Cocytus

Efficient and Available In-memory KV-Store with Hybrid Erasure Coding and Replication

Heng Zhang, Mingkai Dong, Haibo Chen

Institute of Parallel and Distributed Systems
Shanghai Jiao Tong University, China

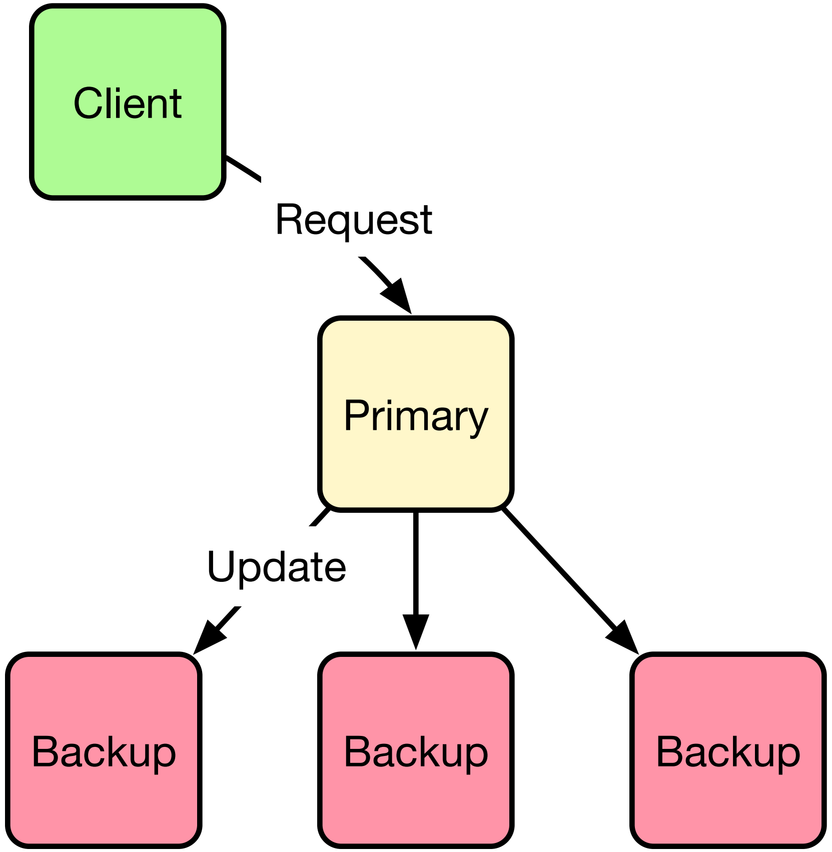
http://ipads.se.sjtu.edu.cn/pub/projects/cocytus

In-memory KV-Stores: Key Building Blocks for Systems

- A key pillar for many systems
  - Data cache (e.g., Memcached in Facebook)
  - In-memory database
- Availability is important for in-memory KV-Stores
  - Services disruption
  - Recovery is time-consuming

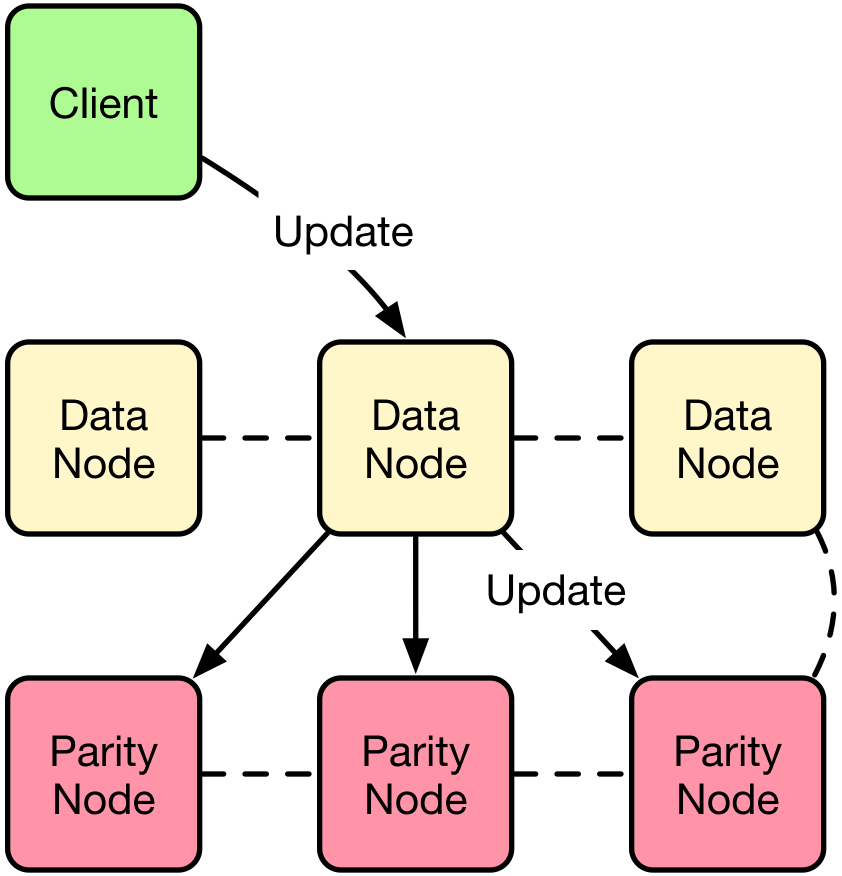
Primary-backup Replication (PBR)

- A common way to achieve availability
  - E.g., Repcached, Redis
- Problems
  - Need M times extra memory to tolerate M failures
  - Redundant data is rarely accessed in strongly consistent systems



Erasure Coding (EC)

- A space-efficient way to prevent data loss
- Widely used in disk storage
  - RAID (Redundant Array of Independent Disks)
  - WAS (Windows Azure Storage)
- Data repair needs to collect data and decode them
  - A lot of computing work and data transfer



Opportunity

- Large network bandwidth
  - Reaches 10Gb/s and 40Gb/s
- Fast speed of CPUs
  - Encoding/Decoding rates can also reach 40Gb/s on single core

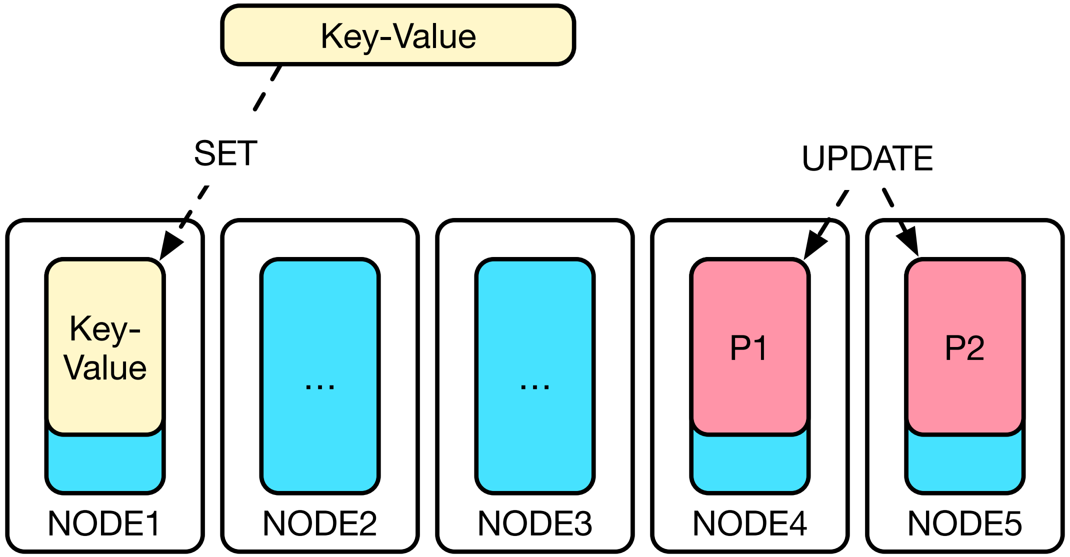
Goal

Erasure Coding + In-memory KV-Stores

⇒ Available and Memory Efficient In-memory KV-stores

Intuited System Design

- K nodes for storing data
- M nodes for storing parity
- Each key-value pair is totally stored on one data node
  - friendly for GET requests



