Towards Cost-Effective and Elastic Cloud Database Deployment via Memory Disaggregation

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The Rise of Cloud-Native Databases

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- **Cloud-native databases**
  - leverage modern cloud infrastructures
  - target high performance, high elasticity, and low price
  - serve as building block for cloud applications

Amazon Aurora

POLARDB

Cloud Spanner

Azure

GaussDB

Elastic Resource Demands

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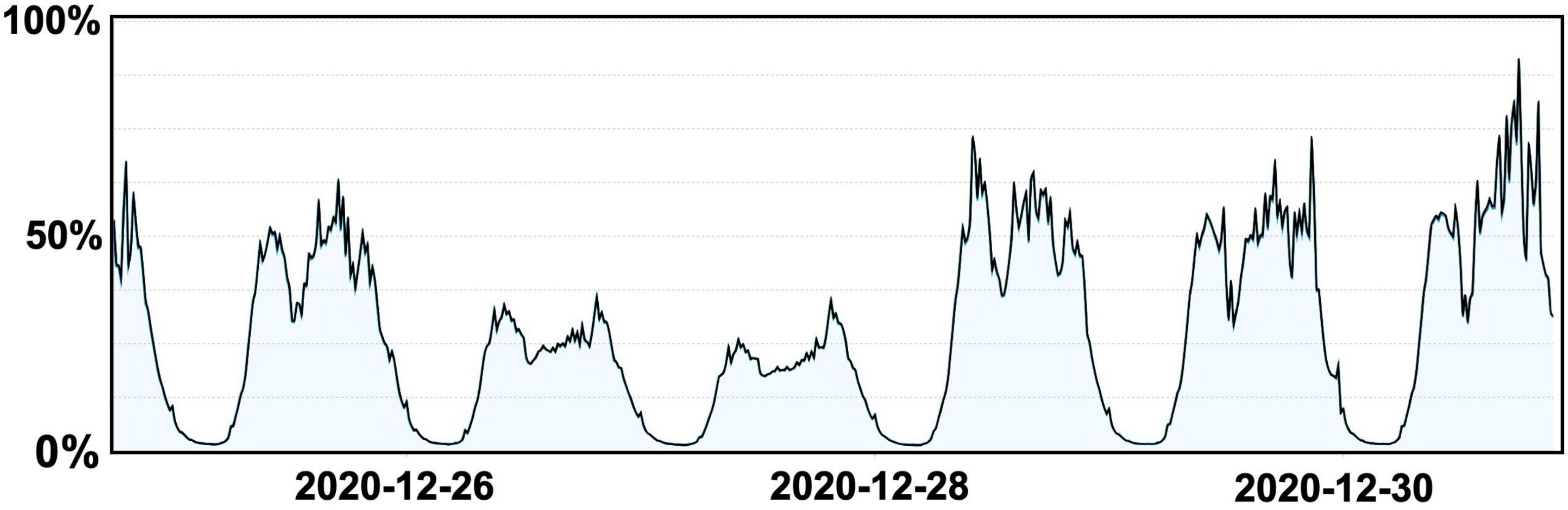
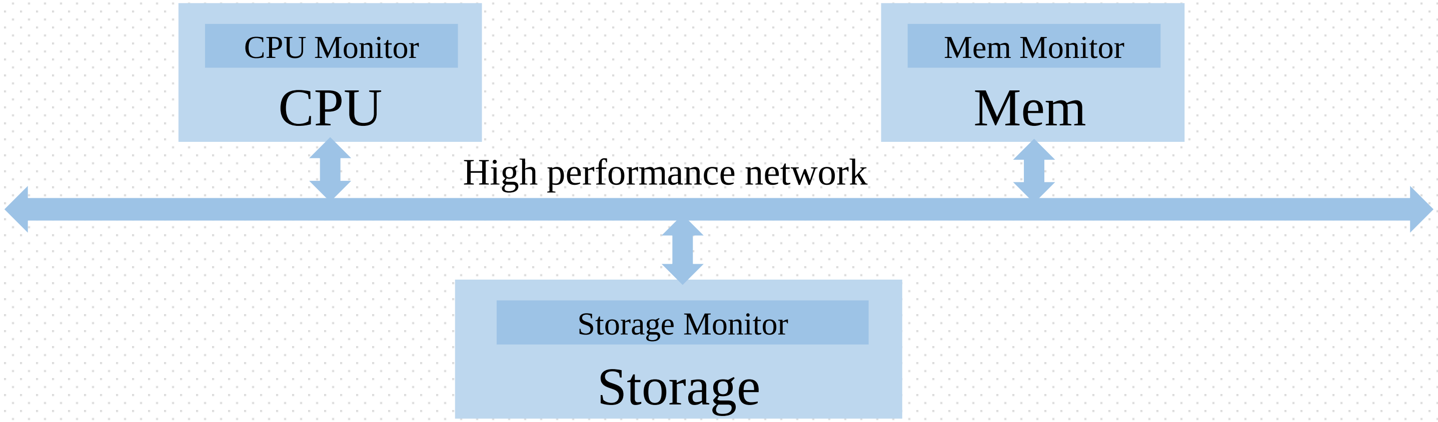
- Most of time, the utilization of CPU is below 50%
- But, for short time periods, it reaches up to 91.27% at peak



The traditional monolithic setup fails to meet the demands.

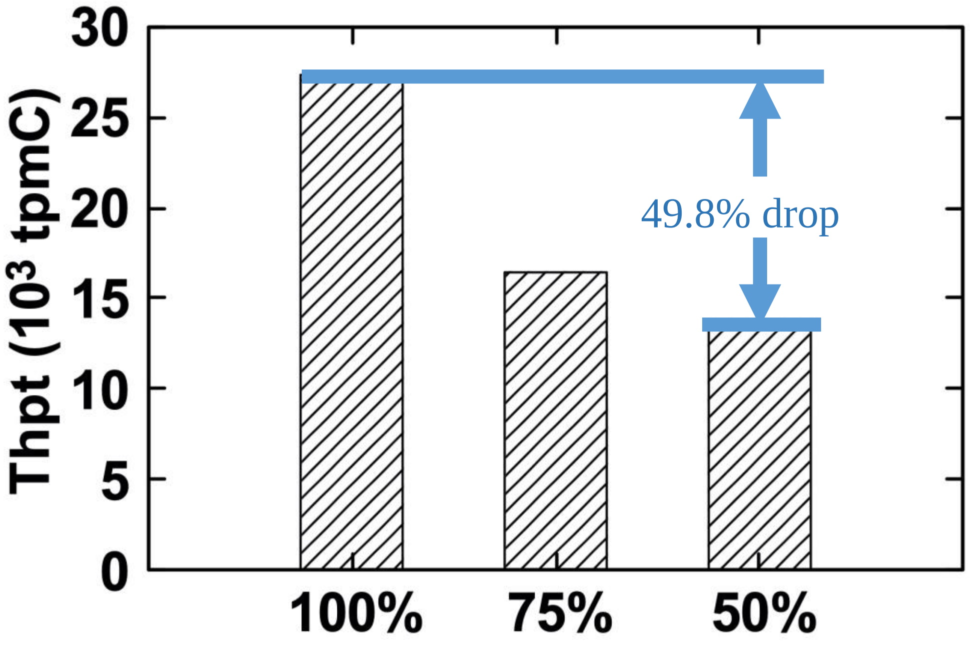
Resource Disaggregation

- **Disaggregated databases**
  - Amazon Aurora [SIGMOD'17], PolarDB [SIGMOD'21]
  - They only focus on compute and storage disaggregation.
- **General disaggregation approaches**
  - LegoOS [OSDI'18], Infiniswap [NSDI'17]
  - High memory access and failure recovery overhead, due to being oblivious to database I/O characteristics and going through traditional I/O stack

