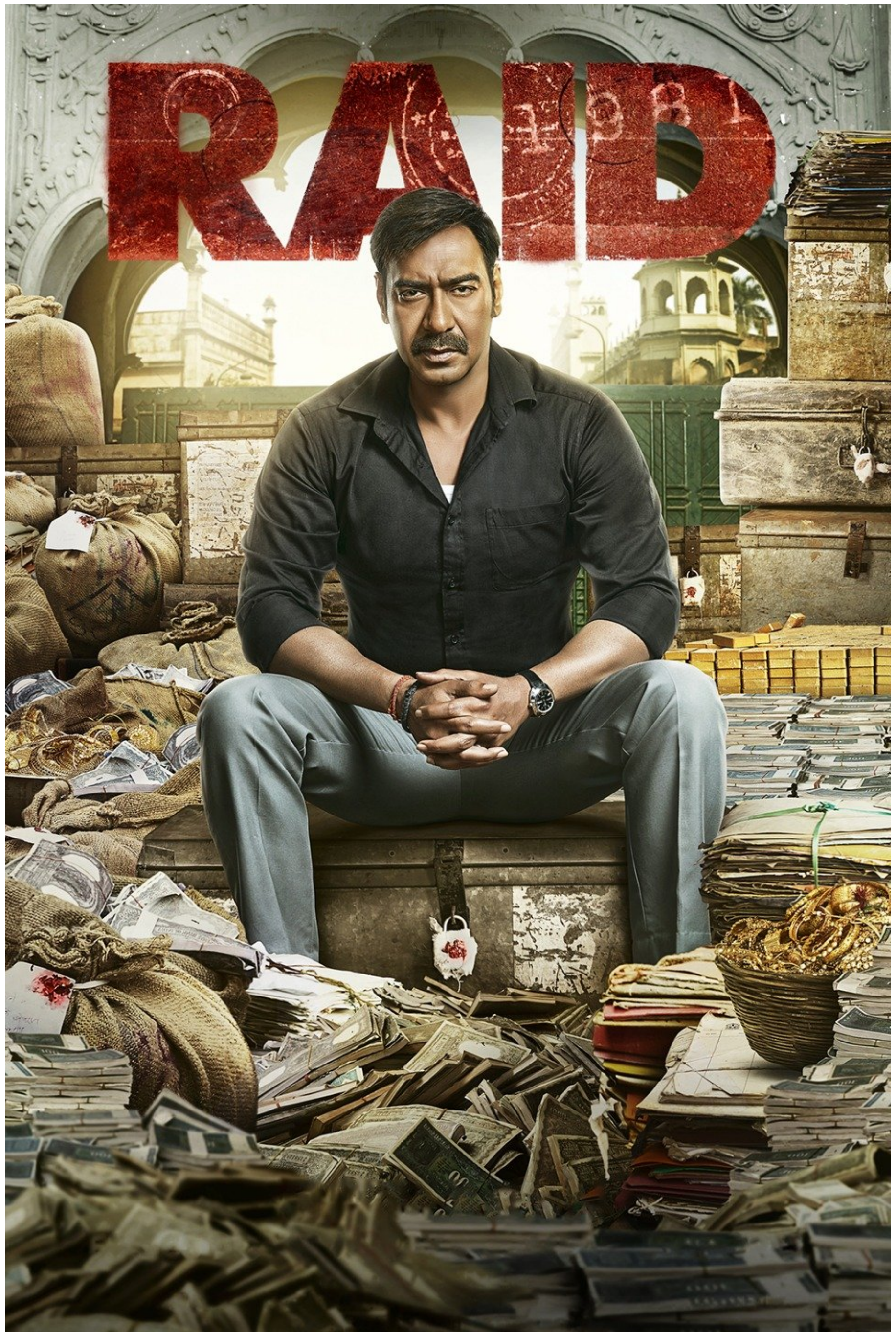
RAID


20oz VALUE SIZE
SC Johnson
A Family Company
Raid
Ant & Roach
KILLS ON CONTACT
MATA AL CONTACTO
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MANTENER FUERA DEL ALCANCE DE LOS NIÑOS
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567g

