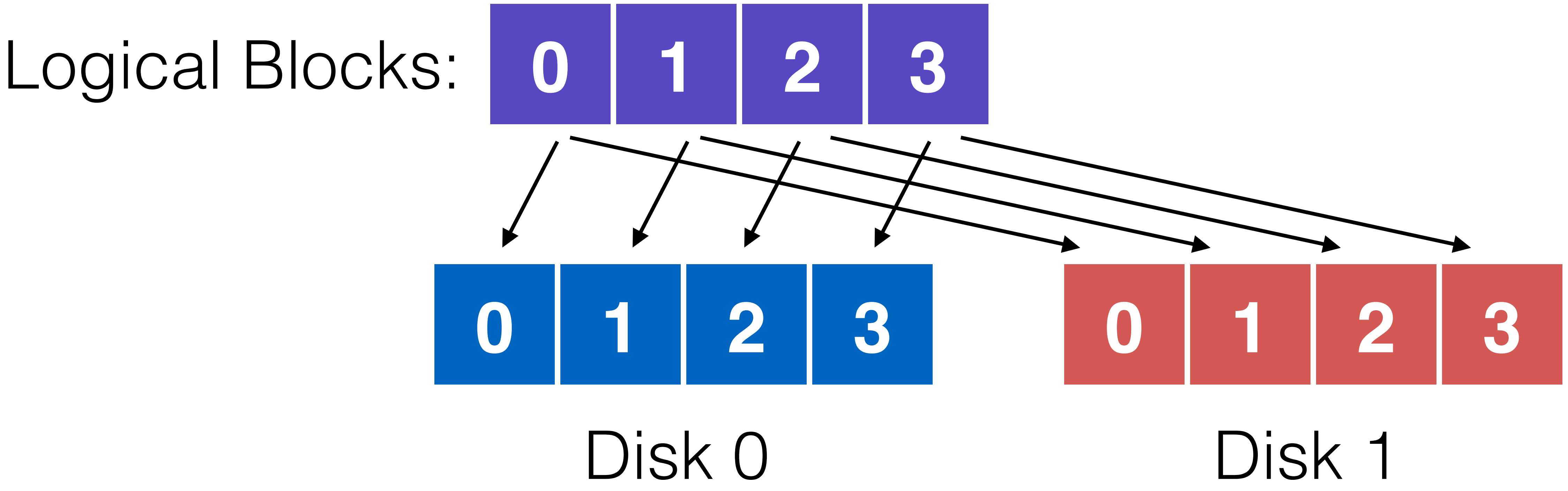
Operating Systems

RAID continued

Nipun Batra

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

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0	0	1	1
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4	4	5	5
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How many disks can fail?

RAID-1: Analysis

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- What is capacity?

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    - N/2 * C

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- Latency

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  - D

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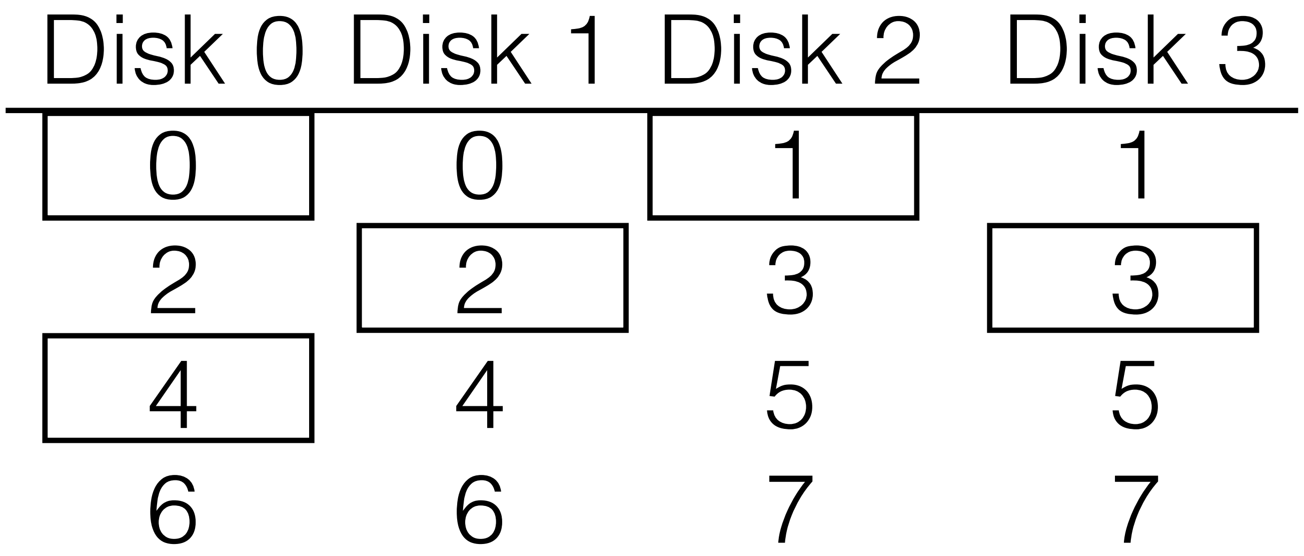

