A Case for Dynamically Programmable Storage Background Tasks

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Motivation and Background

Modern storage infrastructures feature **long** and **complex I/O paths**

- Composed by several layers, such as *hypervisors*, *schedulers*, *databases*, and *file systems*

Layers employ **independent optimizations** to serve applications

- **Partial visibility** of the infrastructure **inhibits** optimal system-wide **performance**
- High levels of **I/O interference** and **performance degradation**
- Degradation amplifies when **concurrent I/O services** compete for shared resources

Motivation and Background

Background tasks are predefined I/O tasks that can rapidly **overload shared resources**

- Compaction, checkpointing, and replication
- Introduce significant **I/O interference** and **workload burstiness**
- Processed in best-effort manner to minimize interference with foreground workflows

The **decision** of **when** and **how** to execute such operations is taken by the **layer** itself, regardless of the overall load on the infrastructure

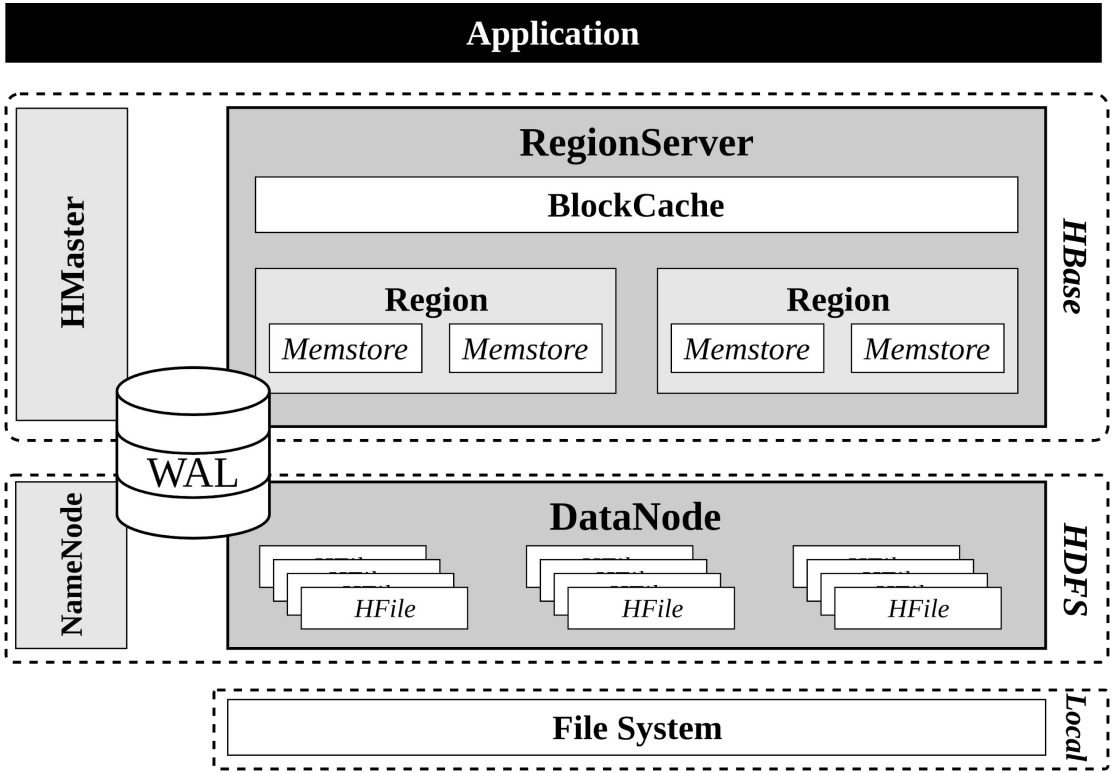
To achieve **optimal holistic performance**, storage background tasks should be **dynamically programmable** and their execution handled in **end-to-end** fashion.

Contributions

- Extensive evaluation of the impact of storage background tasks
  - Impact of **compaction** processes under **HBase**
  - Impact of **checkpointing** processes under **PostgreSQL**
  - Analysis of **mean** and **tail latencies** performance

- Design of a **programmable** storage system to achieve **optimal holistic performance**