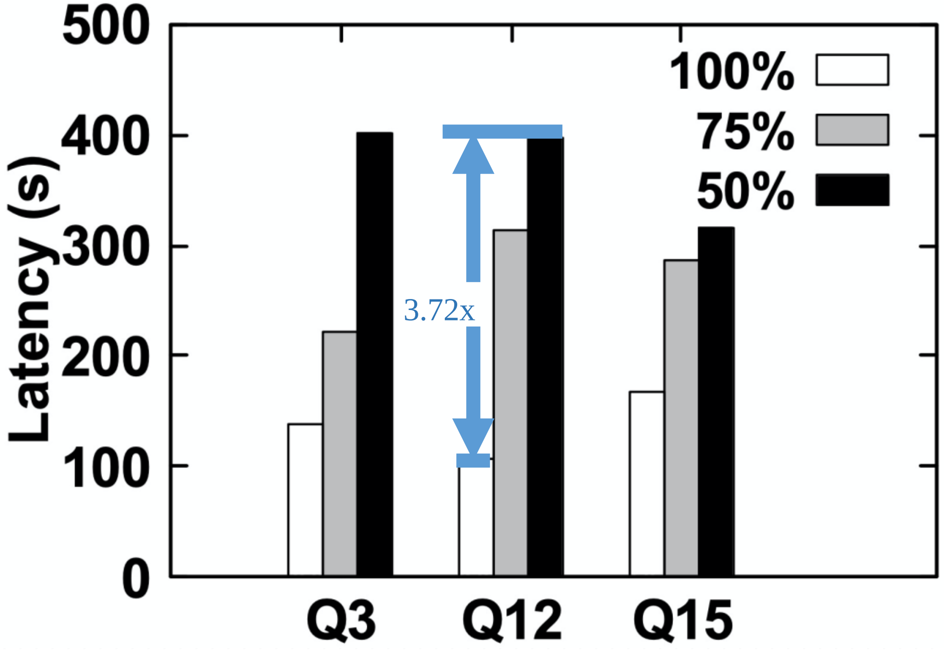


High disaggregation overhead

- Run workloads with Infiniswap
- Remote memory pool is accessed via 25Gbps network



TPC-C Local buffer size / Data set size

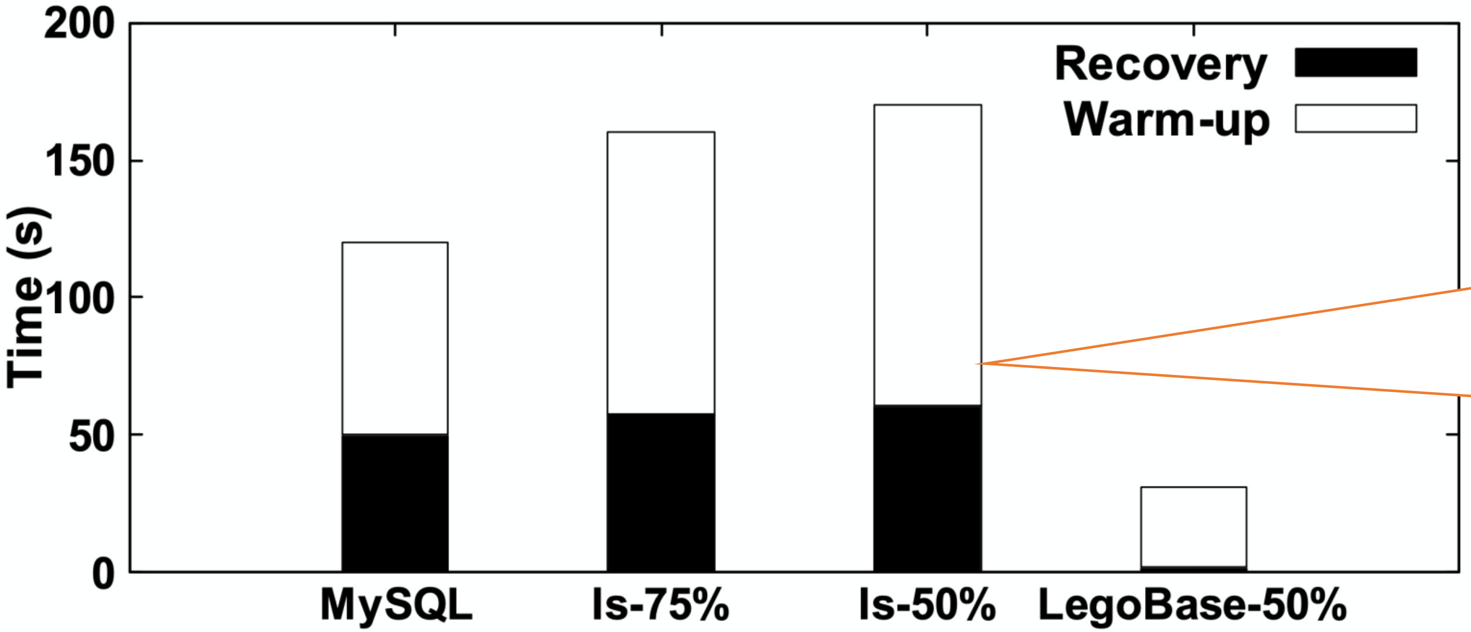


TPC-H Query Number

Takeaway 1: Fast (remote) memory access advocates the co-design of database kernel and memory disaggregation.

High fault recovery cost

- Run MySQL atop Infiniswap with TPC-C and varied remote memory ratios
- Crash the MySQL instance and measure the fail-over time costs

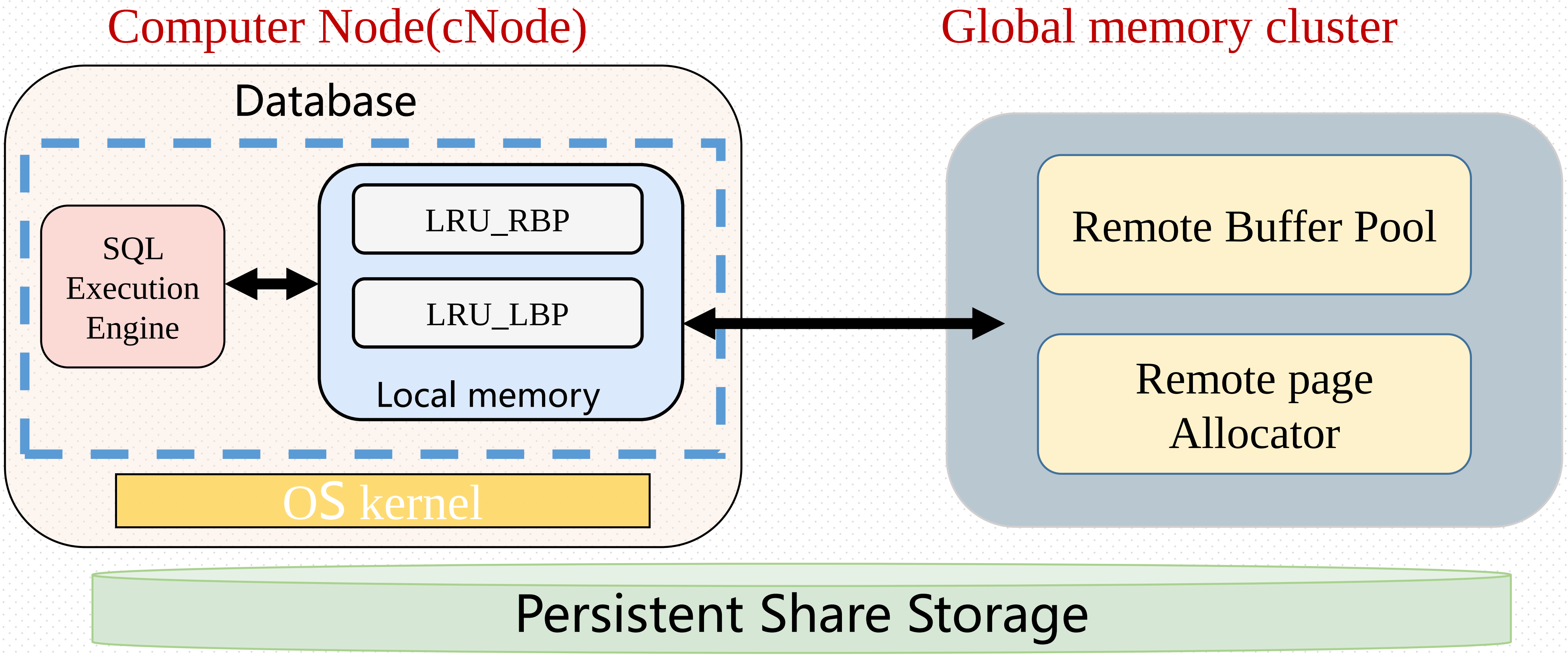


The pages cached remotely are not used, thus precluding fast recovery for local crashes.