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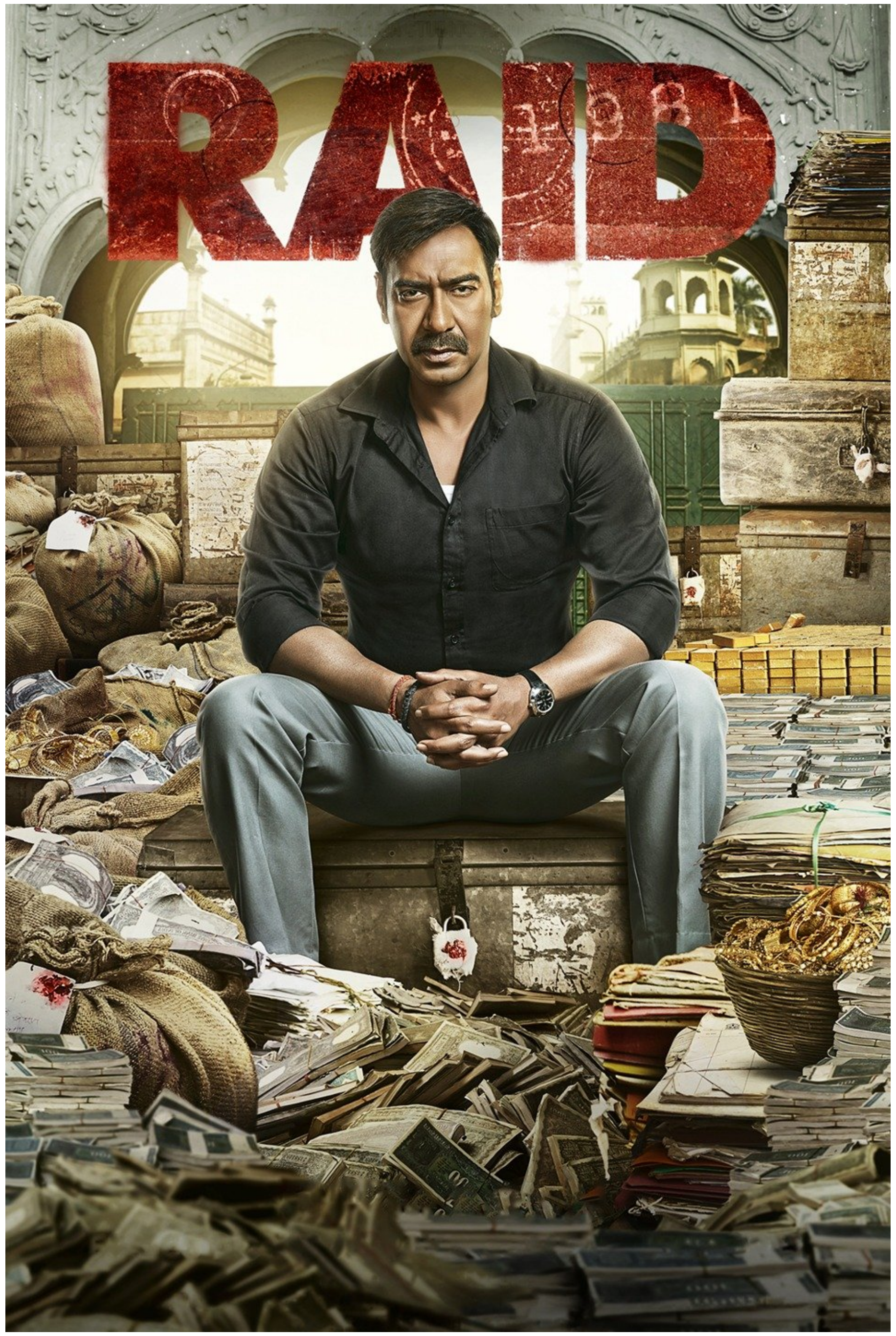
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RocketStor

Only One Disk?

Sometimes we want many disks — why?

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- capacity

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Sometimes we want many disks — why?
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- reliability

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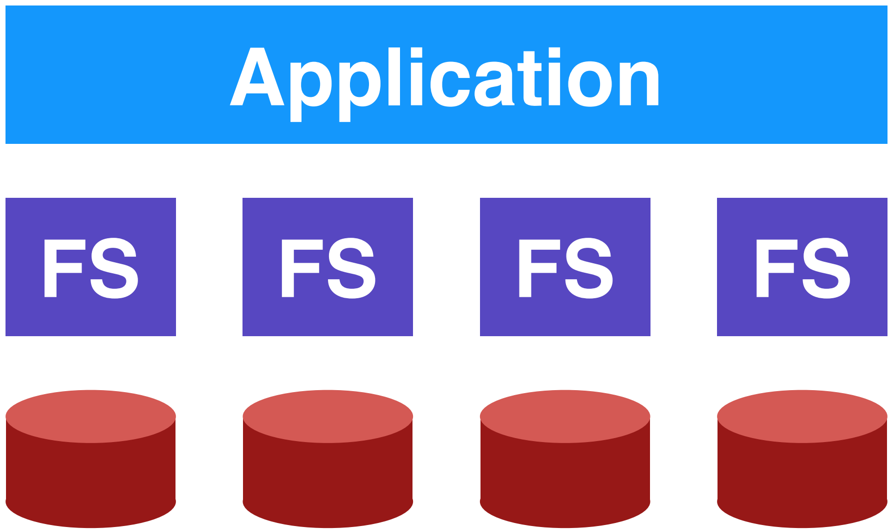
Challenge: most file systems work on only one disk.

