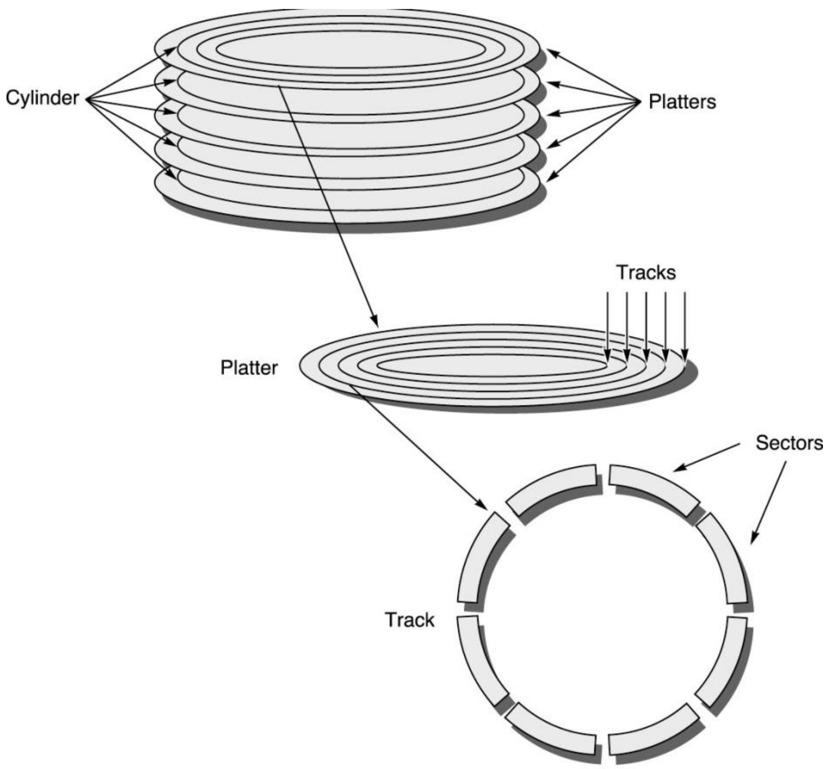
Storage

Magnetic Disks

- To control: Disk Controller
- Disk surfaces are divided into tracks
- Each track is divided into sectors
- Read/Write: a movable arm with a read/write head is located over each surface
- Seek time: time to move the arm over the proper track

  (min seek time, max seek time, and avg seek time)
- Rotation Latency (Rotational Delay): Time for the requested sector to rotate under the head



Average Rotation time = 0.5 /Revolutions Per Minute

e.g. 0.5/(3600RPM) = (0.5*60/ 3600) sec = 8.3 ms

Redundant Arrays of (Inexpensive) Disks

- **Files are "striped" across multiple disks (spreading data over multiple disks)**
- **Force accesses to several disks if the data files are large**
- **Redundancy yields high data availability**
  - **Availability: service still provided to user, even if some components failed**
- **Disks will still fail**
- **Contents reconstructed from data redundantly stored in the array**

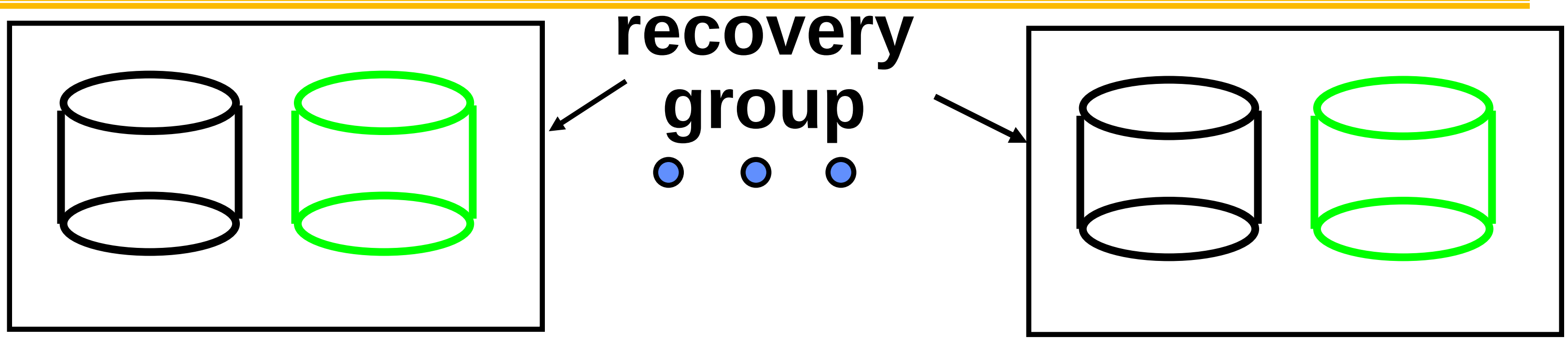
  $\Rightarrow$ **Capacity penalty to store redundant info**

  $\Rightarrow$ **Bandwidth penalty to update redundant info**

RAID 0

- No redundancy
- Sometimes nicknamed JBOD (Just a Bunch of Disks)
- Used as a measuring stick for other RAID levels in terms of cost, performance and dependability.

