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TeraHeap: Reducing Memory Pressure in Managed Big Data Frameworks

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Analytics frameworks need large heaps

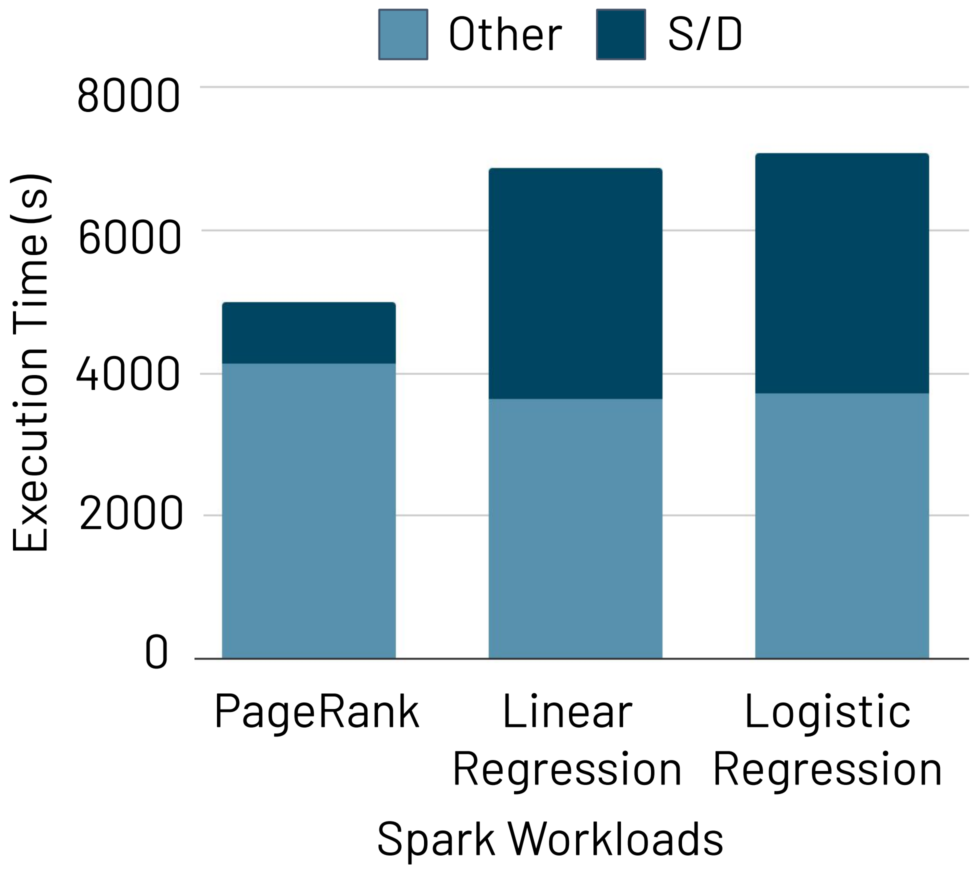
- Analytics frameworks use managed runtimes
- To process **large amounts of data** they need **large heaps**
- Large heaps are **expensive (DRAM)** and **increase GC cost!**
    - DRAM is expensive in dollar cost, energy, and power
    - GC requires expensive scans over large heaps
- For these reasons analytics frameworks avoid large heaps