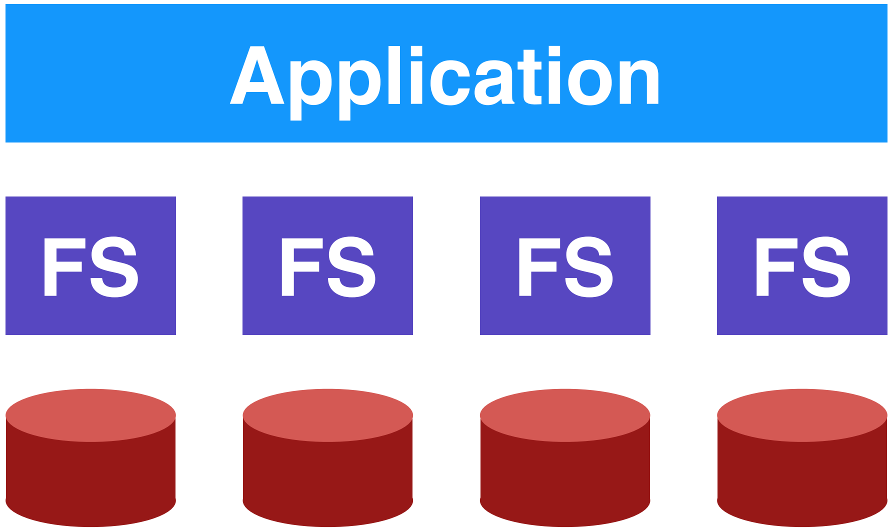
Solution 1: JBOD



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

Solution 1: JBOD

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



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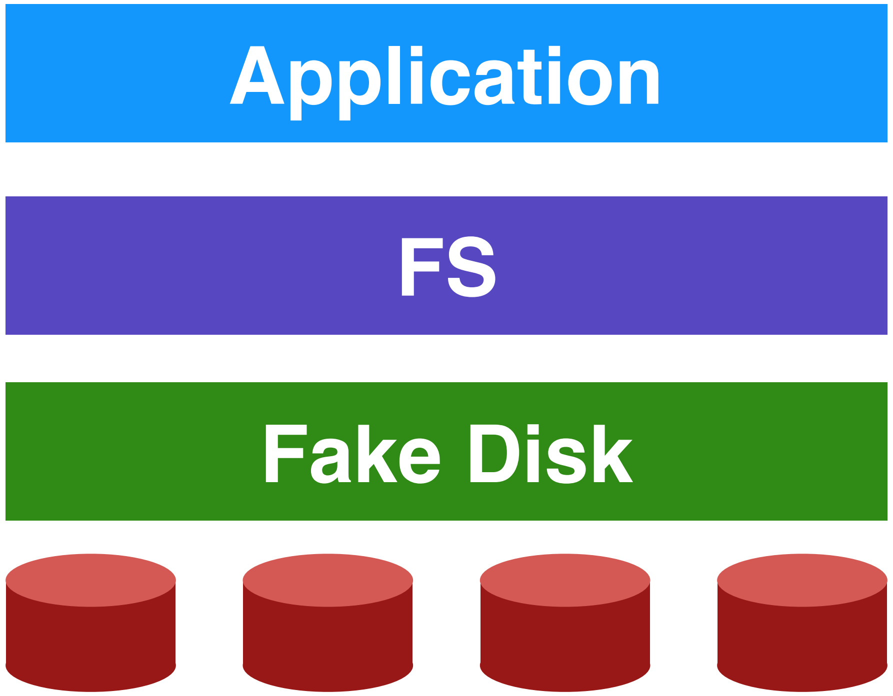
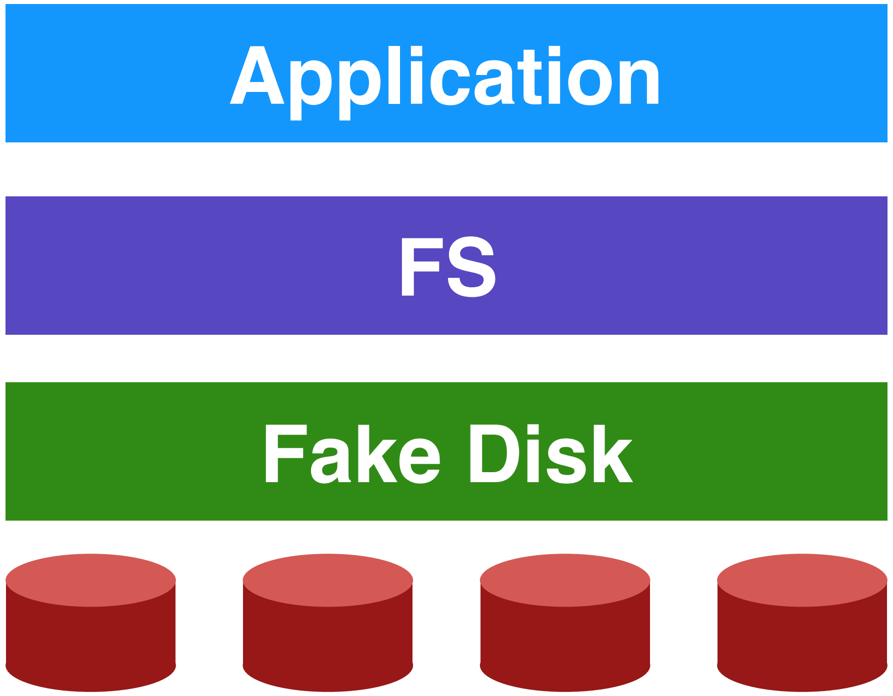


Build logical disk from many physical disks.