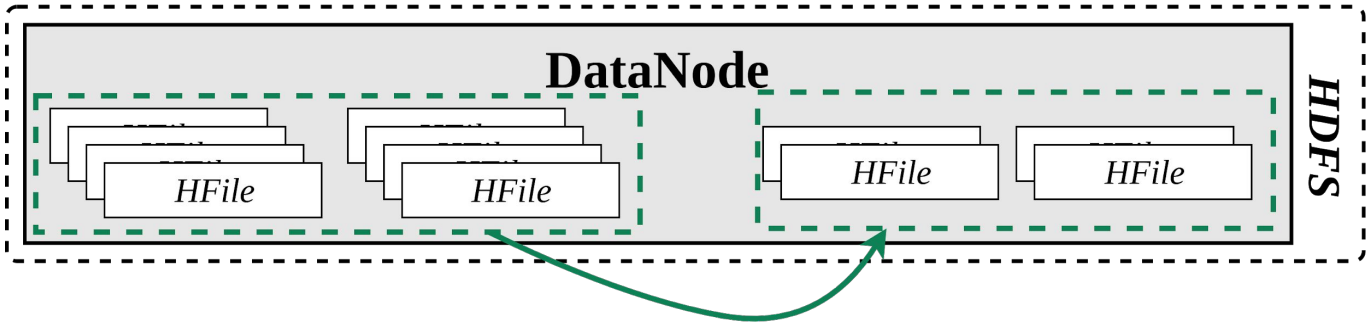
Case Study: HBase



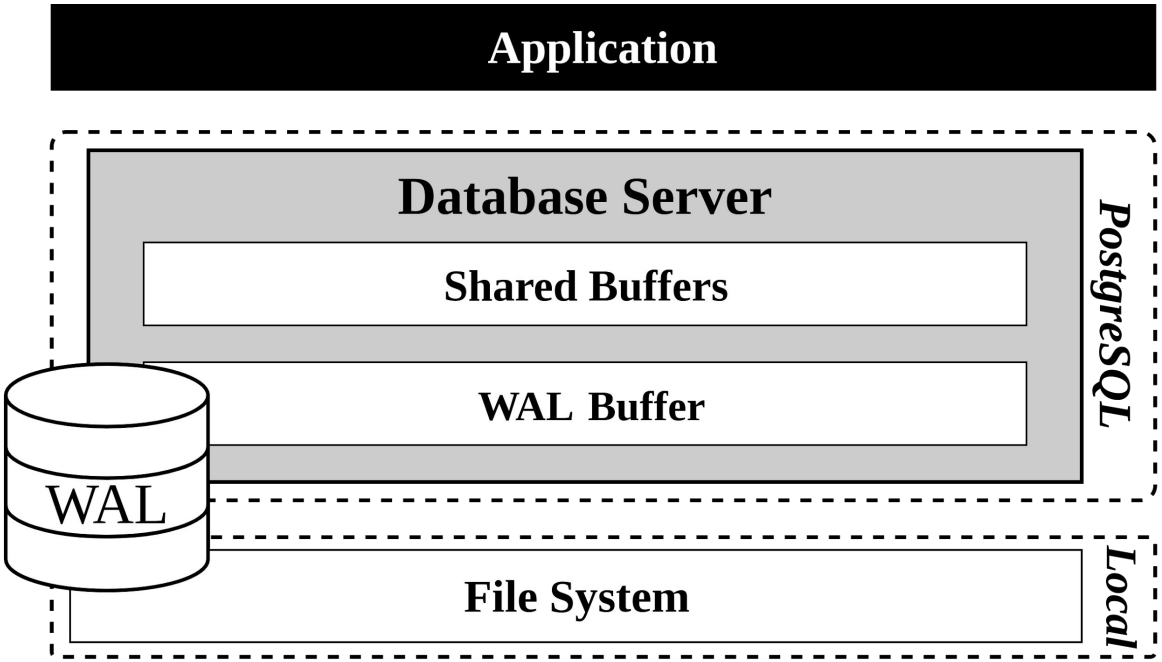
Case Study: HBase

LSM-based design leads to the execution of **background compactions**

- Merges several small-sized HFiles into fewer larger ones
- While improving read performance, compactions introduce I/O interference and burstiness



Case Study: PostgreSQL



Case Study: PostgreSQL

To truncate the log and allow **fast recovery**, PostgreSQL performs **checkpoints**

- Flush dirty data pages in *shared buffers* to disk
- Executed either when the **WAL** file is about to **exceed a certain size** or upon a **timeout**
- **Checkpoint completion target** adjusts the **throughput** at which checkpoints are made
- **Lower bound** leads to **I/O burstiness** and **higher bound** to **longer recovery** times

Methodology

- *How much overhead do these background tasks impose?*
- *How does their overhead vary across operation types?*
- *How does their overhead vary across time?*
- *How do these tasks impact tail latency?*
- *How do these tasks' configuration parameters influence their impact on performance?*

Methodology

Testbed

- HBase 2.0.5 pseudo-distributed mode, backed by HDFS 2.9.2
- PostgreSQL 11.3 backed by an ext4 file system

Workloads*

- *Workload A:* 50% read, 50% update, zipfian
- *Workload B:* 100% update, zipfian
- *Workload C:* 100% read, uniform
- *Workload D:* 5% read, 95% insert, zipfian
- *Workload E:* 95% scan, 5% insert, zipfian
- *Workload F:* 50% read, 50% read-modify-write, zipfian