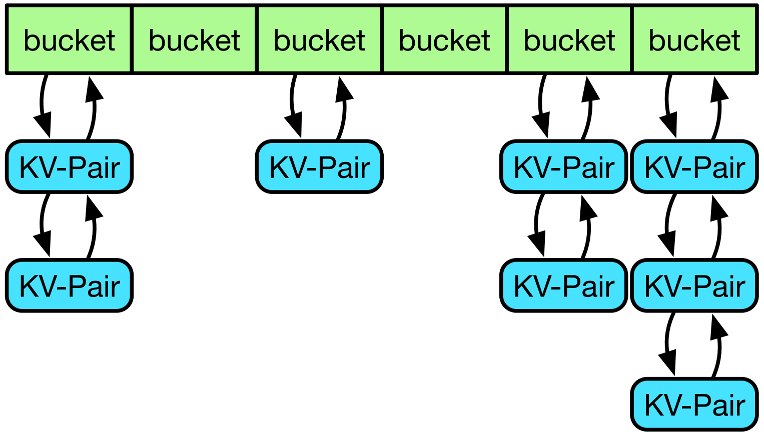
Challenges

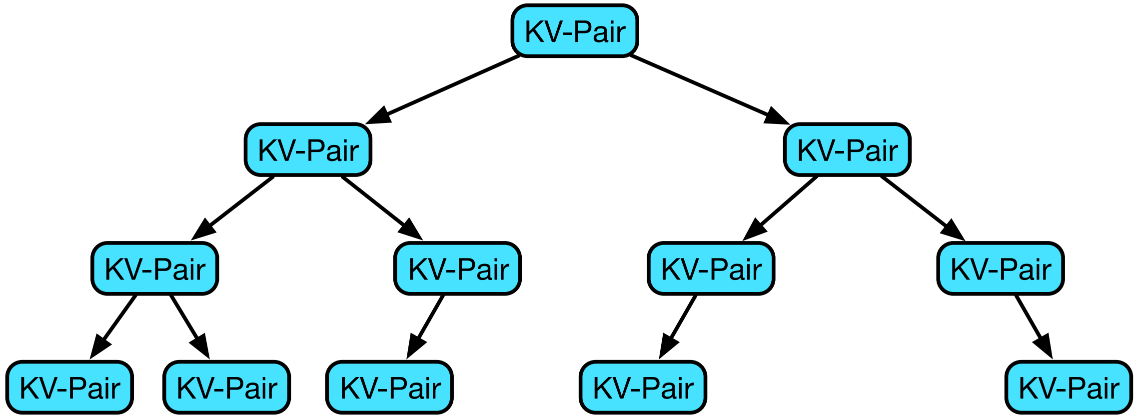
- Excessive metadata update

- Race condition in online recovery

Excessive Update on Metadata

- Metadata is usually achieved by scattered and linked data structure
  - E.g., hash table and binary search tree (BST), two popular data structures for in-memory index





Excessive Update on Metadata

- Metadata is usually achieved by scattered and linked data structure
- Operations on metadata involve many scattered modifications
    - About 4 scattered modifications on allocating memory
    - About 7 scattered modifications on freeing memory
    - About 4 scattered modifications on inserting new item into bucket hash table
    - O(N) scattered modifications on resizing of hash table

Excessive Update on Metadata

- Metadata is usually achieved by scattered and linked data structure
- Operations on metadata involve many scattered modifications
- Erasure coding is not a good choice for metadata
    - Complicated implementation
    - A SET request involve encoding/transfer for 7-14 scattered changes
    - Limit new metadata design

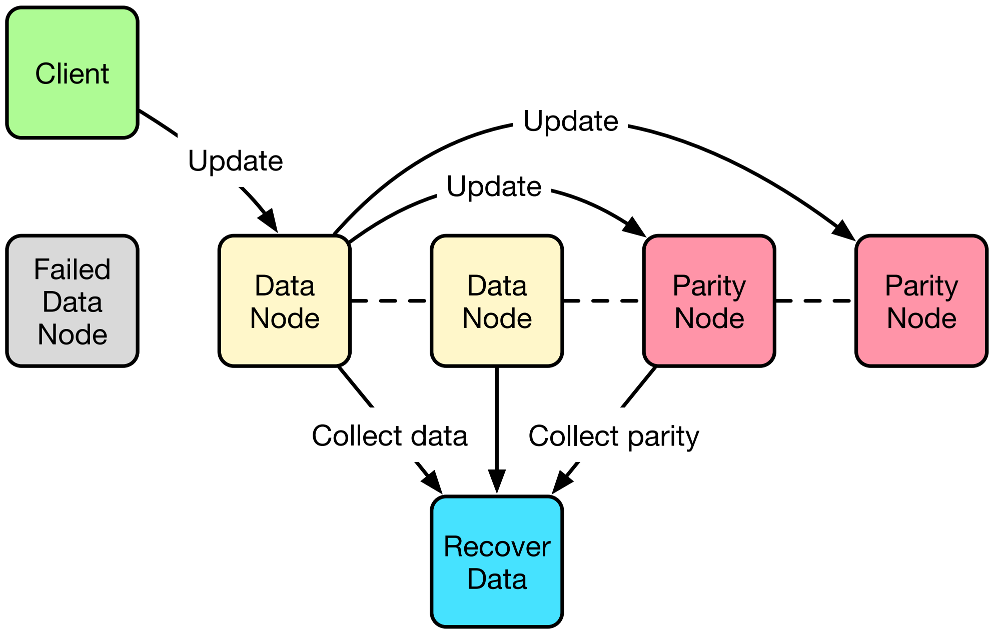
Solution: Separate data and metadata

- Use erasure coding to prevent data (values) loss
  - Pre-allocate virtual memory areas for data and parity
  - Modifications on these areas agree with erasure coding approach

- Use primary-backup replication to prevent metadata loss
  - Index information and allocation information are placed on outside of the area