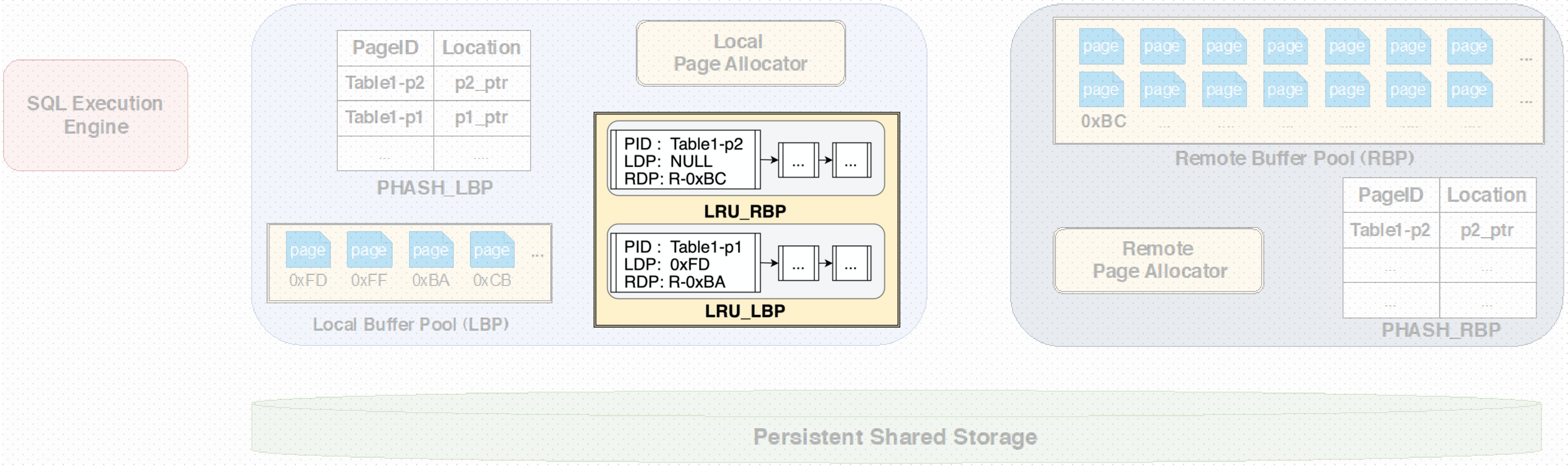
Takeaway 2: Independent fault handling requires to bridge the gap between the monolithic fault tolerance protocol and memory disaggregation.

Database and memory disaggregation co-design

- **Bypass OS kernel and use RDMA**
- **Retain MySQL sophisticated optimizations such as LRU**
- **Leverage DB access patterns and data layout**

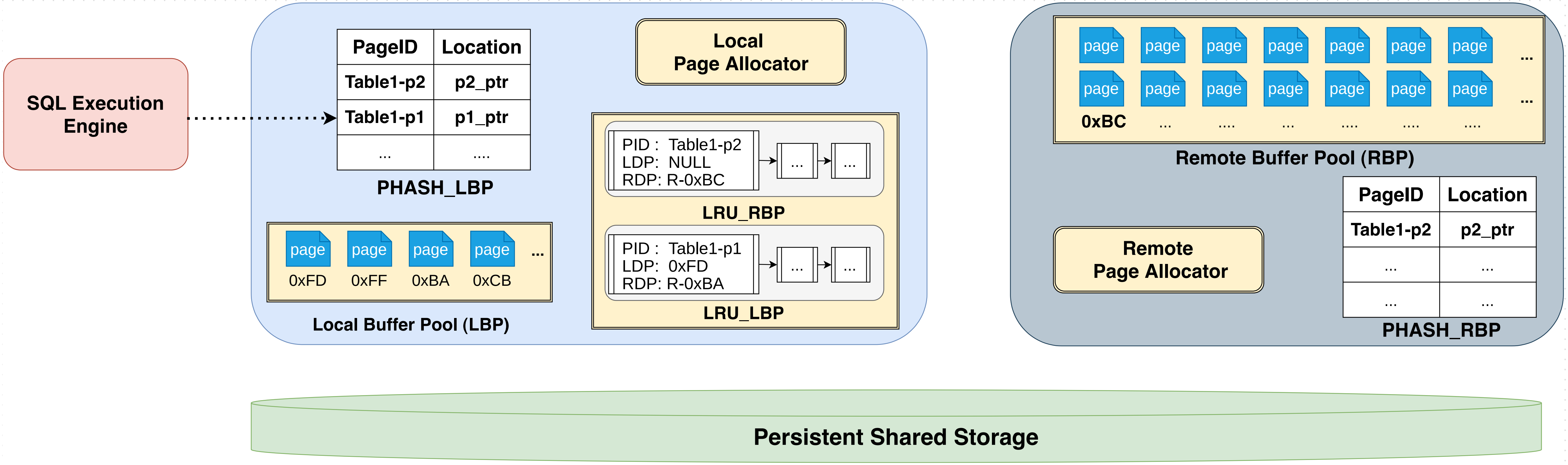


Local and Remote Memory Management



Two-level LRU : hold all metadata of local and remote pages， reduce communications with remote memory node

Local and Remote Memory Management



Page access from local buffer pool

Local and Remote Memory Management

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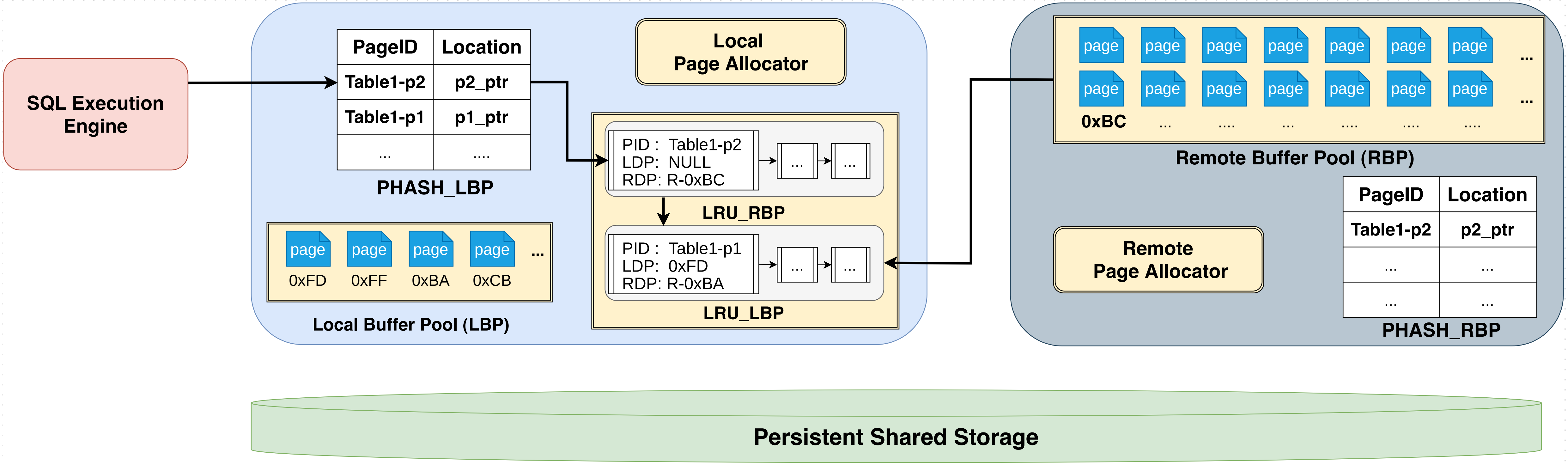