* Workloads previously used in [22]: *"MeT: Workload aware elasticity for NoSQL"*

Results publicly available at https://rgmacedo.github.io/drss19-website/

Methodology

HBase deployments

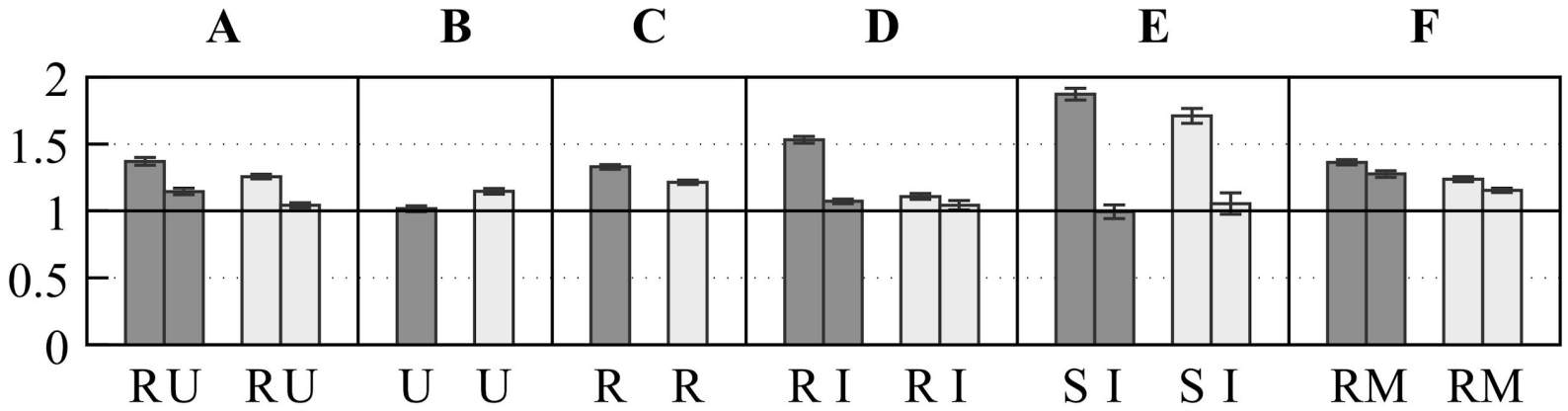
- **With compaction effects.** Execution phase immediately after loading phase
- **Without compaction effects.** Execution phase after a waiting period

PostgreSQL deployments

- 6 configurations with varying **WAL size** and **checkpoint completion target**
- 128MiB and 1024MiB for **maximum WAL size** parameter
- 0.1, 0.5, and 0.9 for **checkpoint completion target** parameter