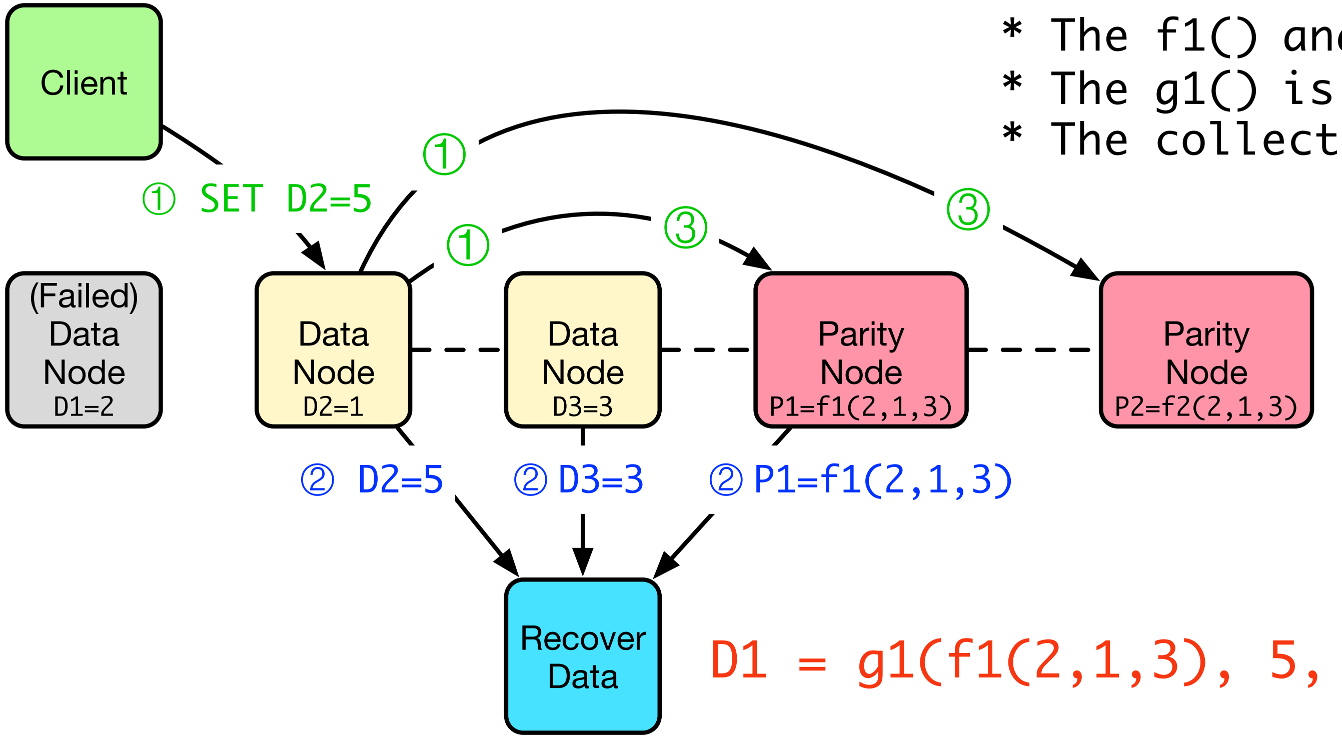
Race Condition in Online Recovery

- Handle GET/SET requests during recovery
- Handling SET request involves update on multiple nodes
- Data repair needs to collect data and parity among nodes



Race Condition in Online Recovery

- The interleaving of SET requests and data repair has race condition

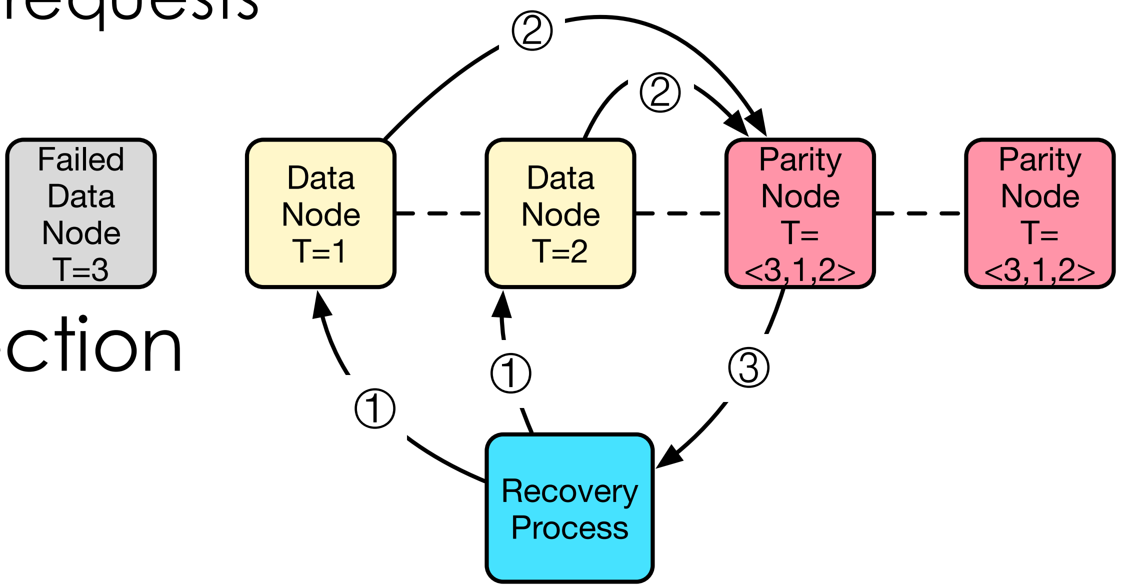


* The f1() and f2() is encoding functions
* The g1() is a decoding function
* The collected parity P1 loses the new update

D1 = g1(f1(2,1,3), 5, 3) != 2

Online Recovery Protocol

- Use logical timestamp to indicate the version of data
  - Attach timestamps on SET requests
  - In-order completion

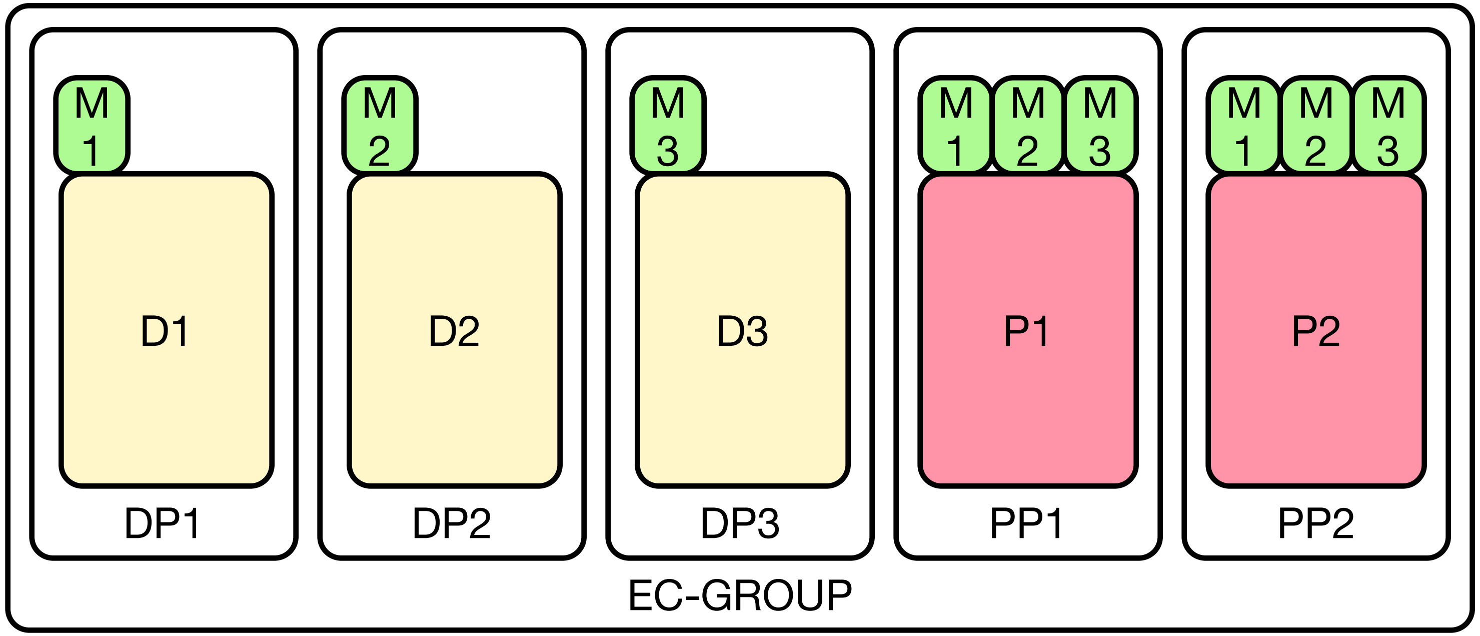


- Three steps for data collection
  1. Start procedure
  2. Decide data versions
  3. Synchronize parity version

