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GateKeeper: Transparent Placement of Big Data Objects in Hybrid Managed Heaps

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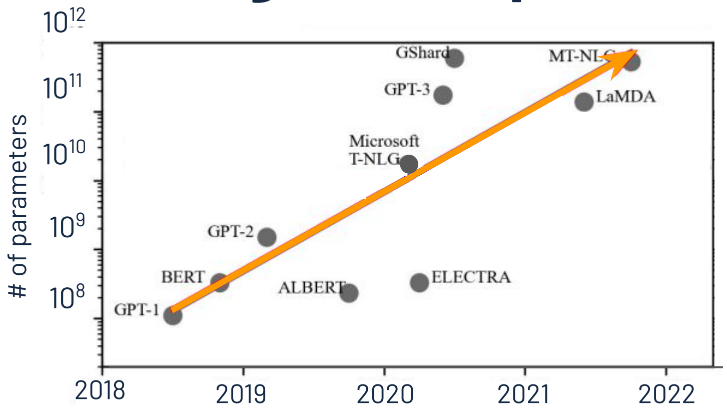
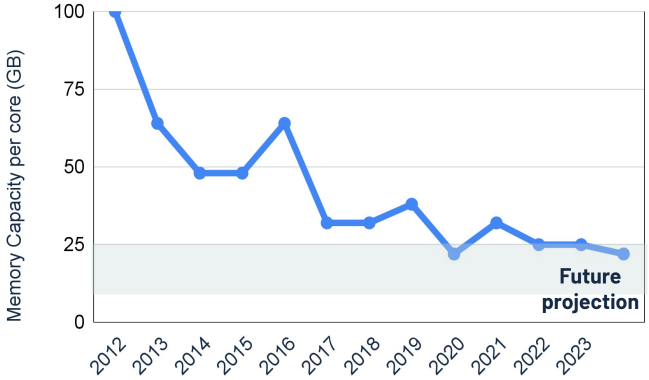
Analytics frameworks need large managed heaps

- 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!
- Fast storage devices are desirable for processing
    - Provide higher capacity than DRAM



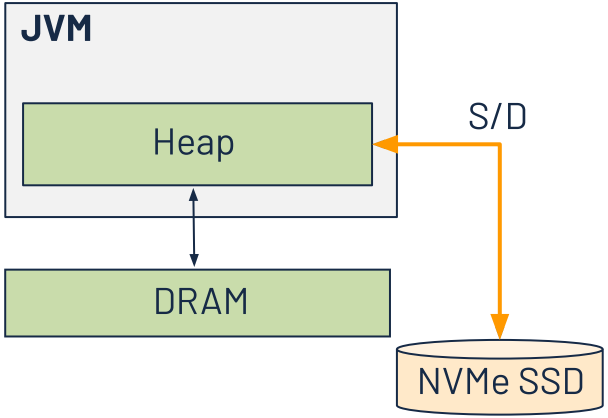
(Source: AI and memory wall)



(Source: Micron’s Perspective on Impact of CXL on DRAM Bit Growth Rate Report)

Common practice: Move objects over fast storage devices

- Analytics frameworks offload objects on fast storage devices (off DRAM)
  - Transform objects to byte stream
  - High serialization/deserialization (S/D) overhead