Page access from remote buffer pool

Local and Remote Memory Management

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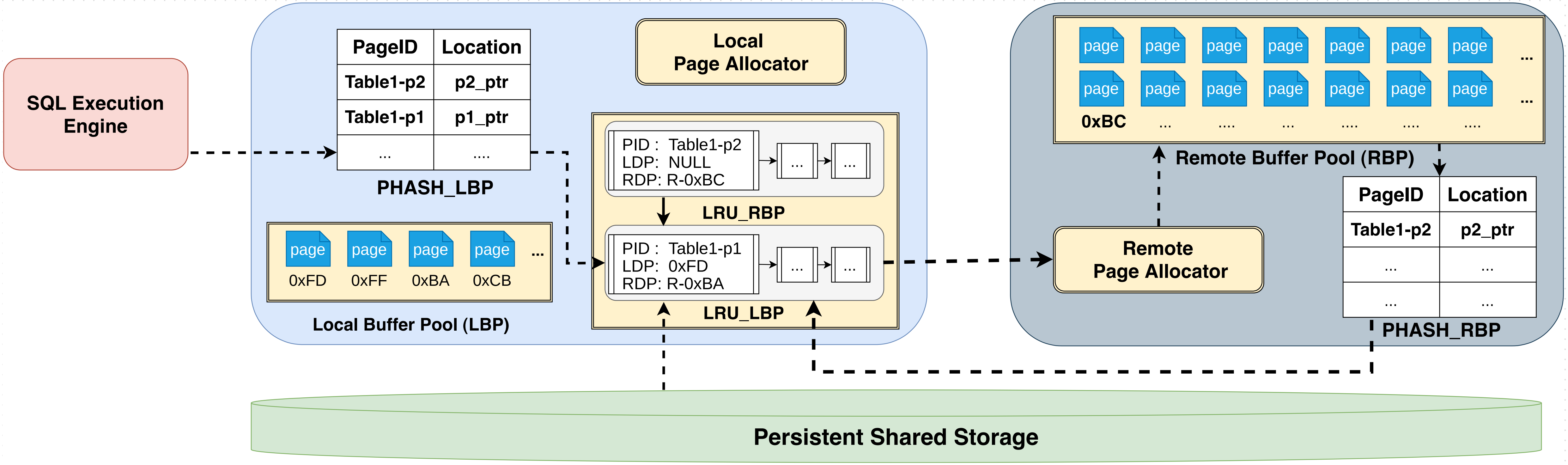

Page access from persistent shared storage

New Fault Tolerance: Two-tier ARIES Protocol

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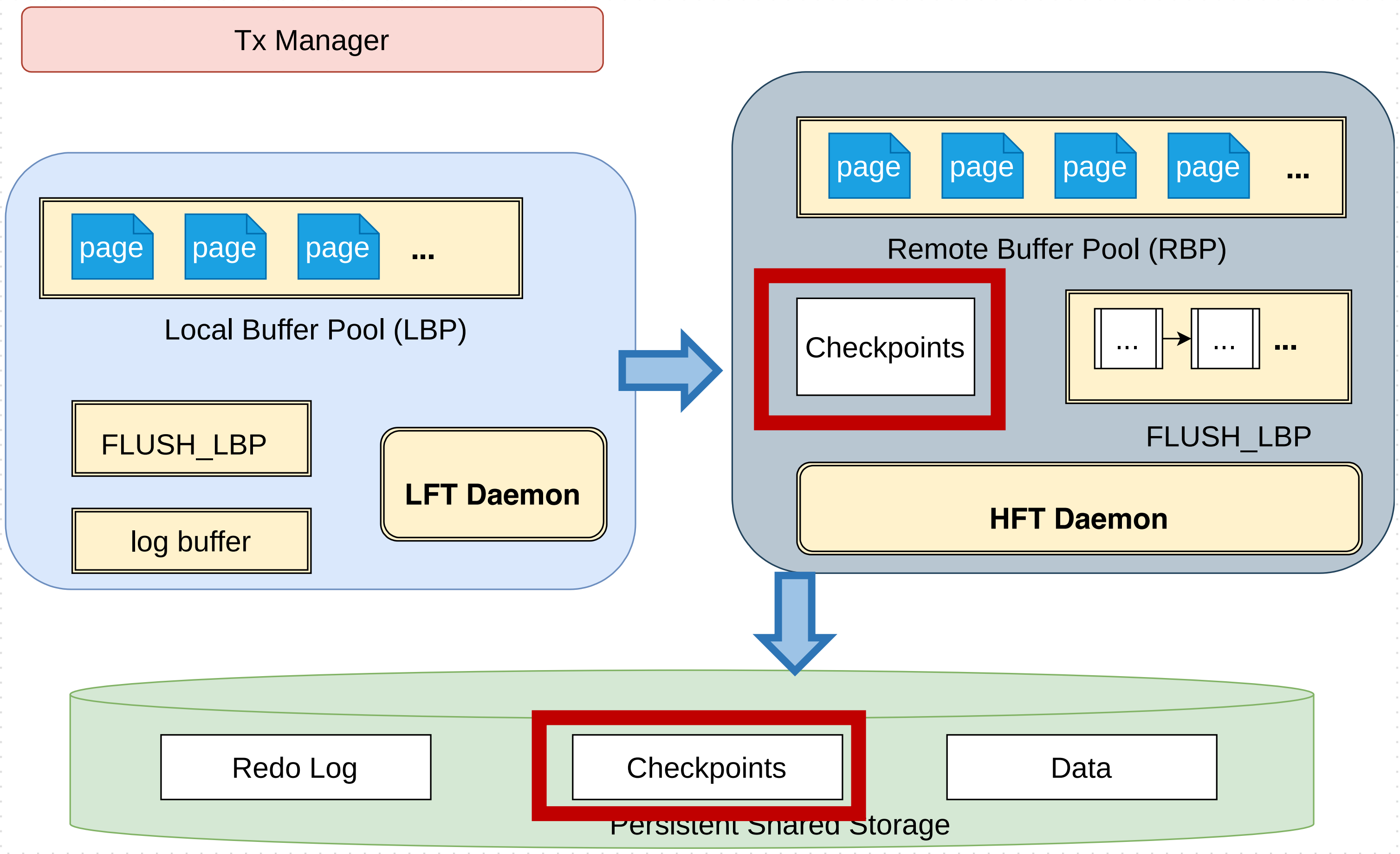

Tier-1 checkpoints

- Compute node flushes fine-grained checkpoints to remote buffer at high speed via RDMA

Tier-2 checkpoints

- Remote mem node flushes big checkpoints to storage as usual for persistence

New Fault Tolerance: Two-tier ARIES Protocol

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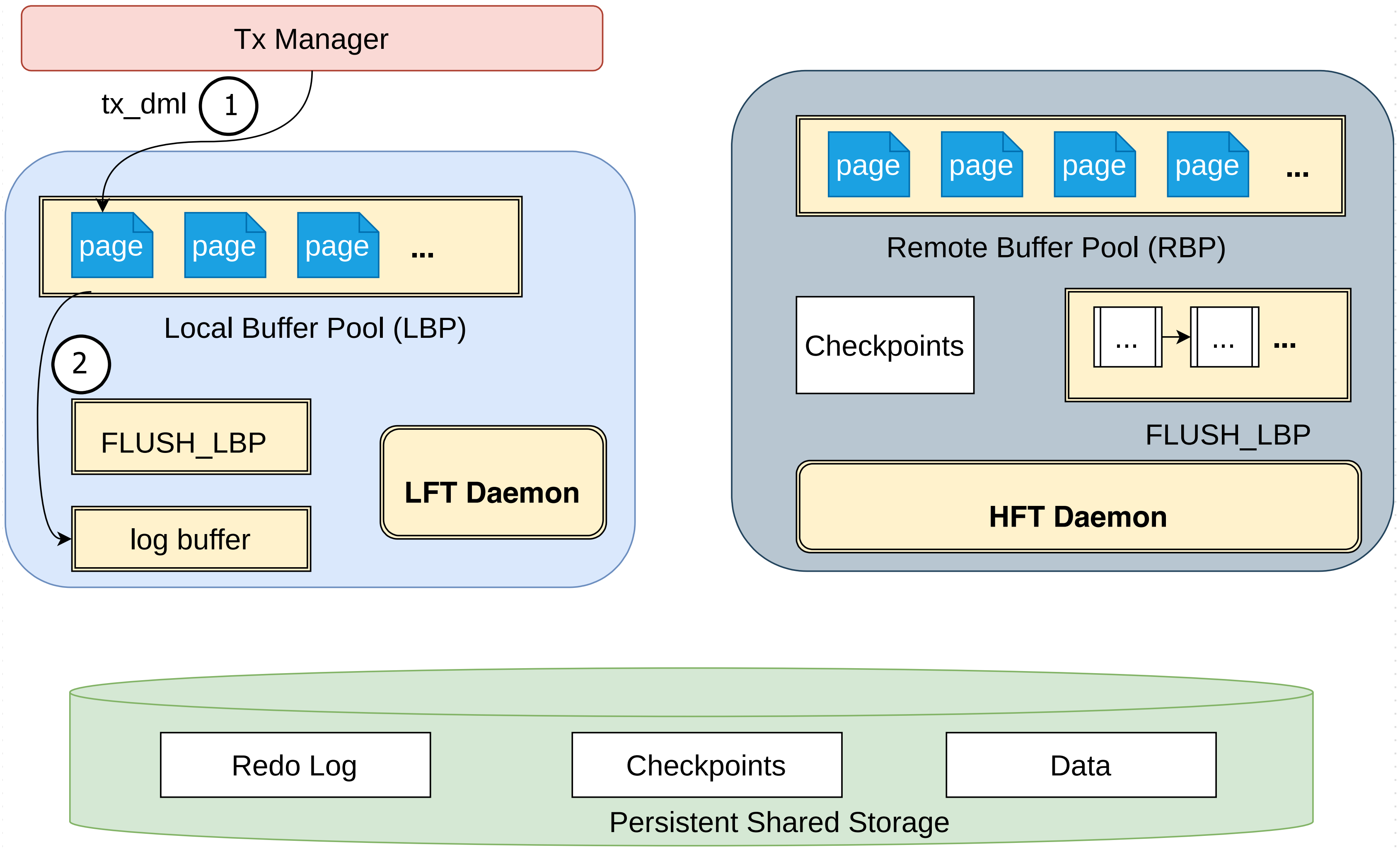