Cocytus Overview

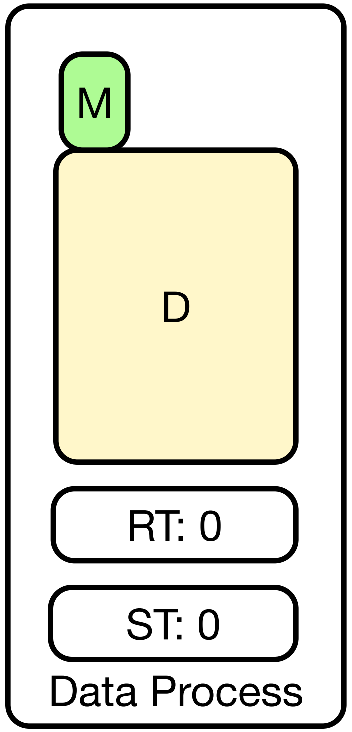
EC-Group

- EC-Group is the basic component in Cocytus
  - A EC-Group consists K data processes and M parity processes
  - Connected by a FIFO channel like a TCP connection



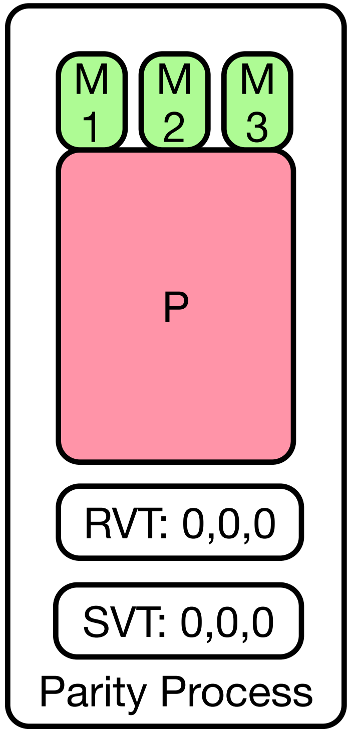
Data Process

- Metadata
  - Index information
  - Allocation information
- Data area
  - A memory area for values
- Logical timestamps
  - A Timestamp for the latest Received SET request (RT)
  - A Timestamp for the latest Stable (completed) SET request (ST)



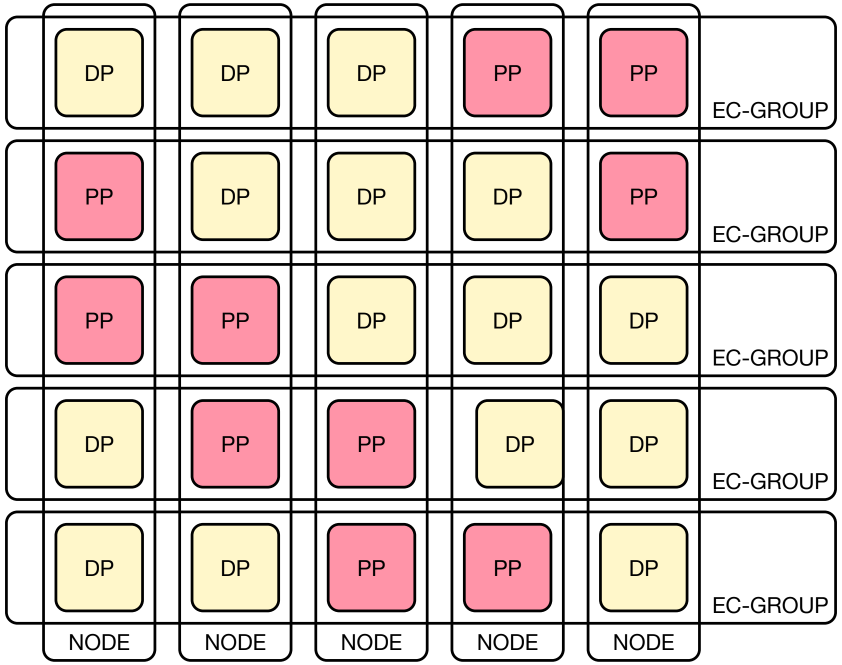
Parity Process

- Metadata replicas of all data processes in the EC-Group
- Parity area
  - A memory area for parity
- Logical timestamps
  - A Timestamp Vector for the latest Received SET requests (RVT[1..K])
  - A Timestamp Vector for the latest Stable (completed) SET requests (SVT[1..K])



Workloads Imbalance

- Data processes and parity processes have different work
- Data processes and parity processes reserve memory in different size

