Motivation:
Why use multiple disks?

Capacity
- More disks allows us to store more data

Performance
- Access multiple disks in parallel
- Each disk can be working on independent read or write
- Overlap seek and rotational positioning time for all

Reliability
- Recover from disk (or single sector) failures
- Will need to store multiple copies of data to recover

RAID: Redundant Array of Inexpensive/Independent Disks

Hardware vs. Software RAID

Hardware RAID
- Storage box you attach to computer
- Same interface as single disk, but internally much more
  - Multiple disks
  - More complex controller
  - NVRAM (holding parity blocks)

Software RAID
- OS (device driver layer) treats multiple disks like a single disk
- Software does all extra work

Interface for both
- Linear array of bytes, just like a single disk (but larger)

RAID-0: Striping

Stripe blocks across disks in a “chunk” size
- How to pick a reasonable chunk size?

How to calculate where chunk # lives?

Disk:
Offset within disk:
RAID-0: Striping

Evaluate for D disks
Capacity: How much space is wasted?
Performance: How much faster than 1 disk?
Reliability: More or less reliable than 1 disk?

RAID-1: Mirroring

Motivation: Handle disk failures
Put copy (mirror or replica) of each chunk on another disk
Capacity:
Reliability:
Performance:

RAID-4: Parity

Motivation: Improve capacity
Idea: Allocate parity block to encode info about blocks
• Parity checks all other blocks in stripe across other disks
Parity block = XOR over others (gives "even" parity)
• Example: 0 1 0 → Parity value?
How do you recover from a failed disk?
• Example: x 0 0 and parity of 1
• What is the failed value?

RAID-4: Parity

Capacity:
Reliability:
Performance:
• Reads
• Writes: How to update parity block?
  • Two different approaches
    • Small number of disks (or large write)
    • Large number of disks (or small write)
  • Parity disk is the bottleneck
RAID-5: Rotated Parity

Rotate location of parity across all disks

Capacity:
Reliability:
Performance:
  - Reads:
  - Writes:
  - Still requires 4 I/Os per write, but not always to same parity disk

Advanced Issues

What happens if more than one fault?
- Example: One disk fails plus “latent sector error” on another
- RAID-5 cannot handle two faults
- Solution: RAID-6 (e.g., RDP) Add multiple parity blocks

Why is NVRAM useful?
- Example: What if update 2, don’t update P0 before power failure (or crash), and then disk 1 fails?
- NVRAM solution: Use to store blocks updated in same stripe
  - If power failure, can replay all writes in NVRAM
- Software RAID solution: Perform parity scrub over entire disk

Conclusions

RAID turns multiple disks into a larger, faster, more reliable disk
RAID-0: Striping
  Good when performance and capacity really matter, but reliability doesn’t
RAID-1: Mirroring
  Good when reliability and write performance matter, but capacity (cost) doesn’t
RAID-5: Rotating Parity
  Good when capacity and cost matter or workload is read-mostly
  Good compromise choice