Solution 2: RAID

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

RAID is:
- transparent
- deployable



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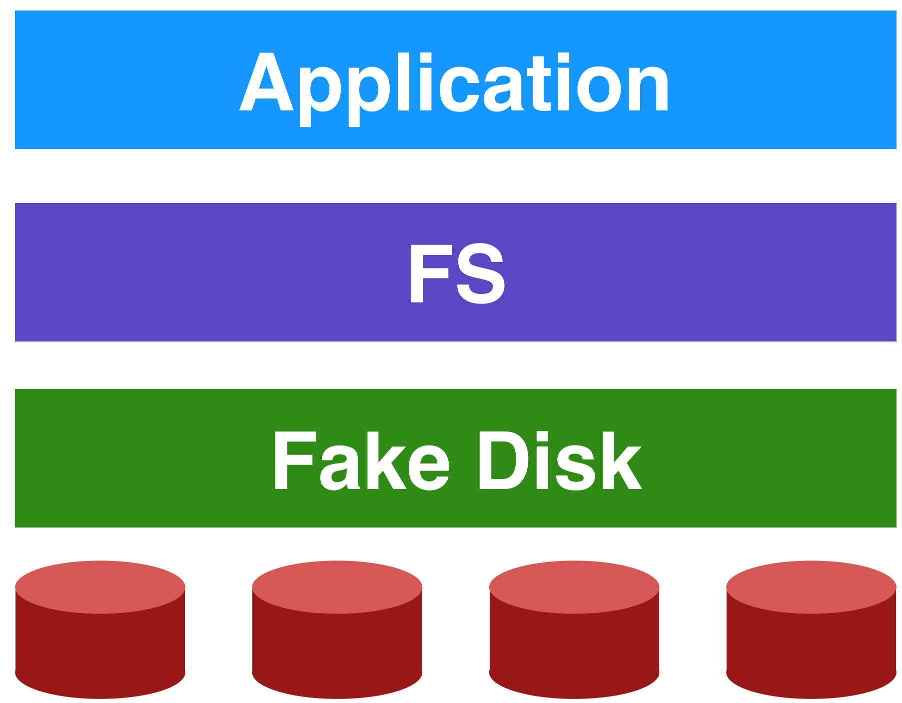

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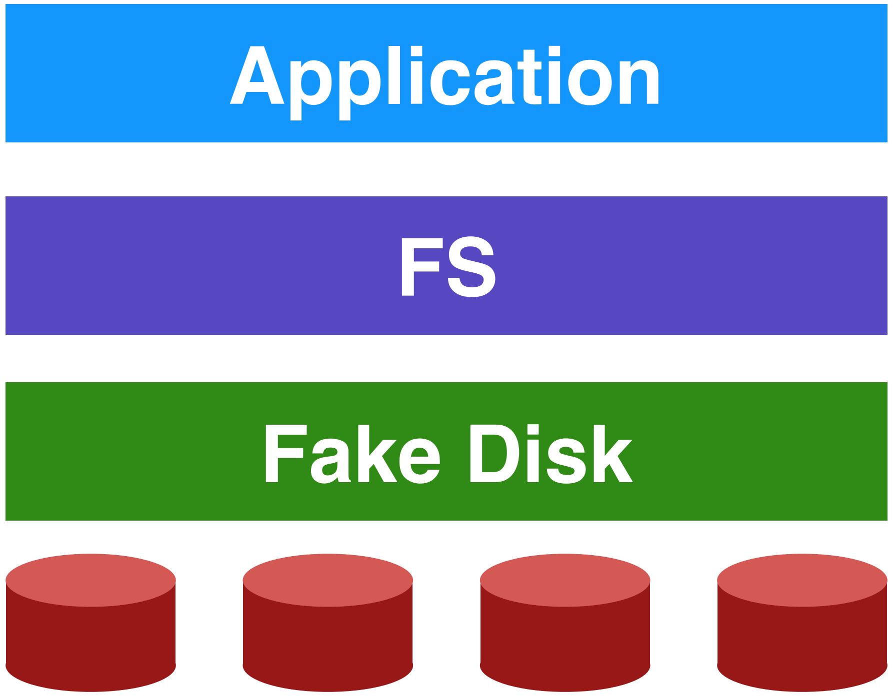