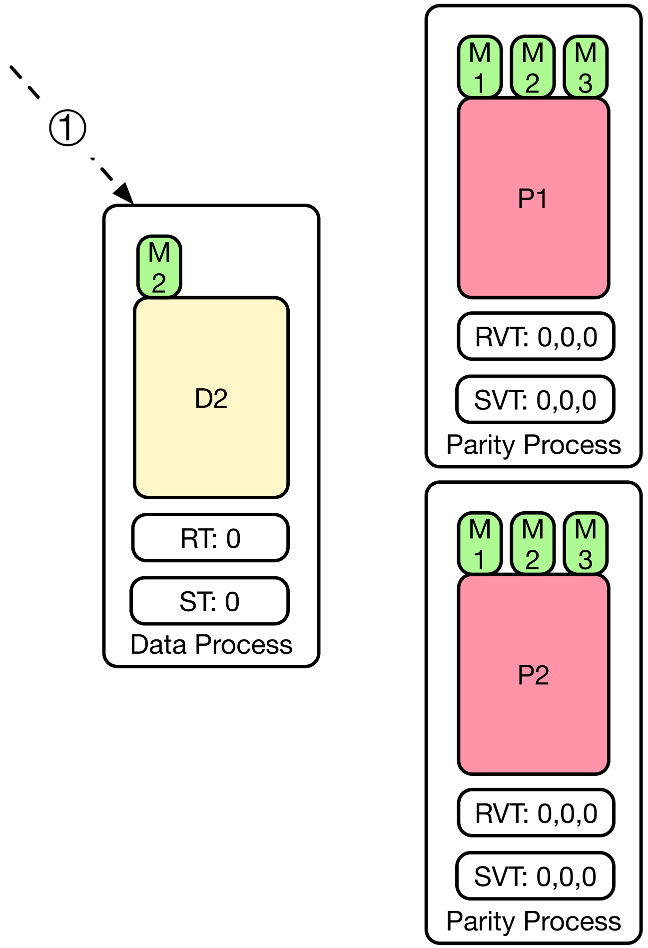


- Solution: interleaved layout

Handling SET Requests

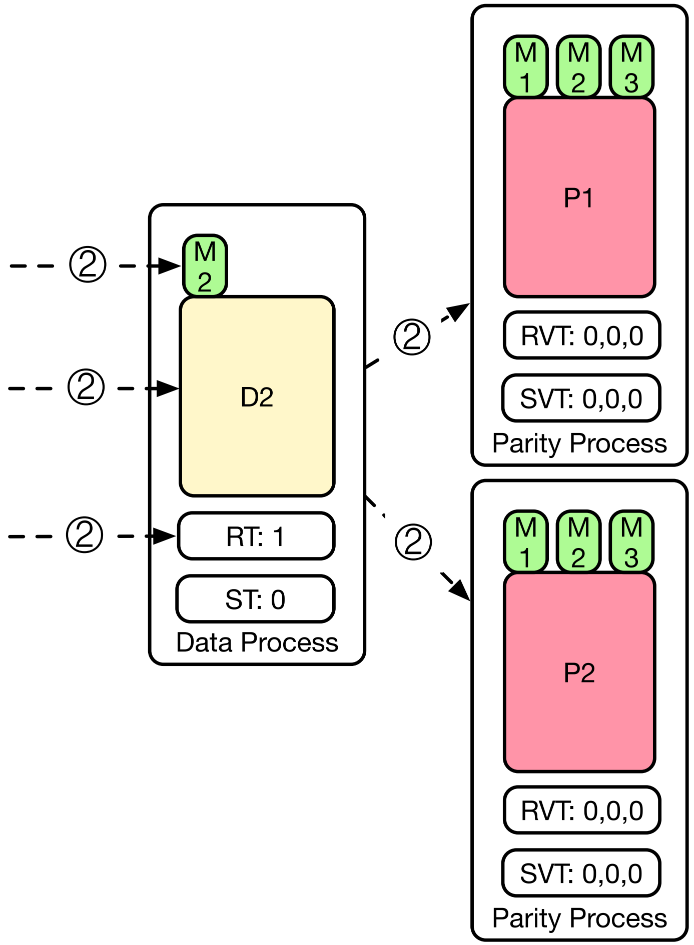
Handling a SET Request

1. Dispatch to a data process



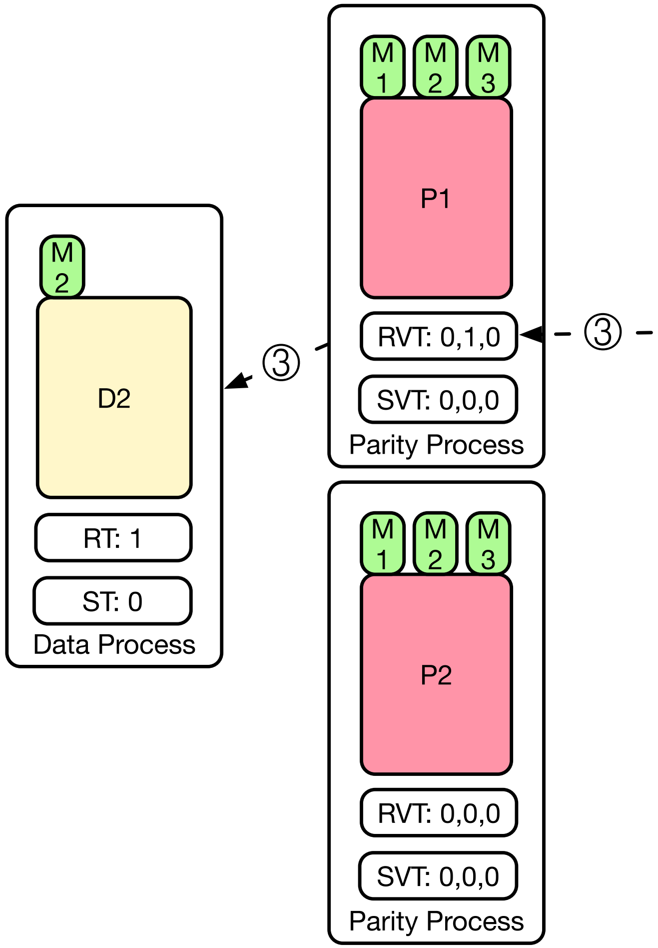
Handling a SET Request

1. Dispatch to a data process
2. Handle the request on the data process
    1. Generate data diff
    2. Update the timestamp
    3. Forward request



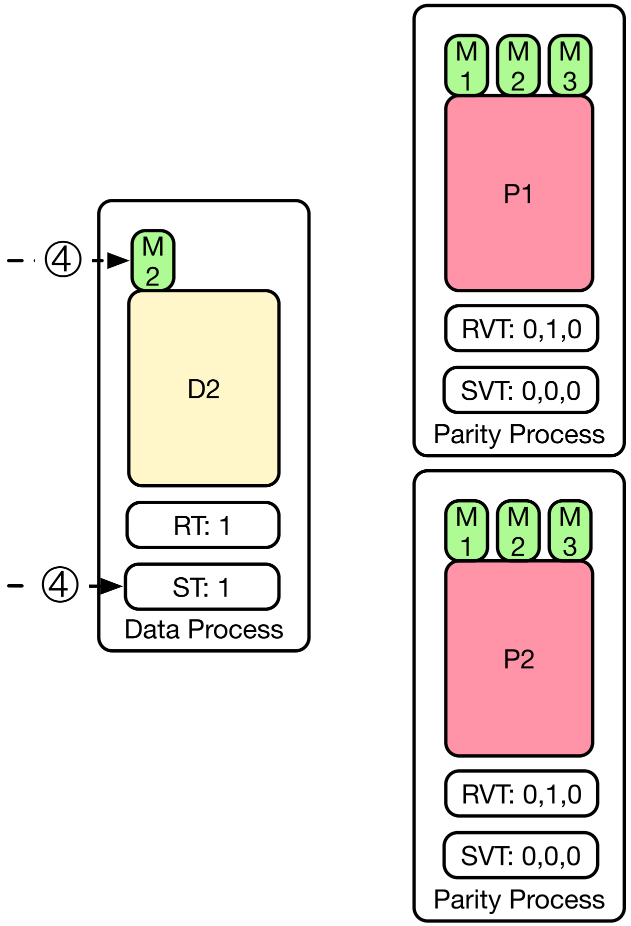
Handling a SET Request

1. Dispatch to a data processes
2. Handle the request on the data process
3. Handle the request on parity processes
    1. Buffer the request
    2. Update the timestamps
    3. Send ACKs



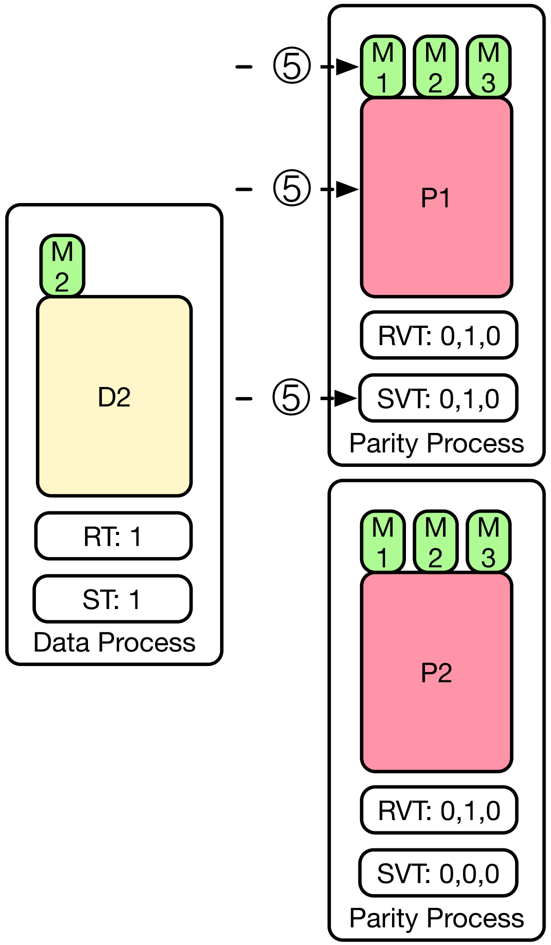
Handling a SET Request

2. Handle the request on the data process
3. Handle the request on parity processes
4. Complete the request on the data process
    1. Update in place
    2. Update the timestamp
    3. Send commit requests