Redundant Arrays of Inexpensive Disks
RAID 1: Disk Mirroring/Shadowing



- Each disk is fully duplicated onto its "mirror"
  Very high availability can be achieved
- Bandwidth sacrifice on write:
  Logical write = two physical writes
  - Reads may be optimized
- Most expensive solution: 100% capacity overhead
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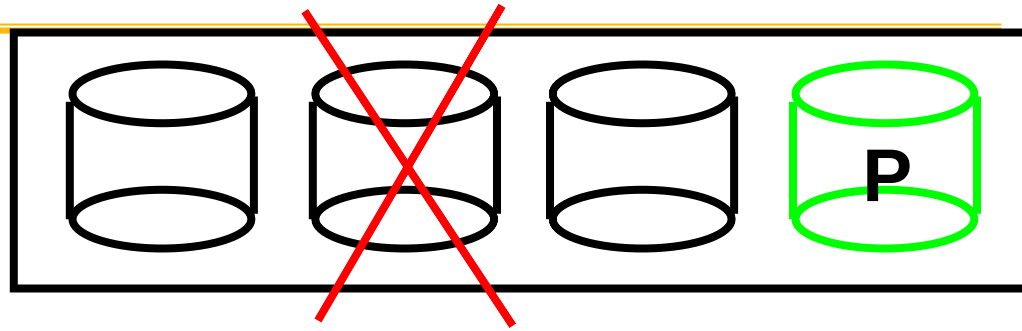
RAID 2

- **Inspired by applying memory-style error correcting codes to disks**
- **RAID 2 not used since other more interesting schemes,**

Redundant Array of Inexpensive Disks
RAID 3: Parity Disk



1	~~1~~	1	1
0	~~1~~	0	1
1	~~0~~	1	0
0	~~0~~	0	0
0	~~1~~	0	1
0	~~1~~	0	1
1	~~0~~	1	0
1	~~1~~	1	1