Common practice: Move objects off-heap

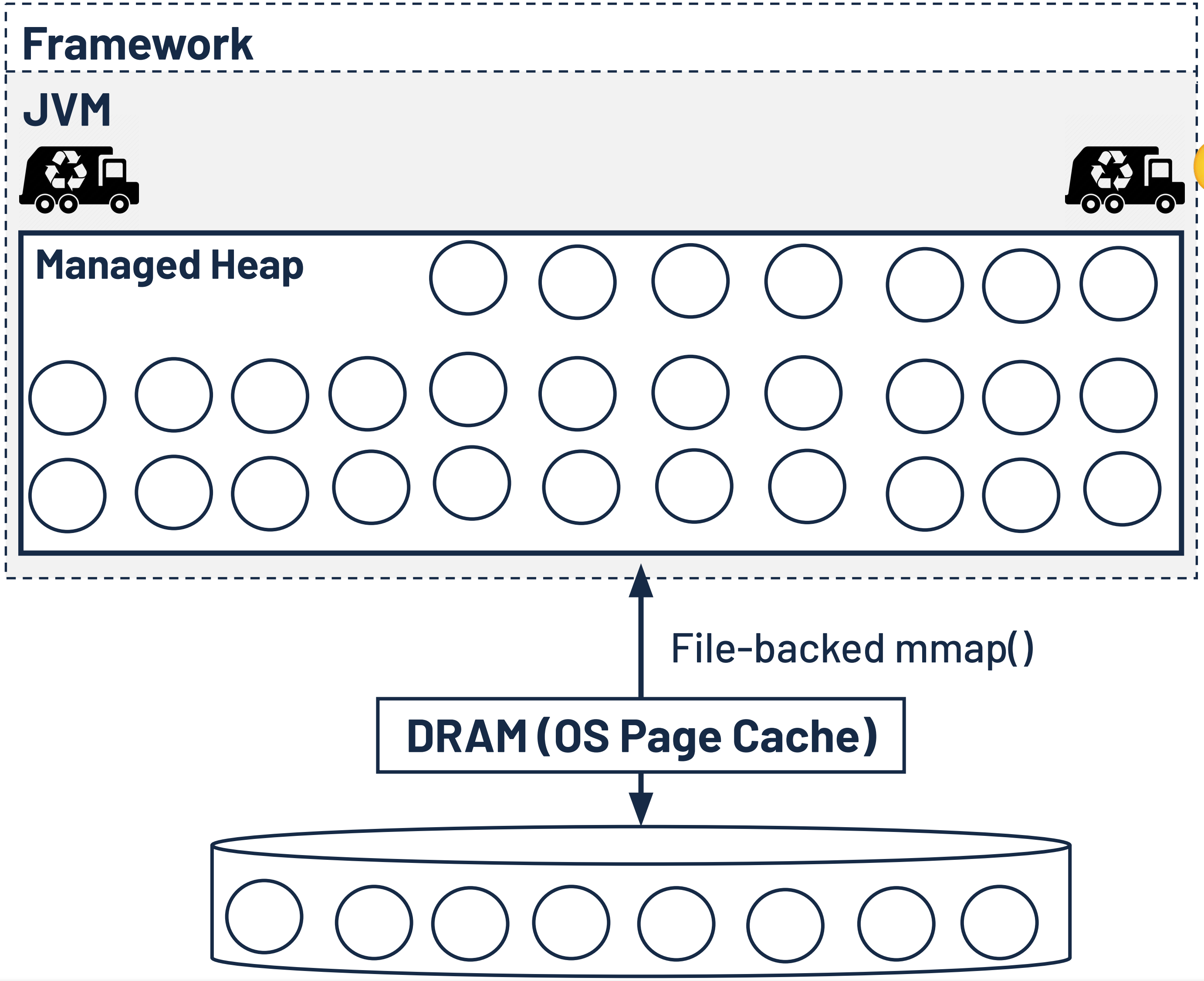
- Off-heap storage in this context means
  - Off DRAM → on fast storage
  - Unmanaged → no GC scans

- Off-heap demands serialization/deserialization (S/D)
  - Transform object closure into byte streams

- S/D is significant problem!
  - Takes up to 47% in Spark workloads
  - Not everything is serializable!
  - Off-heap can be unsafe



