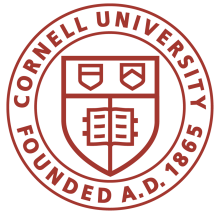
Tiered Replication: A Cost-effective Alternative to Full Cluster Geo-replication

Asaf Cidon, *Robert Escriva*, Sachin Katti,
Mendel Rosenblum and *Emin Gün Sirer*

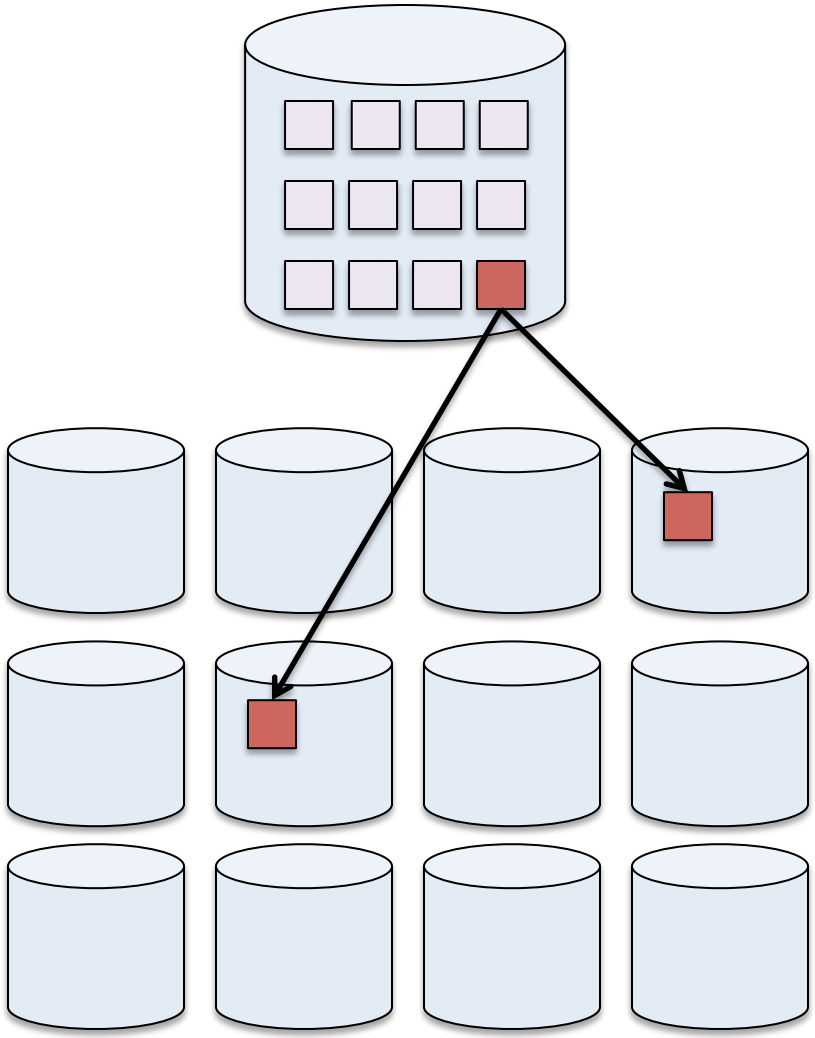


Stanford University



Cornell University

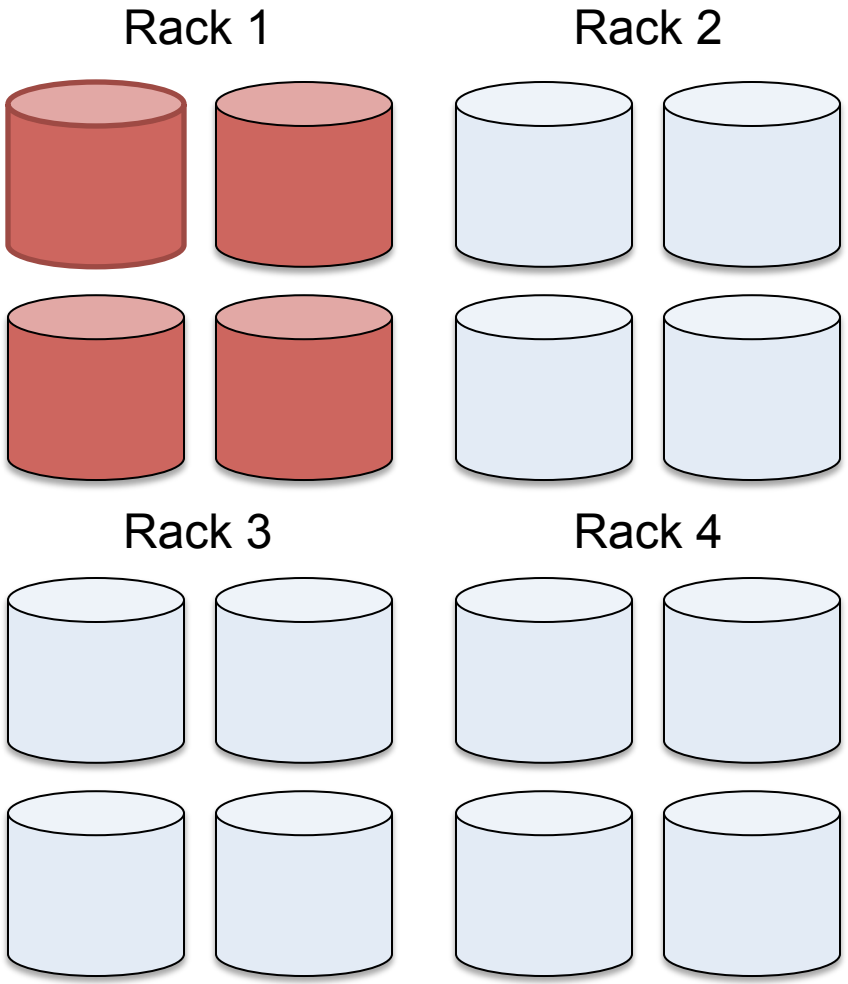
Replication Used for Durability



3-way replication used by:

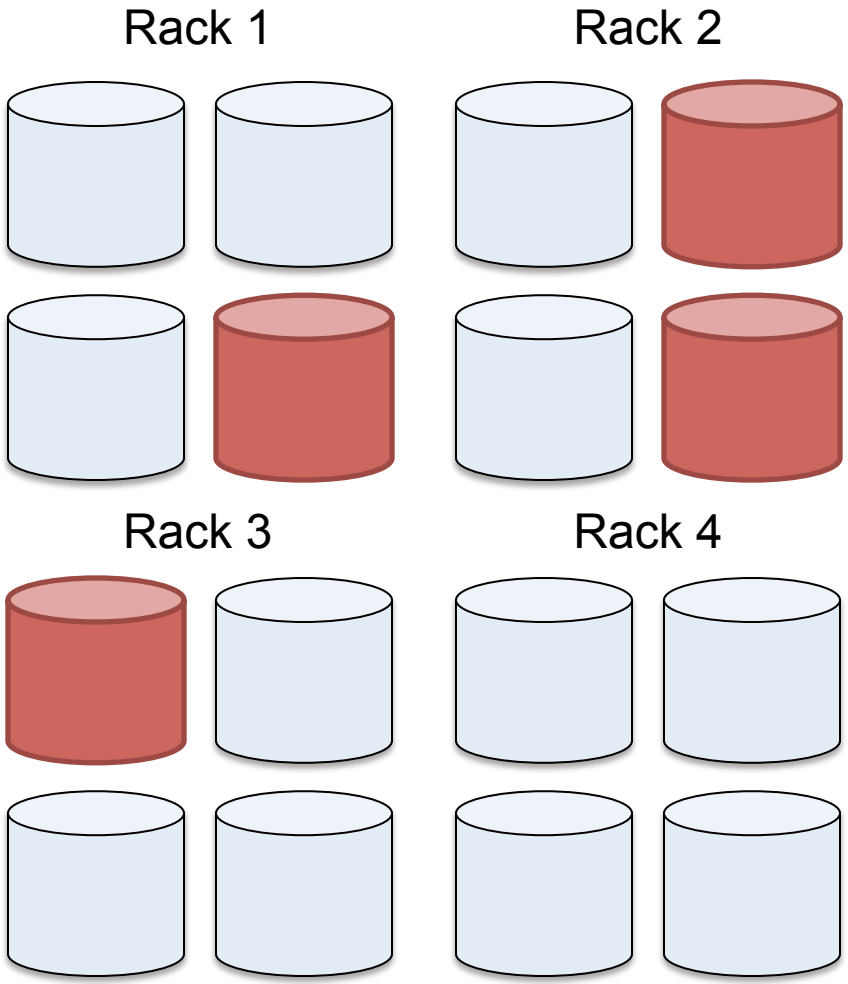
- HDFS
- GFS
- Windows Azure
- …

Independent Node Failures



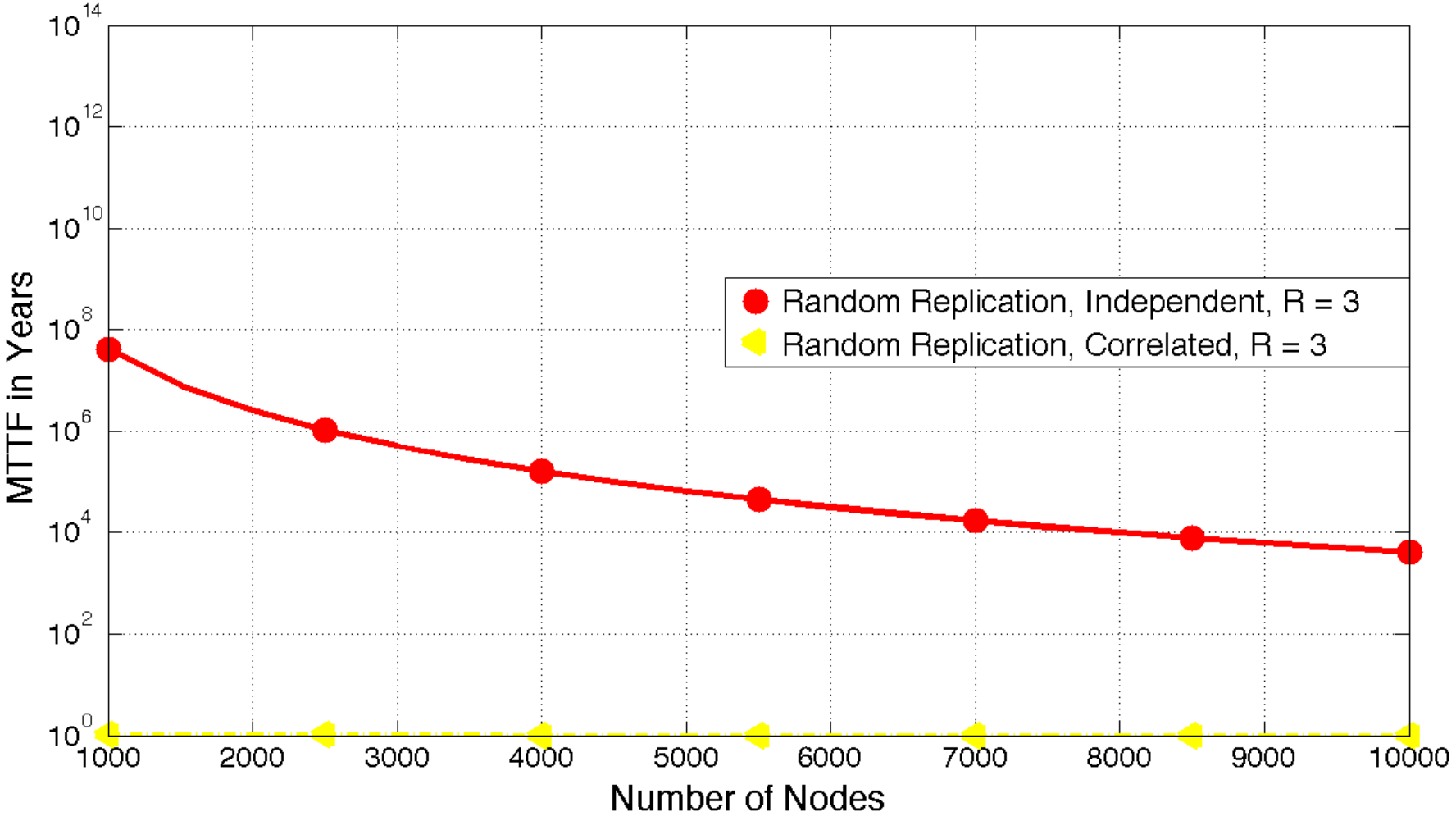
- Frequent
  - 100s a year
- Localized
  - 1 node / 1 rack
- Data Loss Prevention
  - Fast node recovery

Correlated Node Failures

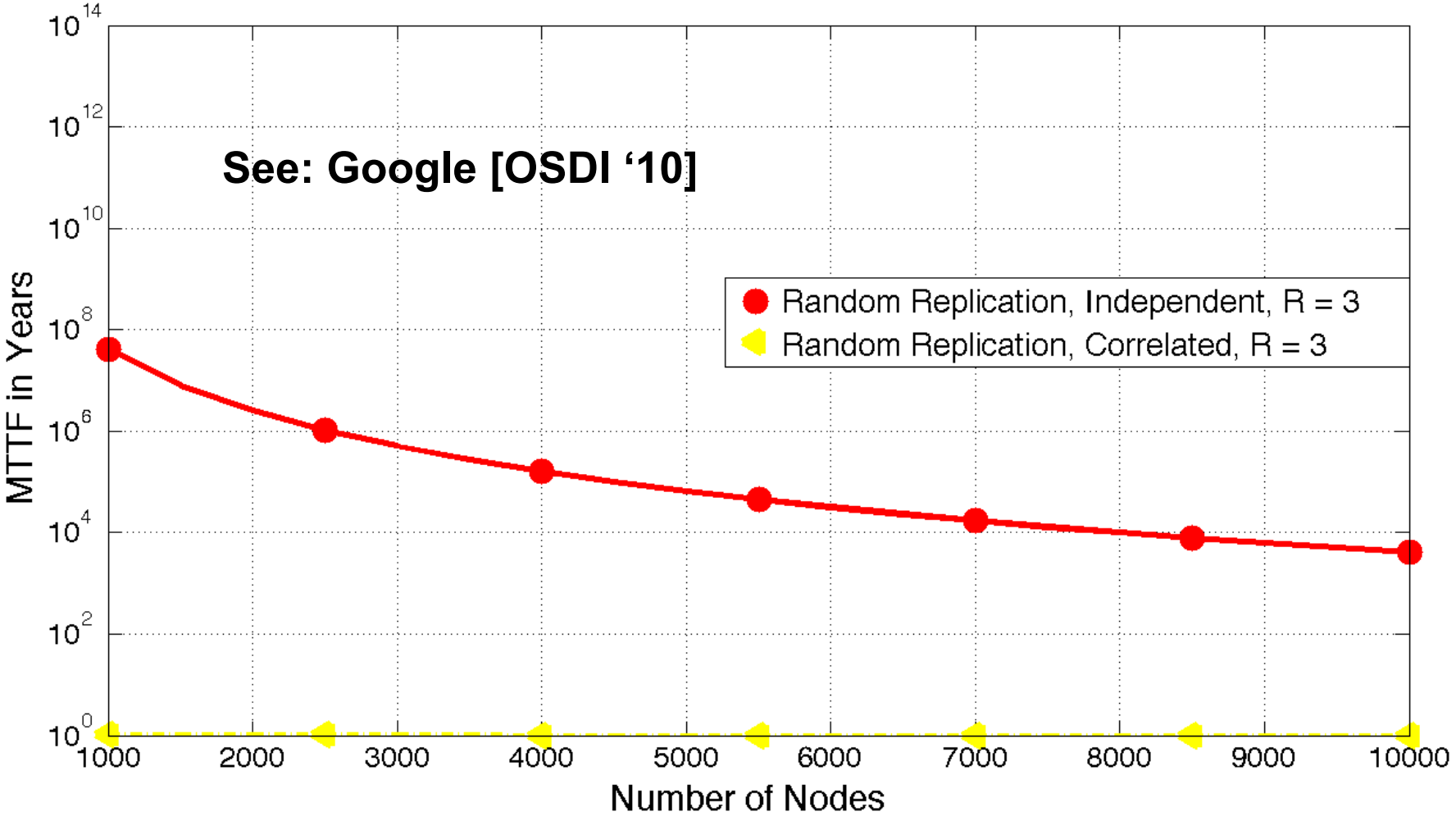


- Infrequent
  - 1-5 a year
- Not localized
  - E.g., power outage
- Data Loss Prevention
  - Geo-replicate