HBase Compactions

Mean latency results



HBase Compactions

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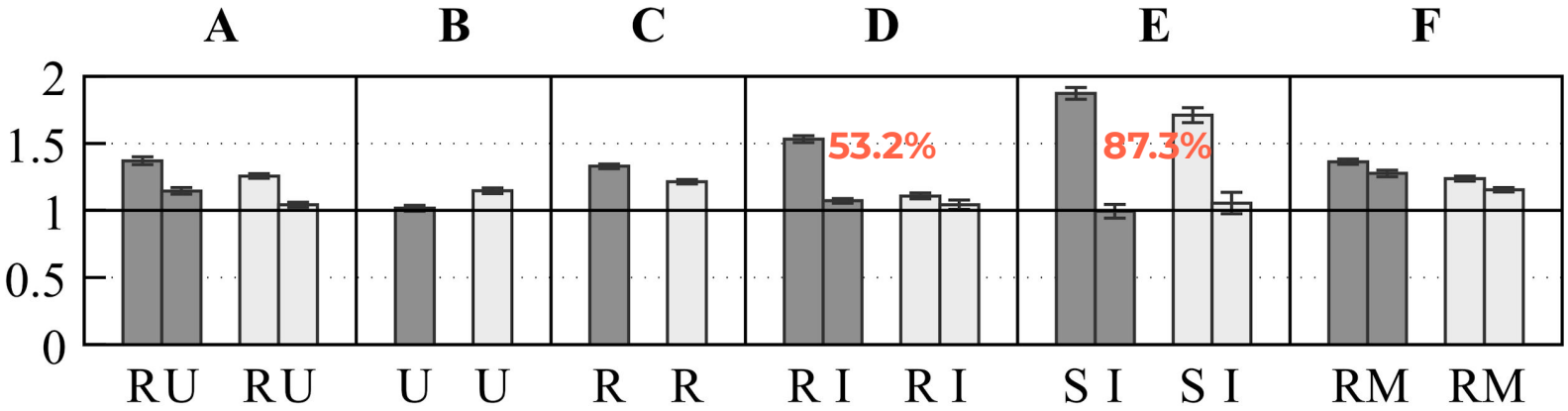
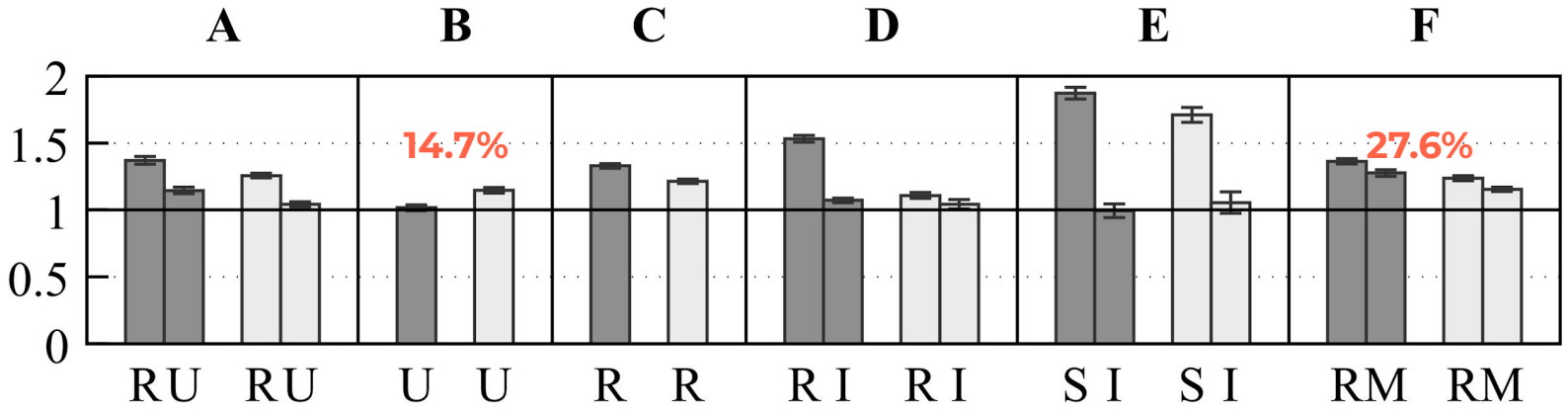


Inherent **dependency over files** being compacted results in **high I/O interference** over read-oriented requests

Read-oriented operations exhibit an **overhead** of at most **955.2%** at the 99th percentile latency

HBase Compactions

Mean latency results



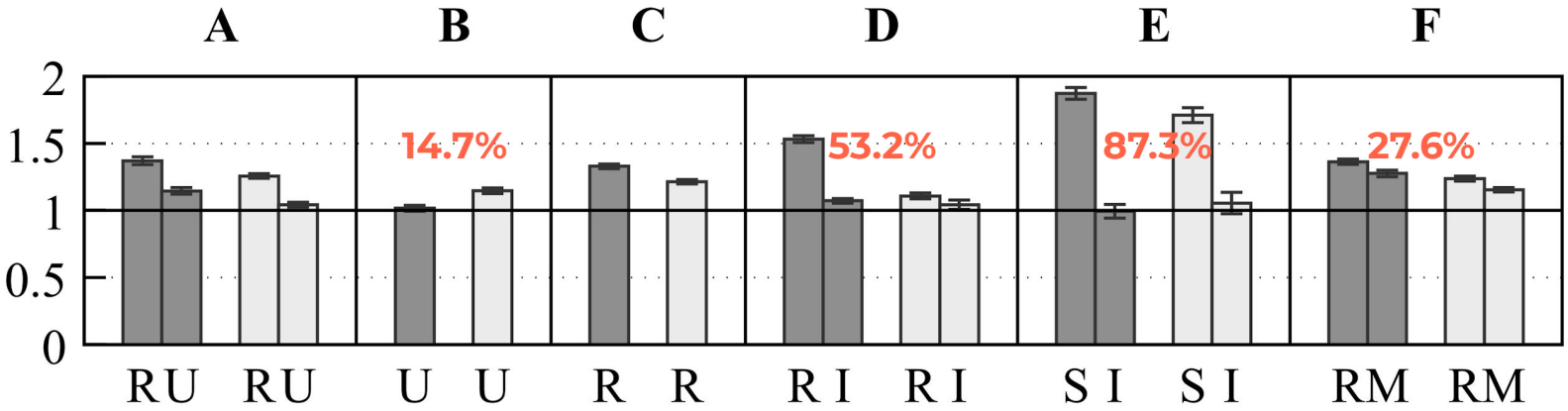
Write operations are **sequentially written** to the WAL and then persisted at the Memstore