Eliminate S/D: Extend the heap over storage

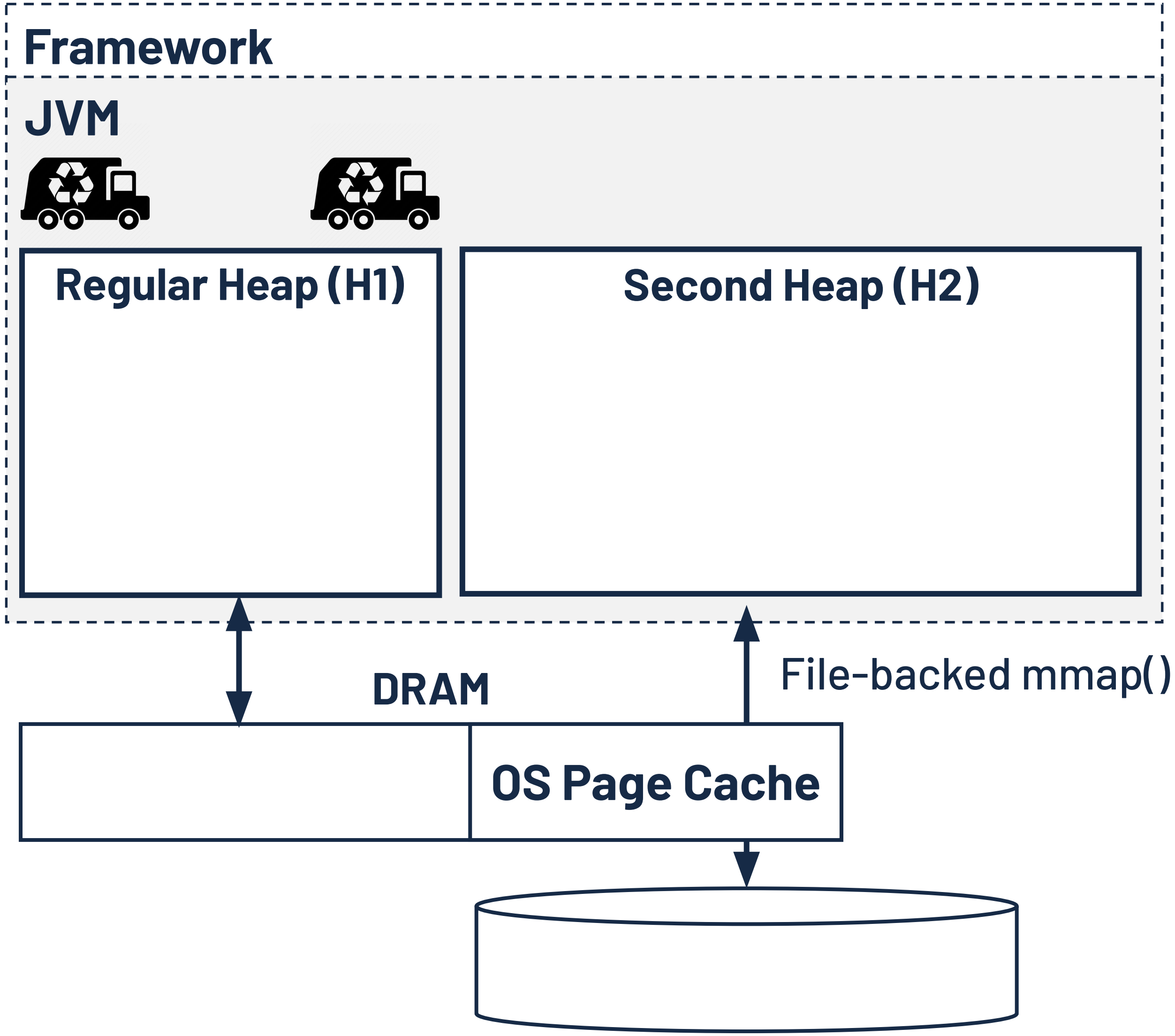


- Today OpenJDK naively uses mmap()

☹️ GC cost increases dramatically!

  - **Random accesses** over storage
  - **Object compaction** over storage
  - High I/O traffic

TeraHeap: Eliminate S/D without increasing GC cost



- Provides the illusion of a single heap
- Avoid GC scans over the device heap
- Custom management for the device heap
  - Lazy GC due to high storage capacity
  - Minimizing I/O traffic

Outline

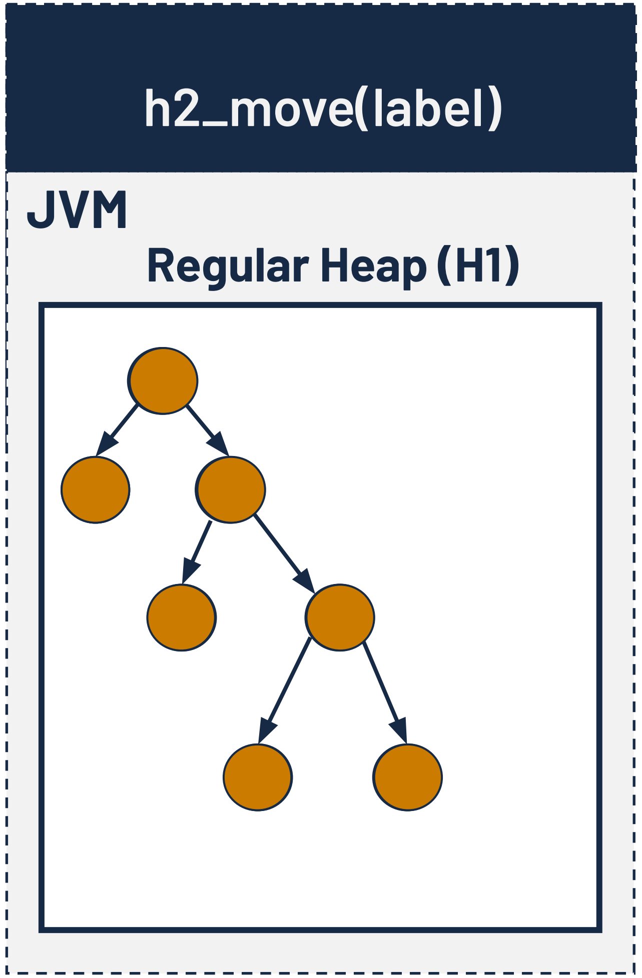
- Motivation

- Design
    - Identify objects for moving to H2
    - Reclaim objects in H2 without GC scans
    - Update cross-heap references with low I/O cost