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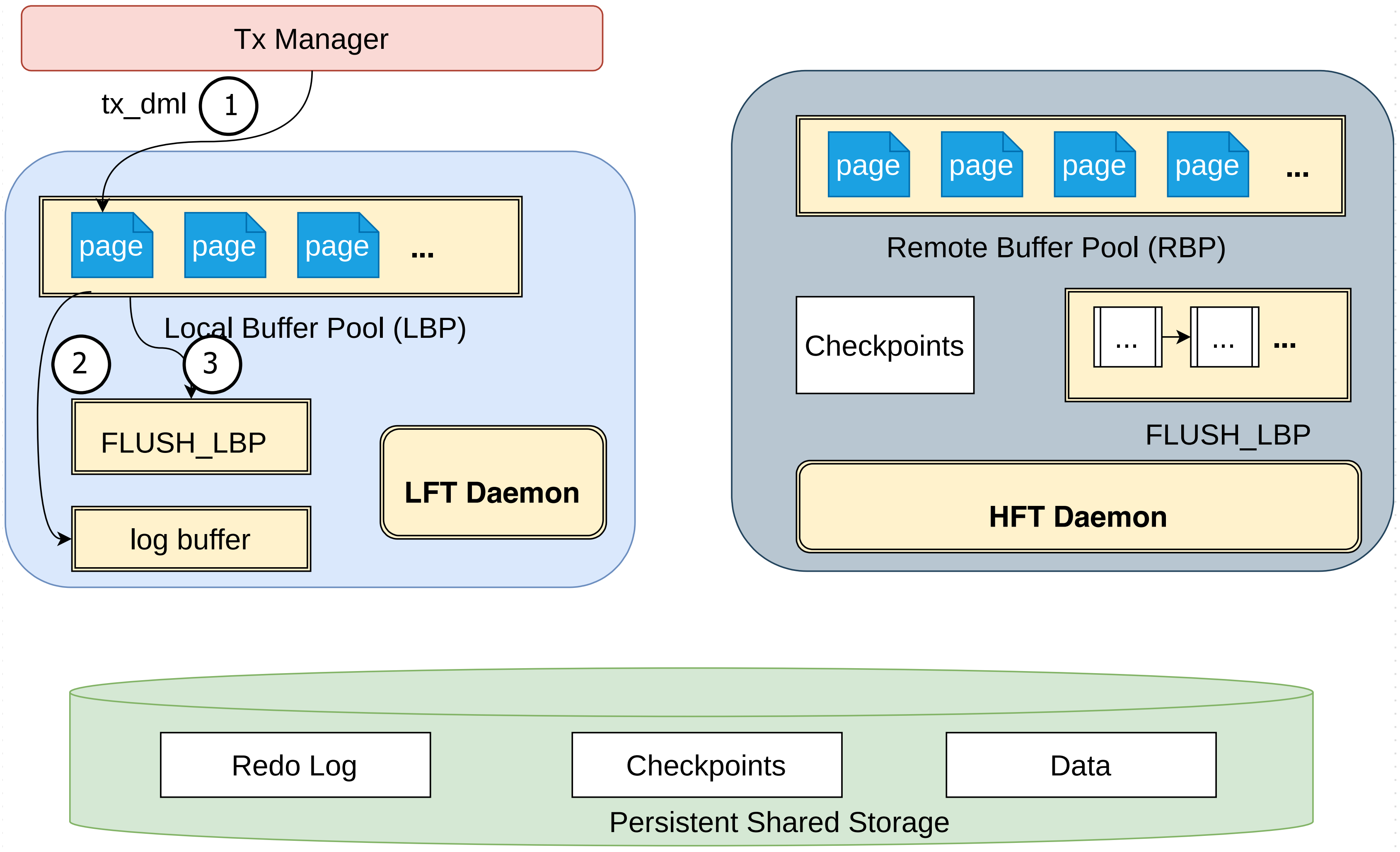

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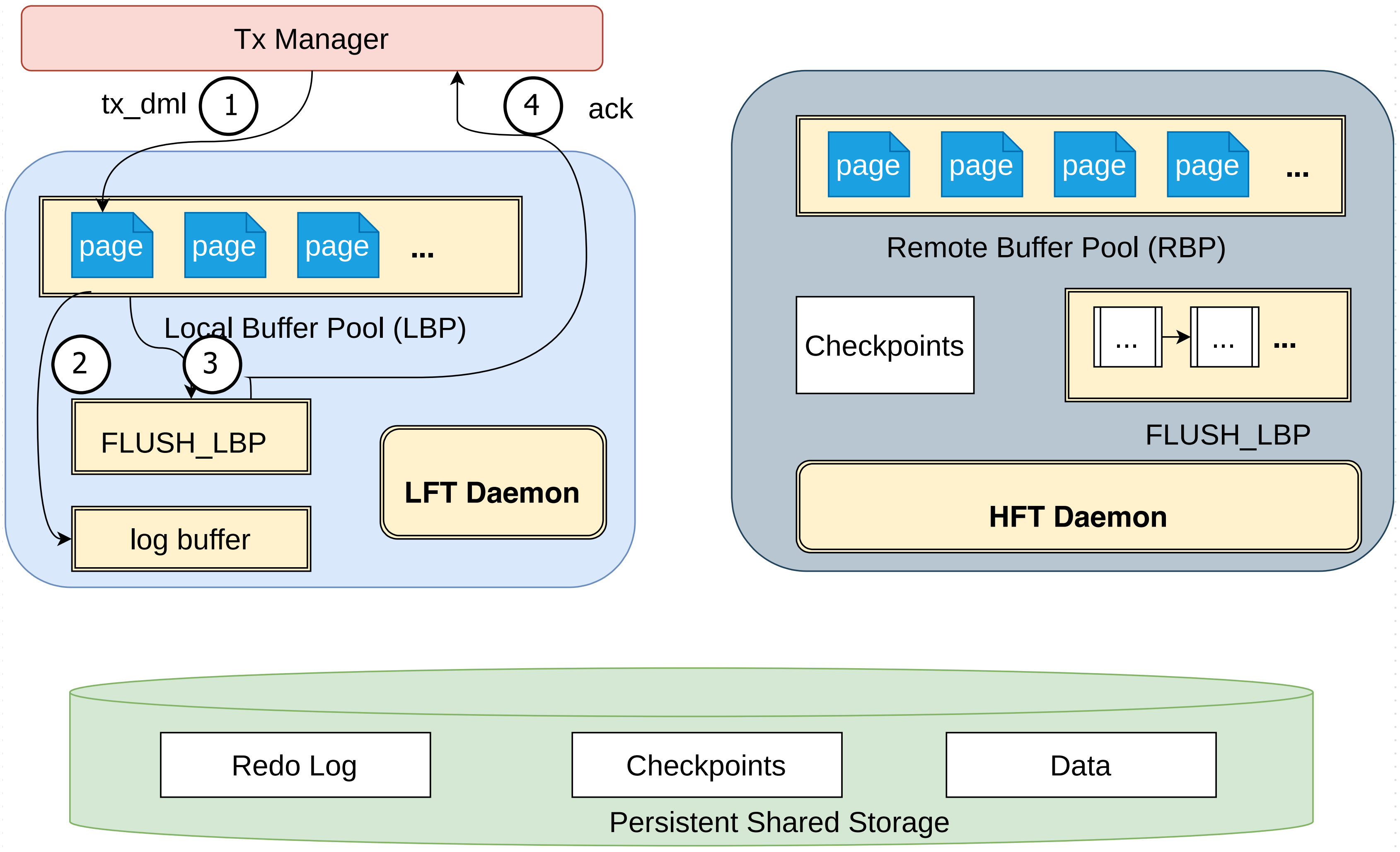