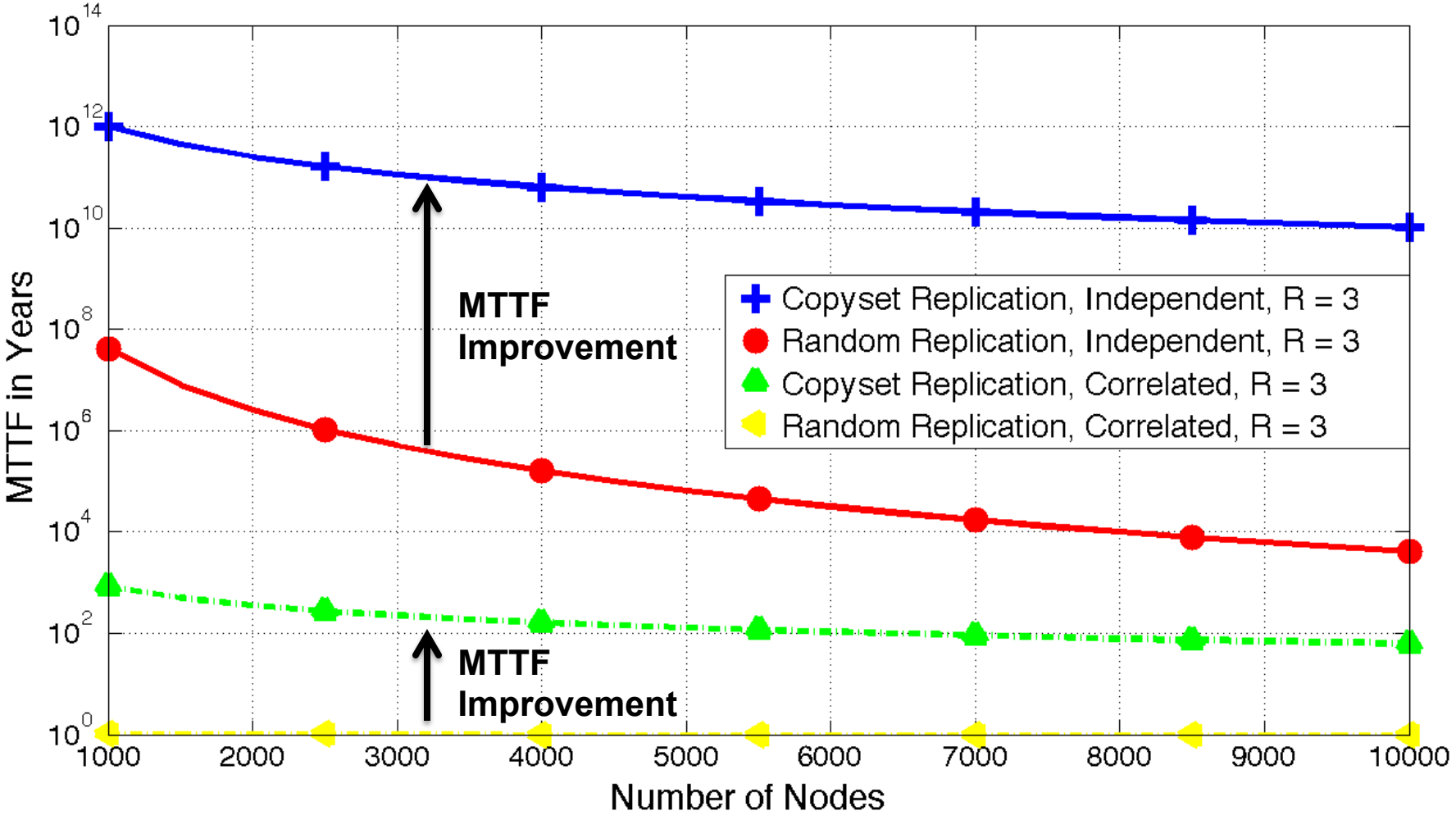
Replication Focused on Wrong Type of Failure



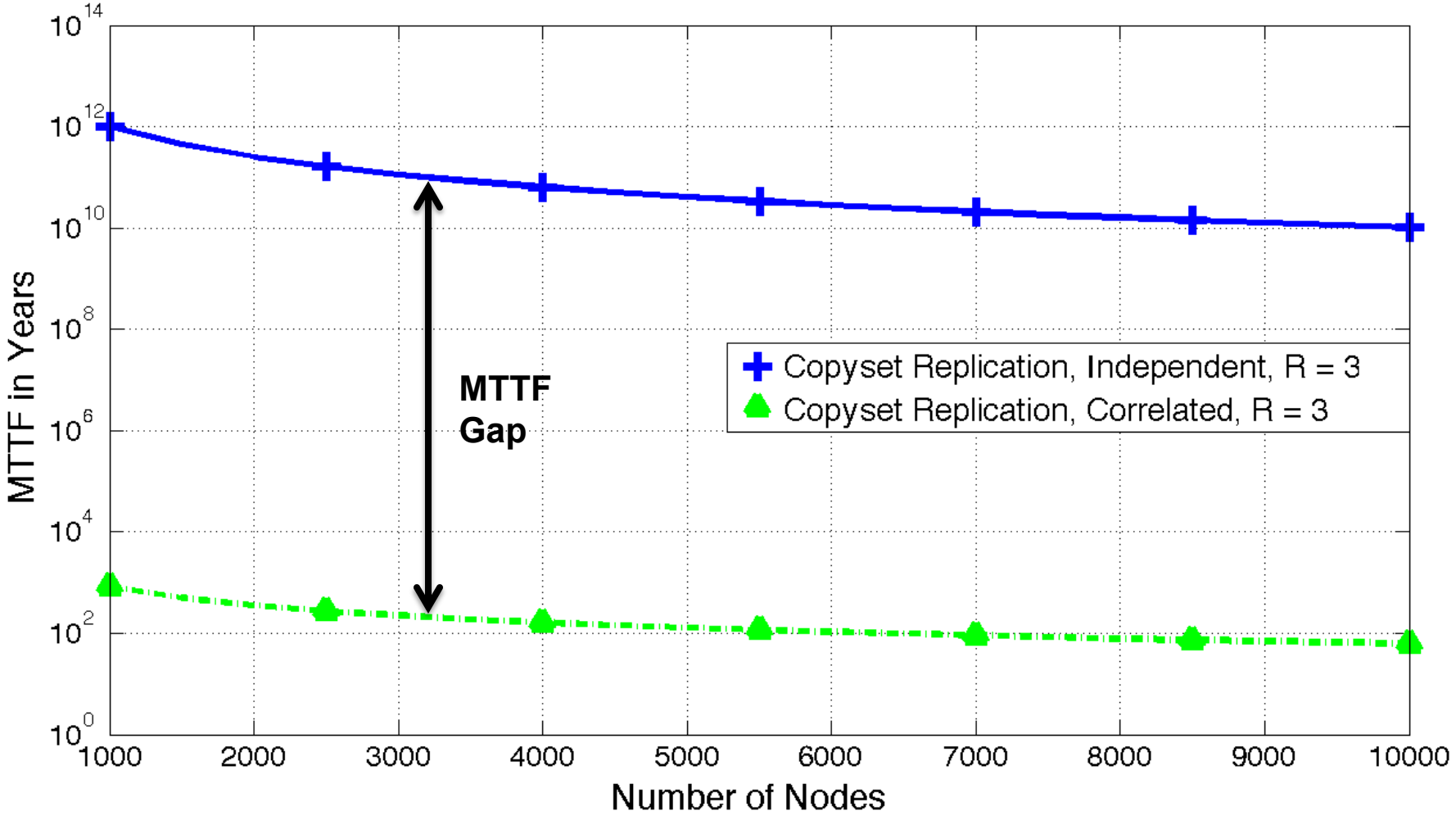
Replication Focused on Wrong Type of Failure



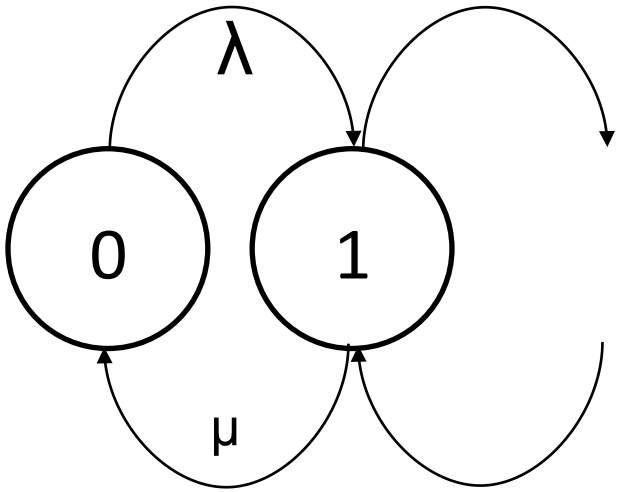
Replication Focused on Wrong Type of Failure