- Evaluation

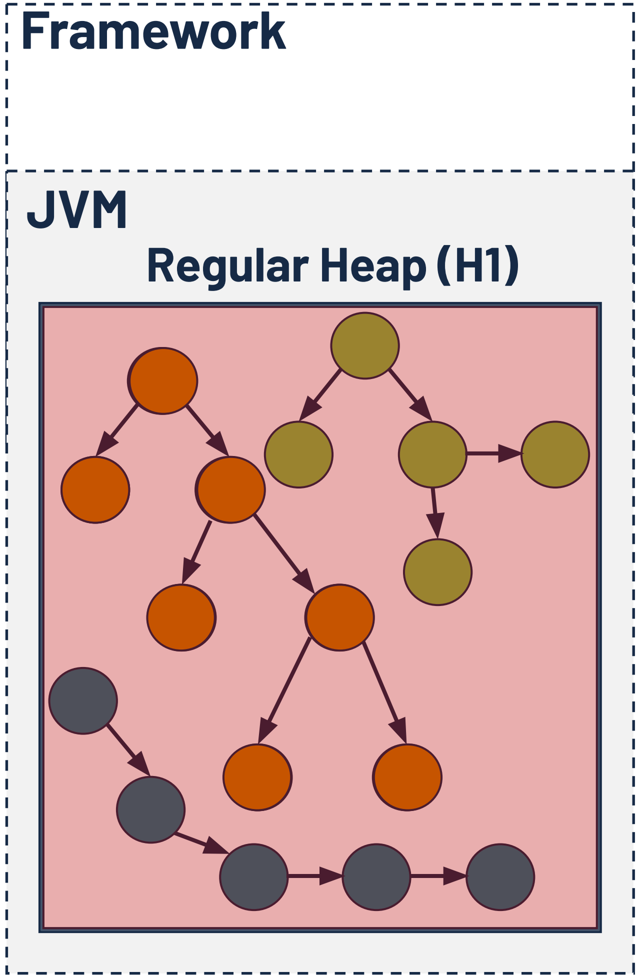
- Conclusions

Move off-heap objects to H2



- Goal: Find **large clusters** of objects with **similar lifetime**
- Frameworks **move** partitions **off-heap**
- Frameworks have **eventually immutable objects**
- TeraHeap provides two hints
  - h2_mark_root(): Mark key object with a label
  - h2_move(): Advice when to move objects to H2
- Move objects to H2 during GC
- GC propagates the label from key object to all reachable objects