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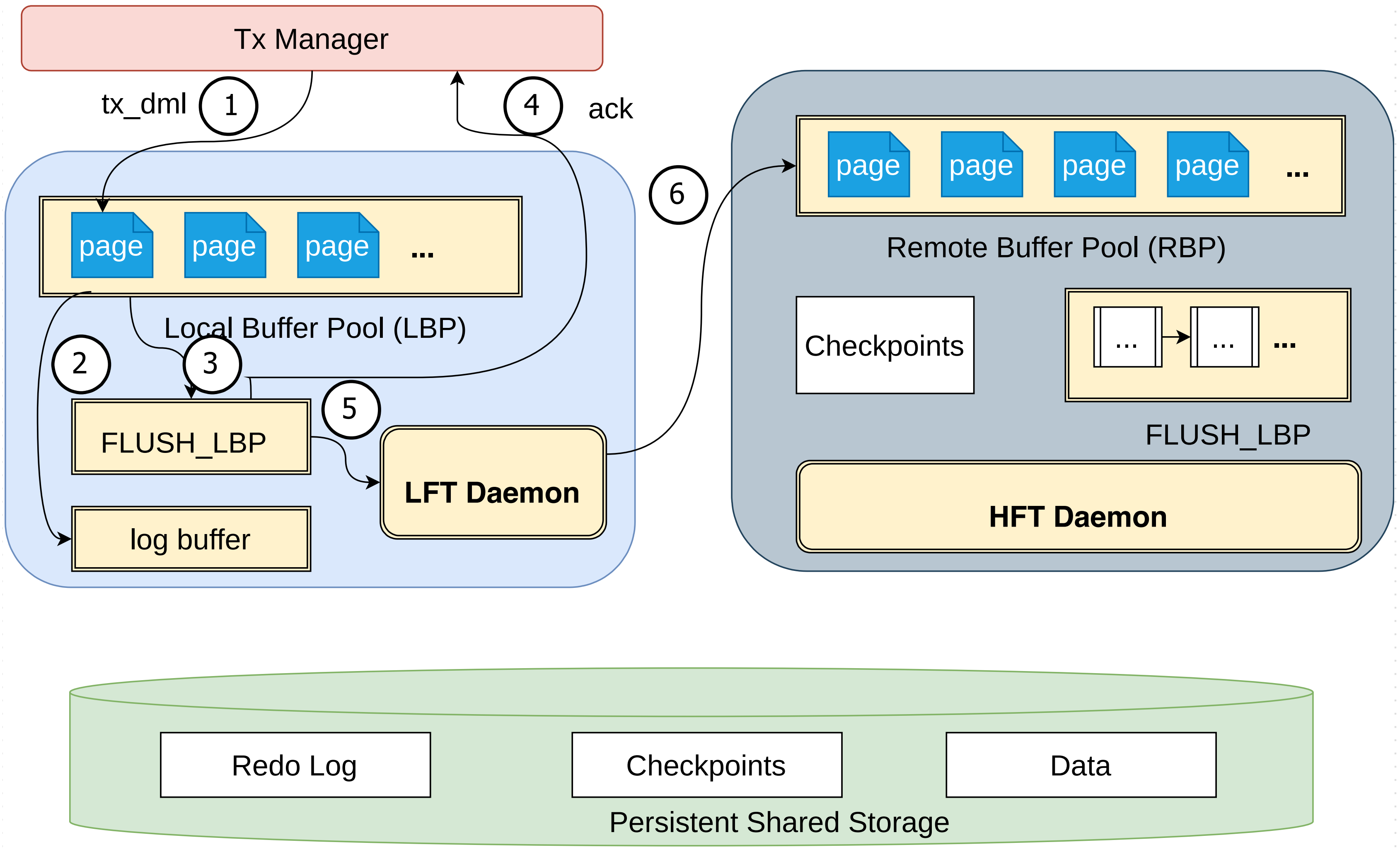

New Fault Tolerance: Two-tier ARIES Protocol

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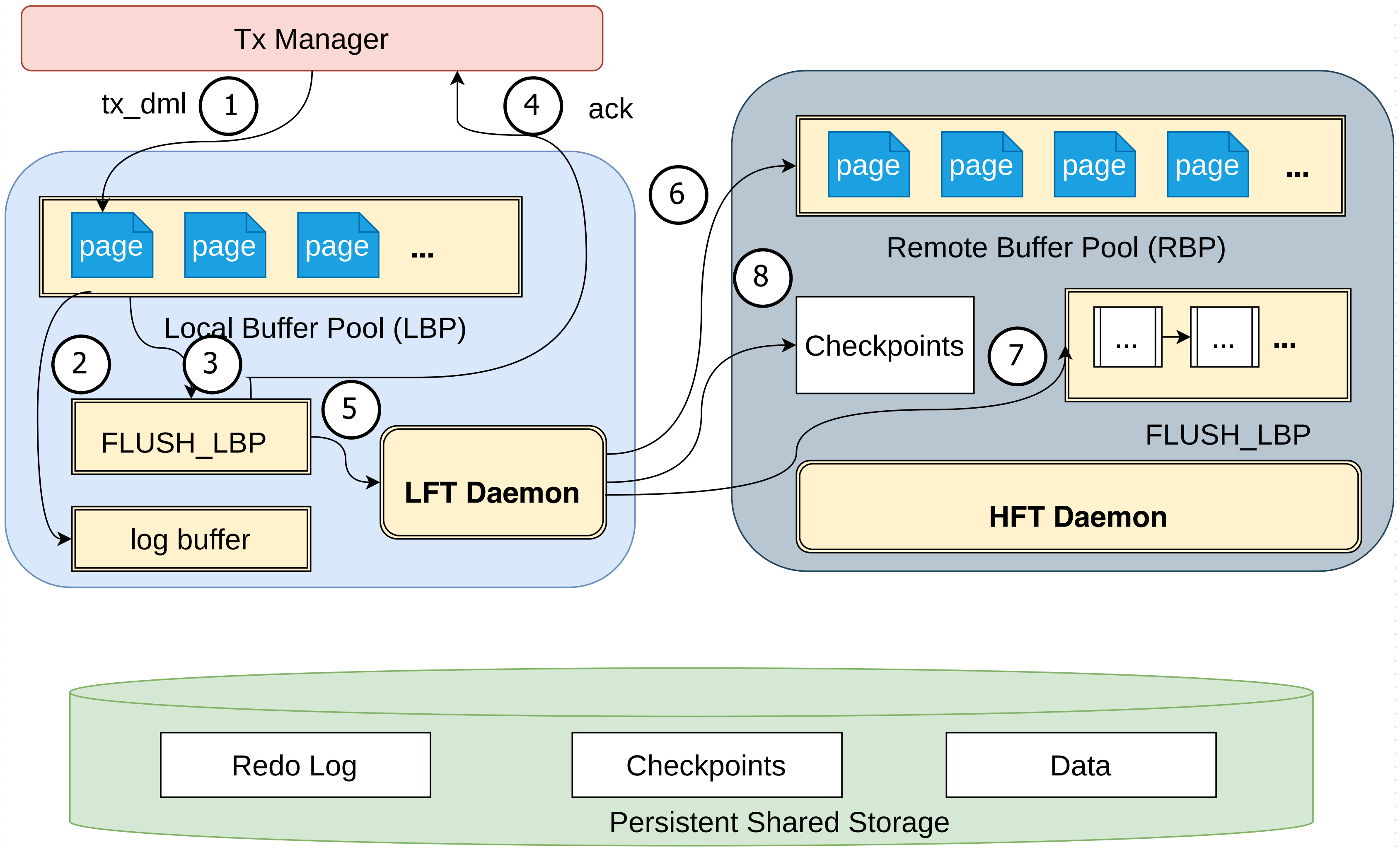

