Paris Research & Innovation Center

Improving the Reliability and Repairability of Storage Systems Using 2D Erasure Coding

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The Problem: Replication is not Cheap

Replication: Why and How?

- Huge volumes of data maintained by storage systems
- To scale-out, it has to be distributed
- Failures are norm rather than exception
- Redundancy is used to guarantee fault tolerance
- Replication is the simplest and the most commonly used form of redundancy
  - Identical copies (de-facto standard: 3 copies)

Replication Can Be Expensive

- According to the "new" conventional wisdom, storage is cheap and replication is always affordable
- But at the scale of petabytes and exabytes, it's not the case anymore
  - e.g., Facebook has 100PB of data and it doubles every year
  - Similar for Cloud Servers
- A 50% reduction in storage would save tens of millions of dollars

Alternatives Needed

- Requirements
  - Lower storage
  - Same or higher reliability
  - No drastic performance degradation

An Incomplete Solution: Erasure Codes

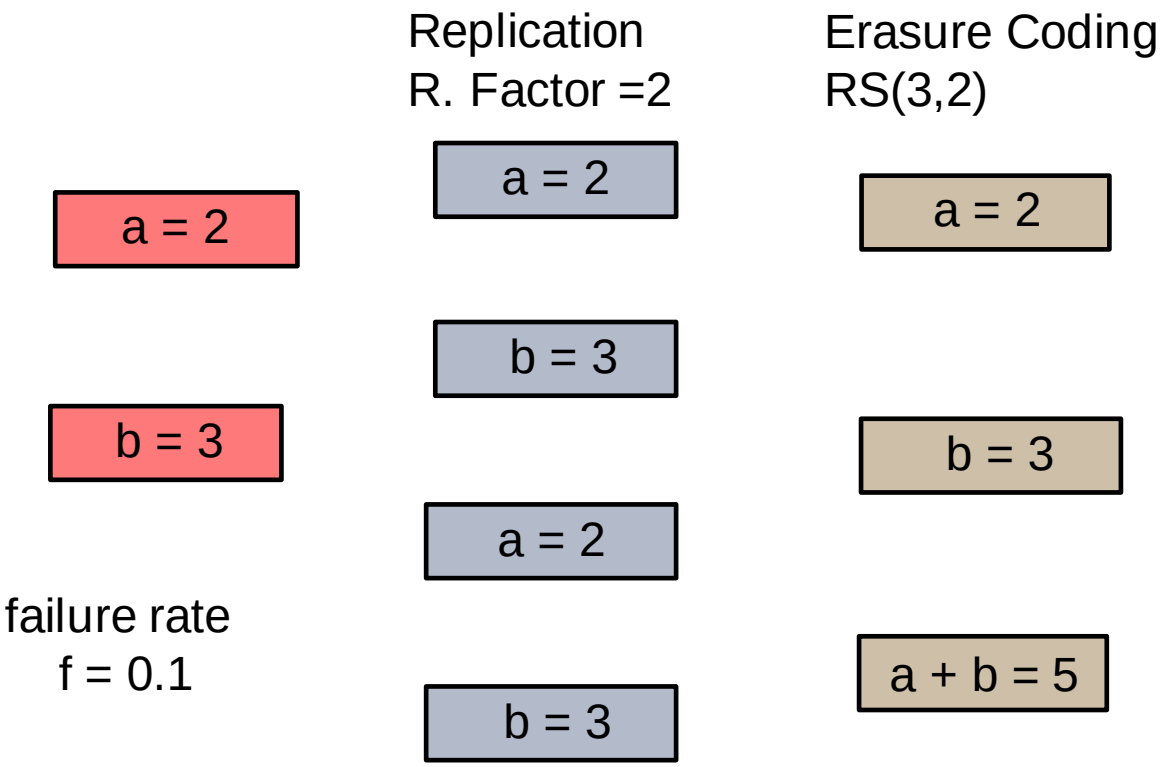
Erasure Codes: History

- Invented by the Coding Theory community
  - A sender; A receiver; An erasure channel in between
  - Along with the data some redundancy in introduced so that receiver can recover the message even if some parts of the data are erased
- Reed-Solomon Codes: RS (n,k)
  - One of the most well-known and widely-used instances
  - Encodes '**k**' data parts into '**n**' encoded parts (n>k)
  - Data can recovered using any k subset of n
- Used in wide range of systems (e.g., satellite communications, CDs, QR codes,…)