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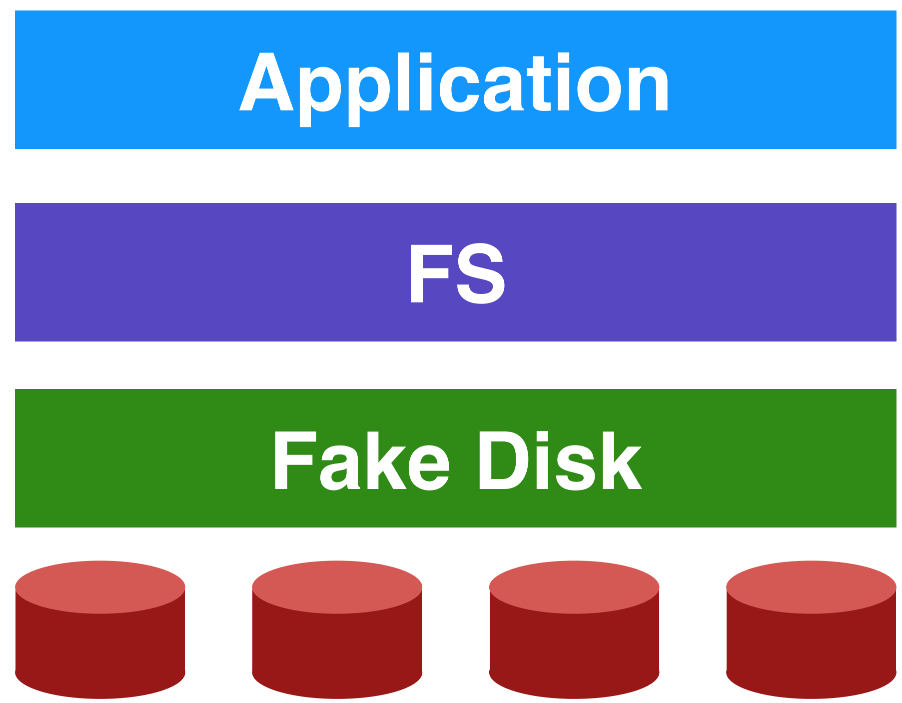

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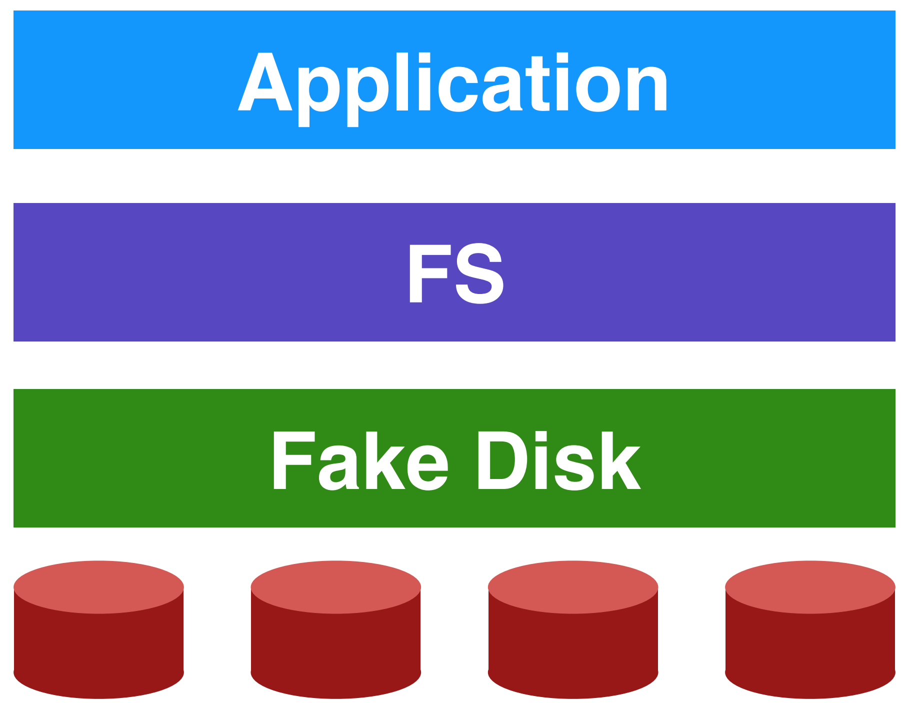

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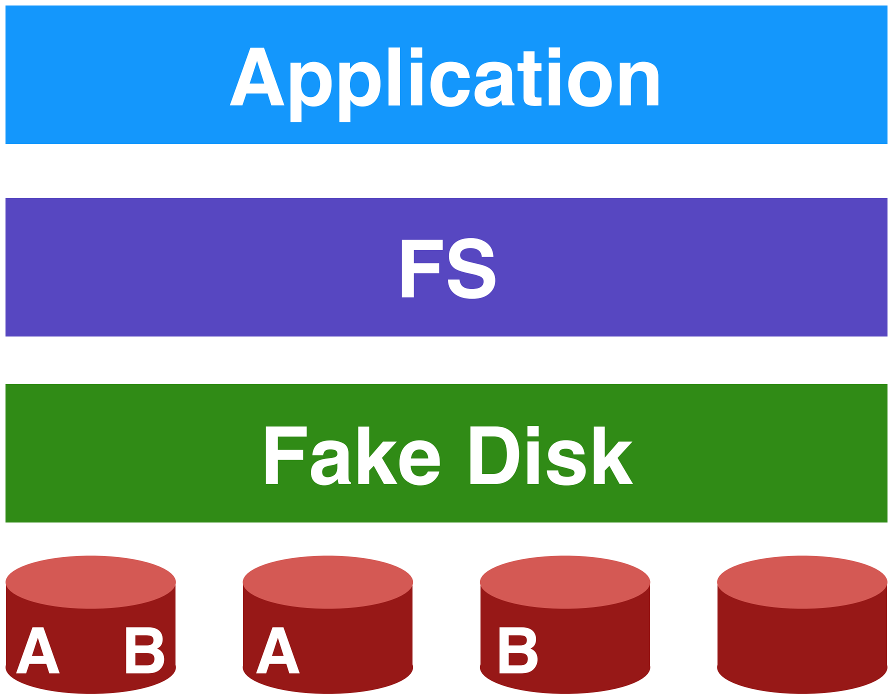