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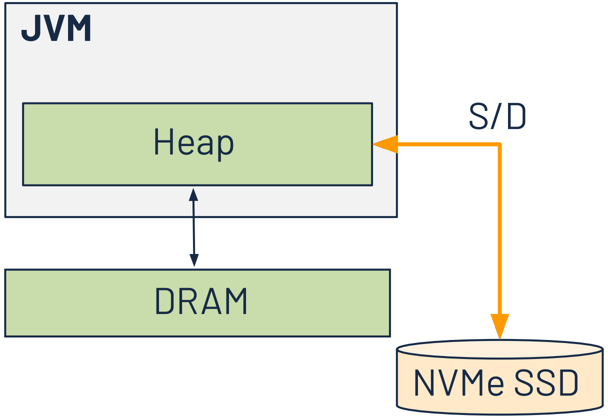
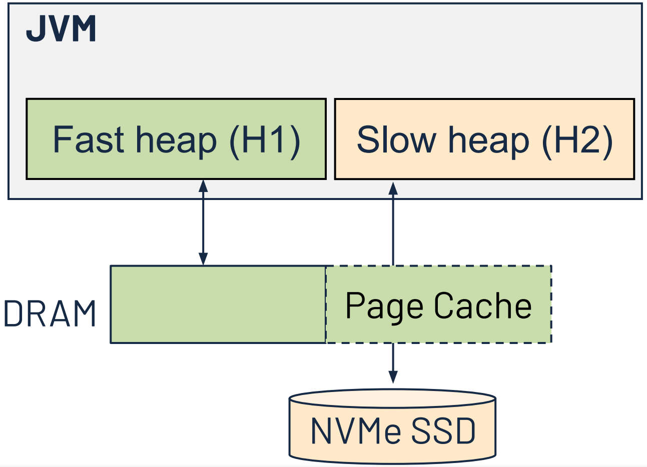
- Recent work, extend managed heaps beyond DRAM **(hybrid heaps)**
  - Direct access to objects → No S/D
  - Two managed heaps → No GC scans over the device





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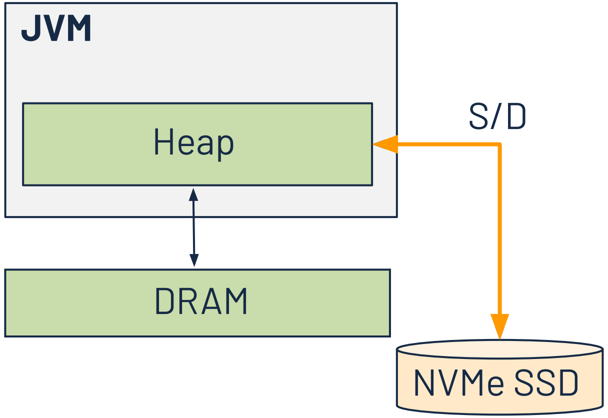
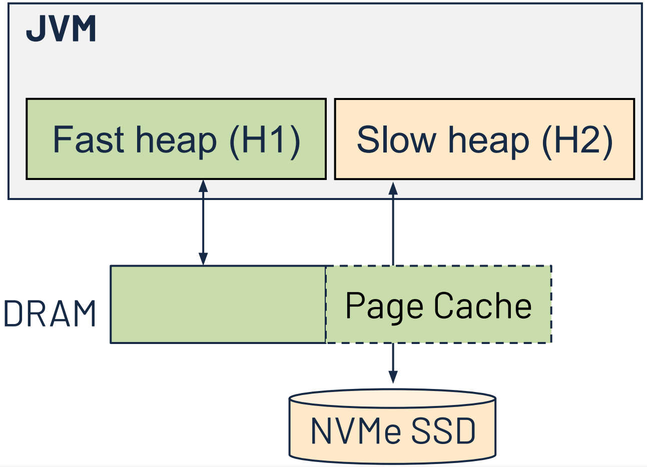
- **Challenge:** Find objects for moving to the device
    - Cope with slow device accesses





Existing object selection approaches

Application modification

Application agnostic

Existing object selection approaches

Application modification

Programming models

- Provide application specific knowledge
- Significant effort for **application writing**

