Prioritized Garbage Collection
Using the Garbage Collector to Support Caching

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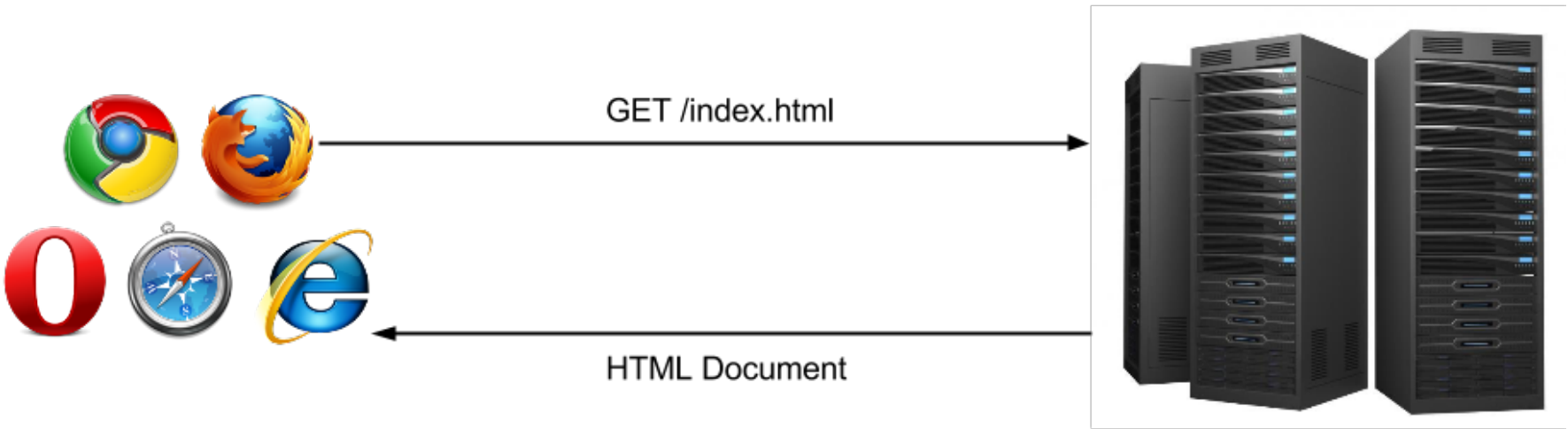
Caches are everywhere



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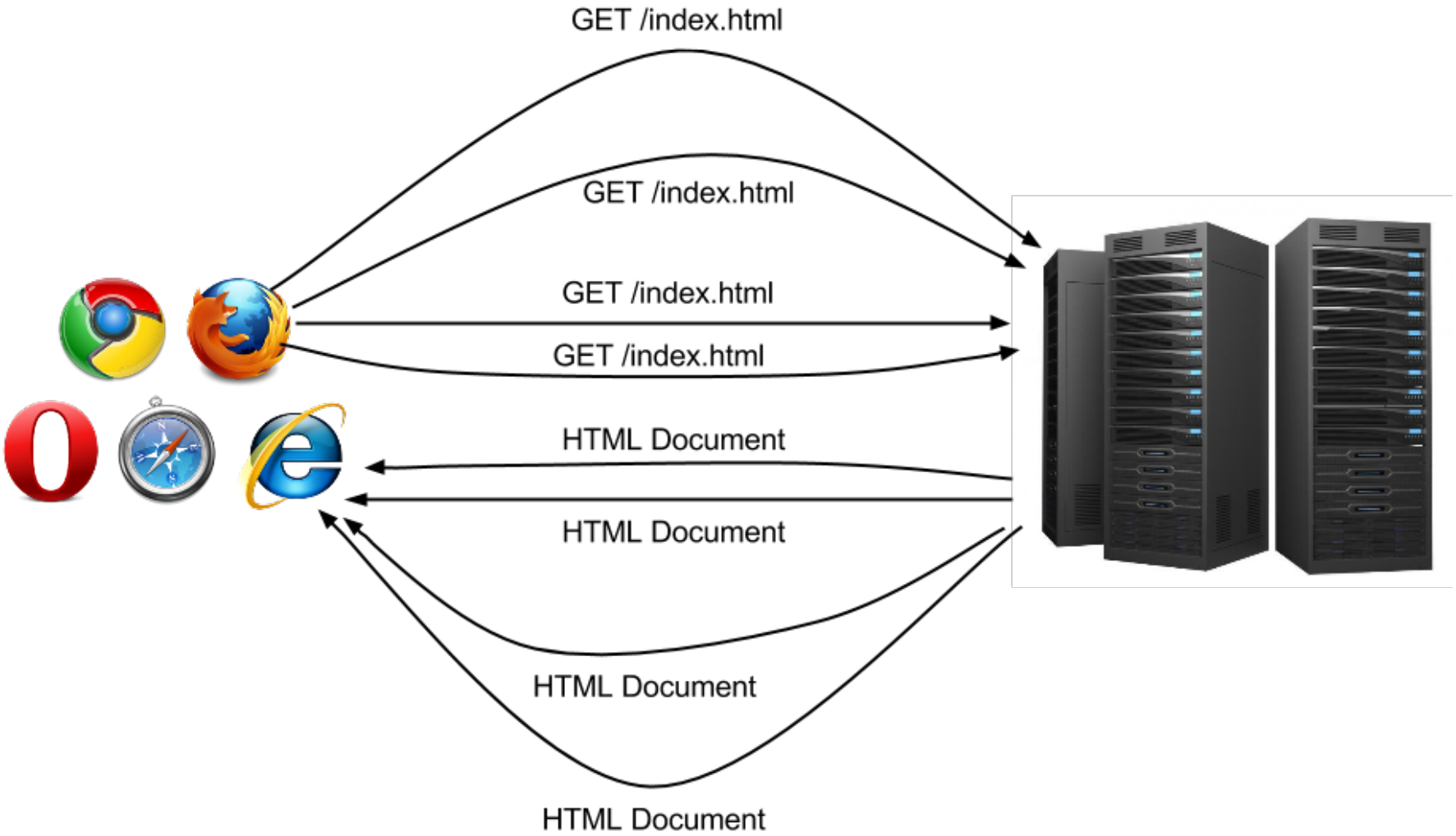