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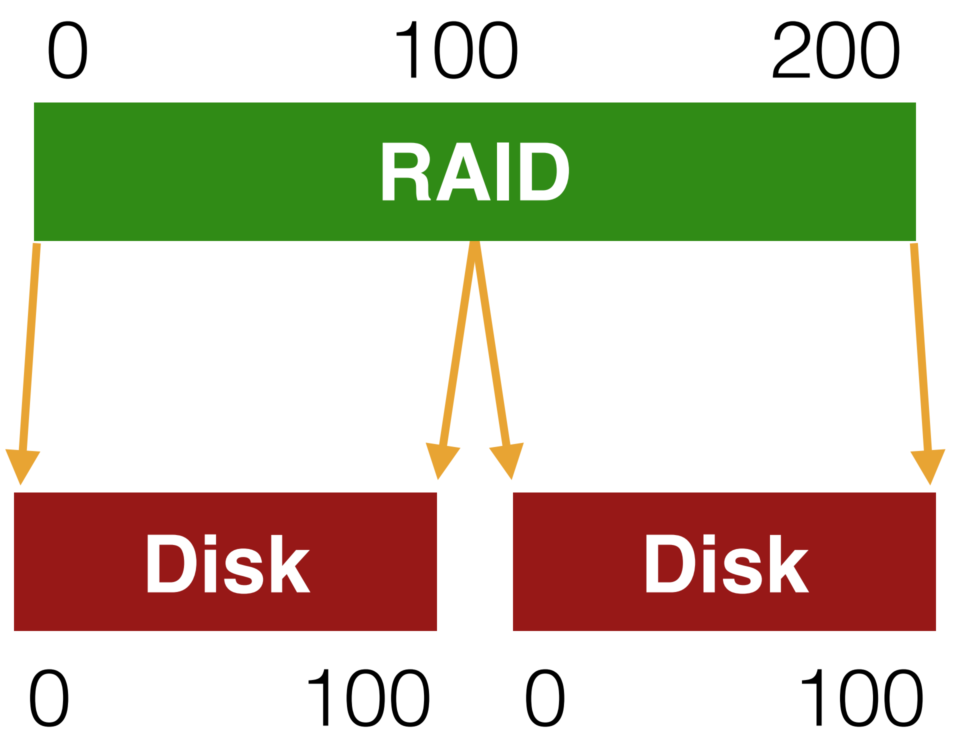
- Strategy: write S/W to build high-quality logical devices from many cheap devices.
- Alternative to RAID: buy an expensive, high-end disk.

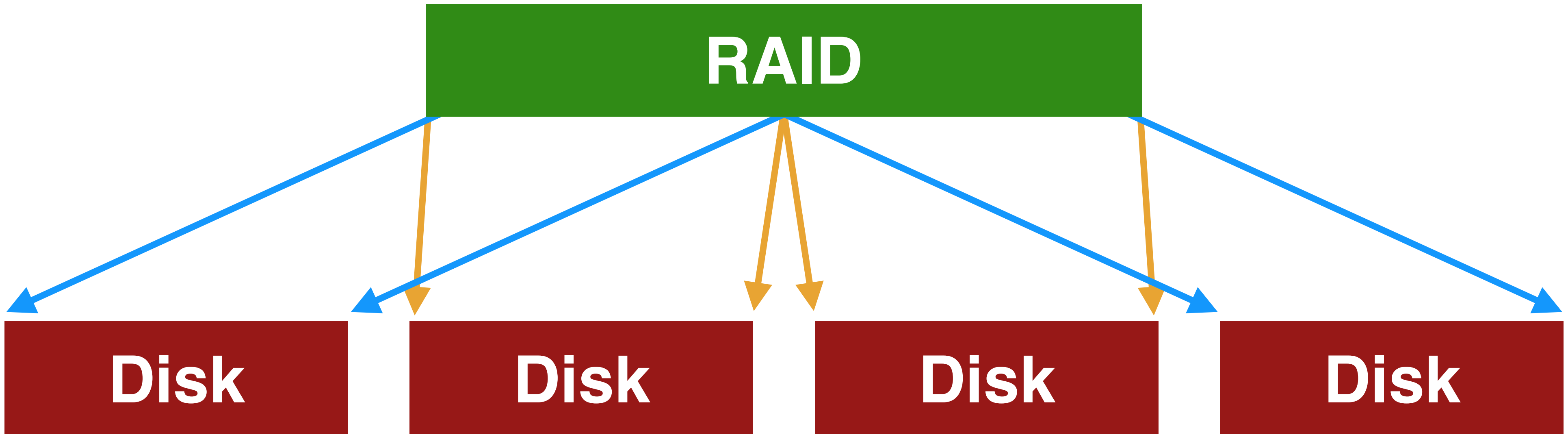
General Strategy

Build fast, large disk from smaller ones.