Erasure Codes: Basics

- Based on linear algebra and finite fields (Galois fields)
- Mathematically complex, but well understood and with many efficient algorithms and implementations (including dedicated hardware circuits)
- Not included in this talk, but I would be happy to provide detailed information afterwards

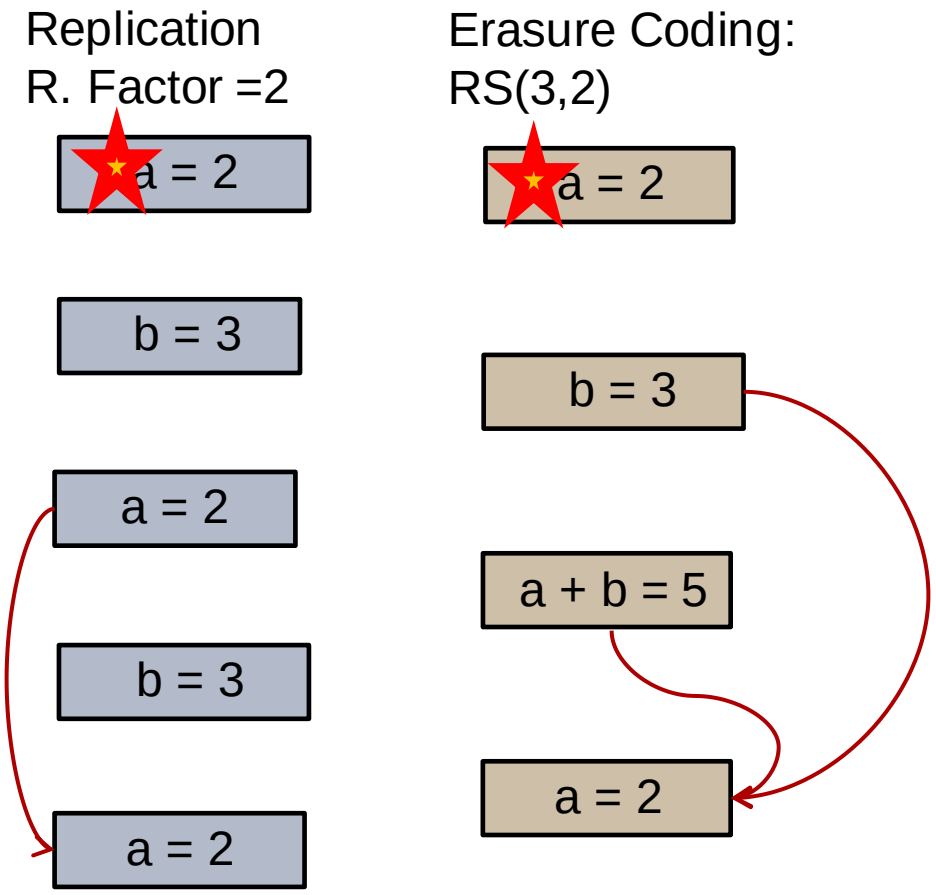
Erasure Codes: Simple Example



25% saving in storage!

In realistic scenarios, it reduces storage by up to **50%** and guarantees **higher availability**

Repair Inefficiency of EC Storages – Example



Cost:	1 blk	2 blks
Fan-in:	1	2

- Repair Metrics:
  - Cost (no. blks)
  - Fan-in (no. nodes)
  - Time
  - …
- The challenge: make the repair fast