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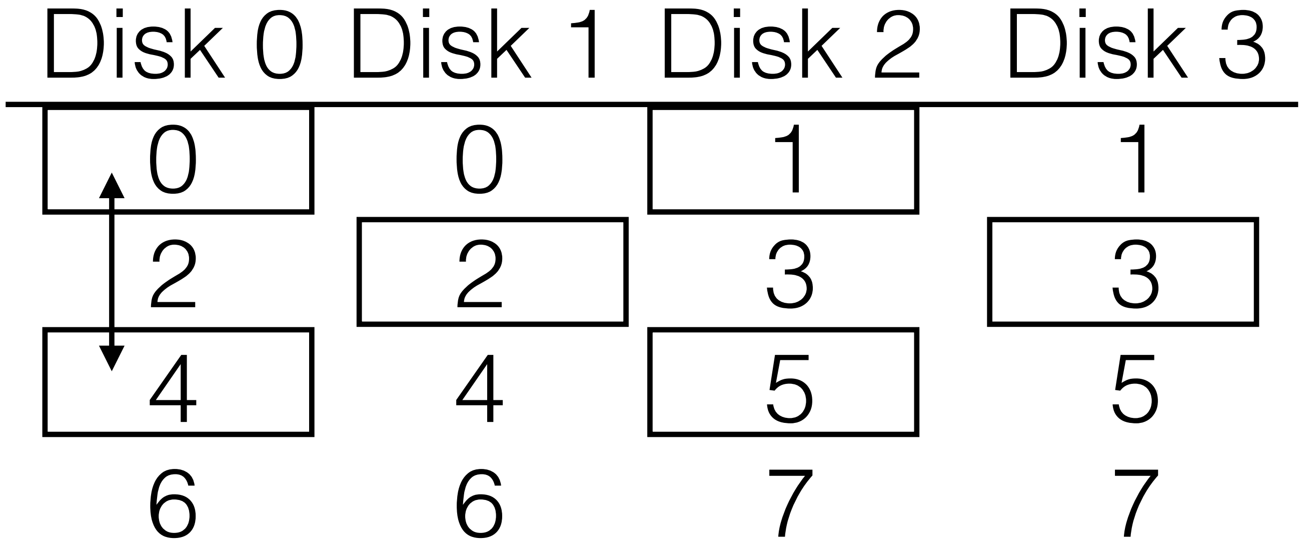
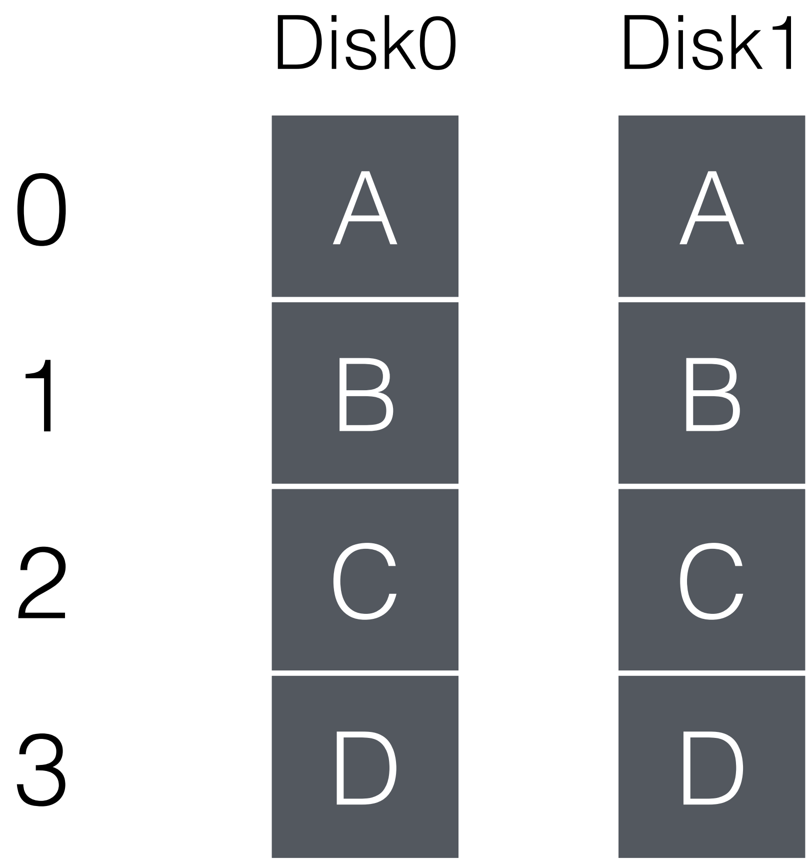


