Terms to know

- RAID (Redundant Array of Inexpensive Disks)
- SLED (Single Large Expensive Disk)
- JBOD (Just a Bunch Of Disks)

Desired goals of any storage device

- Larger capacity
- Better performance
- Increased reliability

Why RAID

- Achieving the above goals through a single disk (SLED) turns out to be a costly solution
- The idea behind RAID is to achieve these goals by using multiple normal disks in clever ways

How RAID works?

- **Transparency:** RAID (though it consists of multiple disks) maintains the previous disk abstraction except that it is exposed as a single large disk to the OS (filesystem).
- **Ease of Deployment:** Thus OS can continue issuing requests for accessing blocks like it did before without any software changes.

RAID configurations

- There are different ways to arrange multiple disks inside a RAID box to achieve different goals where every configuration gives up on one or few goals to achieve another. The goals
  - Performance (how fast?)
  - Capacity (how much data?)
  - Reliability (how many disks can fail without data loss?)
- Configurations
  - RAID-0: striping
  - RAID-1: mirroring
  - RAID-4: parity
  - RAID-5: rotated parity

Performance Analysis

- Effective capacity
- Throughput
- Latency
- Number of disk failures the system could withstand determines the reliability
- Main workloads: Seq read, seq write, rand read, rand write
### Workload/RAID

<table>
<thead>
<tr>
<th>Workload/RAID</th>
<th>RAID 0</th>
<th>RAID 1</th>
<th>RAID 4</th>
<th>RAID 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seq Read</td>
<td>N.S</td>
<td>N/2. S</td>
<td>(N-1)S</td>
<td>(N-1)S</td>
</tr>
<tr>
<td>Seq Write</td>
<td>N.S</td>
<td>N/2. S</td>
<td>(N-1)S</td>
<td>(N-1)S</td>
</tr>
<tr>
<td>Rand Read</td>
<td>N.R</td>
<td>N.R</td>
<td>(N-1)R</td>
<td>N.R</td>
</tr>
<tr>
<td>Rand Write</td>
<td>N.R</td>
<td>N/2.R</td>
<td>R/2</td>
<td>N/4. R</td>
</tr>
</tbody>
</table>

Assume N is the number of disks used in RAID including the parity disk, S is the sequential bandwidth of a single disk and R is the random bandwidth of a single disk.

### Questions

1. What are the advantages/disadvantages of RAID having the same interface as a block device?
2. Given a workload, how would you go about determining the chunk size for RAID 0?
3. If all you cared about was performance, which RAID level would you use and why?
4. Why is RAID 0 the upper limit on performance?
5. Why is sequential write performance on RAID 4 (N-1)S and not NS? Aren’t all the disks in use?
6. For which RAID levels can you increase random write performance by adding more disks?
7. How does RAID 5 solve the small update problem?
8. Why is random read performance for RAID 5 NR instead of (N-1)R like RAID4? Remember we still have to store parity.
9. Random write performance for RAID 5 is NR/4 because each logical request turns into four requests (note that read of data block and parity block happens concurrently). Since this is the case in RAID 4 as well, why isn’t the random write performance R/4 (instead of R/2)?
10. If you write to two disks in parallel, the seek time (on average) is higher than the seek time on a single disk. Why?