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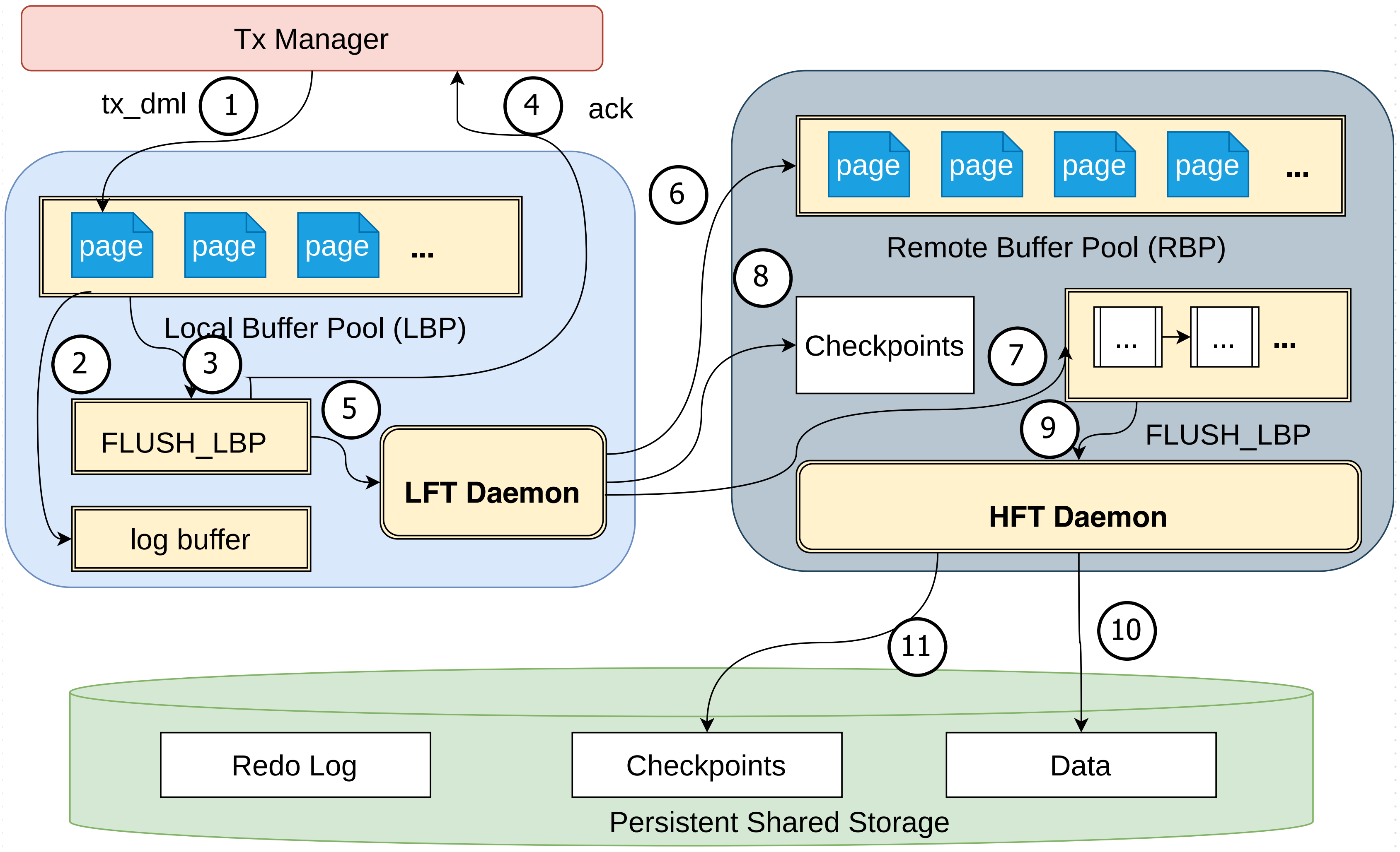

New Fault Tolerance: Two-tier ARIES Protocol

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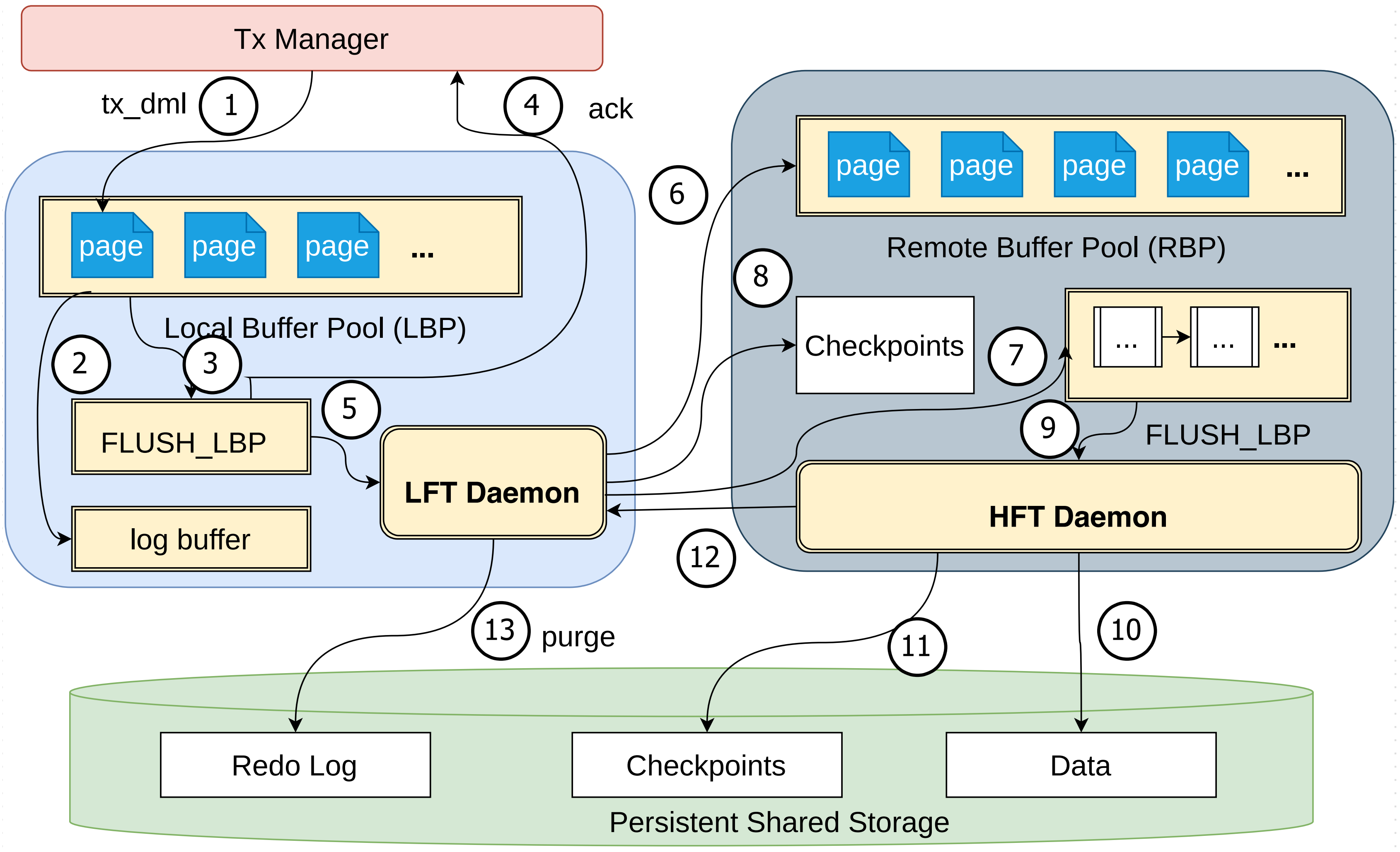
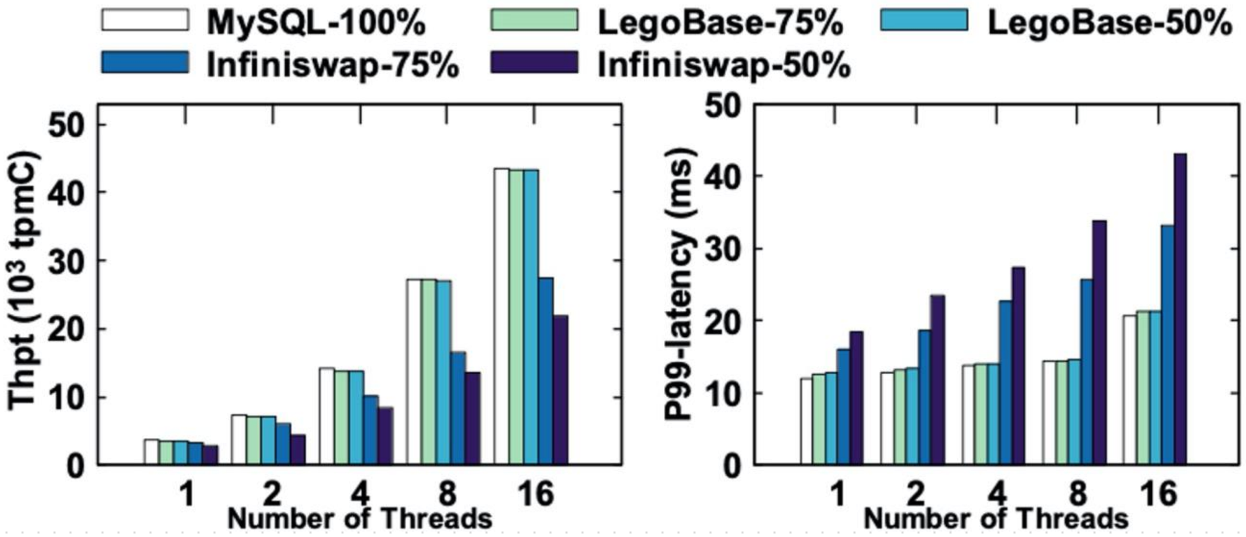