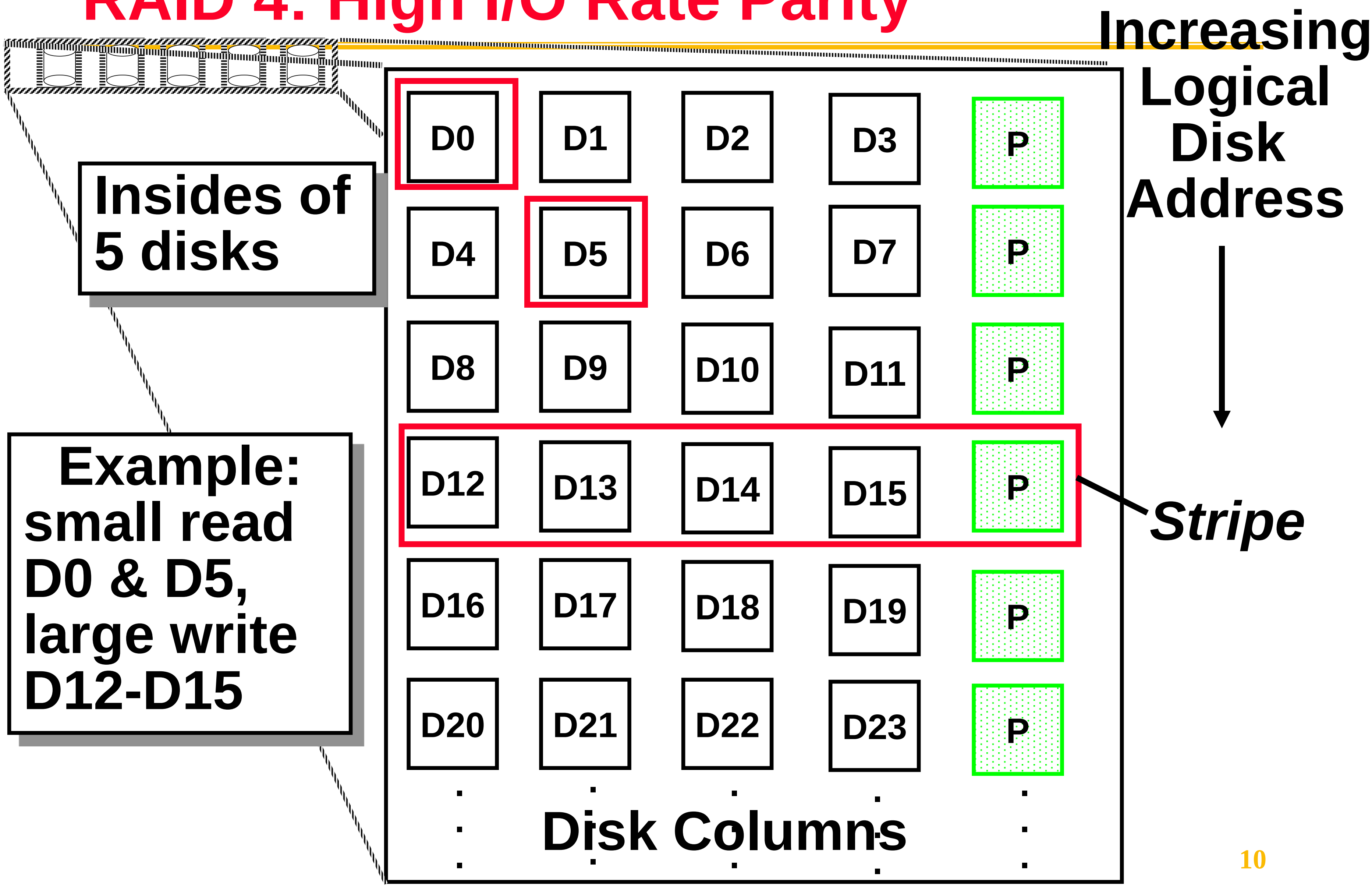
Striped physical records

P contains sum of other disks per stripe mod 2 ("parity")
If disk fails, subtract P from sum of other disks to find missing information

RAID 3

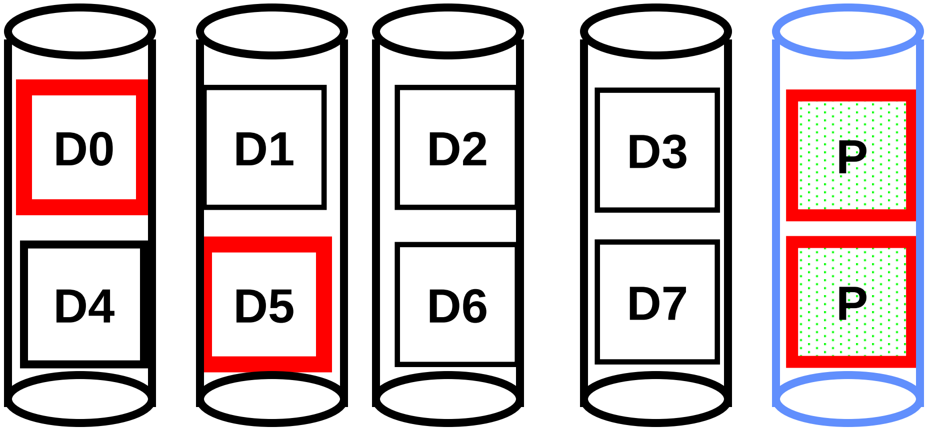
- Sum computed across recovery group to protect against hard disk failures, stored in P disk
- Logically, a single high capacity, high transfer rate disk: good for large transfers
- Wider arrays reduce capacity costs, but decreases availability
- 33% capacity cost for parity if 3 data disks and 1 parity disk