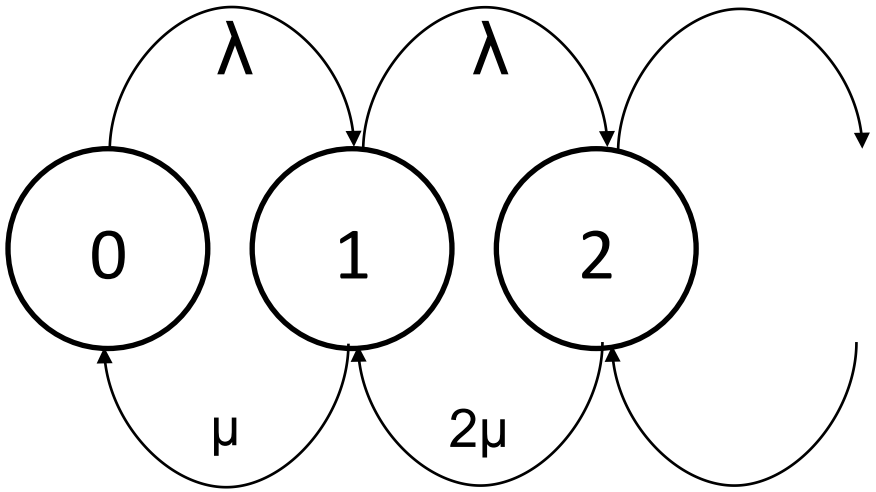
Replication Focused on Wrong Type of Failure



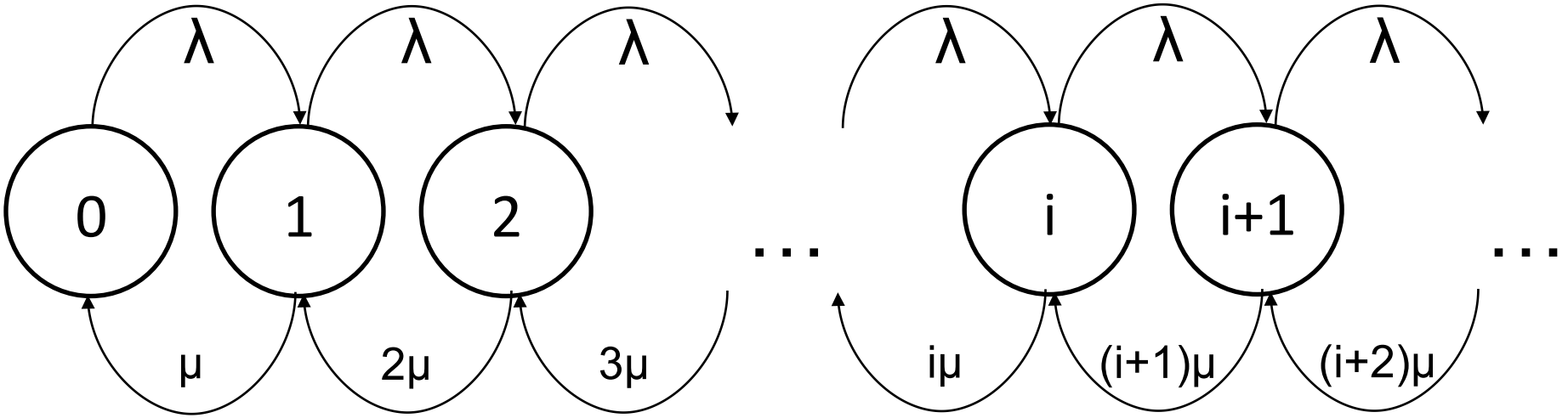
Probability of i Nodes Failing Simultaneously



Probability of i Nodes Failing Simultaneously



Probability of i Nodes Failing Simultaneously

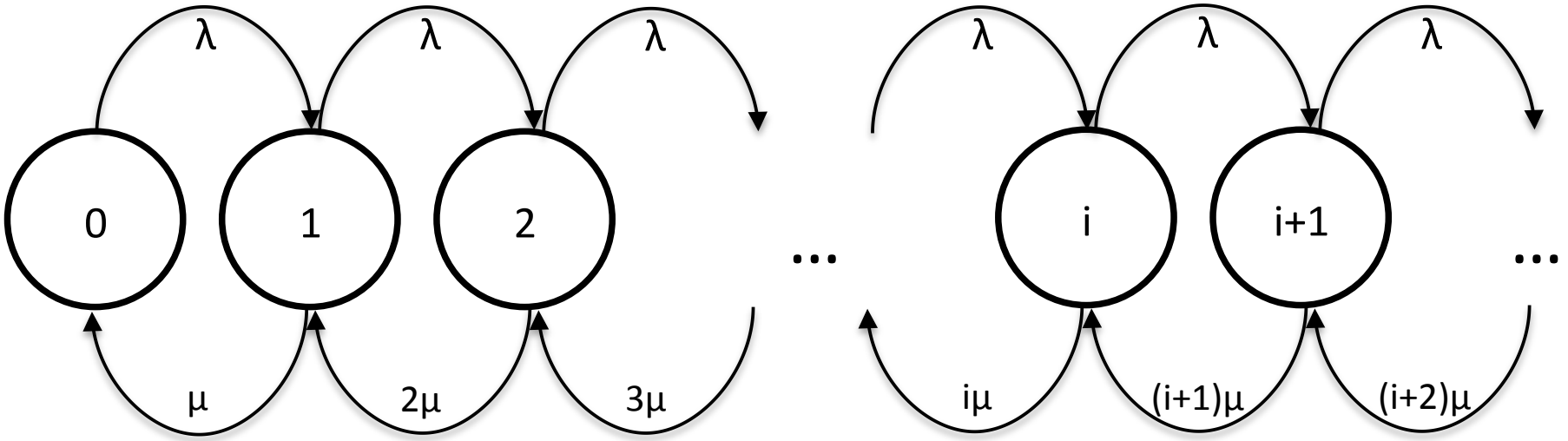


Practical Parameters

- Independent node failure MTTF: 10 years
  - Cluster size: 5,000 nodes
  - **Node failure every 1051 minutes**
- Recovery time of a single node: 60 minutes
  - 10 nodes participate in parallel recovery
  - **6 minute node recovery time**