Handling a SET Request

3. Handle the request on parity processes
4. Complete the request on the data process
5. Complete the request on parity processes
    1. Update corresponding metadata
    2. Update parity area with diff
    3. Update SVT



Recovery

Online Recovery

- When a data process fails, Cocytus chooses a recovery process from parity processes
  - Start two-phases recovery
  - Provide continuously services
- Two-phases recovery
  - Preparation: synchronize parity processes
  - Online data repair: repair the data area while handling requests
- Choose a recovery leader on multiple failures

Preparation

- The recovery process synchronizes stable timestamp for the failed data process
  1. collect corresponding RVT[i]s from all parity processes, where i is the failed data node

After preparation phase, all parity processes are consistent in the failed data process

- Parity processes complete the buffered requests that
  - contain equal or smaller timestamps than the synchronized stable timestamp
  - come from the failed data processes

Preparation

- The recovery process synchronizes stable timestamp for the failed data process
  1. collect corresponding RVT[i]s from all parity processes, where i is the failed data node
  2. choose the minimal one to be the synchronized stable timestamp
  3. broadcast the synchronized stable timestamp to other parity processes
- Parity processes complete the buffered requests that
  - contain equal or smaller timestamps than the synchronized stable timestamp
  - come from the failed data processes

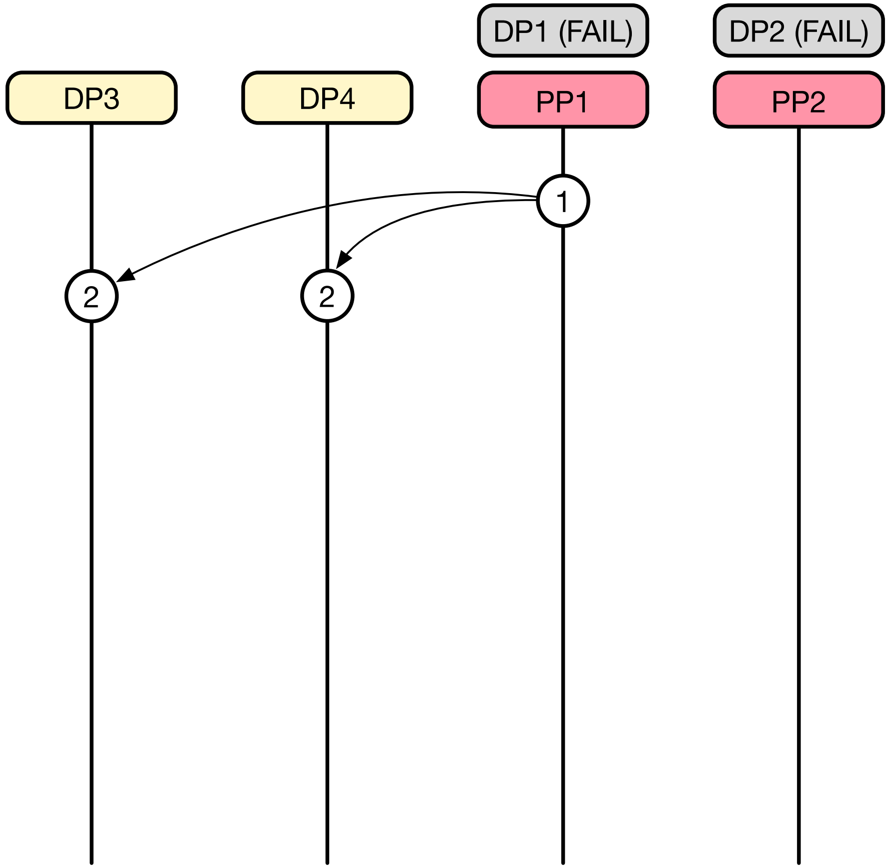
Online Data Repair

- Data area is repaired in a granularity of 4KB page
- Page repair happens
  - When requests need touch a lost page
  - In the background
- Under online recovery protocol