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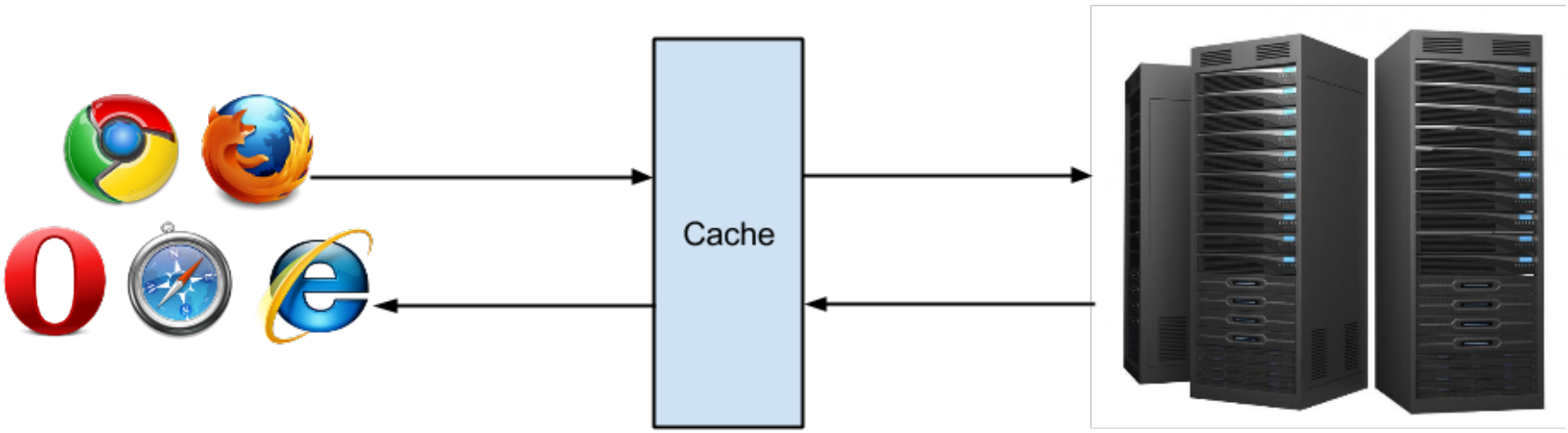