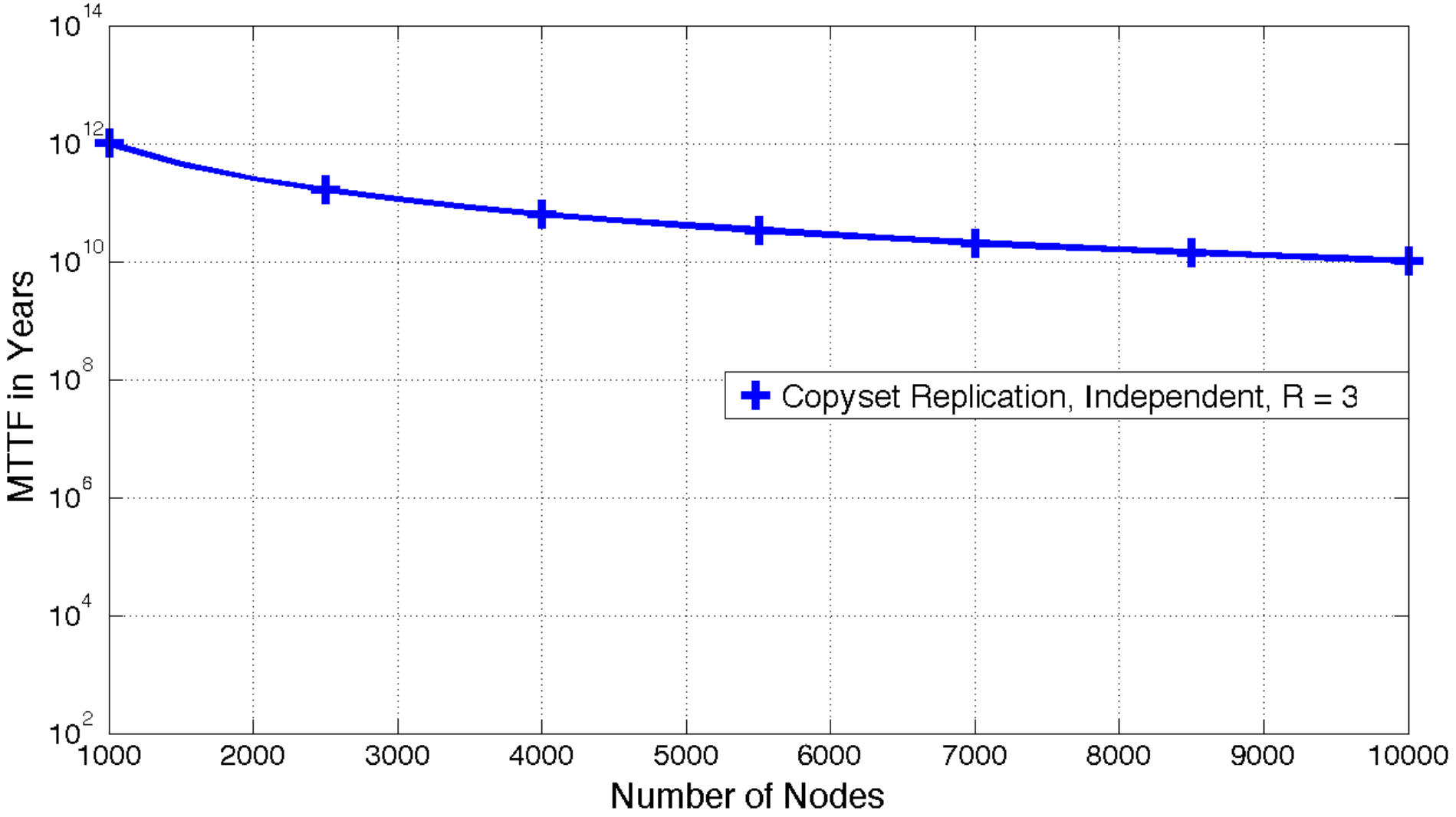
- 6 minutes << 1051 minutes

Markov State > 1 is Improbable

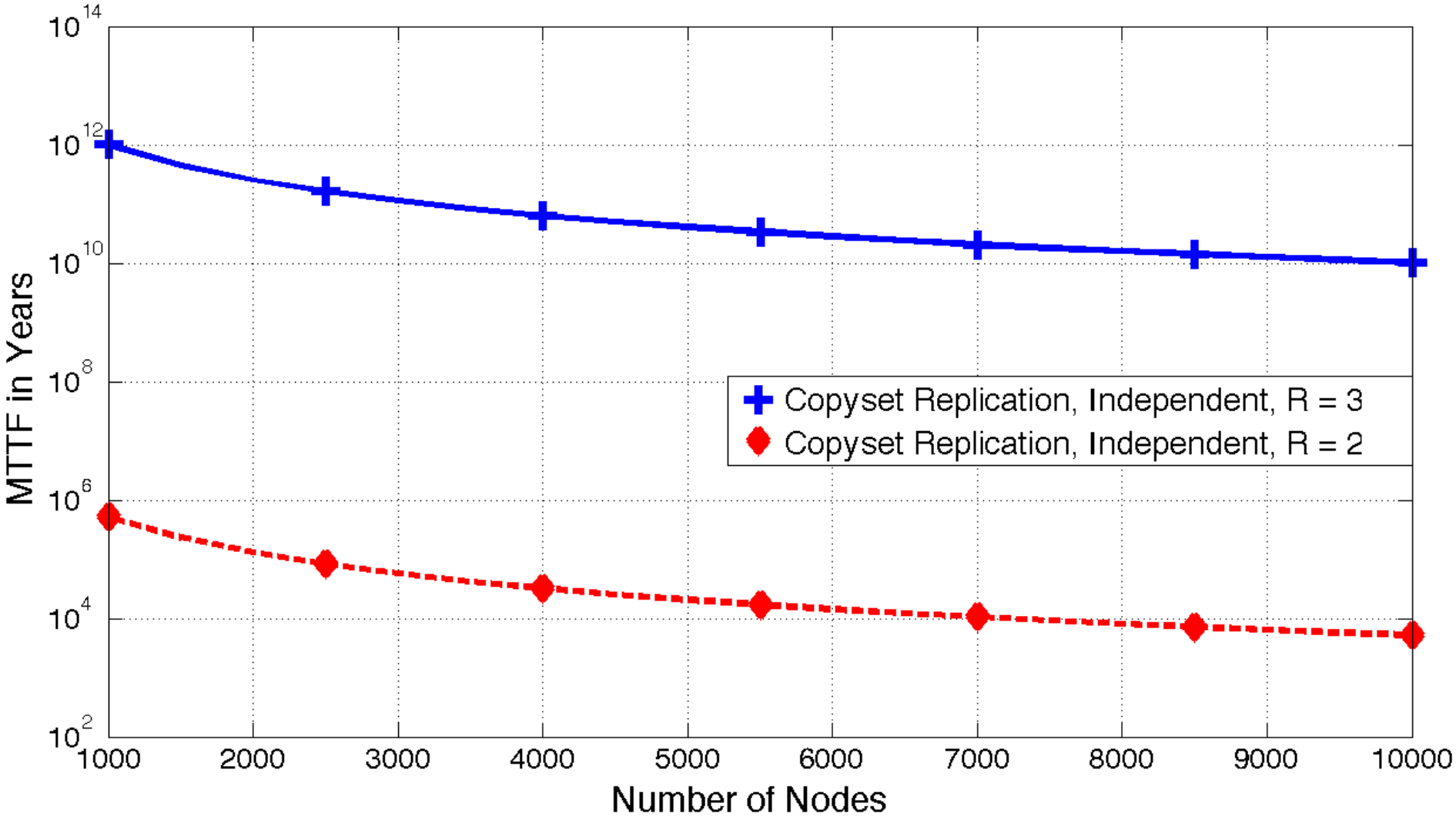


# Nodes	Pr(2)	Pr(3)	Pr(4)
5,000	1.6 x 10^-5	3.1 x 10^-8	4.4 x 10^-11

Simultaneous Independent Node Failures are Rare



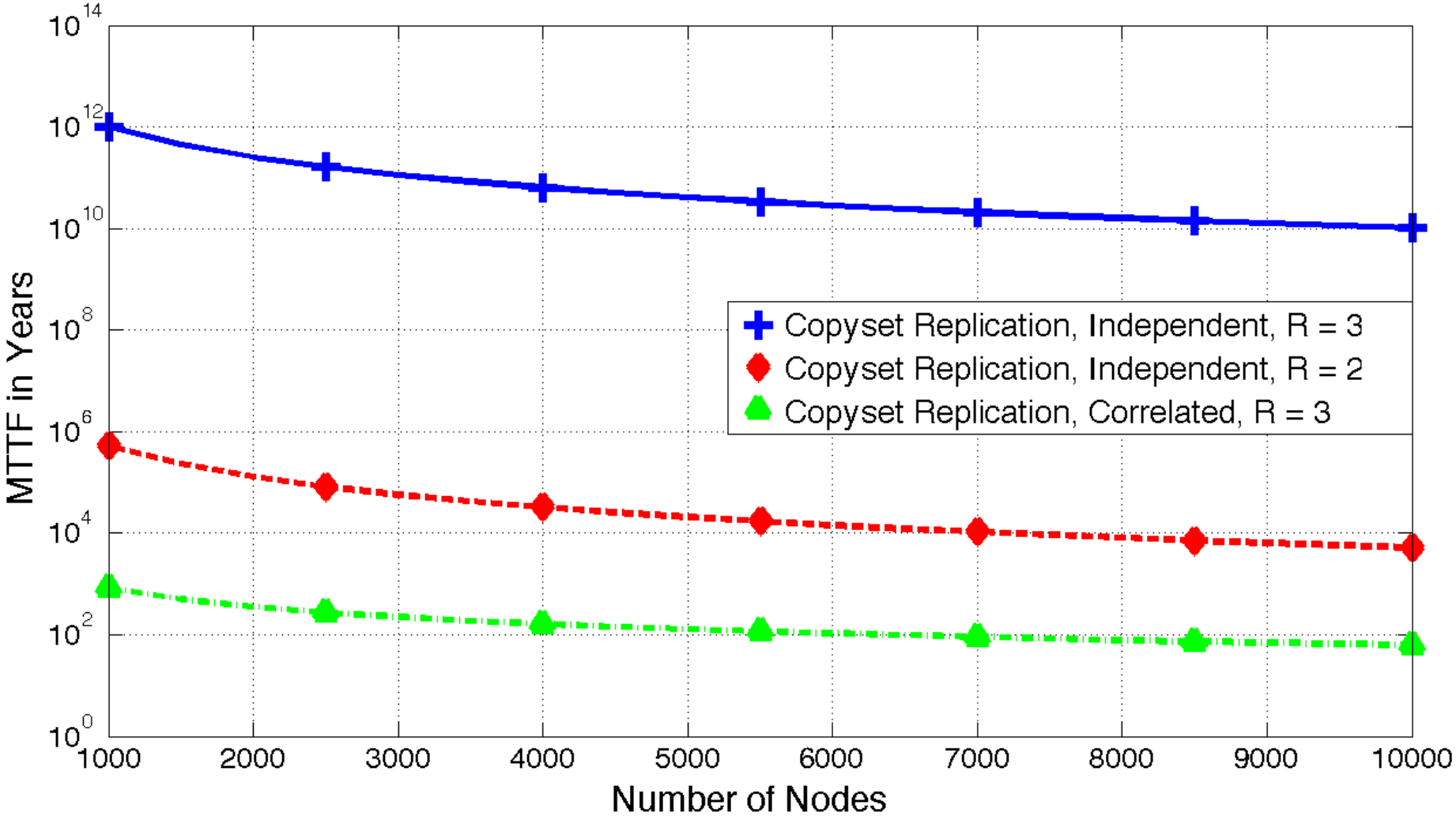
R = 3 is Excessive for Independent Node Failures