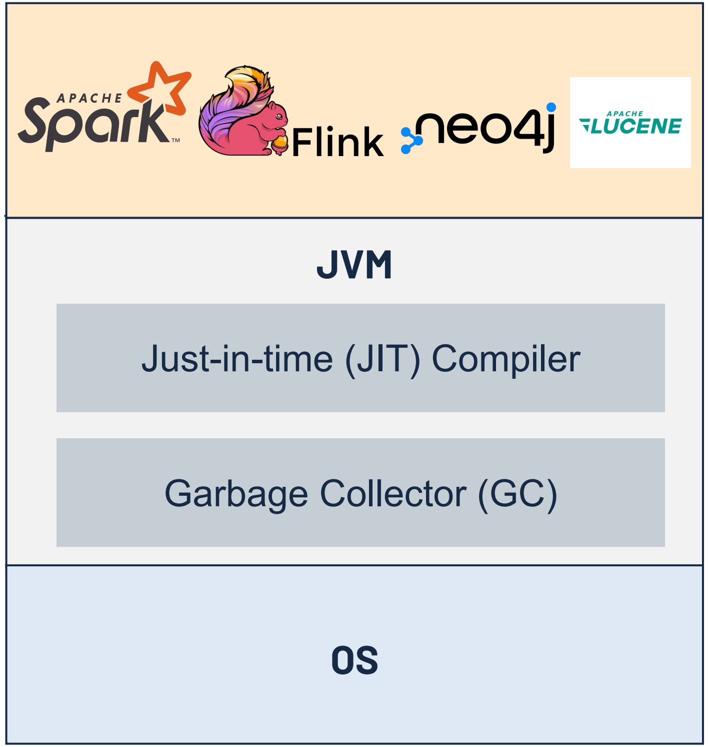
Application agnostic

Code instrumentation via JIT compiler

- Extra instructions before each load/store operation
- Significant **runtime overhead**

Page faults

- Protect/unprotect pages in the virtual address space
- **Signal handling** and **page faults** overheads



JVM

Just-in-time (JIT) Compiler

Garbage Collector (GC)

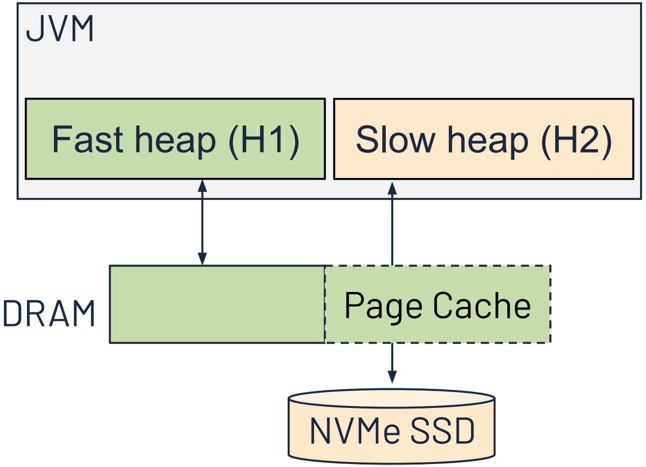
OS

Transparent placement of big data objects in hybrid heaps

- Decide which objects to move from H1 to H2
  - **Avoid code instrumentation** and **page fault** overheads

- Leverage storage capacity to reclaim objects lazily
  - **Reclaim** dead objects **without GC scans on H2**

- Fix wrong decisions (fallback mechanism)
  - **Identify** objects that **increase I/O traffic**
  - **Transfer** objects from H2 to H1 **without scanning H2**



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□ Goal: **Avoid** code instrumentation and page fault overhead

