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FlexHeap: Dynamic DRAM Partitioning Between Managed Heap and Page Cache

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Big data frameworks use mmap for large sized files

- Analytics frameworks use managed runtimes

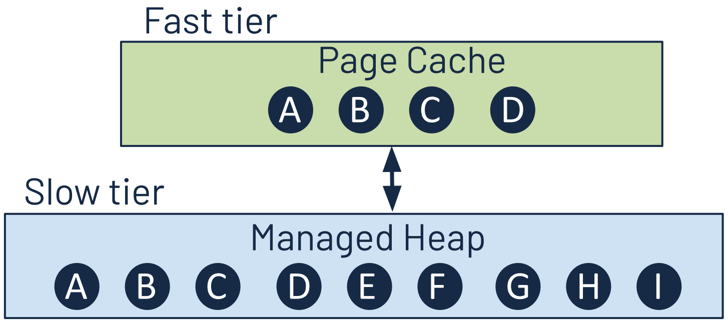
- To process **large amounts of data** they need **large heaps**

- DRAM in a single server **scales slower** than data growth!
  - Increase power consumption and heat dissipation
  - DRAM capacity is declining

- Analytics frameworks extend the managed heap (beyond DRAM) using
  - Fast block-addressable storage devices (e.g., NVMe SSD)
  - Byte-addressable non-volatile memory (NVM)
  - Remote memory

Trade-offs of organization of hybrid managed heaps

Managed heaps with caching

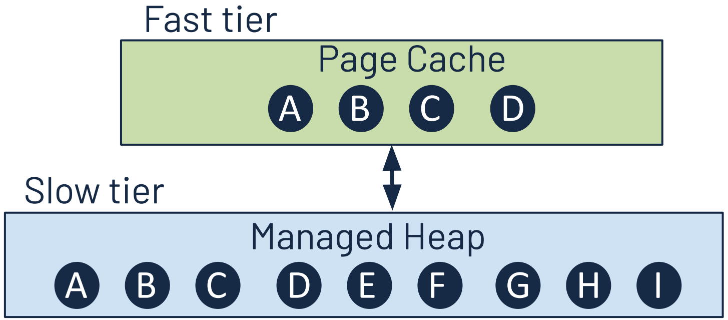


□ Caching hides heterogeneity of the tiers

□ GC scans over the slow tier → High page swappings

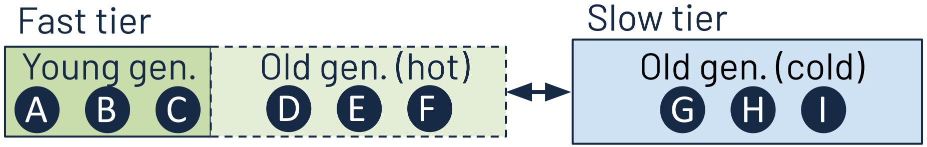
Trade-offs of organization of hybrid managed heaps

Managed heaps with caching



- □ Caching hides heterogeneity of the tiers
- □ GC scans over the slow tier → High page swappings

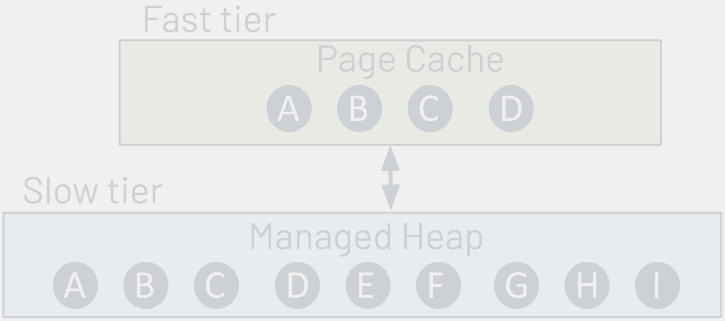
Managed heaps with tiering



- □ Reduced page swappings
- □ High object reference adjustment cost

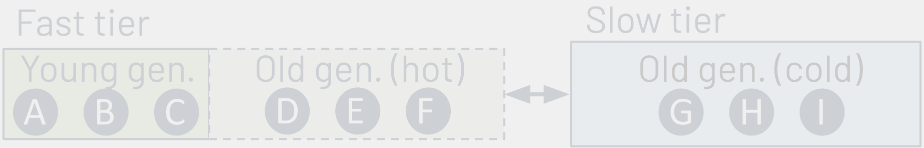
Trade-offs of organization of hybrid managed heaps