Disk 0	Disk 1	Disk 2	Disk 3
0	0	1	1
2	2	3	3
4	4	5	5
6	6	7	7

Crashes

	Disk0	Disk1
0	A	A
1	B	B
2	C	C
3	D	D

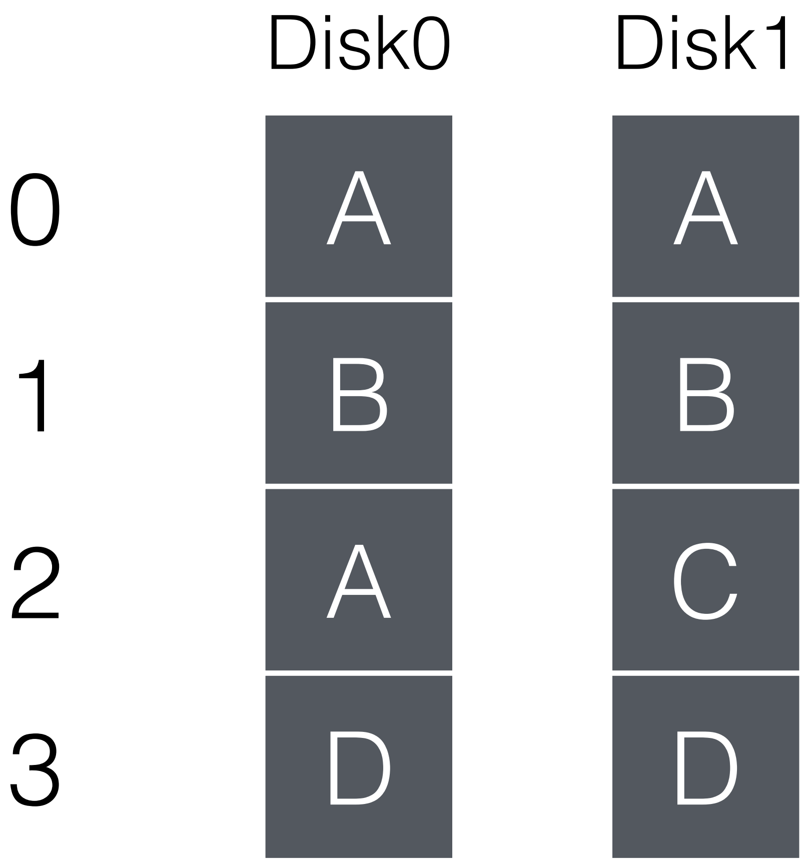
Crashes



	Disk0	Disk1
0	A	A
1	B	B
2	C	C
3	D	D

write(A) to 2

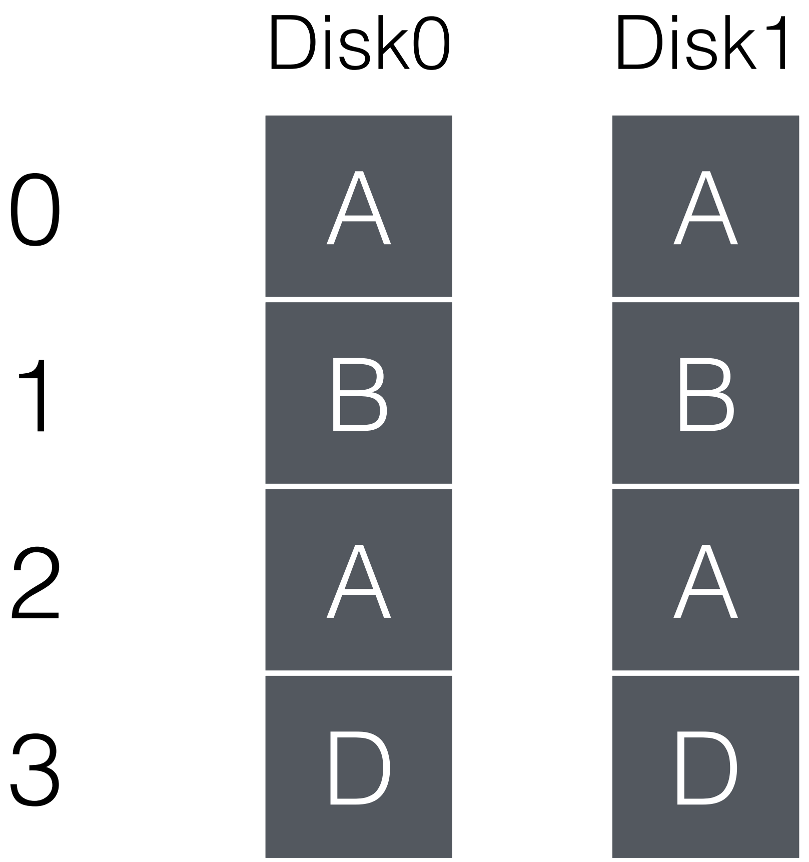
Crashes