Experienced compactions do not impose major disk overload and I/O interference

Performance degradations of at most **40%** at the 99th percentile latency for write operations

HBase Compactions

Mean latency results



CPU utilization remains mostly unaltered

Read and write **disk throughput** experience an **increase** of **33** and **15MiB/s**, respectively

Default **throttling policy limits compaction throughput** to reduce I/O interference

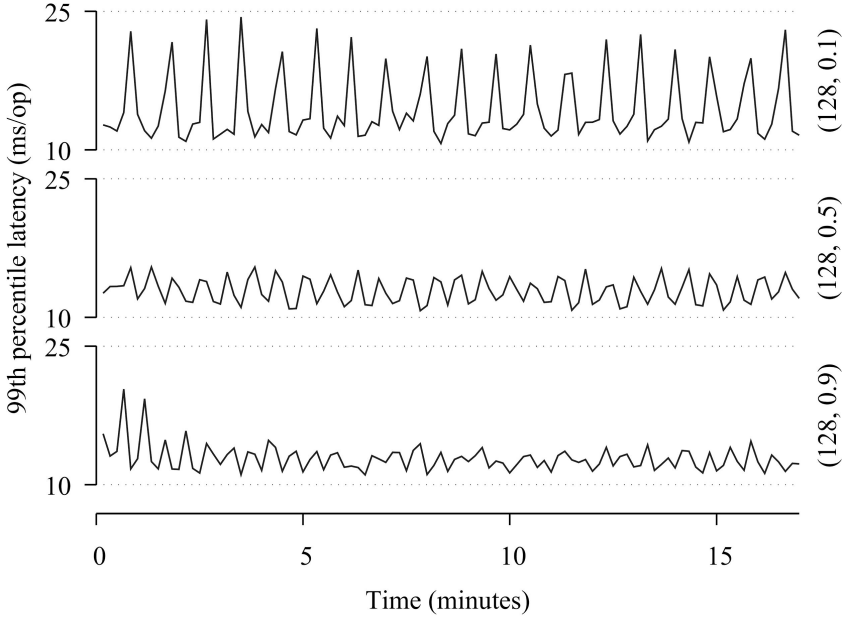
PostgreSQL Checkpointing

Tail latency results

At 99th percentile latency, 0.1, 0.5, and 0.9 completion target configurations experience an **overhead** of at most **61.9%**, **33.2%**, and **33.3%**, respectively

Lower values result in **I/O burstiness**, inhibiting QoS provisioning and sustained performance

Larger values **throttle** WAL write **performance**, occupying disk bandwidth for longer periods



99th percentile latency variation for the update operation for each PostgreSQL configuration, under *Workload A* with 1 thread

PostgreSQL Checkpointing

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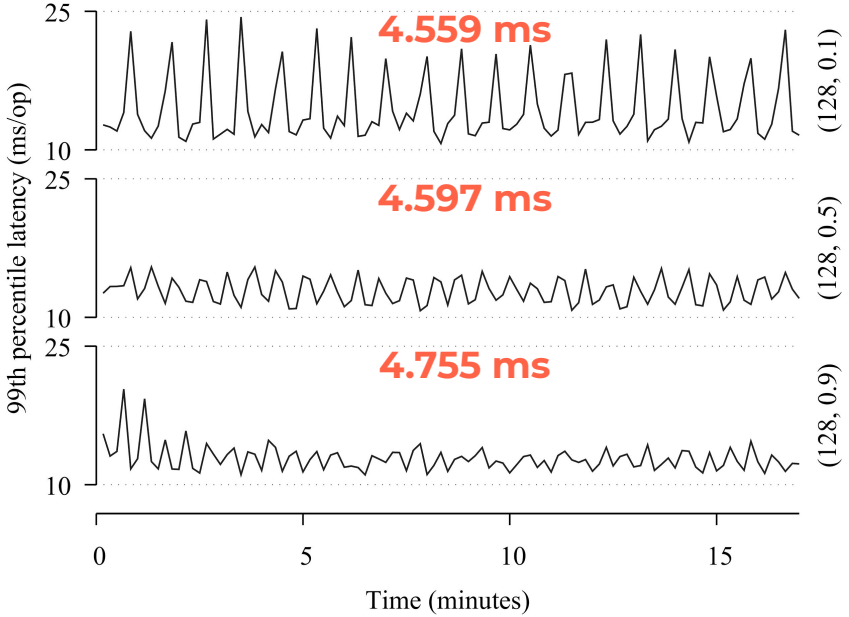


99th percentile latency variation for the update operation for each PostgreSQL configuration, under *Workload A* with 1 thread

