6.033: Fault Tolerance: Reliability via Replication
Lecture 14
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0. Introduction
   - Done with OSes, networking
   - Now: how to systematically deal with failures, or build "fault-tolerant" systems
     - We'll allow more complicated failures and also try to recover from failures
   - Thinking about large, distributed systems. 100s, 1000s, even more machines, potentially logated across the globe.
   - Will also have to think about what these applications are doing, what they need

1. Building fault-tolerant systems
   - General approach:
     1. Indentify possible faults (software, hardware, design, operation, environment, ...)
     2. Detect and contain
     3. Handle the fault
        - do nothing, fail-fast (detect and report to next higher-level), fail-stop (detect and stop), mask, ...
   - Caveats
     - Components are always unreliable. We aim to build a reliable system out of them, but our guarantees will be probabilistic
     - Reliability comes at a cost; always a tradeoff. Common tradeoff is reliability vs. simplicity.
     - All of this is tricky. It's easy to miss some possible faults in step 1, e.g. Hence, we iterate.
     - We'll have to rely on *some* code to work correctly. In practice, there is only a small portion of critical code We have stringent development processes for those components.

2. Quantifying reliability
   - Goal: increase availability
   - Metrics:
     MTTF = mean time to failure
     MTTR = mean time to repair
     MTBF = mean time between failures = MTTF + MTTR
     availability = MTTF / (MTTF + MTTR)
   - Example: Suppose my OS crashes once every month, and takes 10 minutes to recover.
     MTTF = 30 days = 720 hours = 43,200 minutes
     MTTR = 10 minutes
     availability = 43,200 / 43,210 = .9997
   - This is one way to think about reliability! Different systems will get more specific

3. Reliability via Replication
   - To improve availability, add redundancy
   - One way to add redundancy: replication
   - Today: replication within a single machine to deal with disk failures
     - Tomorrow in recitation: replication across machines to deal with machine failures.

4. Dealing with disk failures
   - Why disks?
     - Starting from single machine because we want to improve reliability there first before we move to multiple machines
     - Disks in particular because if disk fails, your data is gone. Can replace other components like CPU easily. Cost of disk failure is high.
   - Are disk failures frequent?
     - Manufactures claim high MTBF, but use AFR to give a more reasonable datapoint (see slides)
     - Even if probability of a specific disk failing is low, the probability of *some* disk failing in a big system is high

5. Whole-disk failures
   - General scenario: entire disk fails, all data on that disk is lost. What to do? RAID provides a suite of techniques.
   - RAID 1: Mirror data across 2 disks.
     - Pro: Can handle single-disk failures
     - Pro: Performance improvement on reads (issue two in parallel), not a terrible performance hit on writes (have to issue two writes, but you can issue them in parallel too)
     - Con: To mirror N disks' worth of data, you need 2N disks
   - RAID 4: With N disks, add an additional parity disk. Sector i on the parity disk is the XOR of all of the sector i's from the data disk.
     - Pro: Can handle single-disk failures (if one disk fails, xor the other disks to recover its data)
       - Can use same technique to recover from single-sector errors
     - Pro: To store N disks' worth of data we only need N+1 disks
     - Pro: Improved performance if you stripe files across the array. E.g., an N-sector-length file can be stored as one sector per disk. Reading the whole file means N parallel 1-sector reads instead of 1 long N-sector read.
       - This is really a result of having N disks of data, not of RAID specifically
       - RAID is a system for reliability, but we never forget about performance, and in fact performance influenced much of the design of RAID.
     - Con: Every write goes to the parity disk.

- RAID 5: Same as RAID 4, except intersperse the parity sectors amongst all N+1 disks to load balance writes. (see slide for diagram)
  - You need a way to figure out which disk holds the parity sector for sector i, but it's done systematically; controller can handle it
- RAID 5 used in practice, but falling out in favor of RAID 6, which uses the same techniques but provides protection against two disks failing at the same time.

6. Your future
   - RAID doesn't solve everything.
     - E.g., what about failures that aren't independent?
   - We are going to work to develop abstractions that allow us to be more systematic about handling failures.
   - Lectures will tackle these abstractions on larger and larger systems.