	Disk0	Disk1
0	A	A
1	B	B
2	A	C
3	D	D

write(A) to 2

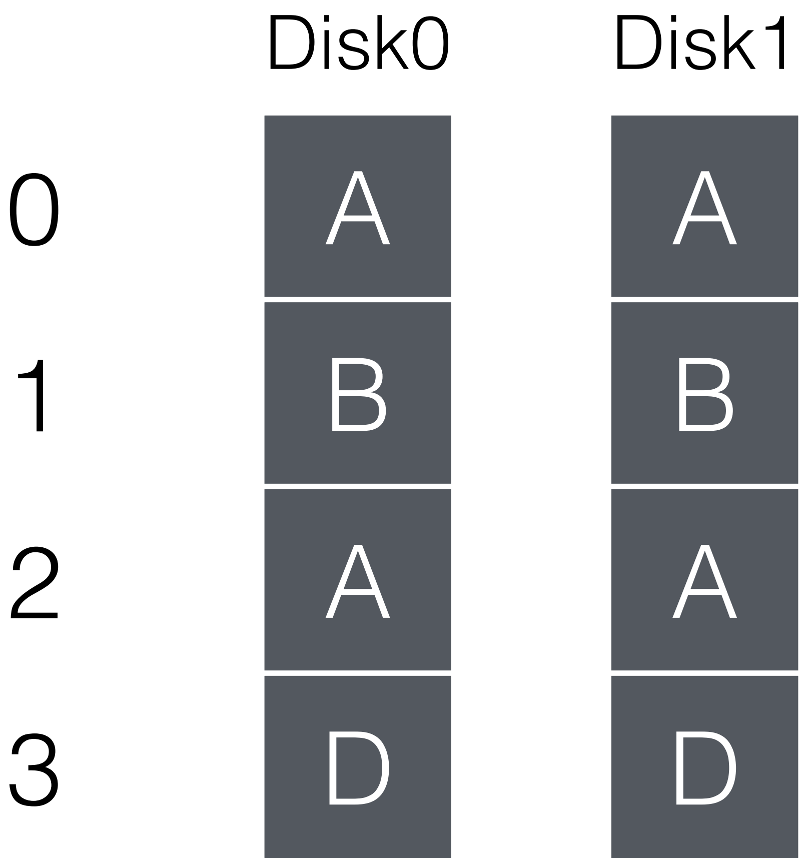
Crashes



	Disk0	Disk1
0	A	A
1	B	B
2	A	A
3	D	D

write(A) to 2

Crashes



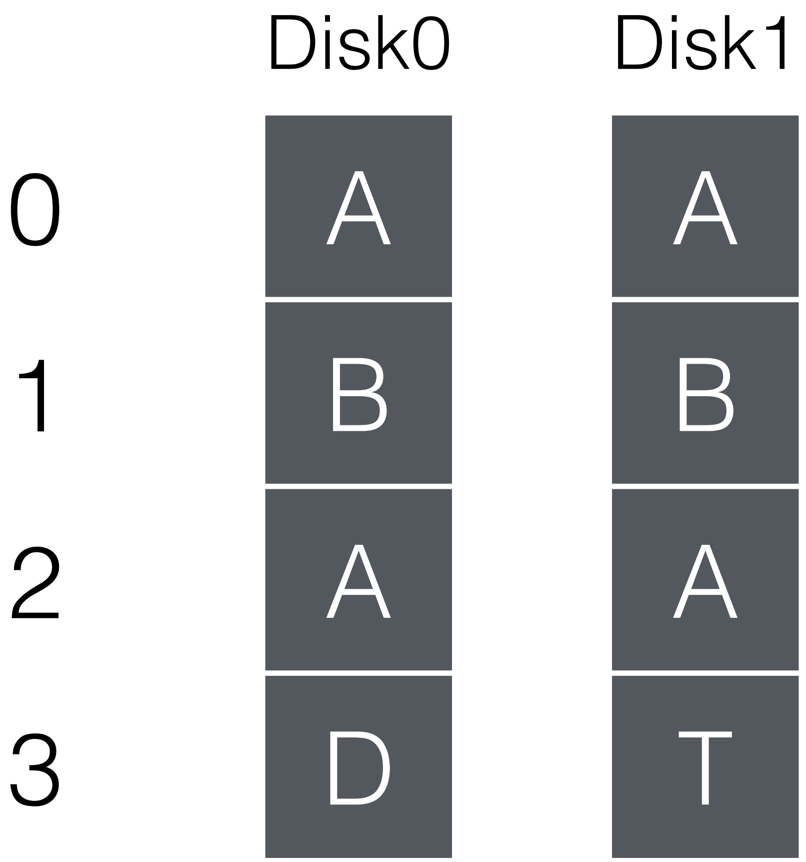
	Disk0	Disk1
0	A	A
1	B	B
2	A	A
3	D	D

Crashes