Experimental Setup

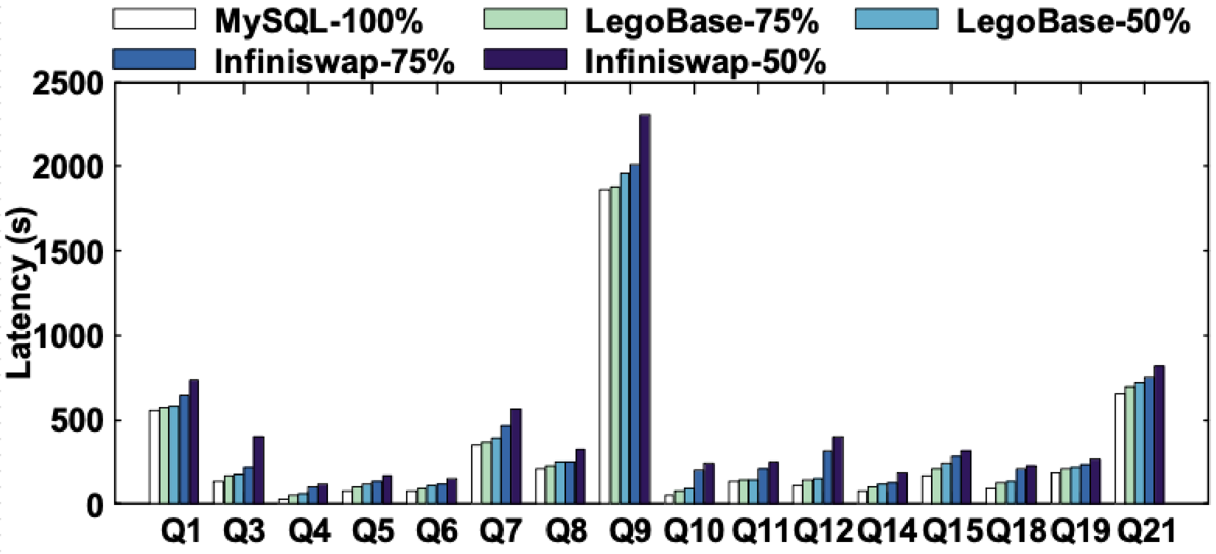
- Hardware configuration
  - Two Intel Xeon CPU E5-2682 v4 processors
  - 512GB DDR4 DRAM
  - 25Gbps Mellanox ConnectX-4 network adapter
- Workloads
  - TPC-C (20GB) / TPC-H (40GB) / Sysbench / Production workloads
- Baseline systems
  - Monolithic MySQL-8.0
  - MySQL over Infiniswap

TPC-C Results



- Compared to the monolithic MySQL setup, Infiniswap worsen by up to 2.01x (2.35×) in Throughput (P99 Latency)
- But, LegoBase brings only up to 3.82% (4.42%) loss in Throughput (P99 Latency)

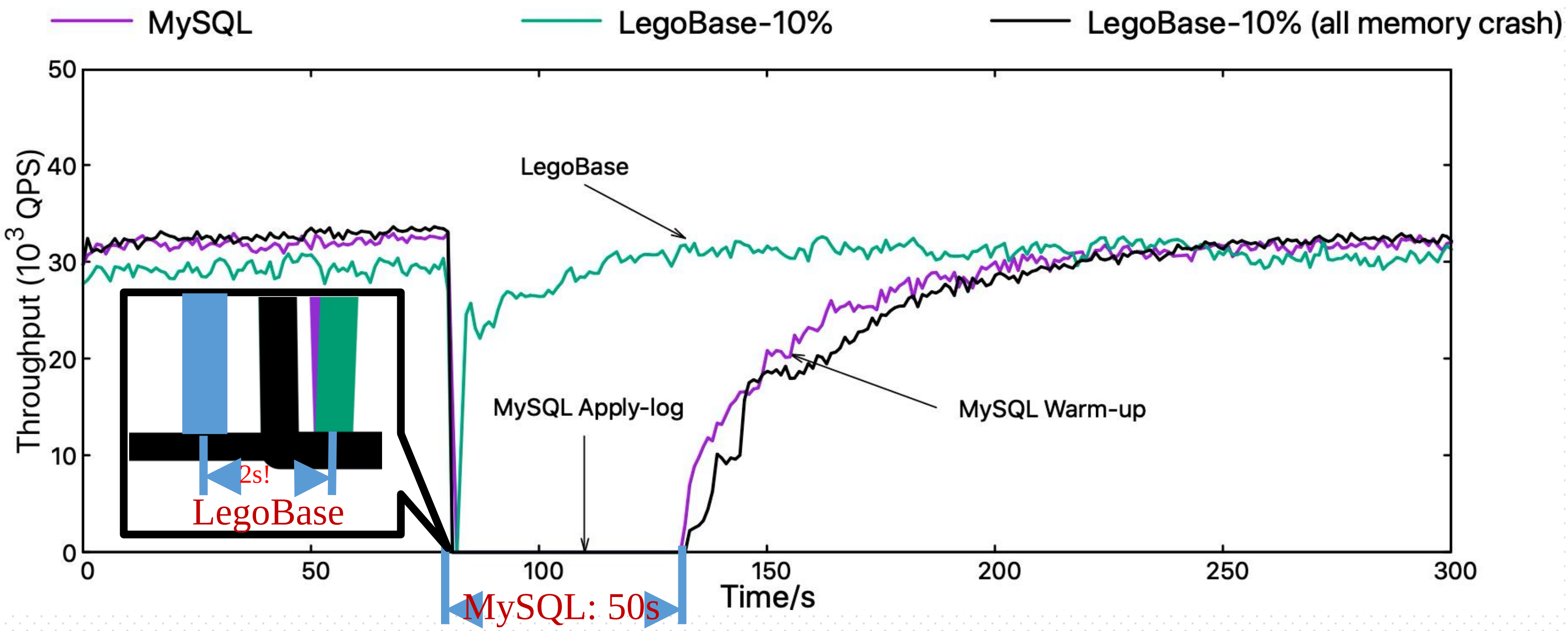
TPC-H Results



TPC-H Query Number

- LegoBase-75%' s latencies are closer to the ones of MySQL-100%
- LegoBase outperforms MySQL over infiniswap: e.g., runs up to 75.7% faster for Q11

Fast State Recovery and Warm-Up



- When all/remote memory crashes, LegoBase resorts to the normal MySQL recovery process.
- But, with only local node crashes, LegoBase can re-use vast majority of remote pages, and significantly reduces the state recovery and warm-up time costs.
- This can also benefit efficient planned hardware re-configurations.

Conclusion

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- **LegoBase is a novel memory-disaggregated cloud-native database architecture.**
- **LegoBase is able to scale CPU and memory capacities independently with comparable performance as the monolithic setup (without using remote memory).**
- **LegoBase can achieve faster state recovery and is more cost-effective than state-of-the-art baselines.**

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Thank you!

http://staff.ustc.edu.cn/~chengli7/