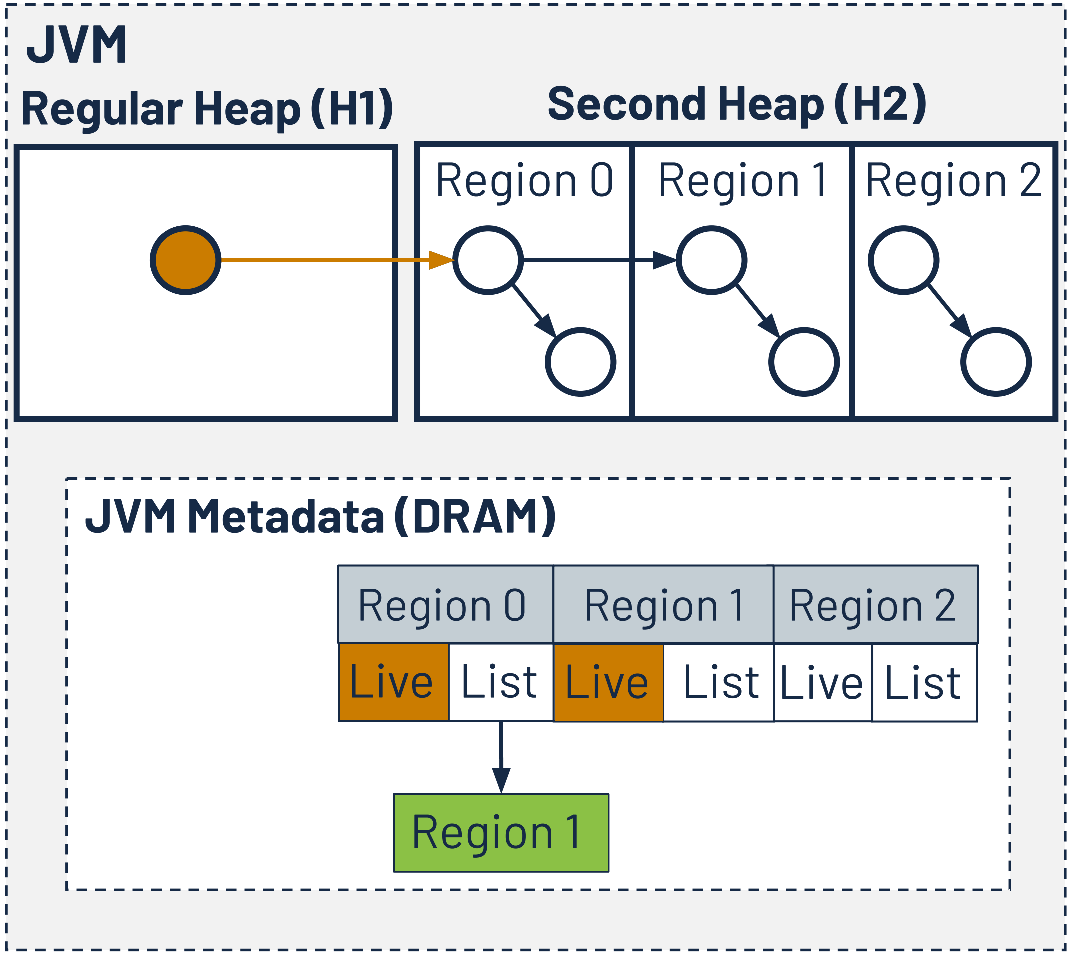
Can move objects to H2 eagerly



☐ Goal: Reduce **memory pressure in H1**

- Increased memory pressure before transfer hint?
- Eager transfers to H2 → decrease memory pressure in H1
- Use a high threshold to identify memory pressure
- Bypass transfer hint
- Move only a few marked objects to H2
  - Reduce **read-modify-write operations** in storage

Leverage storage capacity to free objects lazily



Region 0		Region 1		Region 2	
Live	List	Live	List	Live	List

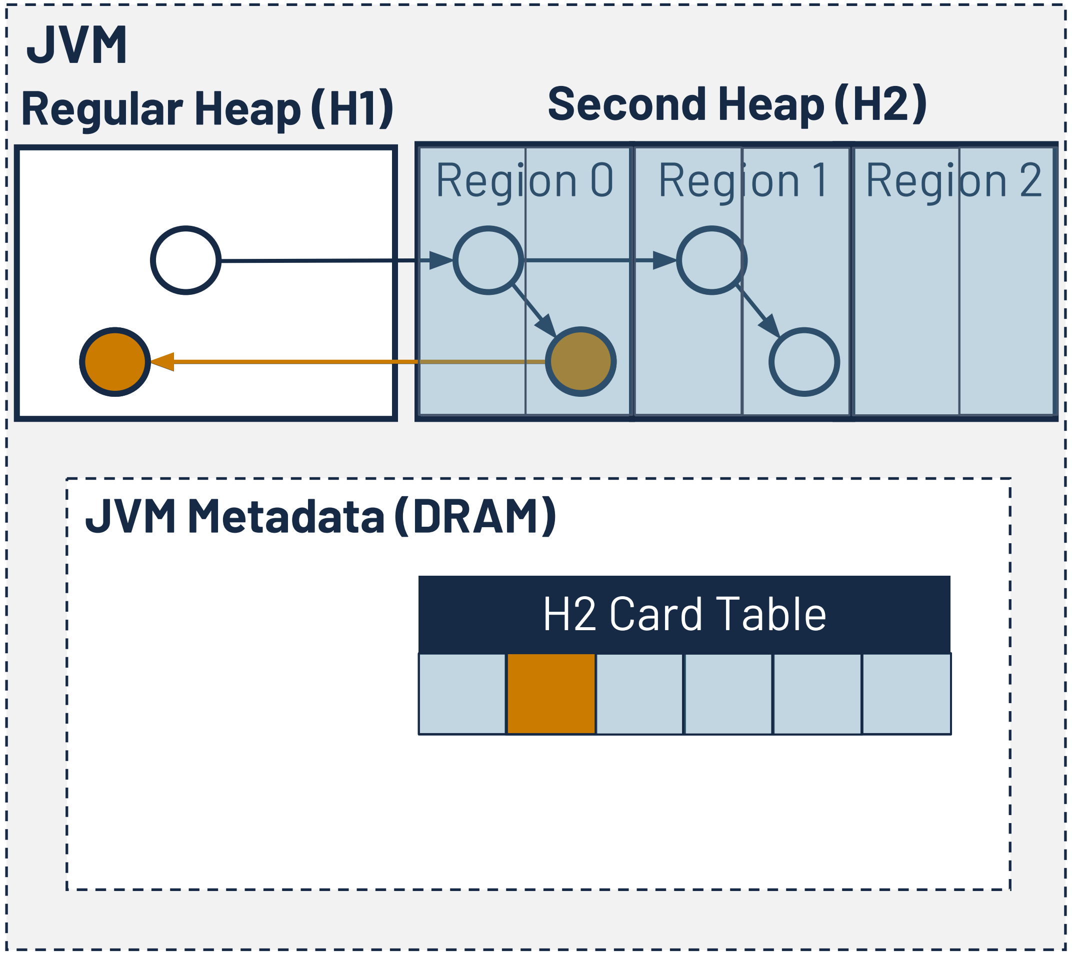
- ☐ Goal: **Reclaim** dead objects **without GC scans**