Correlated Failures

- i nodes fail simultaneously
  - For example, power outage
  - 0.5%-1% of nodes (see Yahoo, LinkedIn reports)

R = 3 is Inadequate for Correlated Failures



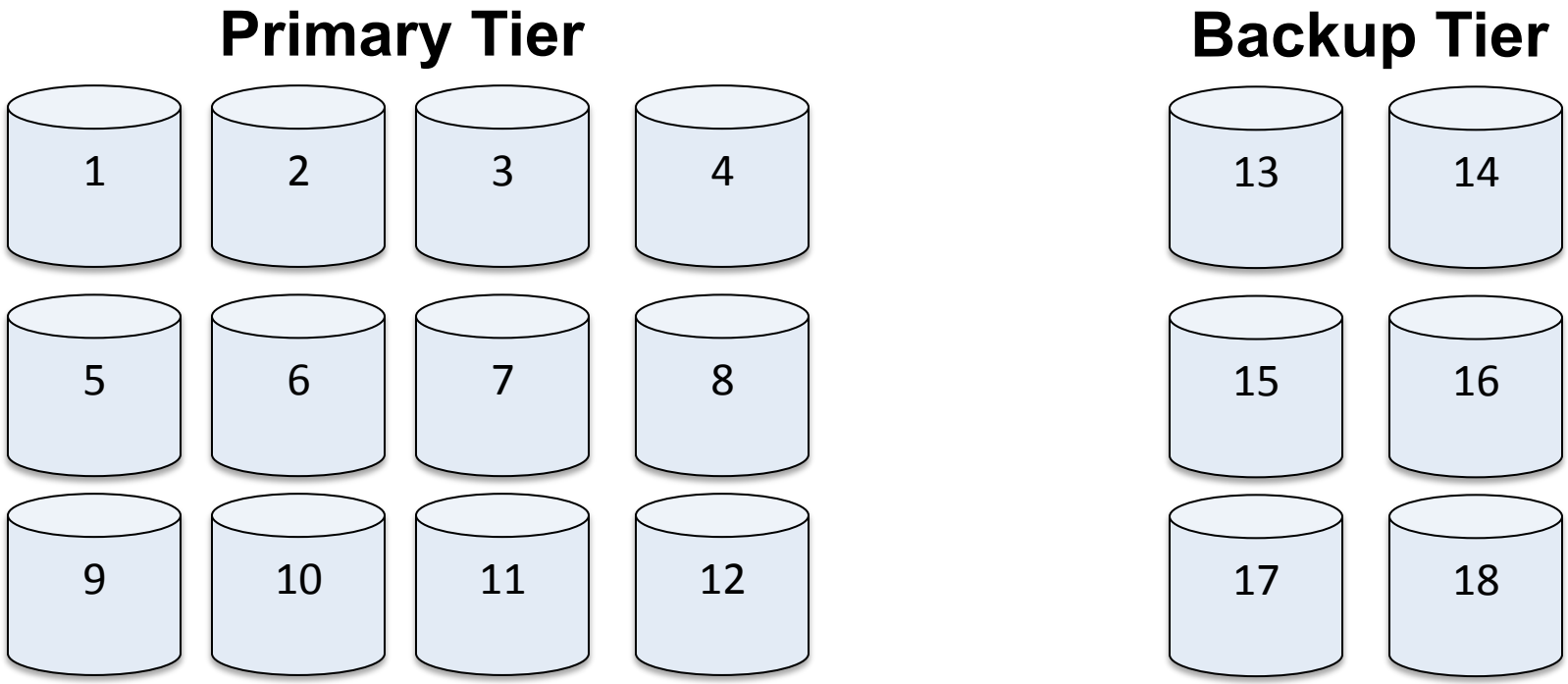
The Third Replica is an Overkill for Independent Node Failures

- Third replica is rarely used for recovery:
  - Read every 100,000 years in the case of independent node failures
  - Read from every 10 years in the case of correlated failures
- Third replica is write dominated

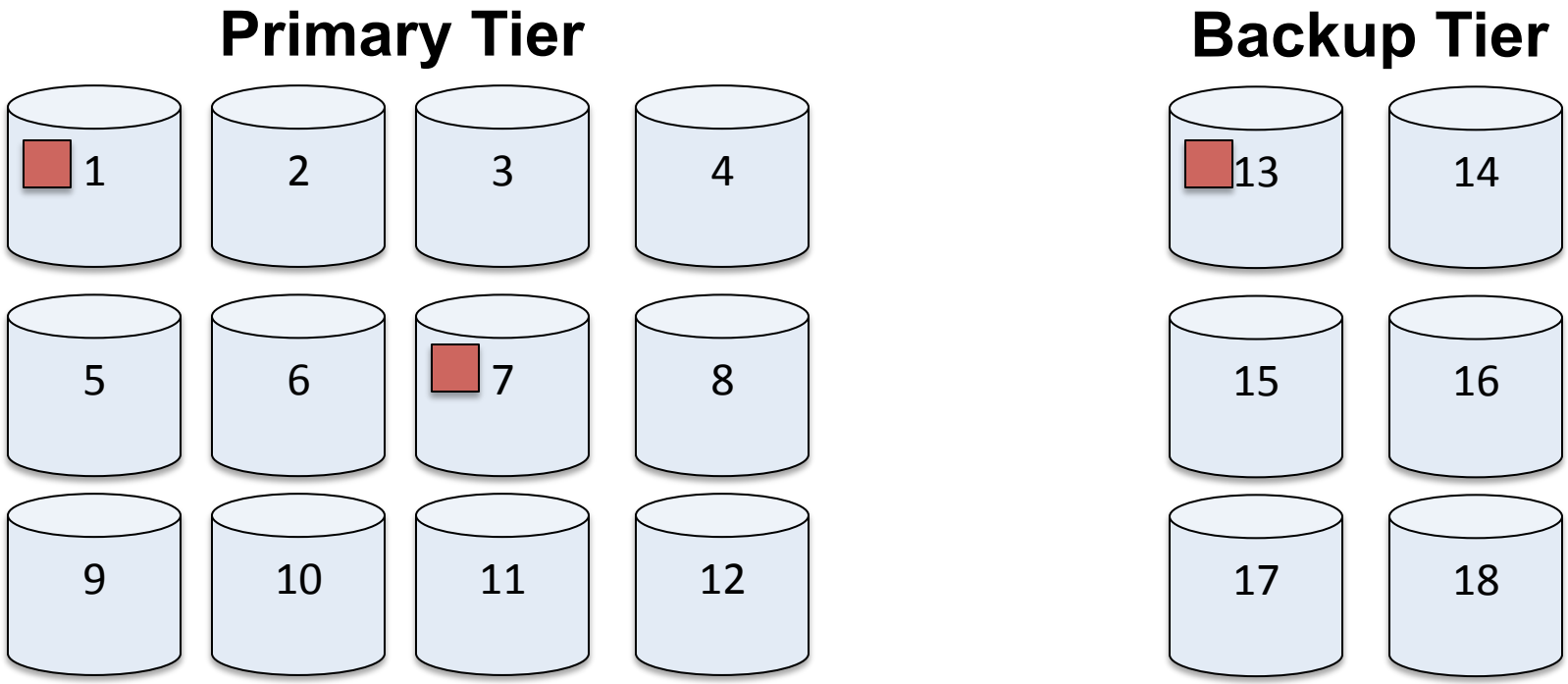
Leveraging Third Replica

- Greater durability against correlated failures
  - Can be “geo-replicated”
  - At the expense of higher node recovery time
- Can be stored cost-effectively
  - Can be compressed/de-duped/coded
  - Stored on disk (in case of SSD cluster) or tape