Managed heaps with caching



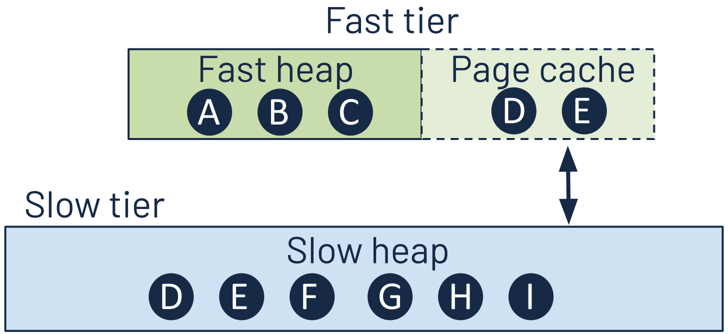
- □ Caching hides heterogeneity of the tiers
- □ GC scans and compactions over the slow tier

Managed heaps with tiering



- □ Reduces page swapping
- □ High object reference adjustment cost

Managed heaps with tiering and caching



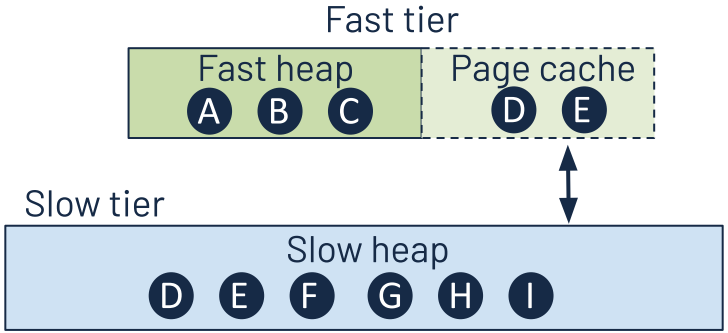
- □ No object reference adjustment cost
- □ No GC scans and compactions to the slow tier

Merge the benefits from both worlds!

Static division of DRAM between fast heap and page cache

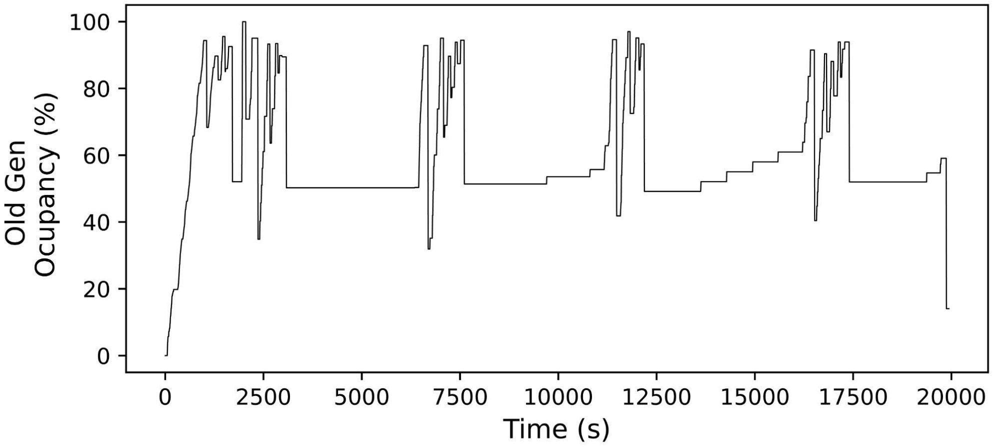
- **Problem 1:** Requiring hand tuning configuration
  - Impractical in real-life deployments
  - Application and dataset change frequently