General Strategy

Add even more disks for reliability.



Mapping

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- RAID

RAID volume is fixed-sized, dense

Redundancy

Redundancy: how many copies?

System engineers are always trying to increase or decrease redundancy.

Increase: replication (e.g., RAID)
Decrease: deduplication (e.g., code sharing)

Redundancy

Increase: improves reliability
Decrease: improves space efficiency

One strategy: reduce redundancy as much is possible. Then add back just the right amount.

Reasoning About RAID

Workload: types of reads/writes issued by app

RAID: system for mapping logical to physical addrs

Metric: capacity, reliability, performance

RAID "algebra", given 2 variables, find the 3

$$f(\mathbf{W}, \mathbf{R}) = \mathbf{M}$$

RAID Decisions

Which logical blocks map to which physical blocks?

How do we use extra physical blocks (if any)?

Workloads

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- Average rotational time - 3 ms
- Transfer rate of disk - 50 MB/s

- Sequential load
  - Transfer Size: 10 MB
  - S = 10 MB/(7+3+(10/50)*1000)ms ~48 MB/s

- Random loads
  - Transfer Size: 10 KB
  - R = 10 KB/(7+3+(10KB/50MB/s)) ~1 MB/s

Metrics

Capacity: how much space can apps use?

Reliability: how many disks can we safely lose?

Performance: how long does each workload take?

Metrics

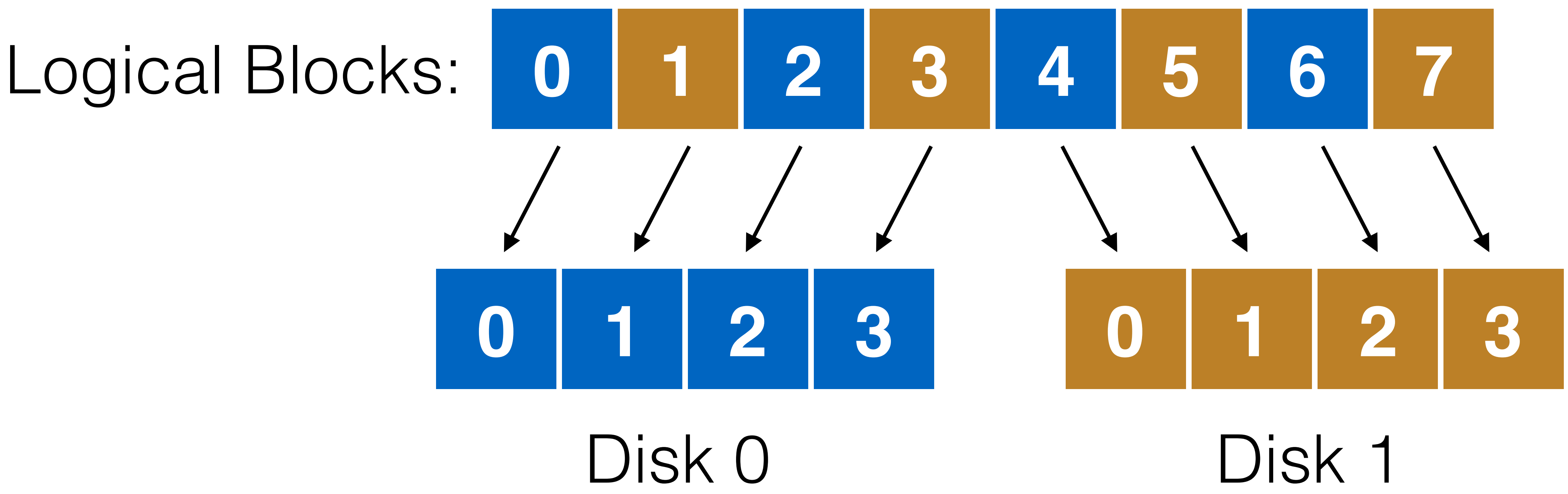
Capacity: how much space can apps use?

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

Performance: how long does each workload take?

RAID-0: Striping

Optimize for capacity. No redundancy (weird name).



Another View

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

4 disks

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

4 disks

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

How to Map

Given logical address A, find:
Disk = A % disk_count
Offset = A / disk_count

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

Chunk Size = 1

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

Chunk Size = 2

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

Chunk Size = 2

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

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stripe:	8	10	12	14
	9	11	13	15

Chunk Size = 2

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

We'll assume chunk size of 1 for today.
Sizes of 64KB are typical in deployment.