Recovery Protocol

Recovery leader

1. Choose the parity participant
2. Notify alive data processes



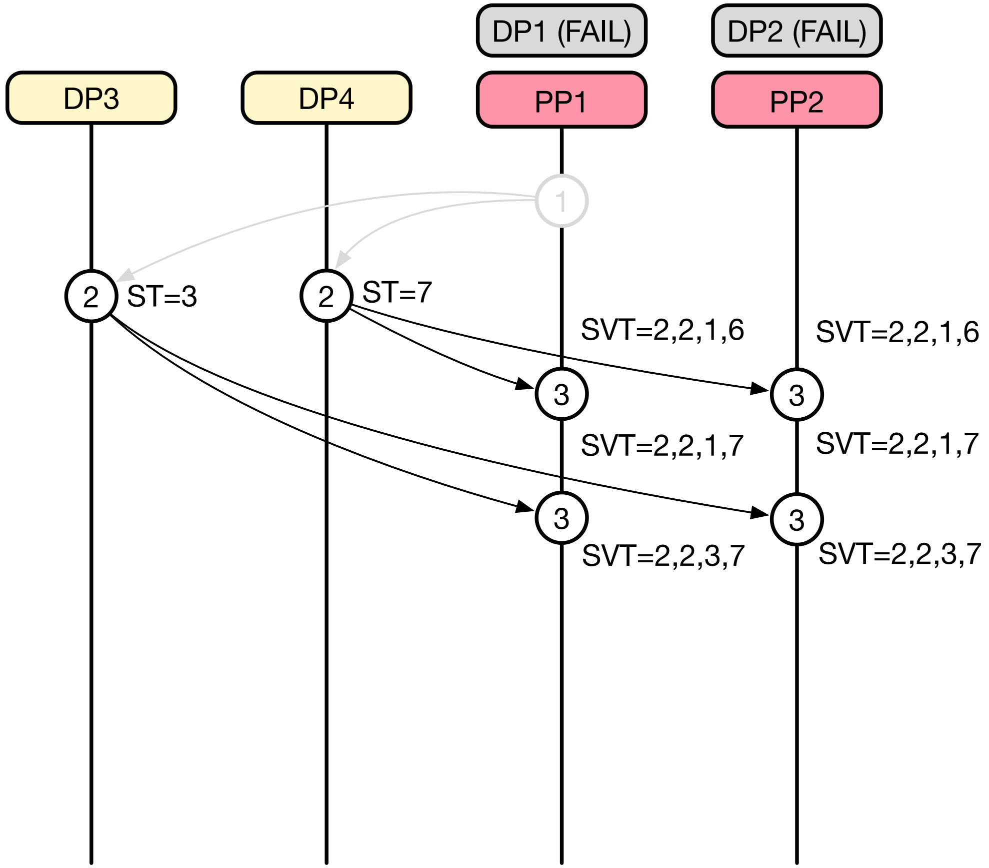
Recovery Protocol

Data processes

1. Decide stable timestamp
2. Send data page

Parity processes

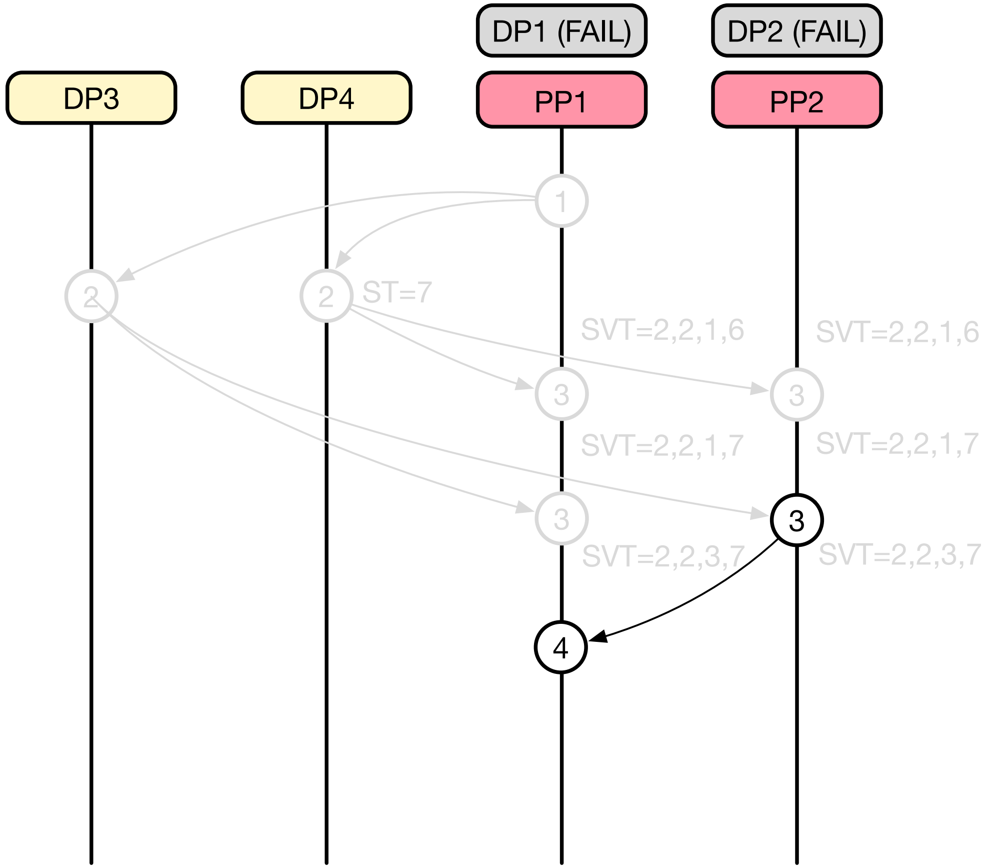
1. Synchronize the stable timestamps
2. Do partial decoding