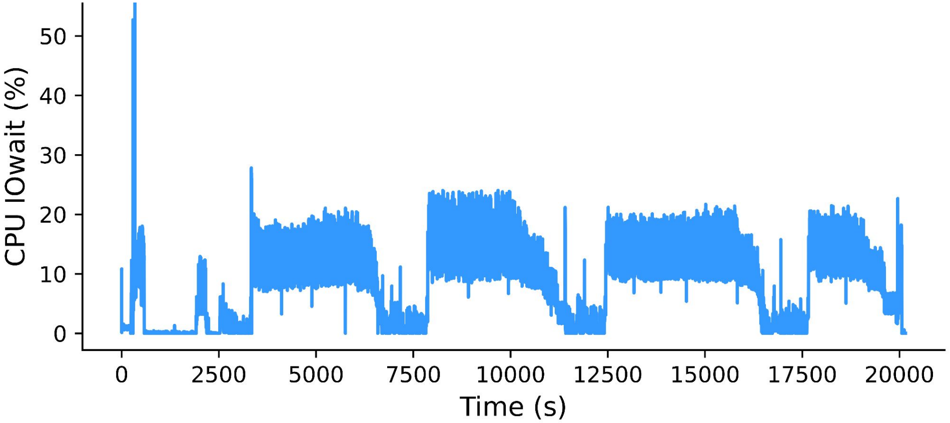
- **Problem 2:** Changing application behavior
  - Different memory requirements at different periods



Shortcomings of static division of DRAM in TeraHeap

- Applications have different phases
- Demand space for H1
  - Generate large amount of objects
  - High memory pressure ⟶ High GC
- Demand space for page cache
  - Heavily access objects in H2
  - High I/O traffic
- **Dynamic division of DRAM is essential!**





Outline

- Motivation

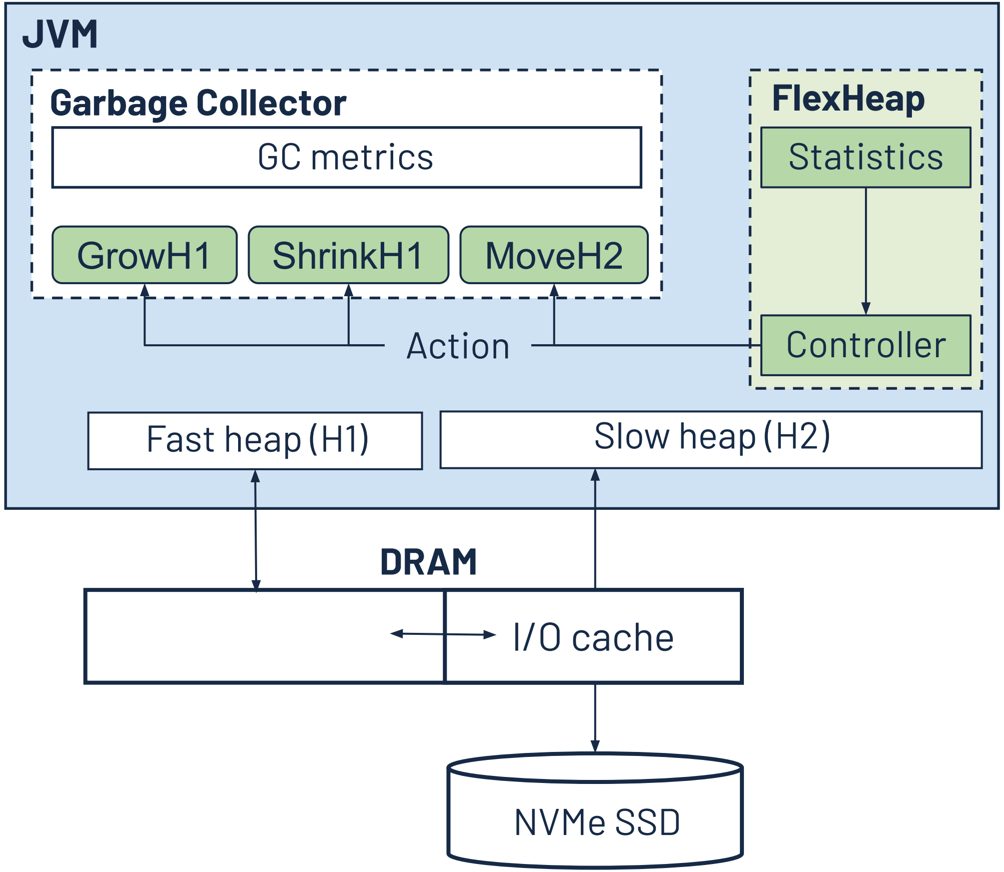
- FlexHeap design
  - Considering GC and I/O overheads
  - Repartitioning DRAM dynamically
  - Enhance responsiveness in application behavior changing