Discussion

Compaction and checkpointing heavily **impact** foreground tasks performance

HBase **throttles** compaction throughput

- Does not provide the building block to dynamically adapt such settings
- Applications experience compaction effects for longer periods of time

PostgreSQL **cannot dynamically adjust** checkpointing activity to the overall load of the infrastructure

Storage tasks should be **dynamically programmable** to achieve **optimal holistic performance**

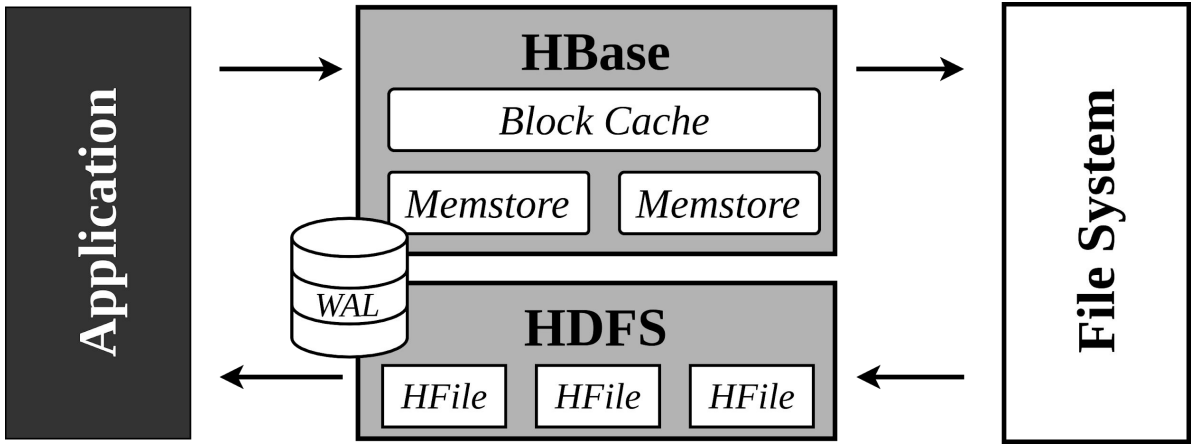
Programmable Storage Background Tasks

Following the **Software-Defined Storage** principles

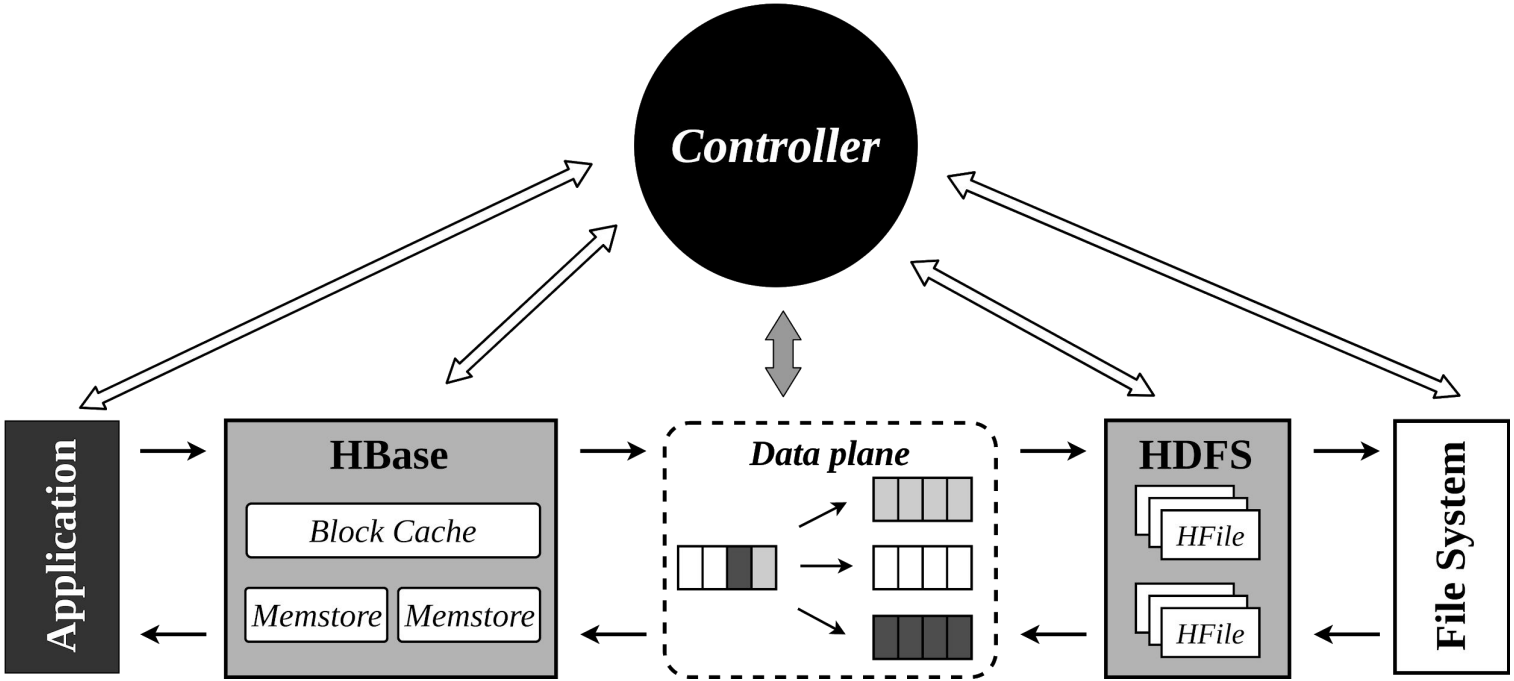
- **Decouple** background **mechanisms** and **policies**
- At layer level, a **data plane dynamically adapts** background activities
- At infrastructure-level, **policy-enabled controller** provides **adaptable end-to-end control**