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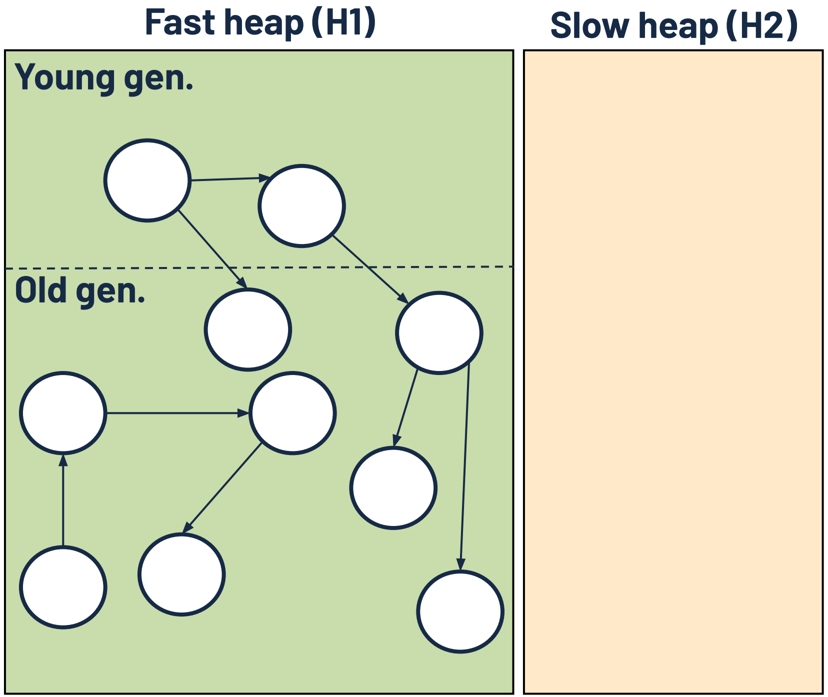
  - Young generation for newly created objects
  - Old generation for mature objects



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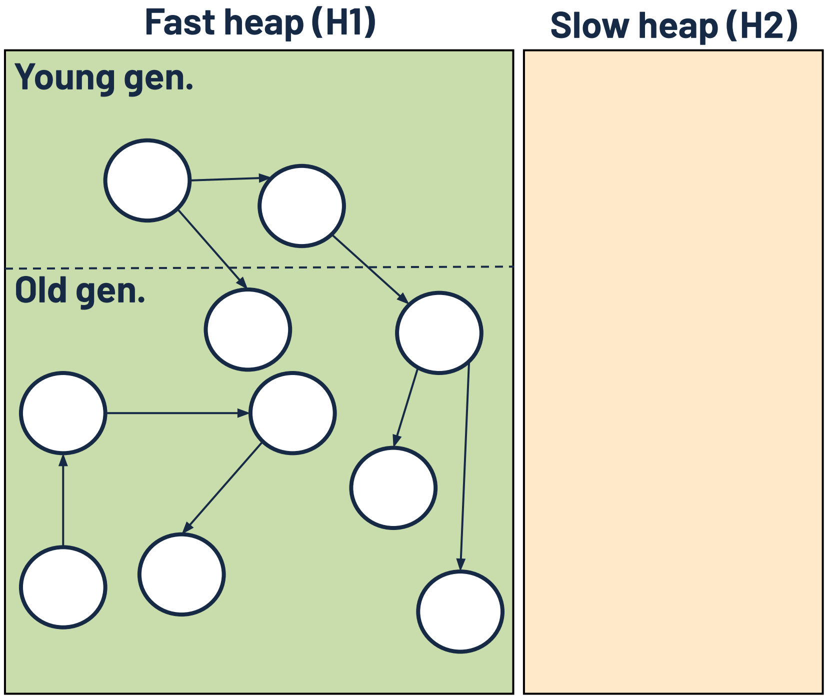
  - Increase the age of each object (epochs)
- High memory pressure in H1
  - Move objects from H1 to H2
  - Transfer objects with earliest epoch