- TeraHeap organizes H2 in fixed-sized regions
  - Objects with same label in the same region
  - Reclaim whole regions **(bulk free)**

- Per region DRAM metadata **(avoid object access)**
  - Live bit → region liveness
  - Dependency list → cross-region references

- GC identifies H2 live regions
  - Free regions by zeroing regions metadata

Preserve correctness of object liveness



☐ Goal: **Track** H2 to H1 references with **low I/O cost**

- Card table (byte array in DRAM)
  - One byte per fixed-size H2 segments
  - Large segments to reduce card table size
- Categorize cards to scan less segments
- Based on GC type, we scan specific segments

Testbed

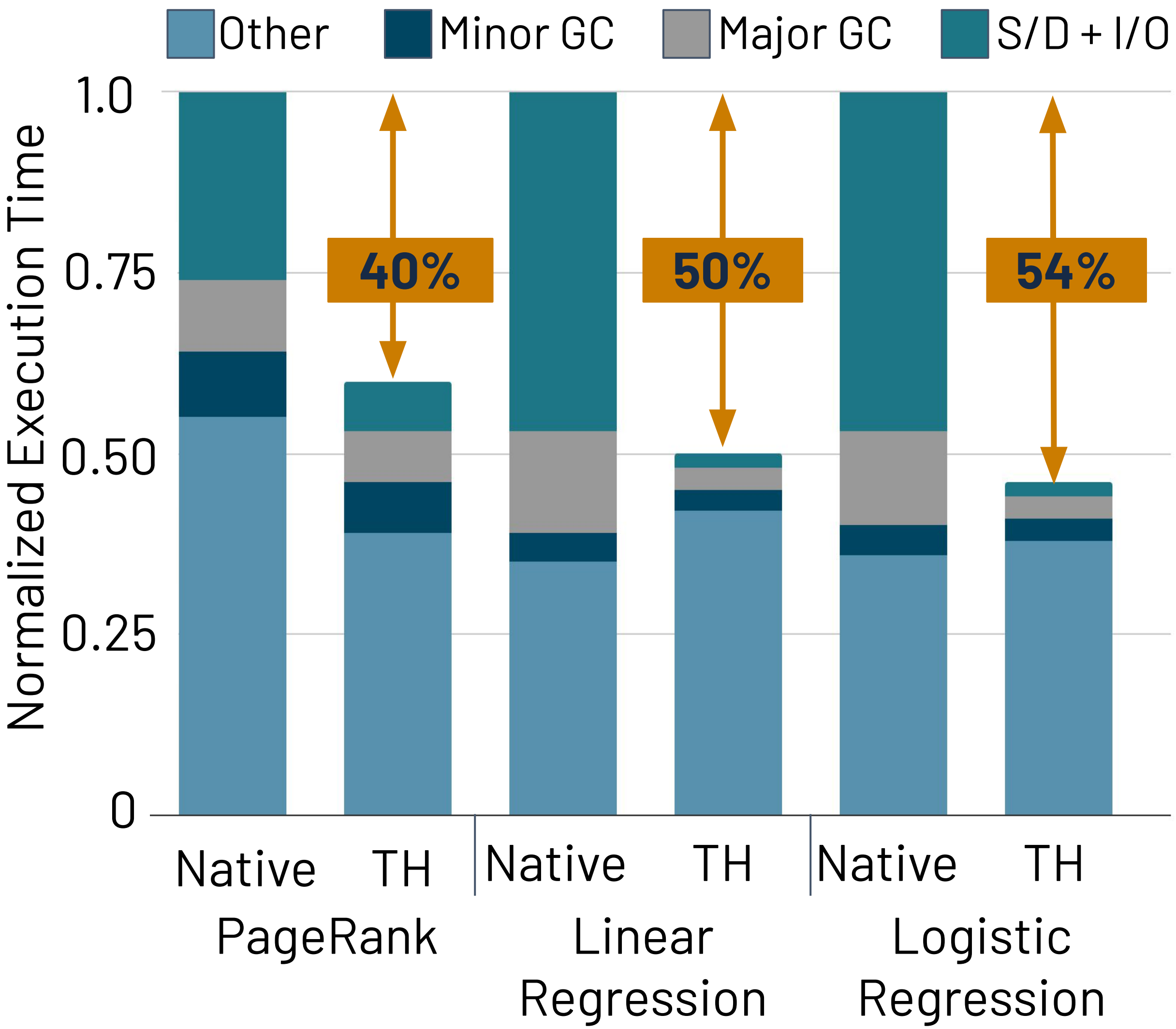
- We implement TeraHeap in OpenJDK 8 (we now support OpenJDK 17)
    - Extend Parallel Scavenge garbage collector
    - Extend interpreter, C1 and C2 (JIT) compilers to support updates in H2