- Evaluation

- Conclusions

FlexHeap

- Dynamically division of DRAM between H1 and I/O cache for slow heap
  - Reduce memory pressure
  - Reduce I/O traffic
- Transparent mechanism
  - No application or OS modifications
- Adapt to application with dynamic changing behavior
- Makes practical the fast and slow heap approach

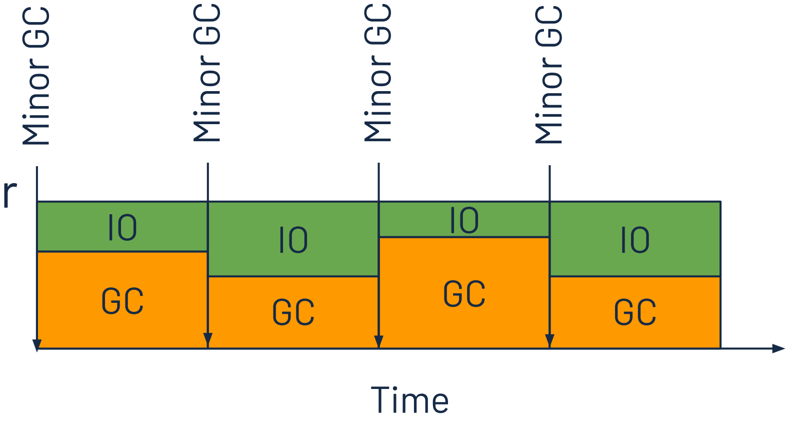


Considering GC and I/O overheads

- FlexHeap divides its execution
  - Sampling intervals between minor GC cycles

- I/O cost in terms of CPU iowait time

- For the GC cost FlexHeap estimate the next major GC cycle pause time



$$F_{i-1} = \frac{FreeSpace}{SizeH1} \qquad (1)$$