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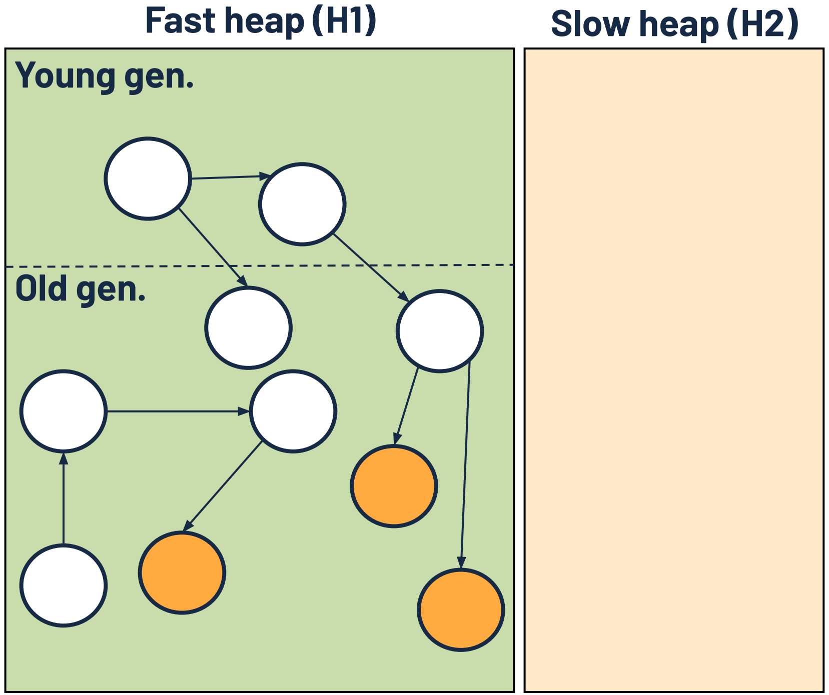

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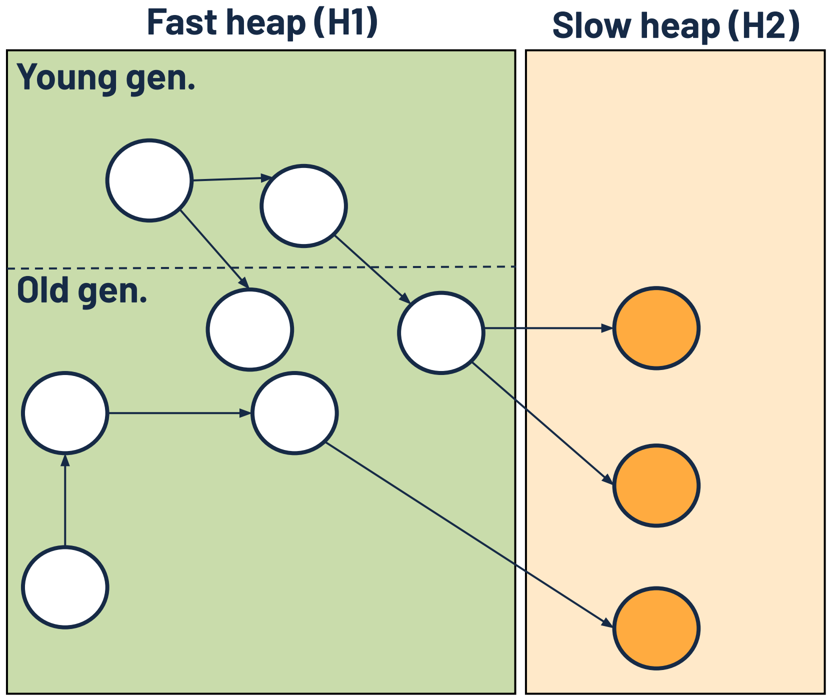
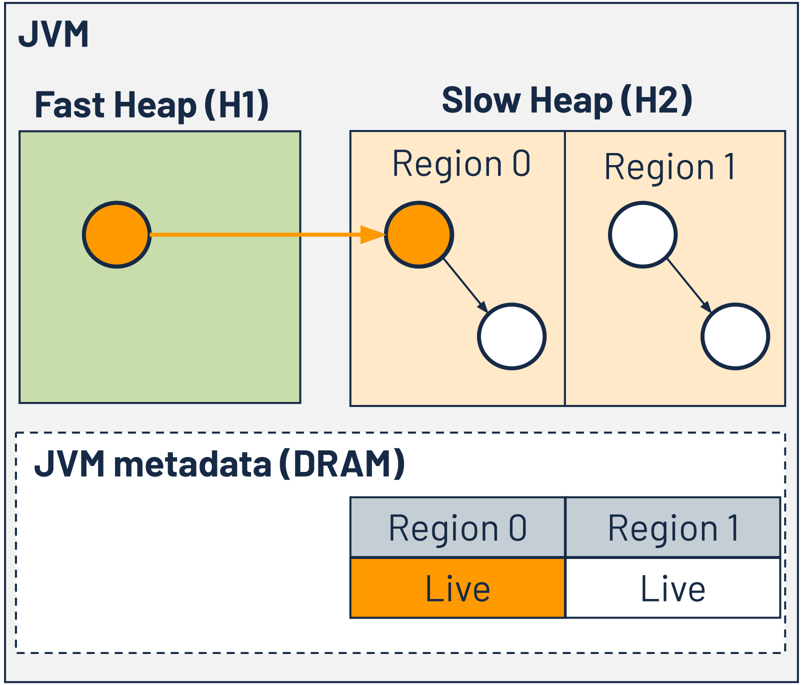