- We use one servers with 2 TB NVMe SSD and 256 GB DRAM
    - Also, we evaluate TeraHeap with NVM

- Real world applications
    - Spark with SparkBench suite
    - Giraph with Graphalytics benchmark suite

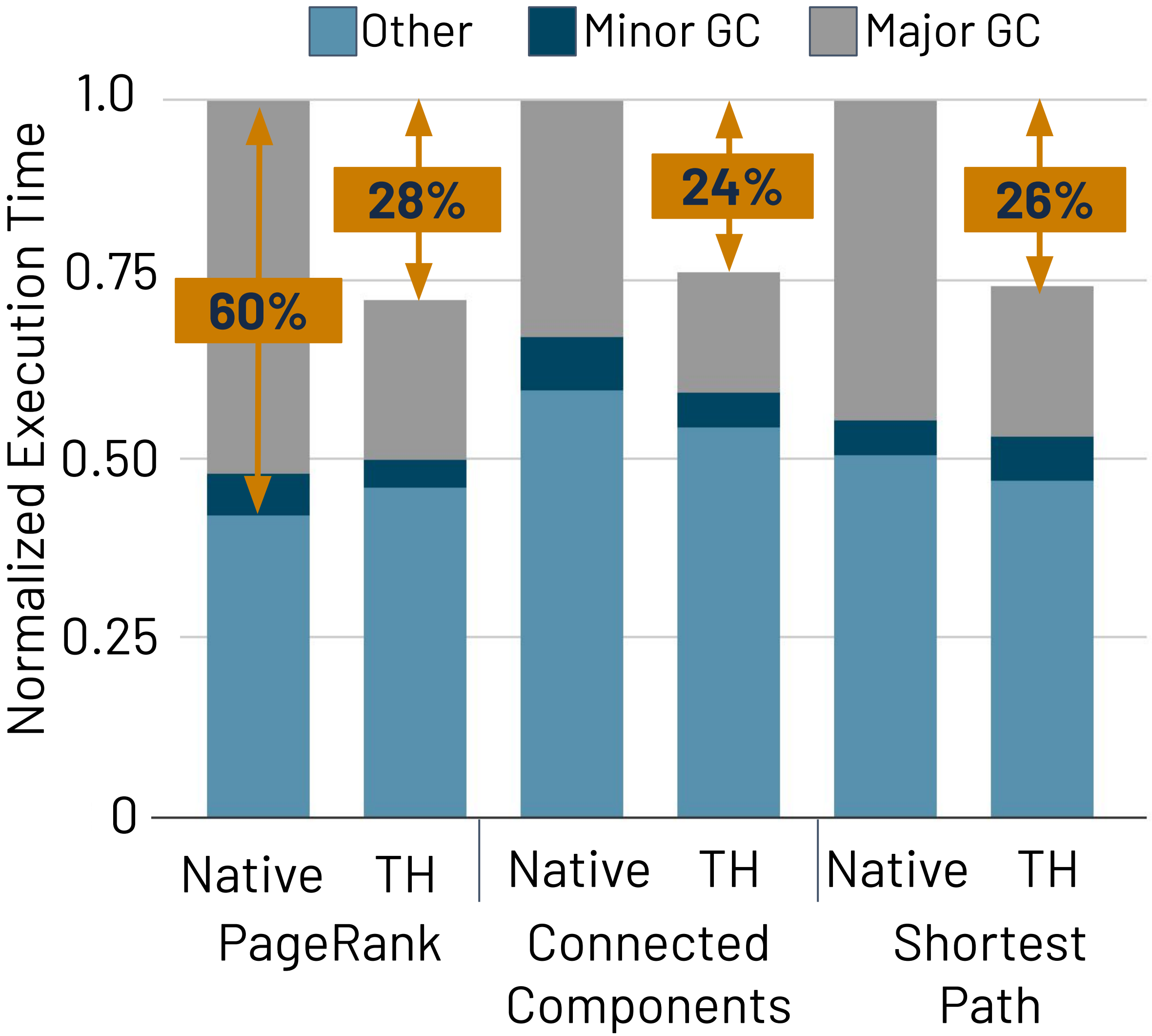
- Limit DRAM capacity using cgroups

TeraHeap outperforms native Spark by up to 54%



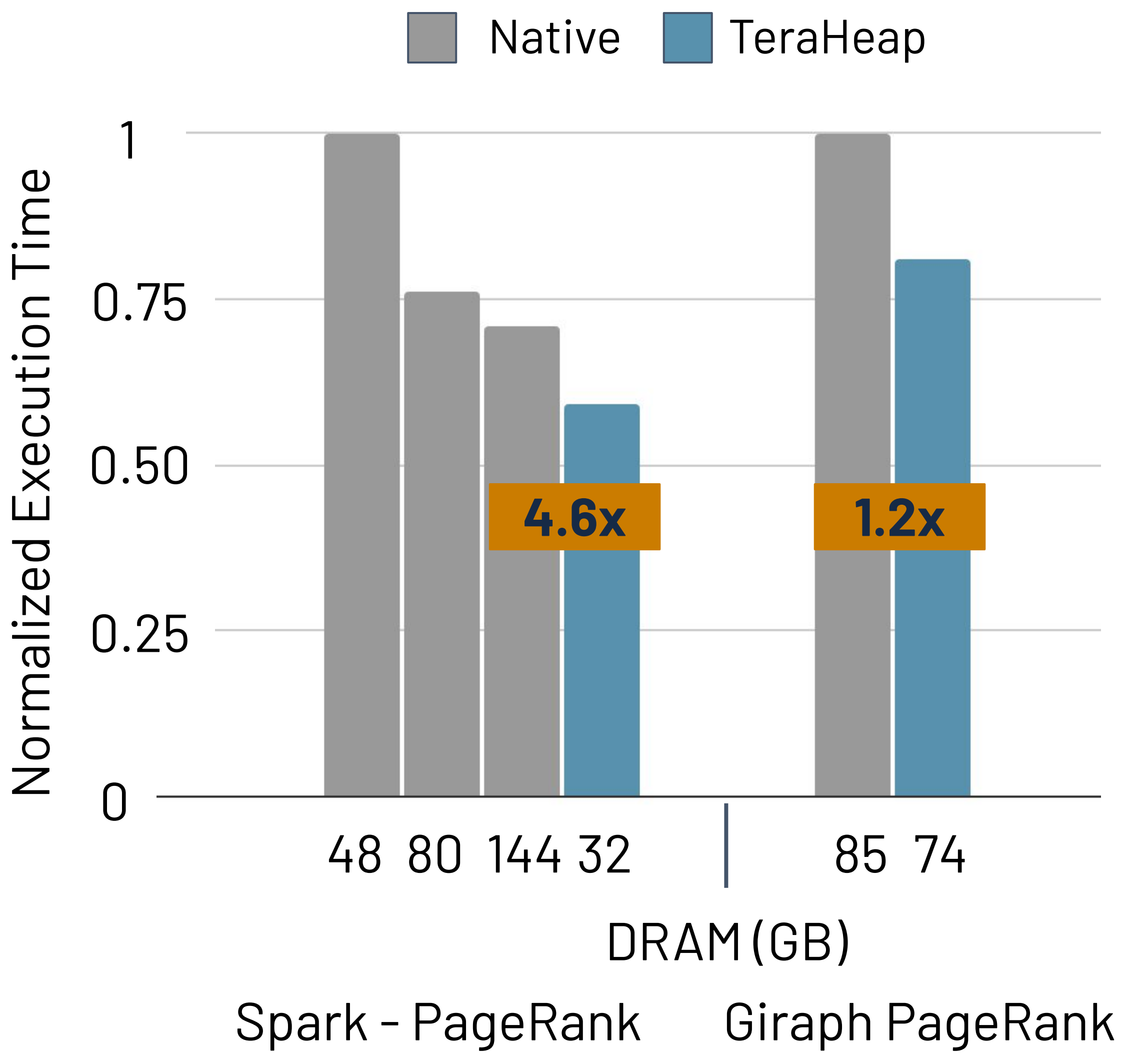
- Teraheap reduces S/D overhead
- S/D in TeraHeap is due to shuffling

TeraHeap outperforms native Giraph by up to 28%



- Main performance improvement
  - Reduction of major GC (up to 50%)
- Off-heap **reduces** heap pressure **temporarily**
  - Giraph processes objects **only on-heap**
  - Increases heap pressure → Increased GC!

TeraHeap reduces DRAM requirements



- Provide direct access to H2 objects
- Outperforms native Spark using 4.6x less DRAM
- Outperforms native Giraph using 1.2x less DRAM

Key Takeaways

- Analytics frameworks deal with large datasets using S/D

- TeraHeap provides the illusion of single managed heap
    - No S/D and no GC scans in the device heap for freeing space

- Improves native Spark and Giraph performance by up to 54% and 28%

- TeraHeap requires up to 4.6x less DRAM

Future work

- Eliminate hints by dynamically determining which objects to move to H2

TeraHeap: Reducing Memory Pressure for Managed Big Data Frameworks

Artifacts Available acm V1.1

Artifacts Evaluated acm Functional V1.1

github.com/CARV-ICS-FORTH/teraheap

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