Redundant Arrays of Inexpensive Disks
RAID 4: High I/O Rate Parity



Small Writes

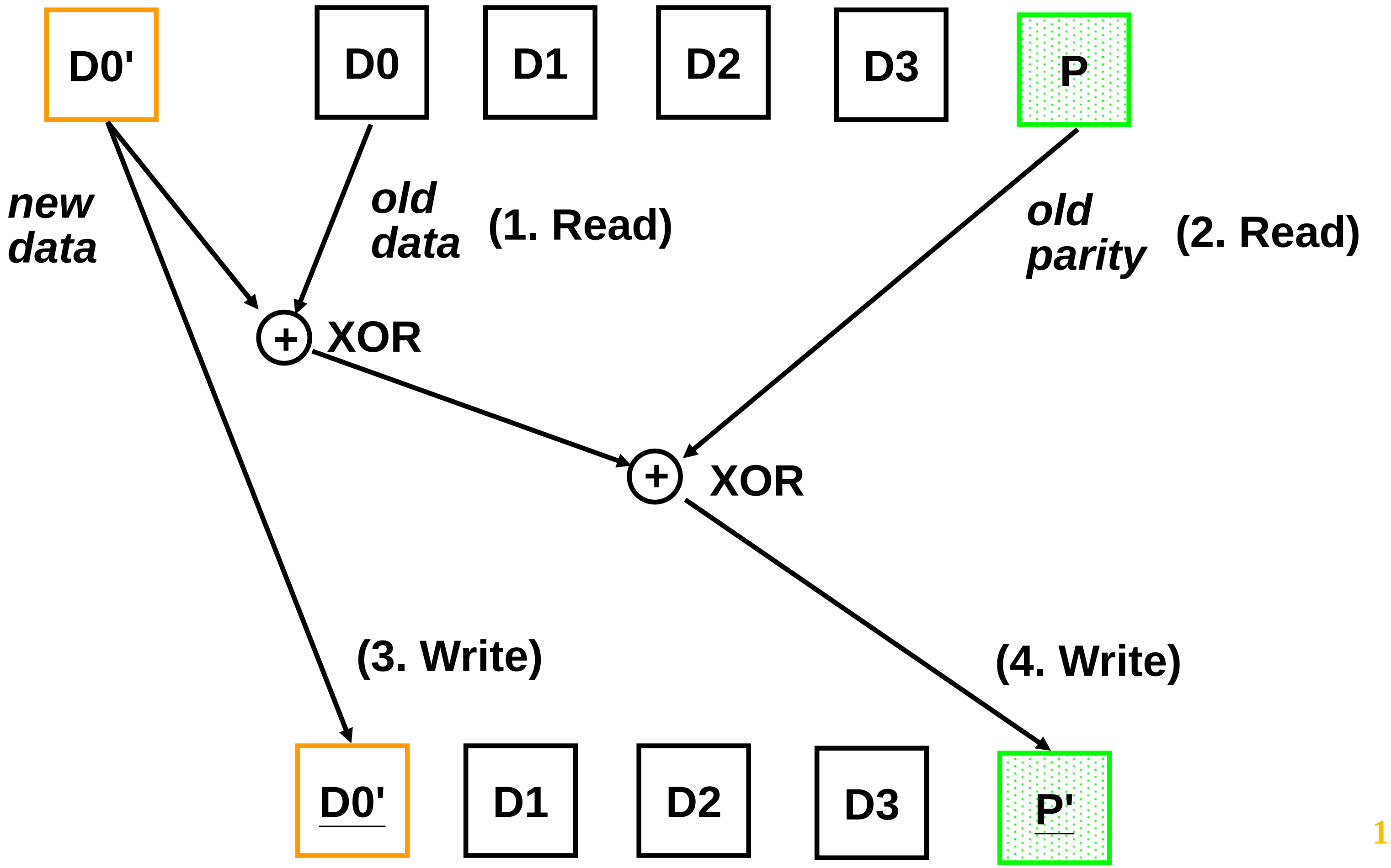
- RAID 4 works well for small reads
- Small writes (write to one disk):
  - Option 1: read other data disks, create new sum and write to Parity Disk
  - Option 2: since P has old sum, compare old data to new data, add the difference to P
  - RAID4 takes Option 2
- In RAID4: Small writes are limited by Parity Disk: Write to D0, D5 both also write to P disk