	Disk0	Disk1
0	A	A
1	B	B
2	A	A
3	D	D

write(T) to 3

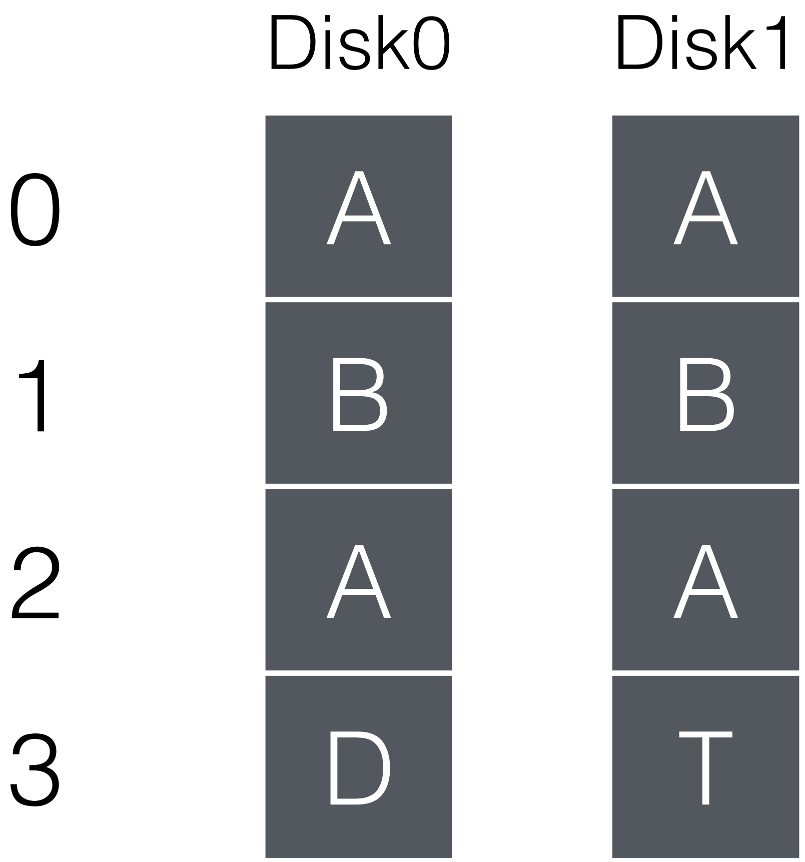
Crashes



	Disk0	Disk1
0	A	A
1	B	B
2	A	A
3	D	T

write(T) to 3

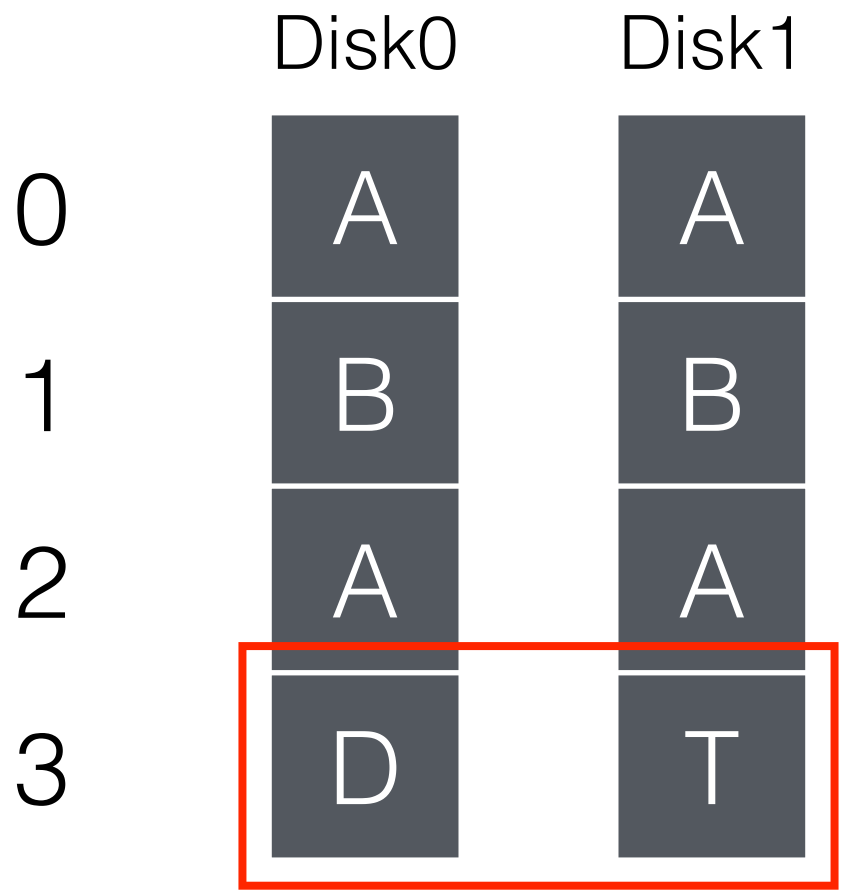
Crashes



	Disk0	Disk1
0	A	A
1	B	B
2	A	A
3	D	T

CRASH!!!