Recovery Protocol

Parity processes

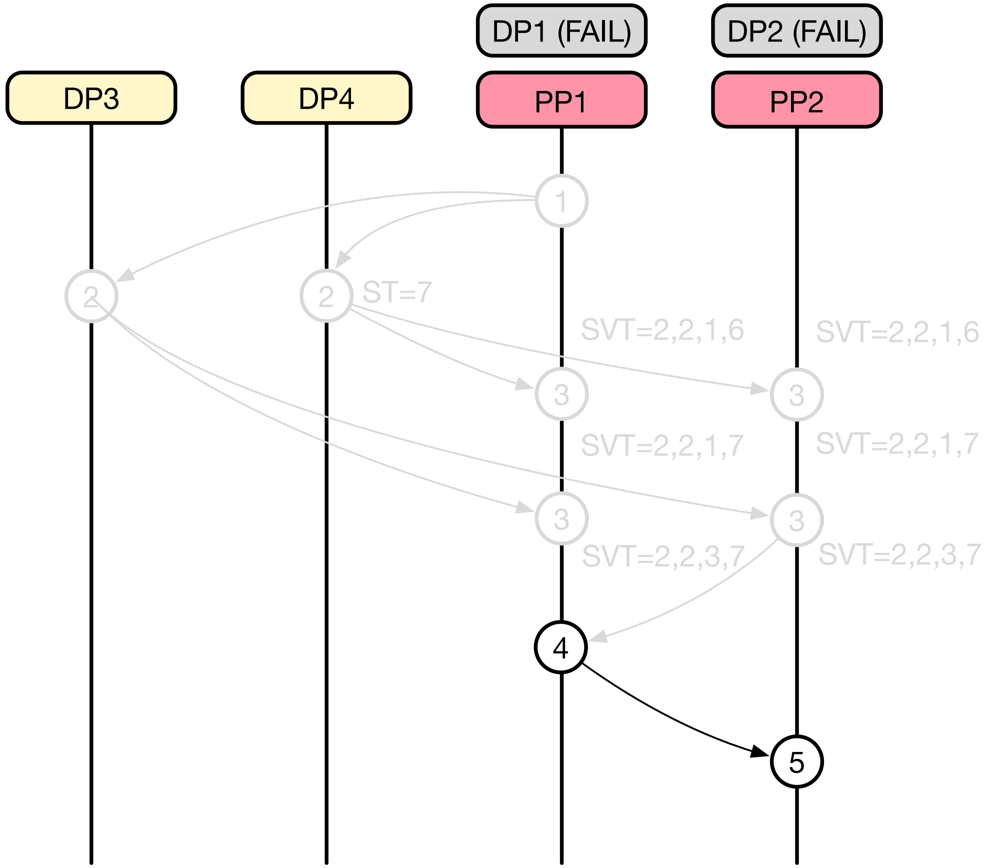
1. send partially decoded parity



Recovery Protocol

Recovery leader

1. Complete the decoding
2. Send recovered data pages to other recovery processes



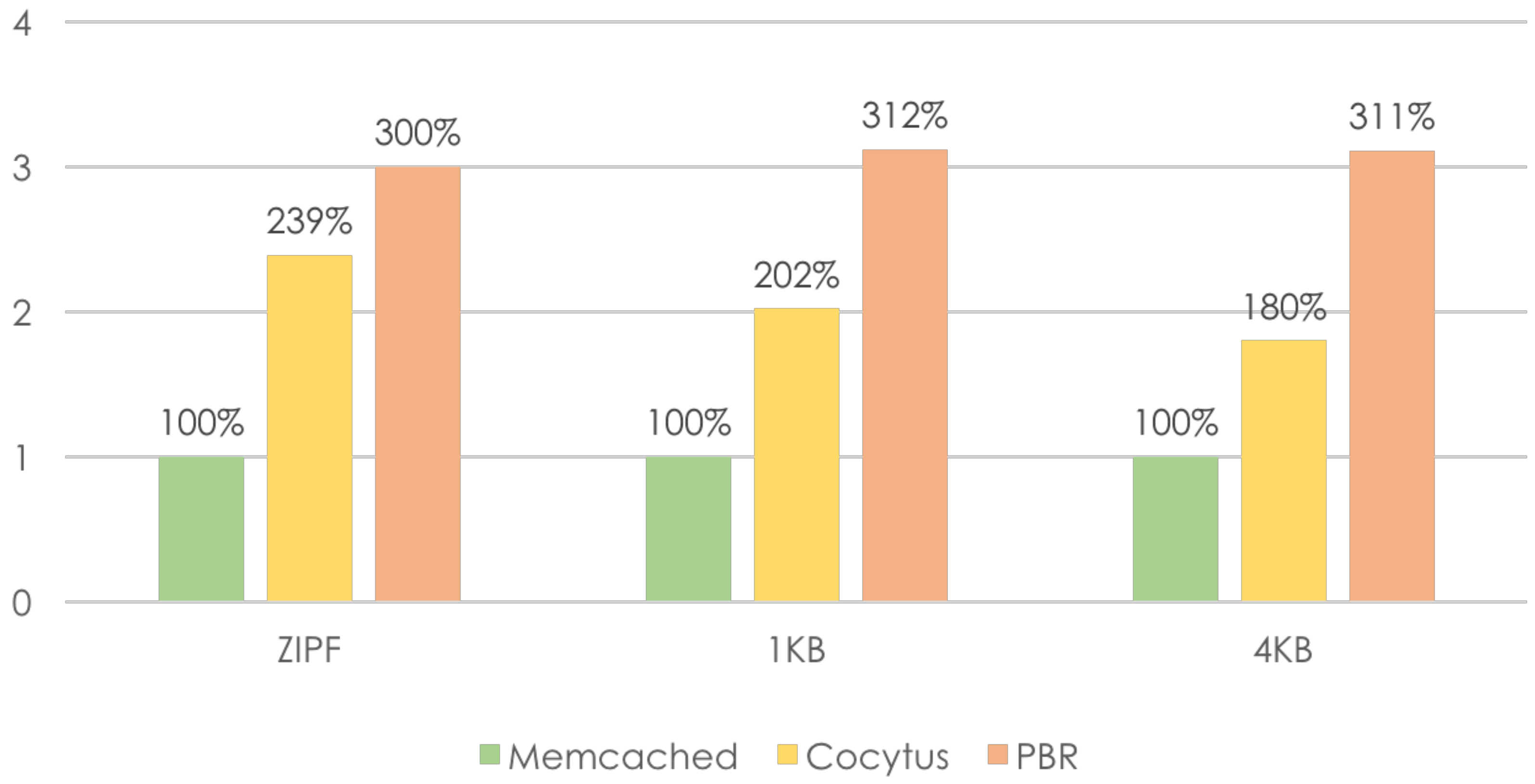
Implementation

- Cocytus is implemented on Memcached 1.4.21
  - Implement a similar primary-backup replication version for comparison
- Coding Scheme
  - Reed-Solomon code provided by Jerasure

Evaluation

- 5-node cluster for server
  - 5 EC-Groups for Cocytus, each contains 3 DPs and 2 PPs
  - 15 primary processes and 30 backup processes for primary-backup replication version
  - 15 original processes for Memcached
- 1 node for client, 20 cores
  - Run YCSB benchmark with 80 threads
- 10Gbps network

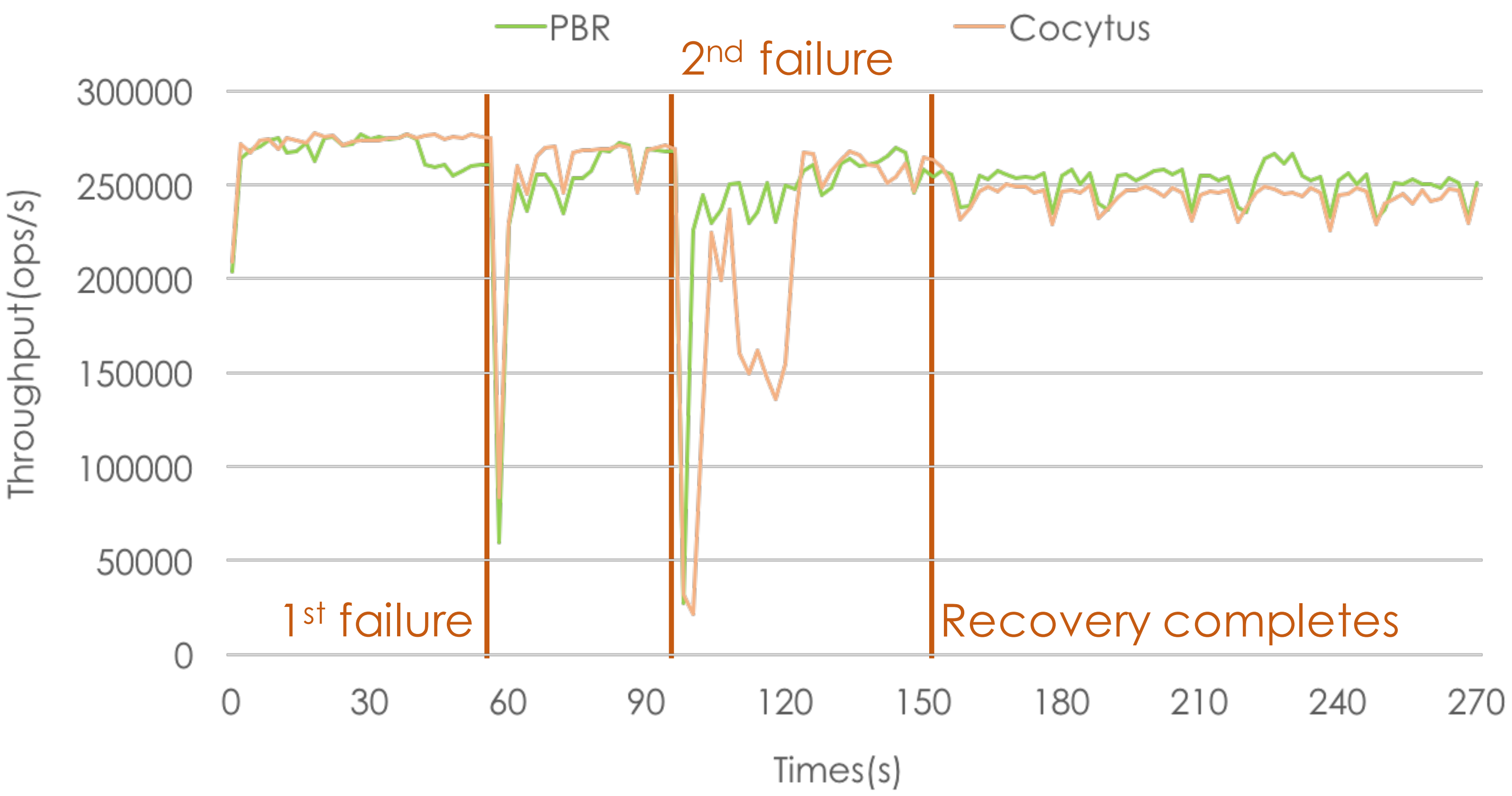
Memory Consumption



*ZIPF: Zipfian distribution over the range from 10B to 1KB

Recovery

(R:W=95%:5% & 1KB-size value & 12GB data/node)



CPU Overhead

Read:Write	Memcached	PB Replication		Cocytus	
	15 processes	15 primary processes	30 backup processes	15 data processes	10 parity processes
50%:50%	231%CPUs	439%CPUs	189%CPUs	802%CPUs	255%CPUs
95%:5%	228%CPUs	234%CPUs	60%CPUs	256%CPUs	54%CPUs
100%:0%	222%CPUs	230%CPUs	21%CPUs	223%CPUs	15%CPUs

Related Work

- Separation of work
  - Gnothi[ATC' 12], UpRight[SIGOPS' 09] …
- Erasure coding
  - WAS[ATC' 12], XORing Elephants[VLDB' 13] …
- Replication
  - Mojim[ASPLOS' 15], RAMCloud[SOSP' 11] …
- Key-value stores
  - Pilaf[ATC'13], FaRM[NSDI'14], HERD[SIGCOMM'14], and C-Hint[SoCC'14] …

Conclusion

- Replication approach is quit memory-consuming for in-memory KV-Stores
- Cocytus combines erase coding and replication to achieve efficient and available in-memory KV-Store
- Cocytus could achieve better memory efficiency with low overhead compared with primary-backup replication on read-mostly workloads

Thanks

http://ipads.se.sjtu.edu.cn