$$NetGCPauseTime = P \cdot (1 - F_{i-1}) \qquad (2)$$

$$TimeToGC = \frac{F_i \cdot T_{i-1}}{F_{i-1}} \qquad (3)$$

$$GCTime = \frac{NetGCPauseTime}{TimeToGC} \cdot T_{interval} \qquad (4)$$

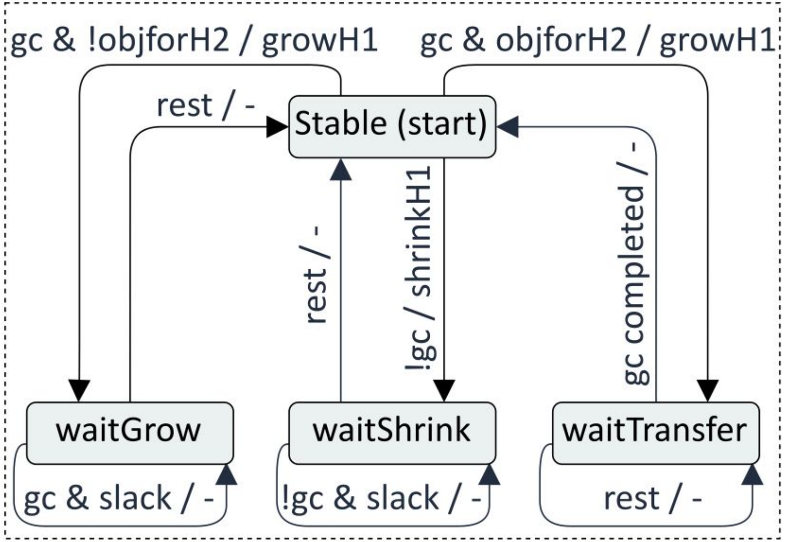
Repartitioning DRAM dynamically

- FlexHeap compares GC and I/O every minor GC

- Possible actions:
  - Increase the size of H1 **(GrowH1)**
  - Move objects to H2 **(MoveH2)**
  - Shrinking H1 to grow page cache **(ShrinkH1)**

- OS moves memory between H1 and page cache
  - Delay in observing the resizing action impact

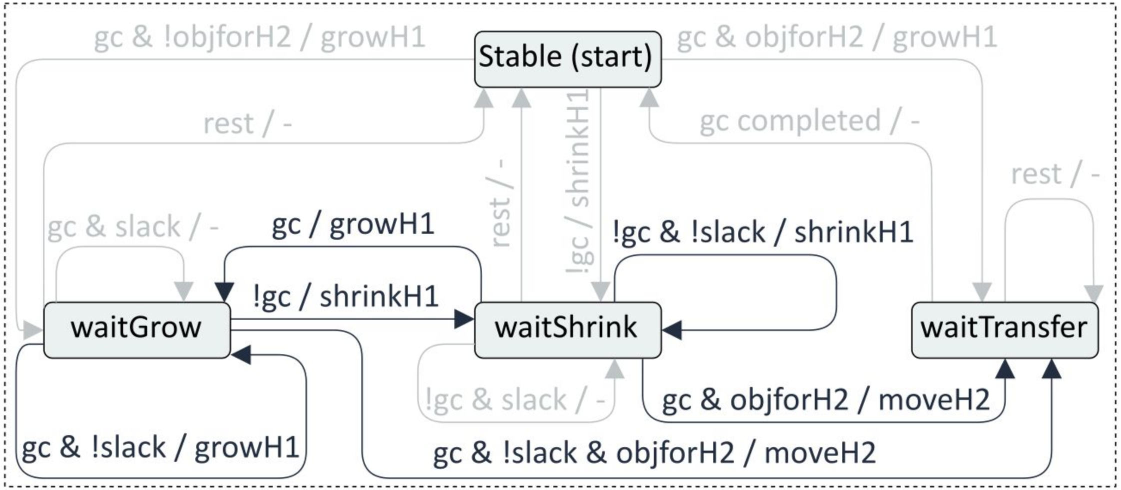
- FlexHeap stops making decisions until their effect occurs