Leverage storage capacity to free objects lazily

□ Goal: **Reclaim** dead objects **without GC scans**

- GateKeeper organize H2 in fixed-sized regions
  - Objects from same root in the same region
  - Reclaim whole regions **(bulk free)**
- Per region DRAM metadata **(no object access)**
  - Live bit → region liveness
- GC identifies H2 live regions
  - Free regions by zeroing regions metadata



Region 0	Region 1
Live	Live

Fix wrong placement decision

□ Goal: **Identify** objects that **increase I/O traffic**

- Portion of DRAM is a cache for H2 to reduce slow accesses
  - Require cache locality → workloads behavior changing

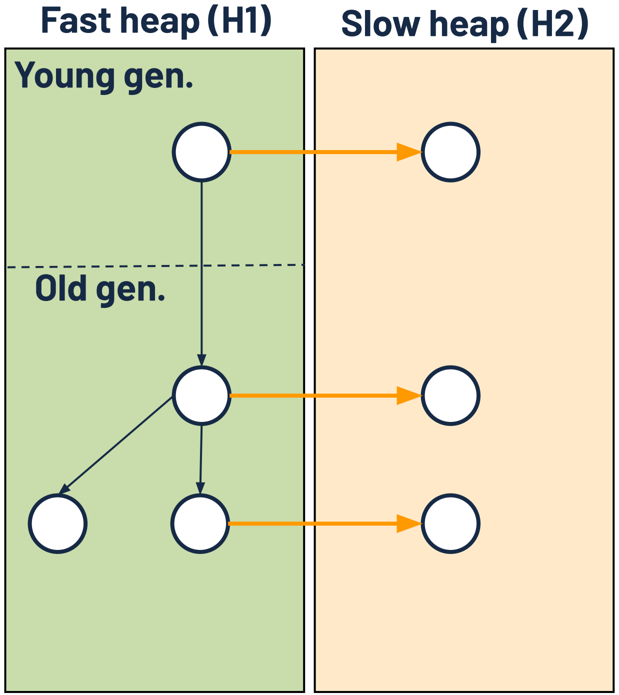
- We use a kernel module to track H2 active pages
  - Maintain metadata per region
  - Track dirty pages

- GateKeeper scans H2 page cache on every minor GC
  - Mutator threads are stopped
  - No synchronization interference with GC threads

Fix wrong decision placement

□ Goal: **Transfer** objects from H2 to H1 **without scanning H2**

- Transfers from H2 to H1 needs objects references update
  - Requires scans to H2 → high I/O traffic
- Transfer primitive arrays and leaf objects to H2
  - Alleviate references between H2 objects
  - Only forward references (H1 to H2) exists
- Moving primitive objects from H2 to H1 require only forward references update
  - GC marking phase: finds forward references



Key Takeaway

- Data growth is higher than DRAM capacity scaling

- Analytics frameworks require large managed heaps to process very big datasets

- Fast storage devices (e.g., NVMe SSDs) provide higher capacity than DRAM

- Extend managed heaps over NVMe SSD to cope with data growth

- GateKeeper: Decide transparently what object to move from the fast to the slow tier
    - With low runtime overhead
    - Transfer objects from the slow to the fast tier efficiently

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