Minimize I/O variability and interference, and ensure QoS provisioning and resource fairness

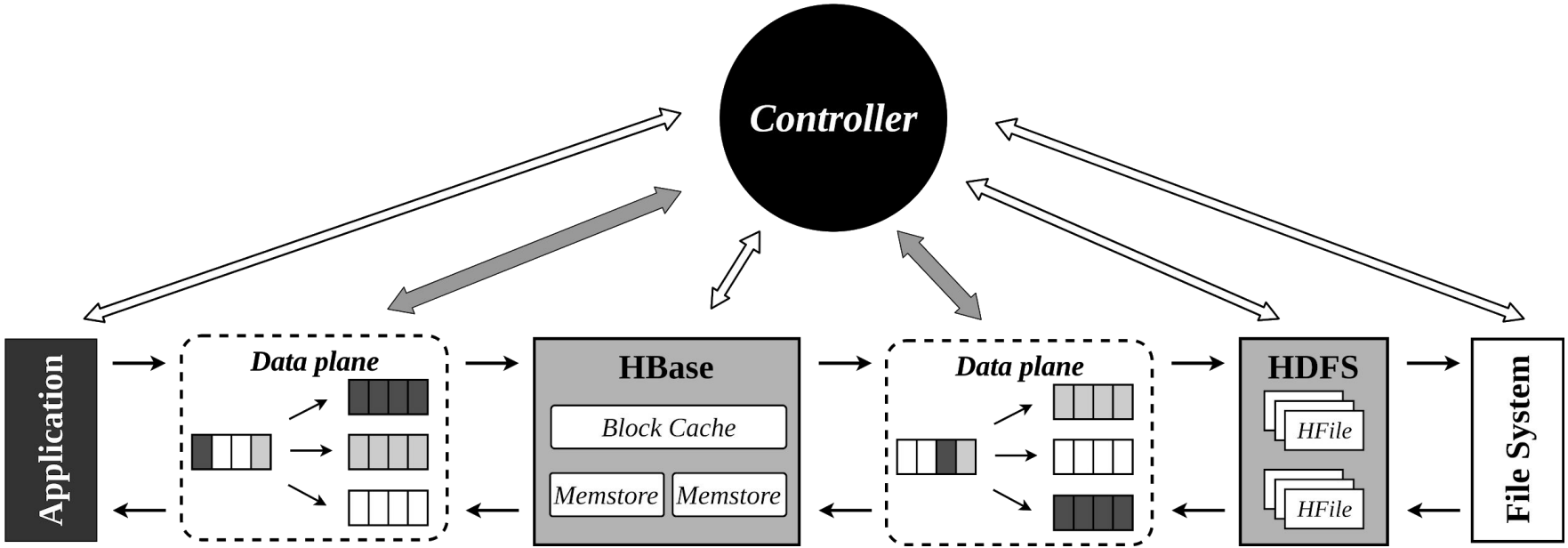
Programmable Storage Background Tasks



Programmable Storage Background Tasks



Programmable Storage Background Tasks



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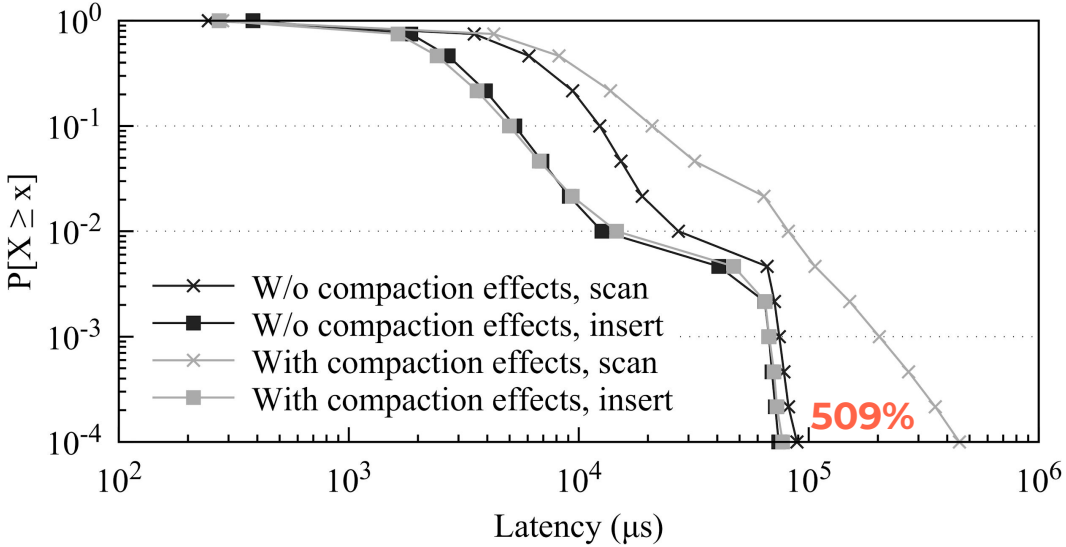
HBase Compactions

Tail latency results

Performance degradations of at most **40%** at the 99th percentile latency for write operations

Read-oriented operations exhibit an **overhead** of at most **955.2%**

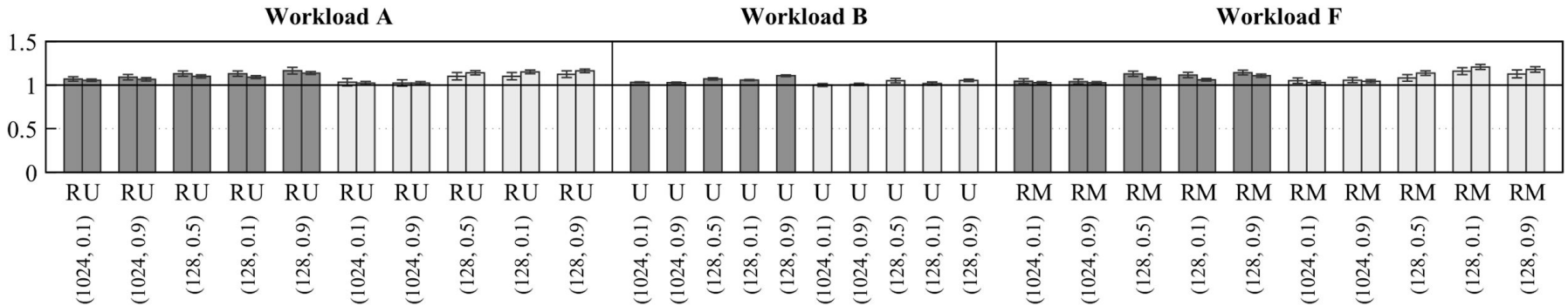
Read-modify-write experiences a **281% overhead**



Complementary cumulative distribution function (CCDF) for the latency of *Workload E* with 10 threads

PostgreSQL Checkpointing

Mean latency results



Read and write operations are equally exposed to performance variations

128MiB WAL size **degrades performance** of at most **20.7%**, **13.9%**, and **17.8%** under 0.1, 0.5, and 0.9 checkpoint completion target

Case Study: HBase

Highly available NoSQL database, made of *RegionServers* and an *HMaster*

- Tables are **horizontally partitioned** by row key ranges into *Regions*
- Writes are first persisted in a **WAL** and then written to a *Memstore* (write-oriented cache)
- Reads **hierarchically traverse** the data store, accessing the *Block Cache*, *Memstore*, and *HFiles*
- Generation of different *HFiles* per *Memstore* leads **read amplification**

Case Study: HBase

LSM-based design leads to the execution of **background compactions**

- **Minor compaction.** Merges several small-sized HFiles into fewer larger ones
- **Major compaction.** Merges all HFiles into a single larger one, removing deleted entries
- While improving read performance, compactions introduce I/O interference and burstiness

Case Study: PostgreSQL

Relational database that handles requests from multiple applications

- Writes are first mapped to a *shared buffer* and then written to a *WAL buffer*
- On commit, changes are **sequentially written** to a **WAL file** on disk
- Reads **hierarchically traverse** the database, accessing the *shared buffer*, *OS cache*, and *disk*

Methodology

Testbed

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Execution scenario

- Single and multi-threaded
- Loading phase with 12.5M records (≈16GiB)
- Runs executed 10M operations or when 17 minutes had elapsed
- System state was recreated after each run

Results publicly available at https://rgmacedo.github.io/drss19-website/