RAID-0: Analysis

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- What is capacity?

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- What is capacity?
  - N * C

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RAID-0: Analysis

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  - 0

RAID-0: Analysis

- What is capacity?
  - N * C
- How many disks can fail?
  - 0
- Throughput?

RAID-0: Analysis

- What is capacity?
  - N * C
- How many disks can fail?
  - 0
- Throughput?
  - Sequential read and write — N*S

RAID-0: Analysis

- What is capacity?
  - N * C
- How many disks can fail?
  - 0
- Throughput?
  - Sequential read and write — N*S
  - Random read and write — N*R

RAID-0: Analysis

- What is capacity?
  - N * C
- How many disks can fail?
  - 0
- Throughput?
  - Sequential read and write — N*S
  - Random read and write — N*R
  - Latency?

RAID-0: Analysis

- What is capacity?
  - N * C
- How many disks can fail?
  - 0
- Throughput?
  - Sequential read and write — N*S
  - Random read and write — N*R
  - Latency?
    - D

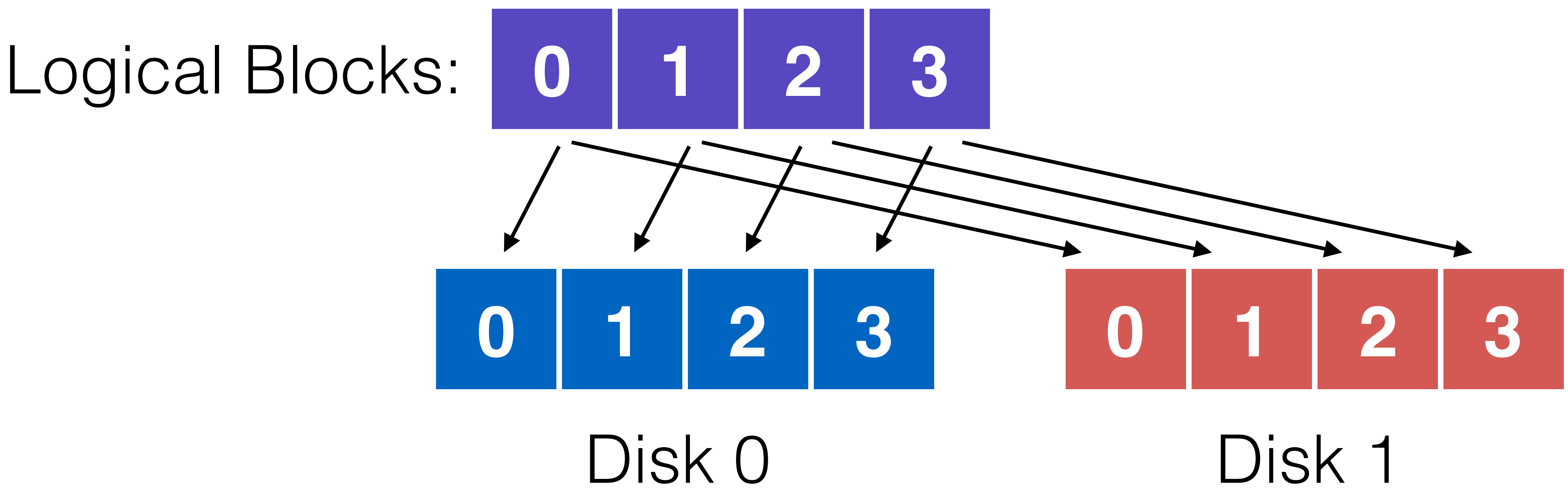
RAID-0: Analysis

- What is capacity?
  - N * C
- How many disks can fail?
  - 0
- Throughput?
  - Sequential read and write — N*S
  - Random read and write — N*R
  - Latency?
    - D

Buying more disks improves throughput, but not latency!

RAID-1: Mirroring

Keep two copies of all data.



Assumptions

Assume disks are **fail-stop**.
- they work or they don't
- we know when they don't

Tougher Errors:
- latent sector errors
- silent data corruption

2 disks

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

4 disks

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

4 disks

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

How many disks can fail?

RAID-1: Analysis

RAID-1: Analysis

- What is capacity?

RAID-1: Analysis

- What is capacity?
    - N/2 * C

RAID-1: Analysis

- What is capacity?
  - N/2 * C
- How many disks can fail?

RAID-1: Analysis

- What is capacity?
  - N/2 * C
- How many disks can fail?
  - 1 or N/2 (best case)

RAID-1: Analysis

- What is capacity?
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RAID-1: Analysis

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- How many disks can fail?
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- Throughput?
  - Sequential write — (N/2)*S

RAID-1: Analysis

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  - N/2 * C
- How many disks can fail?
  - 1 or N/2 (best case)
- Throughput?
  - Sequential write — (N/2)*S
  - Sequential read — (N/2)*S

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  - Sequential write — (N/2)*S
  - Sequential read — (N/2)*S
  - Random write — (N/2)*R

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0	0	1	1
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