Towards a Complete Solution: CORE

State-of-the-Art

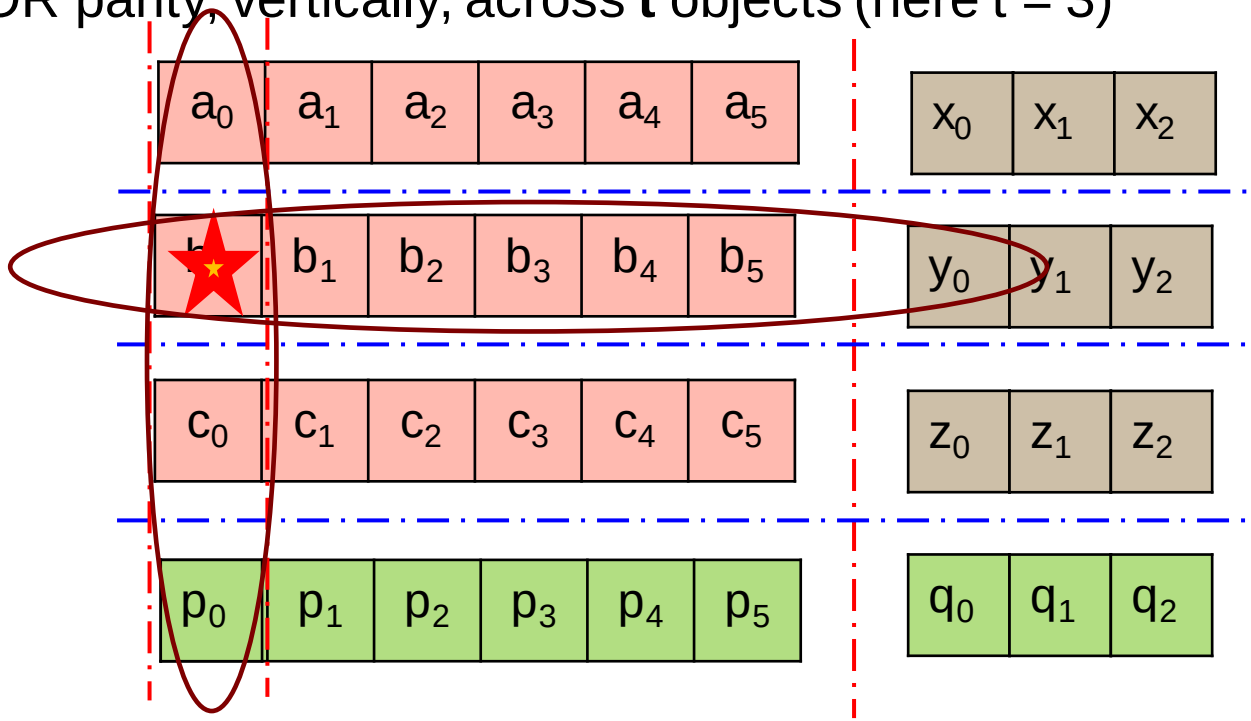
- Theory approaches
  - New Codes with inherently better repairability
    - e.g., Regenerating Codes [Dimakis et. al, 2010]
    - e.g., Self-repairing Codes [Oggier and Datta, 2011]
  - Mathematically complex
  - No real-system implementation
- Engineering approaches
  - Codes on Codes
  - Easier to understand
  - Possible to reuse the existing implementations and optimizations
  - Examples:
    - Local Reconstruction Codes (**LRC**) in Microsoft Azure
    - **CORE: C**ross-**O**bject **RE**dundancy

CORE - The Basic Idea

- Introduce **two different kinds of redundancy**
  - Erasure Code for individual objects
    - for availability
  - RAID-4 like parity across encoded pieces of different objects
    - for repairability

CORE - Example

- Three objects
- Reed Solomon (n=9,k=6) horizontally and individually
- XOR parity, vertically, across **t** objects (here t = 3)



Bandwidth Usage: 3 blks (instead of 6 blks)

CORE – Essential Properties

- Reduces the repair cost (no. blocks)
- Reduces repair fan-in
- Requires a much cheaper computation in most of the cases (XOR vs. RS)
  - Can be further optimized by pipelining
- Retains comparable storage overhead

CORE: Performance Analysis

- Analytically
  - Versus Reed-Solomon coding and Microsoft's LRC codes
  - CORE and LRC much more efficient in repairs
  - For same storage overhead, CORE provides higher availability than LRC
  - Details in the paper
- Experimentally
  - Versus Reed-Solomon coding