Crashes



	Disk0	Disk1
0	A	A
1	B	B
2	A	A
3	D	T

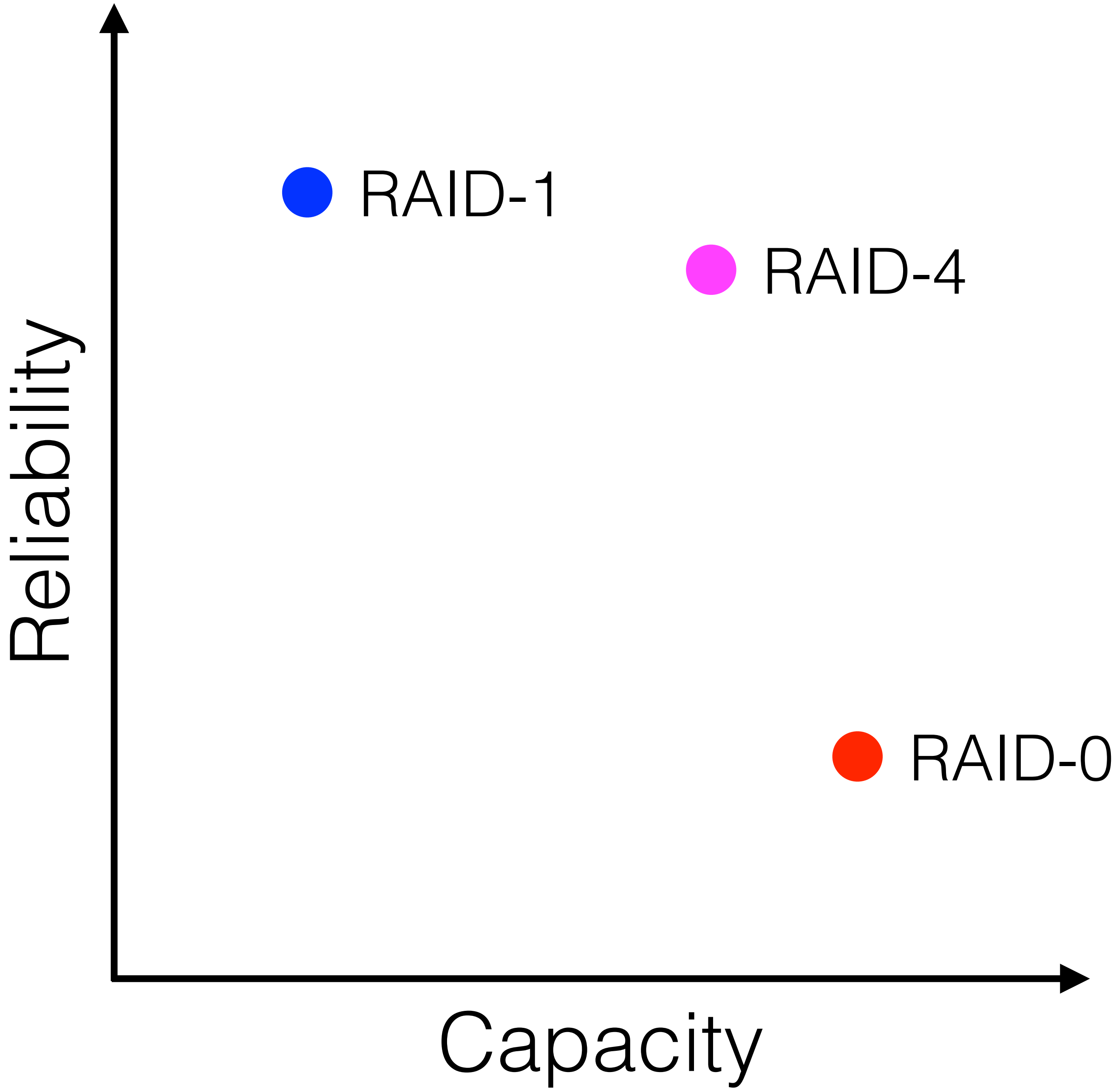
after reboot, how to
tell which data is right?

H/W Solution

Problem: Consistent-Update Problem

Use non-volatile RAM in RAID controller.

RAID-4 compared to RAID-1 and RAID-0



Strategy

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- Use parity disk.

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- In algebra, if an equation has N variables, and N-1 are know, you can often solve for the unknown.

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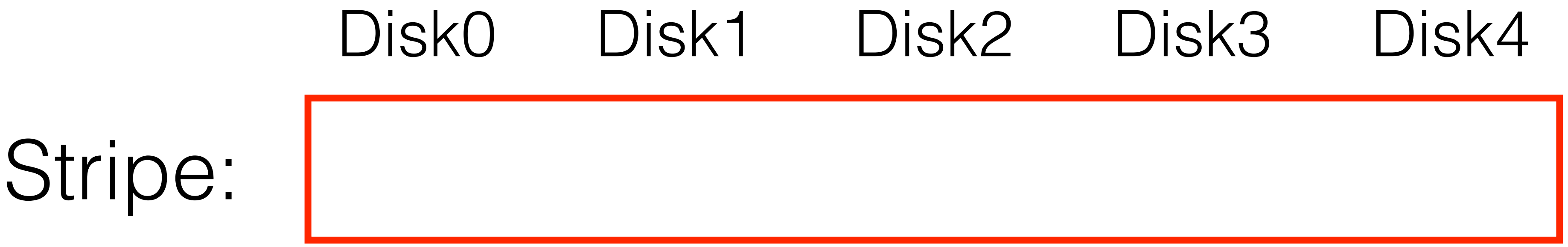
Strategy

- Use parity disk.
- In algebra, if an equation has N variables, and N-1 are know, you can often solve for the unknown.
- Treat the sectors across disks in a stripe as an equation.
- A failed disk is like an unknown in the equation.