Enhance responsiveness in application behavior changes

- FlexHeap follows multihop decision paths
    - Reduce responsiveness

- Add new FSM transitions
    - Allows FlexHeap to jump to certain states



Testbed

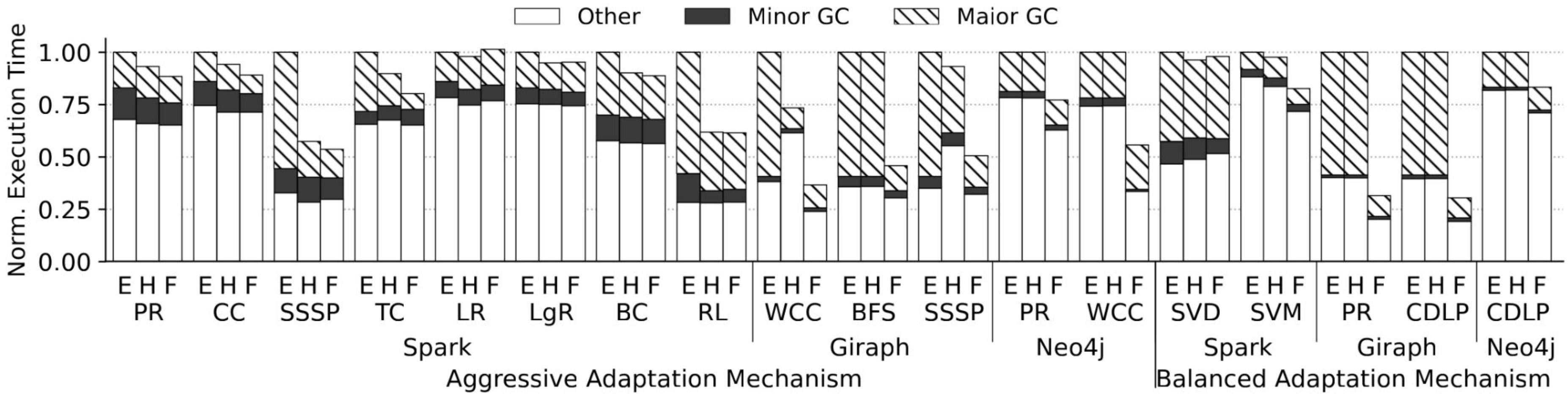
- We implement FlexHeap on top of TeraHeap
  - TeraHeap uses Parallel Scavenge garbage collector
  - OpenJDK 17 and OpenJDK8

- We use one servers with 2 TB NVMe SSD and 256 GB DRAM

- Real world application
  - Spark with Spark benchmark suite
  - Giraph with Graphalytics benchmark suite
  - Neo4j with Graphalytics benchmark suite

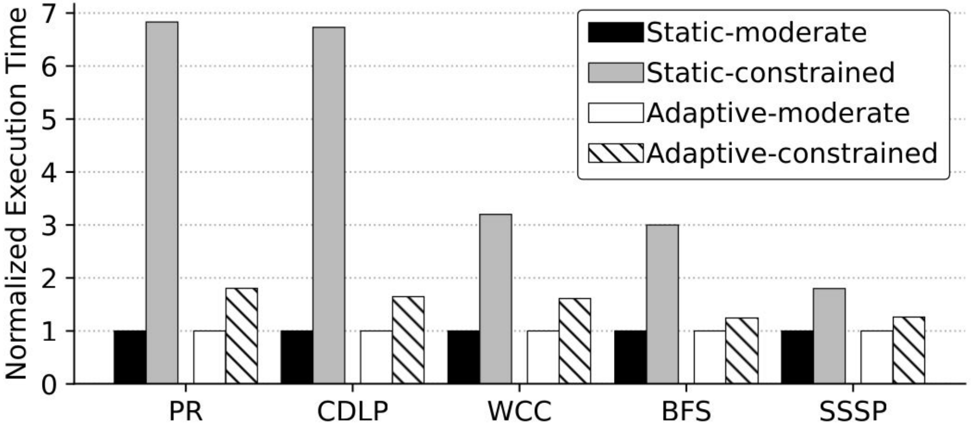
- Limit DRAM capacity with cgroups

Static vs dynamic memory adjustment



- The performance gains range from 5% (Spark-LgR) to 70% (Giraph-CDLP)
- FlexHeap improves performance between 3% and 73% (13 out of 18 workloads)
- Reduction of GC and I/O cost up to 80%

Performance with limited DRAM



- FlexHeap reduces DRAM capacity demands between 1.3× (BFS) and 1.6× (SSSP)

- Acceptable performance degradation ranging from 1.2× (BFS) to 1.8× (PR)

Key Takeaway

- Hybrid heaps setups exhibit dynamic variation in memory requirements

- Size of fast heap dominates GC cost

- Size of page cache dominates I/O cost for accessing objects in the slow heap

- FlexHeap dynamically divides a fixed DRAM budget between
  - Fast heap
  - I/O page cache

- FlexHeap adapts to the behavior of real-world big data analytics frameworks
  - Improves performance up to 73% compared to static approaches

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