Implementation

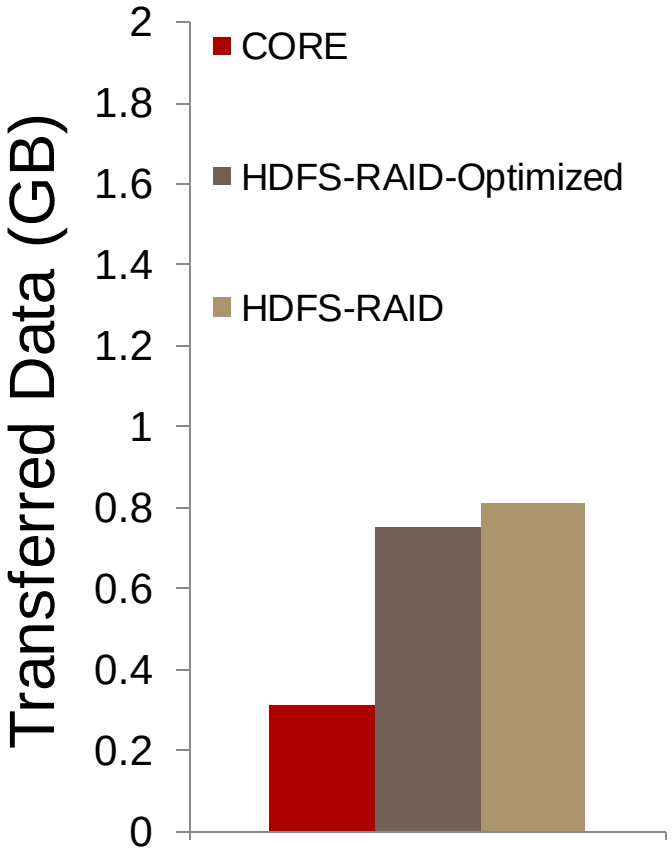
- HDFS-RAID
  - Developed at Facebook
  - Wraps around Apache HDFS
- Optimized HDFS-RAID
  - **Opt1**:Repair using exactly "k" blocks
    - Beneficial in network-scarce setups
  - **Opt2**: Simultaneous repairs (avoiding "doomed" recoveries)
- Integrated into HDFS-RAID
  - Named StorageCORE
  - Available at:

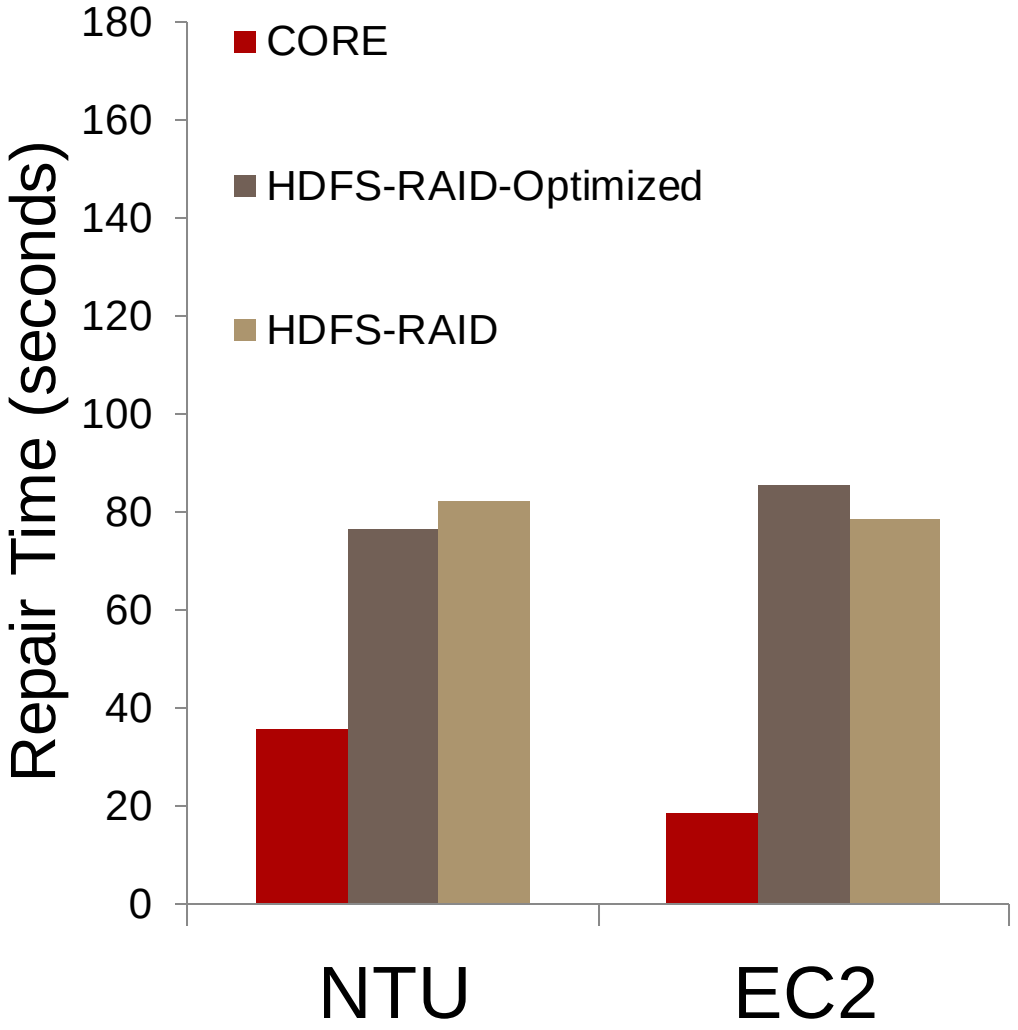
http://sands.sce.ntu.edu.sg/StorageCORE/

Experiments - Setup

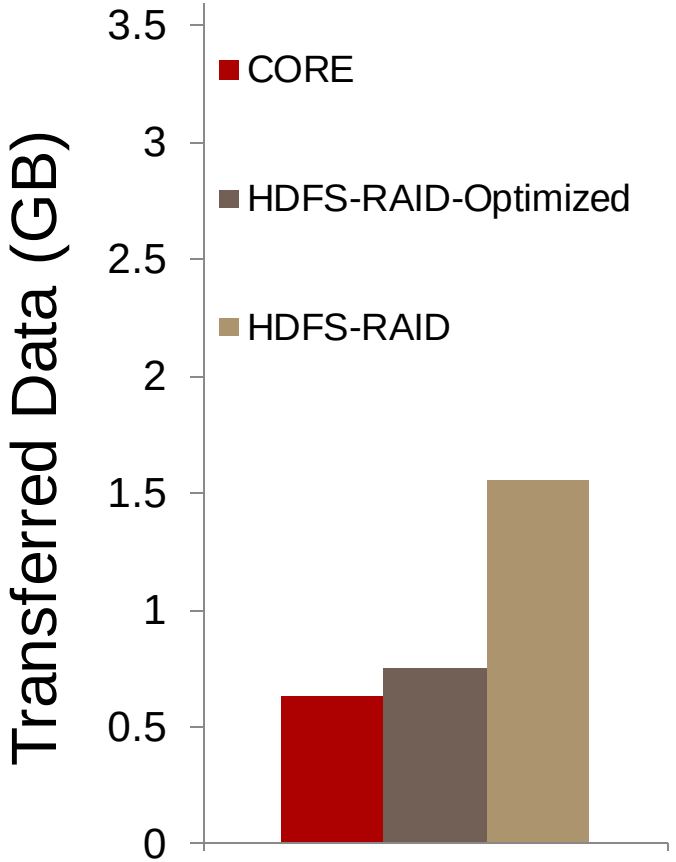
- Two different clusters, each of 20 nodes
  - A network-critical cluster (**NTU**)
  - A computation-critical cluster (**EC2**)
- Coding parameters
  - (n=14,k=12,t=5)
    - Similar to Microsoft's
  - (n=9,k=6,t=3)
    - Similar to Google's