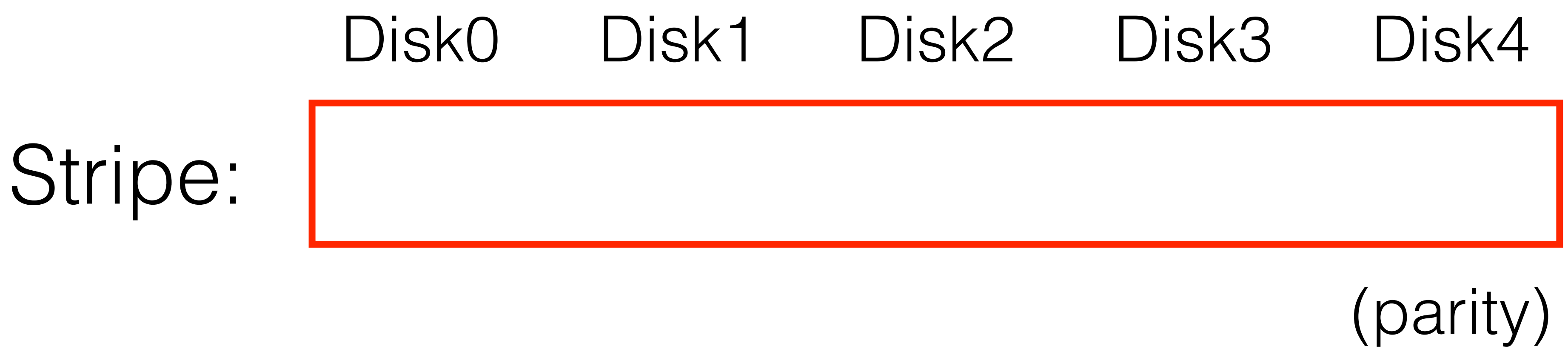
Example



Disk0 Disk1 Disk2 Disk3 Disk4

Stripe:

Example



Disk0 Disk1 Disk2 Disk3 Disk4

Stripe:

(parity)

Example

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	5	3	0	1	
					(parity)

Example

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	5	3	0	1	9
					(parity)

Example

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	5	X	0	1	9
					(parity)

Example

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	5	3	0	1	9
					(parity)

Example

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	2	1	1	X	5
					(parity)

Example

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	2	1	1	1	5
					(parity)

Example

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	3	0	1	2	X
					(parity)

Example

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	3	0	1	2	6
					(parity)

Parity Functions

Which functions could we use to compute parity?

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	0	1	0	1	XOR(0,1,0,1)=0
					(parity)

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	00	01	10	11	(XOR(0,0,1,1), XOR(0,1,0,1))=00
					(parity)

RAID-4: Analysis

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- What is capacity?

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  - (N-1) * C

RAID-4: Analysis

- What is capacity?
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- How many disks can fail?

RAID-4: Analysis

- What is capacity?
  - (N-1) * C
- How many disks can fail?
  - 1

RAID-4: Analysis

- What is capacity?
  - (N-1) * C
- How many disks can fail?
  - 1
- Throughput?

RAID-4: Analysis

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  - Sequential write — (N-1)*S

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  - Sequential read — (N-1)*S

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- Throughput?
  - Sequential write — (N-1)*S
  - Sequential read — (N-1)*S
  - Random read — (N-1)*R

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  - (N-1) * C
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  - Sequential write — (N-1)*S
  - Sequential read — (N-1)*S
  - Random read — (N-1)*R
  - Random write?

RAID-4: Analysis for Random Write …

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	0	1	0	1	XOR(0,1,0,1)=0
					(parity)

RAID-4: Analysis for Random Write …

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	0	1	0	1	XOR(0,1,0,1)=0
					(parity)

- Want to: **Write** 0 to Disk 1

RAID-4: Analysis for Random Write …

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	0	1	0	1	XOR(0,1,0,1)=0
					(parity)

- Want to: **Write** 0 to Disk 1
- **Read** old value of Disk 1

RAID-4: Analysis for Random Write …

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	0	1	0	1	XOR(0,1,0,1)=0
					(parity)

- Want to: **Write** 0 to Disk 1
- **Read** old value of Disk 1
- **Read** old value of parity

RAID-4: Analysis for Random Write …

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	0	1	0	1	XOR(0,1,0,1)=0
					(parity)

- Want to: **Write** 0 to Disk 1
- **Read** old value of Disk 1
- **Read** old value of parity
- If New value of Disk 1 == Old value of Disk 1, Do nothing

RAID-4: Analysis for Random Write …

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	0	1	0	1	XOR(0,1,0,1)=0
					(parity)

- Want to: **Write** 0 to Disk 1
- **Read** old value of Disk 1
- **Read** old value of parity
- If New value of Disk 1 == Old value of Disk 1, Do nothing
- Else, **Write** new flipped parity and **Write** new value to Disk 1

RAID-4: Analysis for Random Write …

	Disk0	Disk1	Disk2	Disk3	Disk4
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- Each random write, needs 2 reads and 2 writes

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- Each random write, needs 2 reads and 2 writes
- Assume we get 2 writes: Disk 0 and Disk 1

RAID-4: Analysis for Random Write …

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	0	1	0	1	XOR(0,1,0,1)=0
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- Each random write, needs 2 reads and 2 writes
- Assume we get 2 writes: Disk 0 and Disk 1
  - Both wait to read and write Parity Disk