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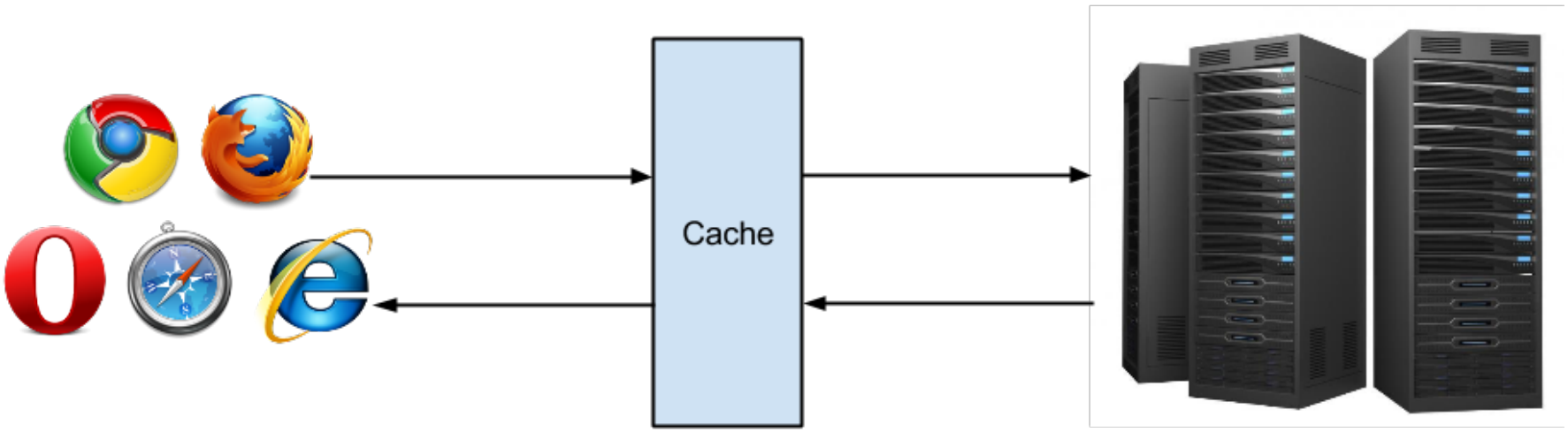
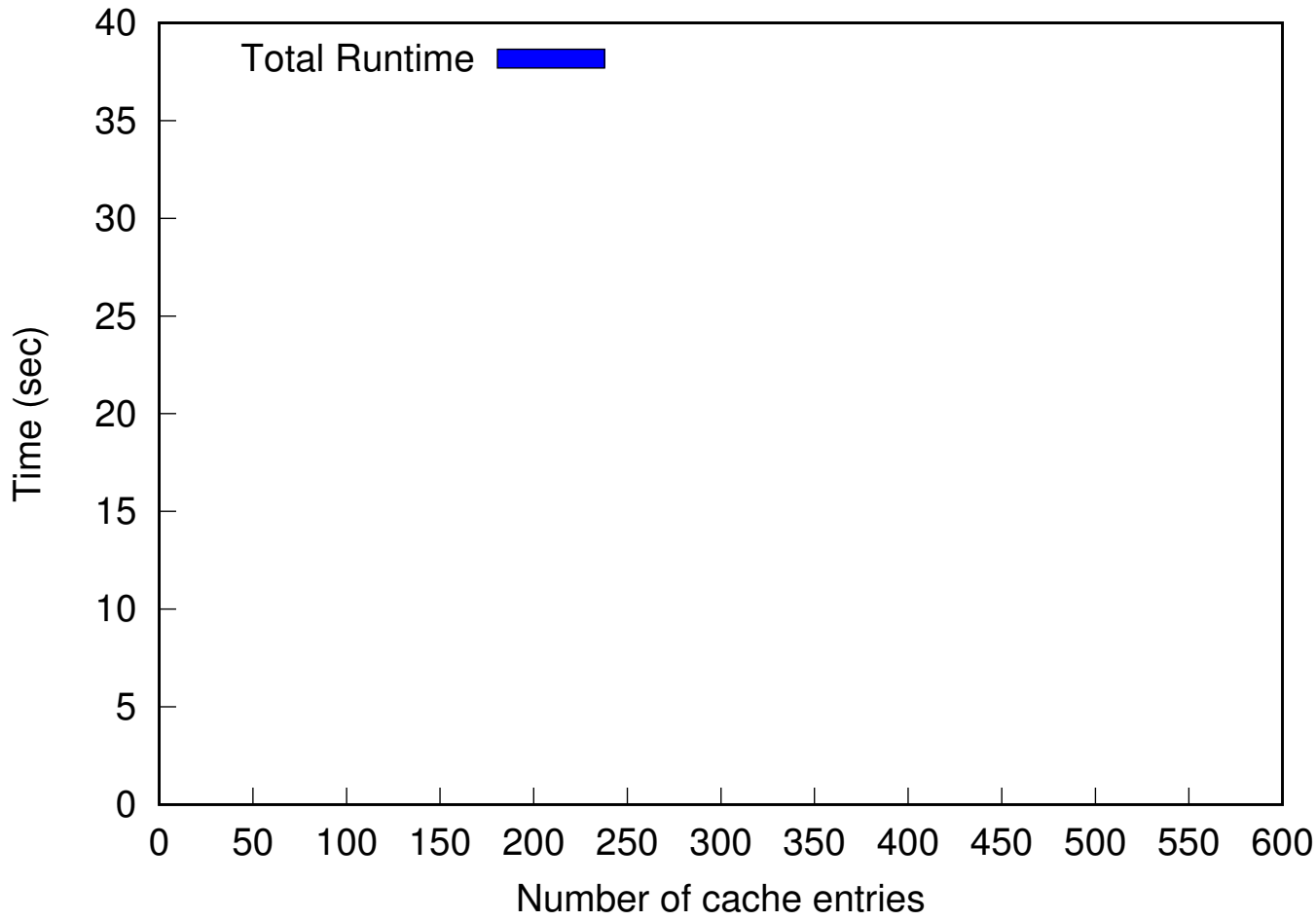


