

ECE566 Enterprise Storage Architecture

Individual Homework #1: Drives and RAID

Directions:

- This assignment will be completed in **INDIVIDUALLY**. While you can discuss concepts with others both within and outside your group, actual steps and answers should not be shared!
- The solutions should be collected in a PDF file and submitted via GradeScope.

1 HDD vs. SSD performance [25pts]

1.1 HDD thought experiment [5]

You are optimizing software where the bottleneck is random I/O access to a hard disk drive. You identify two possible improvements: (a) a change to the on-disk data structure so that related data is closer together and often contiguous, or (b) a change so that each record is compressed to a smaller size, but the on-disk layout is otherwise unaffected. Without knowing any additional facts, which do you guess is worth trying first? Why? [5]

1.2 Choosing between HDD and SSD [20]

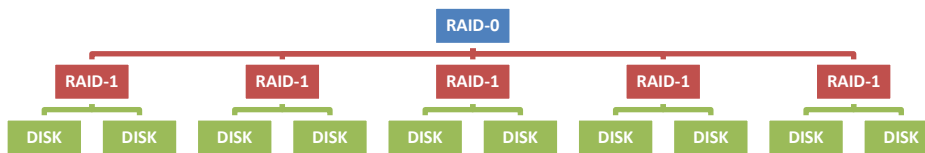
You have a workload that requires 60 TB of capacity and 200,000 IOPS of random I/O performance, mostly reads. You're going to support it with a storage array, and are deciding between buying Samsung 870 EVO 4TB SSDs or Seagate IronWolf Pro 16TB NAS HDDs.

- (a) Research the two drives, and identify published benchmarks for IOPS performance (don't trust manufacturer datasheets). Hint: Storage Review is a well-known third-party reviewer of storage devices. You can assume the I/O size is 4kB. Include a link to your sources. [4]
- (b) Identify the current street price for each drive. Include a link to your sources. [4]
- (c) Ignoring RAID effects and assuming performance is simply additive, how many SSDs are needed? Is this number driven by capacity or performance? [4]
- (d) Ignoring RAID effects and assuming performance is simply additive, how many HDDs are needed? Is this number driven by capacity or performance? [4]
- (e) How much would each option cost, and which is cheaper? [4]

2 RAID [70 pts]

2.1 RAID layouts [25]

- (a) How many disks can fail in a 4-disk RAID-0 without data loss? What fraction of the storage is dedicated to redundancy? What is the read throughput relative to using a single disk? The write throughput? [5]
- (b) How many disks can fail in a 2-disk RAID-1 without data loss? What fraction of the storage is dedicated to redundancy? What is the read throughput relative to using a single disk? The write throughput? [5]
- (c) How many disks can fail in a 6-disk RAID-5 without data loss? What fraction of the storage is dedicated to redundancy? What is the read throughput relative to using a single disk? [5]
- (d) How many disks can fail in an 18-disk RAID-6 without data loss? What fraction of the storage is dedicated to redundancy? What is the read throughput relative to using a single disk? [5]
- (e) Assume a RAID-1+0 with 10 disks organized into a RAID-0 of five 2-disk RAID-1 sets, as shown below:



What is the minimum number of disk failures that can cause data loss? What is the maximum that can fail *without* data loss? What fraction of the storage is dedicated to redundancy? [5]

2.2 RAID reliability modeling [10]

Let's do some statistics to understand how big we can safely make RAID arrays. If you need a refresher, [this tutorial](#) can remind you how to compute the probability of at least k events of probability p happening over n trials. In our case, k will be the number of drive failures to cause data loss (2 for RAID5, 3 for RAID6), p is the annual failure rate of our drives, and n is the number of drives in the array. Assume a constant 4% annual drive failure rate ($p=0.04$).

- (a) What is the maximum number of drives we can put in a RAID 5 array such that the annual probability of data loss for the array is under 1%? [5]
- (b) What is the maximum number of drives we can put in a RAID 6 array such that the annual probability of data loss for the array is under 1%? [5]

Hint to check your work: the answer to part (a) is a power of two; the answer to part (b) is prime.

2.3 RAID details [40]

- (a) What role do *hot spares* play in RAID deployments? [10]
- (b) Why is a RAID configuration **not** the same as a backup solution? Describe a scenario in which data loss could occur without disk failure. [10]
- (c) Many vendors have developed extensions to the standard RAID levels, and studying these can offer interesting insight into the engineering trade-offs involved in designing a storage subsystem. **Choose one** of the questions below to research and answer. The Wikipedia article "[Non-standard RAID Levels](#)" can be a good starting point in your research. [20]
 - 1. The Linux software RAID driver ("md") has a dedicated RAID-10 mode that offers some unique features. In this approach, describe the "near" and "far" layouts. What benefits to these techniques have?
 - 2. What is RAID-1E? What is the storage overhead for this approach? For a 5-disk RAID-1E, what is the minimum number of disk failures needed to cause data loss, and *which* disks must fail in this scenario? What is the maximum number of disks that can fail *without* data loss? What performance effects does this approach have?
 - 3. What is the primary advantage of RAID 5E, 5EE, and 6E? What are the disadvantages? What factors would influence you to choose one of these approaches over a traditional RAID approach?
 - 4. BeyondRAID (from the Drobo line of consumer storage devices) and Synology Hybrid RAID (from Synology storage devices) both allow drives of varying capacity to be used while still providing single-disk-failure redundancy. How do these technologies work? How could you replicate such a layout using nothing but normal partitioning and a software RAID system, e.g. Linux "md"?