RAID-4: Analysis for Random Write …

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	0	1	0	1	XOR(0,1,0,1)=0
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- Want to: **Write** 0 to Disk 1
- **Read** old value of Disk 1
- **Read** old value of parity
- If New value of Disk 1 == Old value of Disk 1, Do nothing
- Else, **Write** new flipped parity and **Write** new value to Disk 1
- Each random write, needs 2 reads and 2 writes
- Assume we get 2 writes: Disk 0 and Disk 1
  - Both wait to read and write Parity Disk
  - R/2 throughput (**independent of N**)

RAID-4: Analysis for Random Write …

	Disk0	Disk1	Disk2	Disk3	Disk4
Stripe:	0	1	0	1	XOR(0,1,0,1)=0
					(parity)

- Want to: **Write** 0 to Disk 1
- **Read** old value of Disk 1
- **Read** old value of parity
- If New value of Disk 1 == Old value of Disk 1, Do nothing
- Else, **Write** new flipped parity and **Write** new value to Disk 1
- Each random write, needs 2 reads and 2 writes
- Assume we get 2 writes: Disk 0 and Disk 1
  - Both wait to read and write Parity Disk
  - R/2 throughput (**independent of N**)
- Latency for random write is 2D (2 parallel reads and 2 parallel writes)

RAID-5 (Improve Random Write Performance)

Disk0	Disk1	Disk2	Disk3	Disk4
-	-	-	-	P
-	-	-	P	-
-	-	P	-	-

...

RAID-5: Analysis

0a) What is capacity? **(N-1) * C**

0b) How many disks can fail? **1**

0c) Throughput? **???**

0d) Latency? D for read and 2*D for write

RAID-5: Throughput

What is steady-state throughput for

- sequential reads?
- sequential writes?
- random reads?
- random writes?

RAID-5: Throughput

What is steady-state throughput for

- sequential reads? **(N-1) * S**
- sequential writes? **(N-1) * S**
- random reads? **N * R**
- random writes? **N * R / 4**

RAID-5: Throughput

What is steady-state throughput for

- sequential reads?	**(N-1) * S**	
- sequential writes?	**(N-1) * S**	
- random reads?	**N * R**	**(N-1) * R**
- random writes?	**N * R / 4**	**R/2**
		RAID-4

All RAID

	Reliability	Capacity
RAID-0	0	C*N
RAID-1	1	C*N/2
RAID-4	1	N-1
RAID-5	1	N-1

All RAID

	Read Latency	Write Latency
RAID-0	D	D
RAID-1	D	D
RAID-4	D	2D
RAID-5	D	2D

All RAID

	Read Latency	Write Latency
RAID-0	D	D
RAID-1	D	D
RAID-4	D	2D
RAID-5	D	2D

but RAID-5 can
do more in parallel

All RAID

	Seq Read	Seq Write	Rand Read	Rand Write
RAID-0	N * S	N * S	N * R	N * R
RAID-1	N/2 * S	N/2 * S	N * R	N/2 * R
RAID-4	(N-1)*S	(N-1)*S	(N-1)*R	R/2
RAID-5	(N-1)*S	(N-1)*S	N * R	N/4 * R

All RAID

	Seq Read	Seq Write	Rand Read	Rand Write
RAID-0	N * S	N * S	N * R	N * R
RAID-1	N/2 * S	N/2 * S	N * R	N/2 * R
RAID-4	(N-1)*S	(N-1)*S	(N-1)*R	R/2
RAID-5	(N-1)*S	(N-1)*S	N * R	N/4 * R

RAID-5 is strictly better than RAID-4

All RAID

	Seq Read	Seq Write	Rand Read	Rand Write
RAID-0	N * S	N * S	N * R	N * R
RAID-1	N/2 * S	N/2 * S	N * R	N/2 * R
RAID-5	(N-1)*S	(N-1)*S	N * R	N/4 * R

All RAID

	Seq Read	Seq Write	Rand Read	Rand Write
RAID-0	N * S	N * S	N * R	N * R
RAID-1	N/2 * S	N/2 * S	N * R	N/2 * R
RAID-5	(N-1)*S	(N-1)*S	N * R	N/4 * R

RAID-0 is always fastest and has best capacity.
(but at cost of reliability)

All RAID

	Seq Read	Seq Write	Rand Read	Rand Write
RAID-0	N * S	N * S	N * R	N * R
RAID-1	N/2 * S	N/2 * S	N * R	N/2 * R
RAID-5	(N-1)*S	(N-1)*S	N * R	N/4 * R

RAID-5 better than RAID-1 for sequential.

All RAID

	Seq Read	Seq Write	Rand Read	Rand Write
RAID-0	N * S	N * S	N * R	N * R
RAID-1	N/2 * S	N/2 * S	N * R	N/2 * R
RAID-5	(N-1)*S	(N-1)*S	N * R	N/4 * R

All RAID

	Seq Read	Seq Write	Rand Read	Rand Write
RAID-0	N * S	N * S	N * R	N * R
RAID-1	N/2 * S	N/2 * S	N * R	**N/2 * R**
RAID-5	(N-1)*S	(N-1)*S	N * R	**N/4 * R**

RAID-1 better than RAID-4 for random write.

Summary

Many engineering tradeoffs with RAID.
(capacity, reliability, different types of performance).

H/W RAID controllers can handle crashes easier.

Transparent, deployable solutions are popular.