Tiered Replication: Greedily Find Copysets

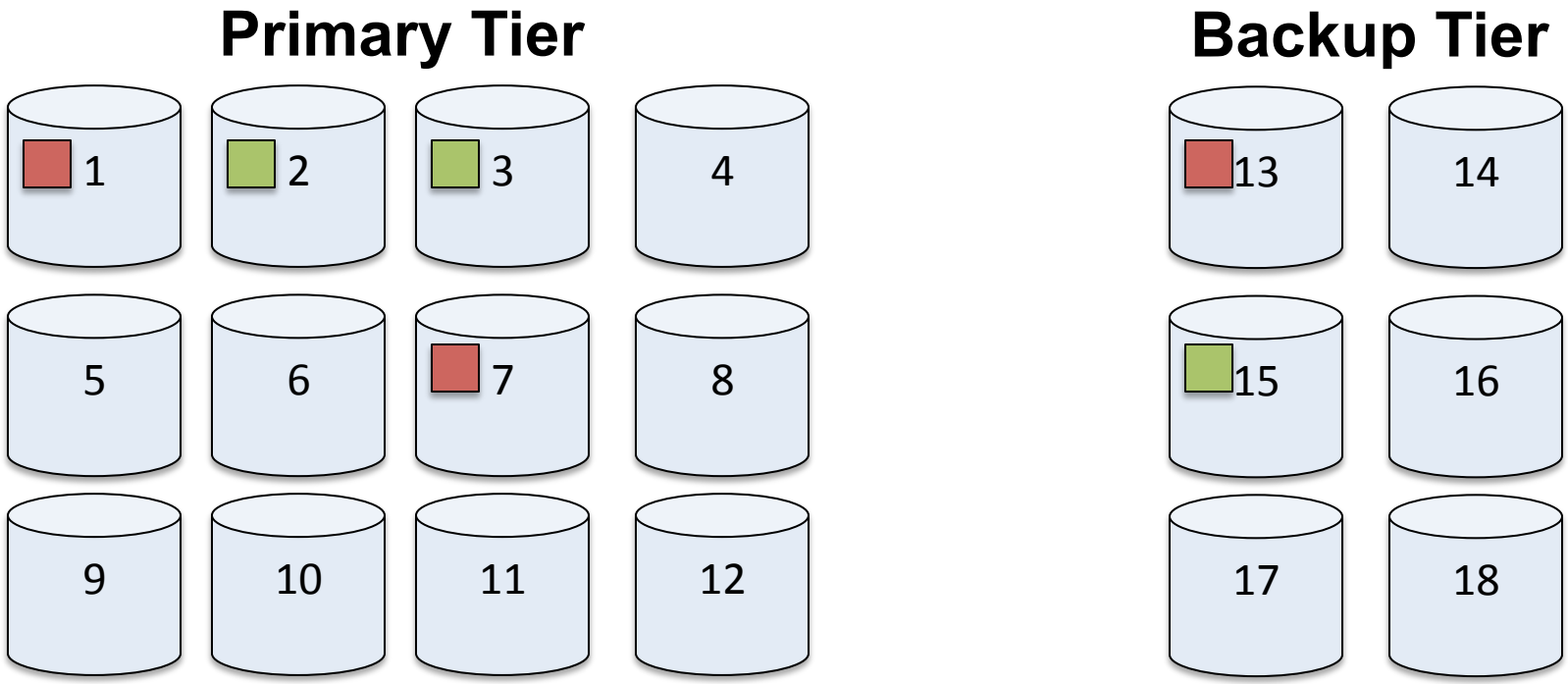


Tiered Replication: Greedily Find Copysets



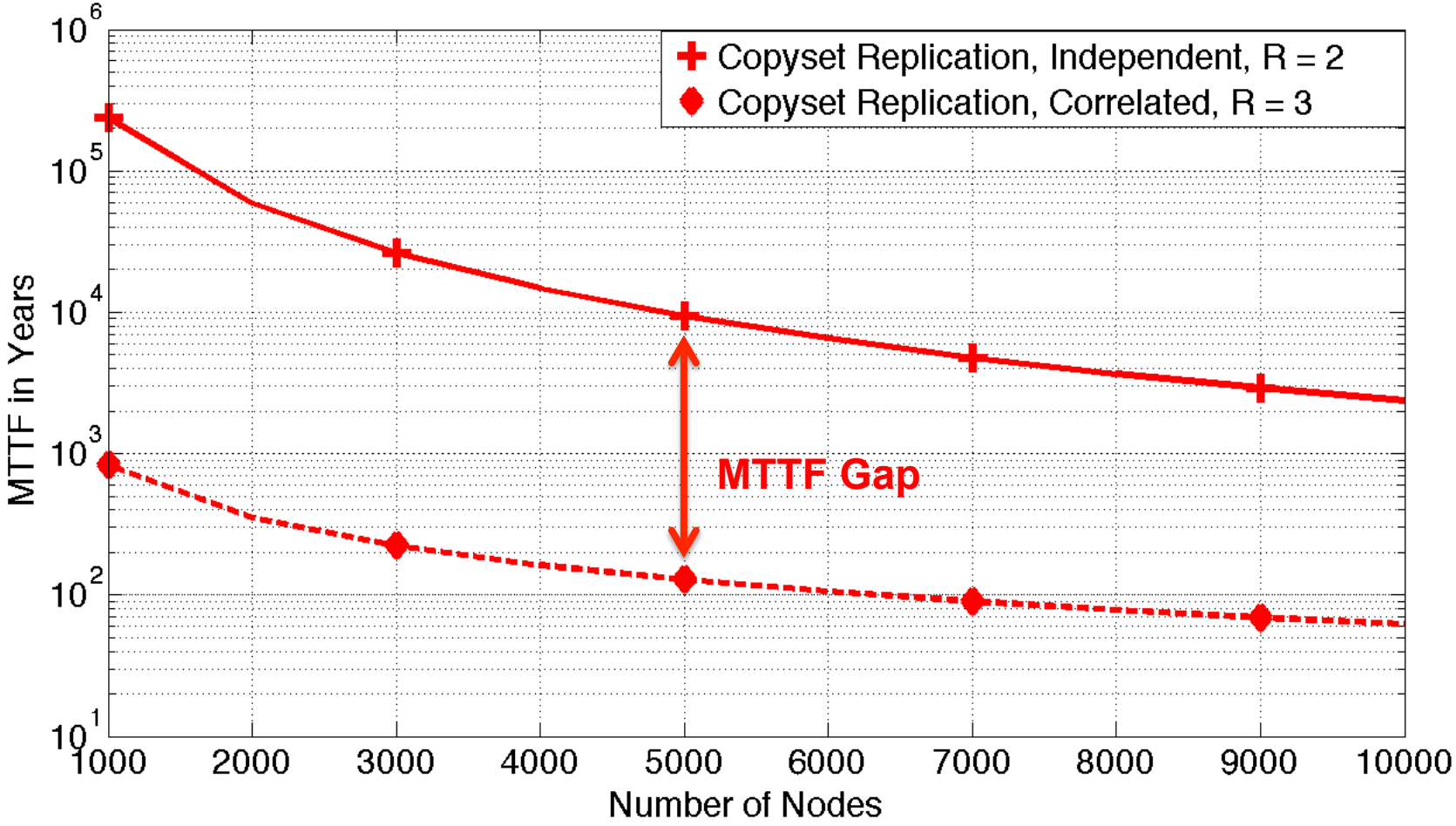
Node 1: (1, 7, 13)