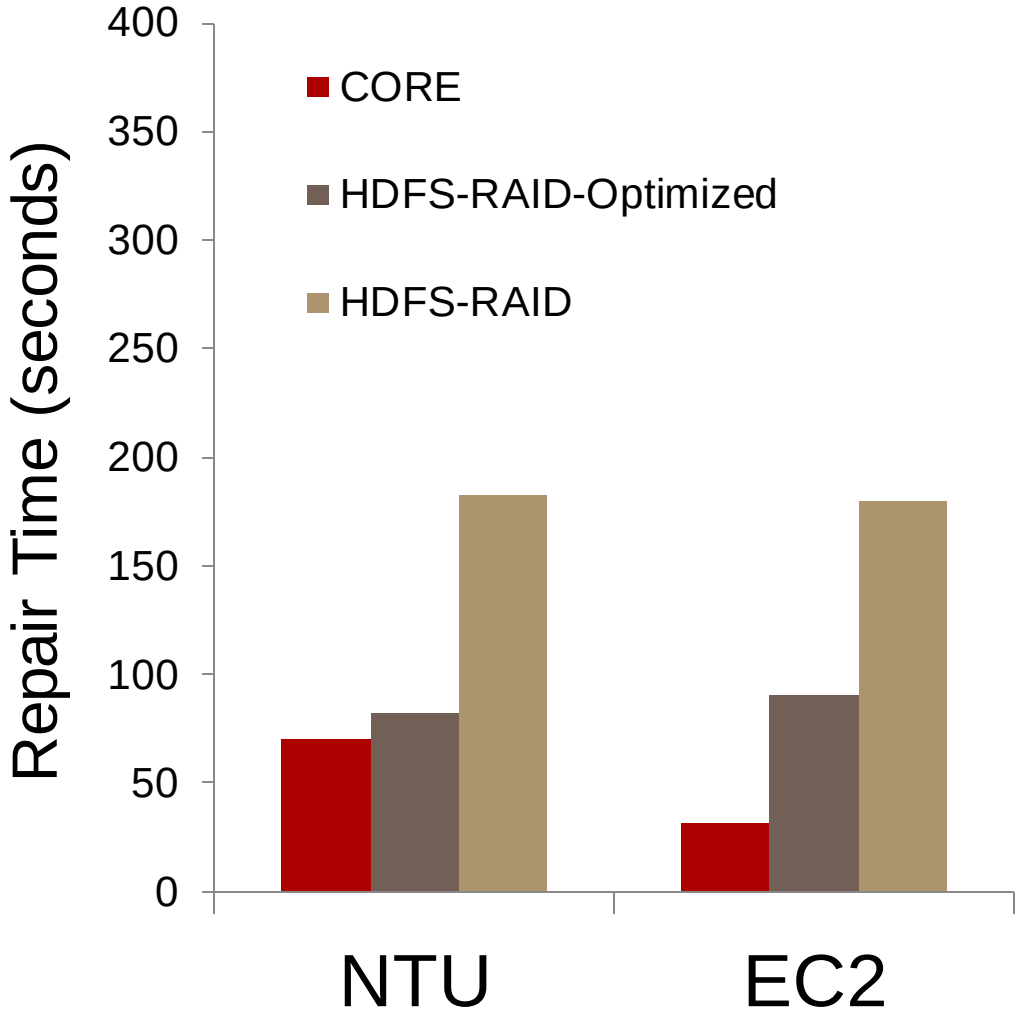
Repairing One Failure (**X**)





Repairing Two Failures (**XX**)





Summary

- At petabytes-scale, replication is prohibitive
- Erasure Coding is an alternative, but it is has some shortcomings, most notably, with repairs
- We proposed CORE, a simple and effective solution
- The benefits of CORE has been shown through experimental and analytical studies
- CORE also poses a range of novel challenges, most notably, efficient scheduling of multiple repairs
  - Our proposed algorithm, RGS, generates efficient schedules

http://sands.sce.ntu.edu.sg/CodingForNetworkedStorage