Small Writes

Option2 of Small Write Algorithm

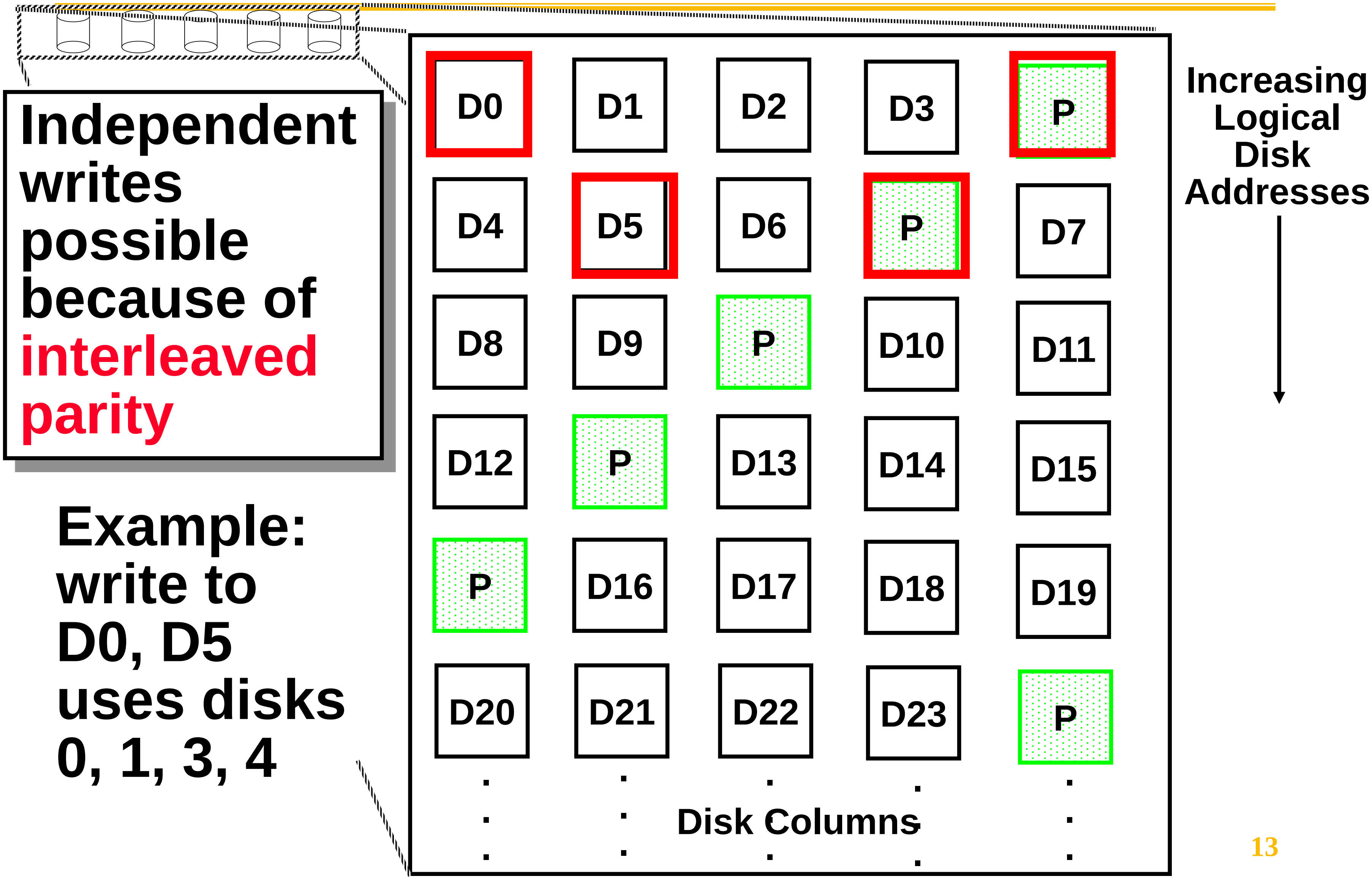
1 Logical Write = 2 Physical Reads + 2 Physical Writes



Redundant Arrays of Inexpensive Disks
RAID 5: High I/O Rate Interleaved Parity

Independent writes possible because of interleaved parity

Example: write to D0, D5 uses disks 0, 1, 3, 4



RAID 6: Recovering from 2 failures

- **Why > 1 failure recovery?**
  - operator accidentally replaces the wrong disk during a failure
  - since disk bandwidth is growing more slowly than disk capacity, the MTT Repair a disk in a RAID system is increasing
    $\Rightarrow$ increases the chances of a 2nd failure during repair since it takes longer
  - reading much more data during reconstruction meant increasing the chance of an uncorrectable media failure, which would result in data loss

RAID 6: Recovering from 2 failures

- Network Appliance's *row-diagonal parity* or *RAID-DP*
- Like the standard RAID schemes, it uses redundant space based on parity calculation per stripe
- Since it is protecting against a double failure, it adds two check blocks per stripe of data.
  - If p+1 disks total, p-1 disks have data; assume p=5
- Row parity disk is just like in RAID 4
  - Even parity across the other 4 data blocks in its stripe
- Each block of the diagonal parity disk contains the even parity of the blocks in the same diagonal

Example p = 5

- Row diagonal parity starts by recovering one of the 4 blocks on the failed disk using diagonal parity
  - Since each diagonal misses one disk, and all diagonals miss a different disk
- Once the data for those blocks is recovered, then the standard RAID recovery scheme can be used to recover two more blocks in the standard RAID 4 stripes
- Process continues until two failed disks are restored