Tiered Replication: Greedily Find Copysets

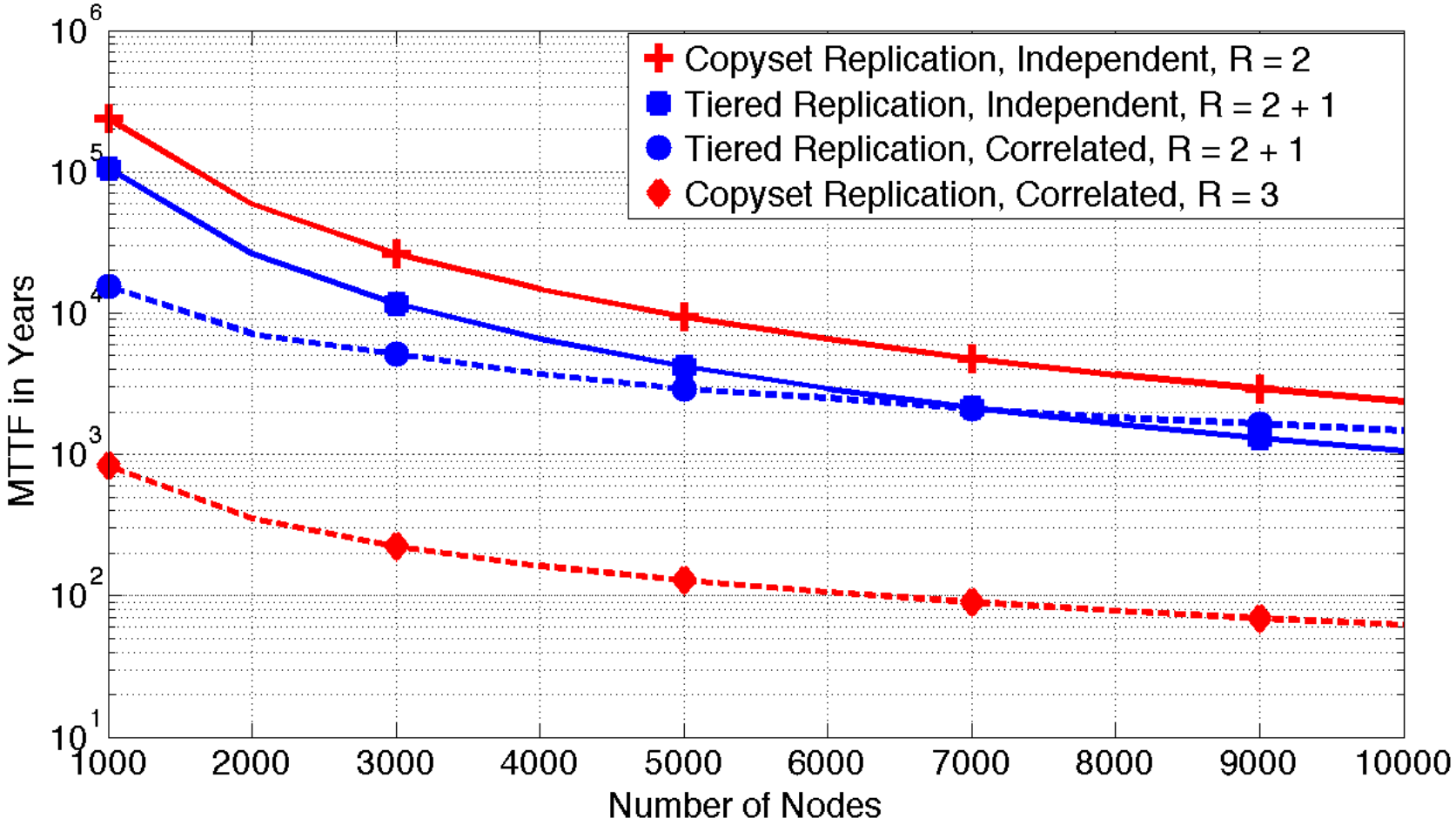


Node 1: (1, 7, 13)
Node 2: (2, 3, 15)

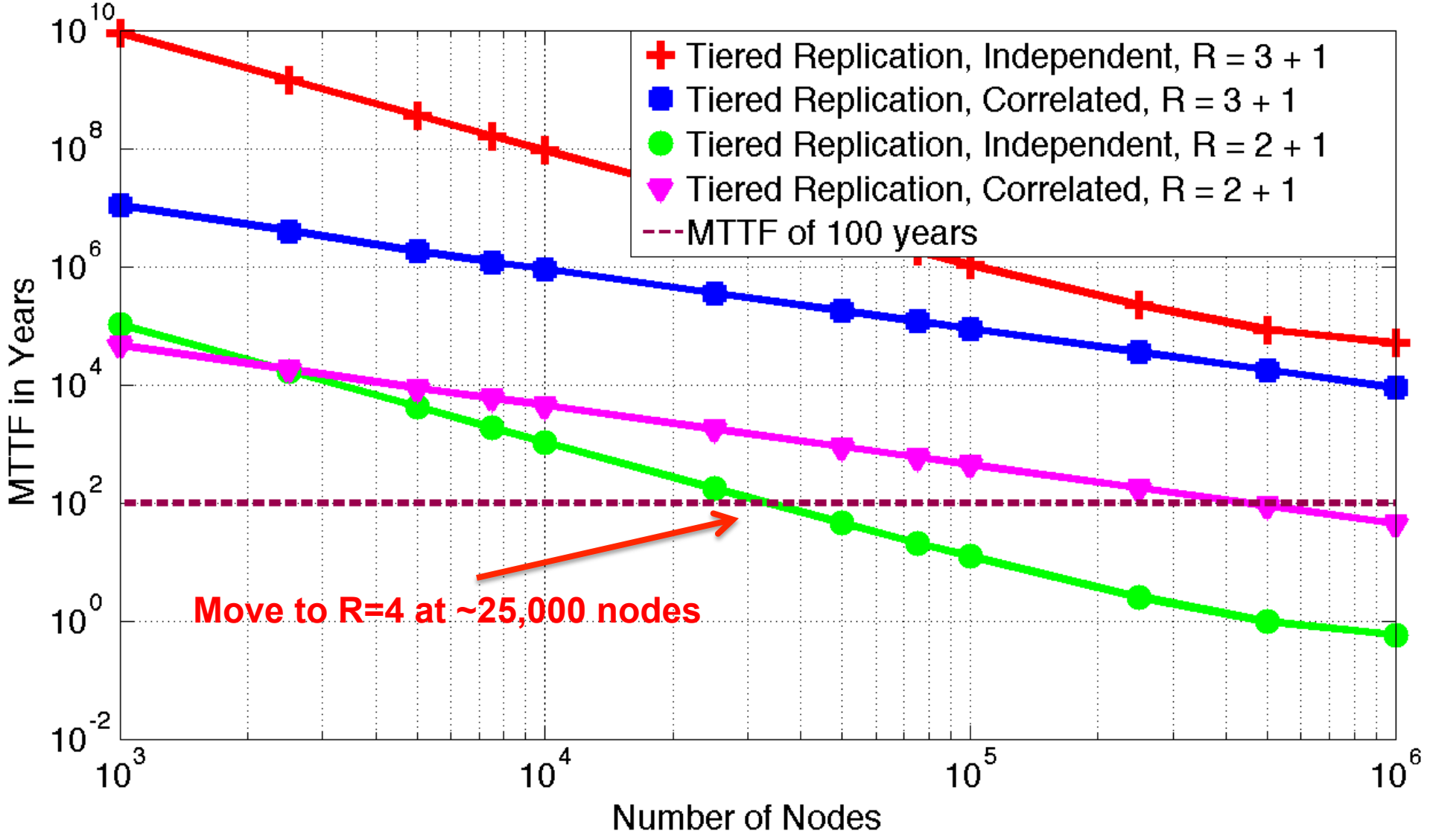
Tiered Replication: Bridging the MTTF Gap



Tiered Replication: Bridging the MTTF Gap



Beyond Three Replicas



Related Work

- Correlated vs. independent node failure
  - Google: Ford et al [OSDI '10]
- Improvements to Random Replication
  - Facebook: Borthakur et al [SIGMOD '11]
  - Copyset Replication: Cidon et al [ATC '13]
- Geo-replication as a solution to correlated failures
  - OceanStore: Kubiatowicz et al [Sigplan '00]
  - SafeStore: Kotla et al [ATC '07]
  - Many others…

Summary

1. Independent node failures: require fast node recovery, R=2 sufficient
2. Correlated node failures: require geo-replication, R=3 insufficient
3. By placing R-th replica on separate infrastructure, we bridge the MTTF gap