Caches are a space-time tradeoff.



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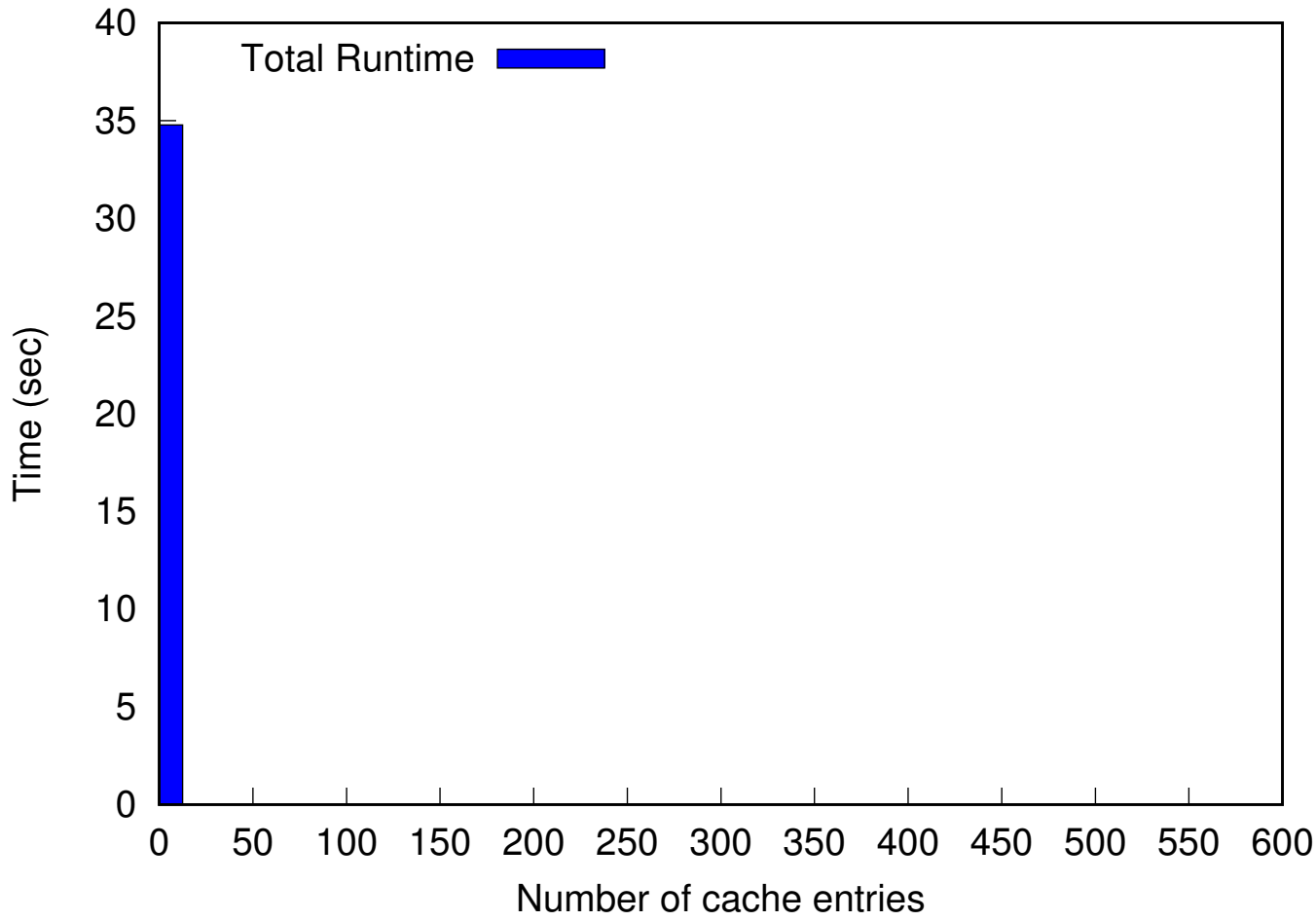

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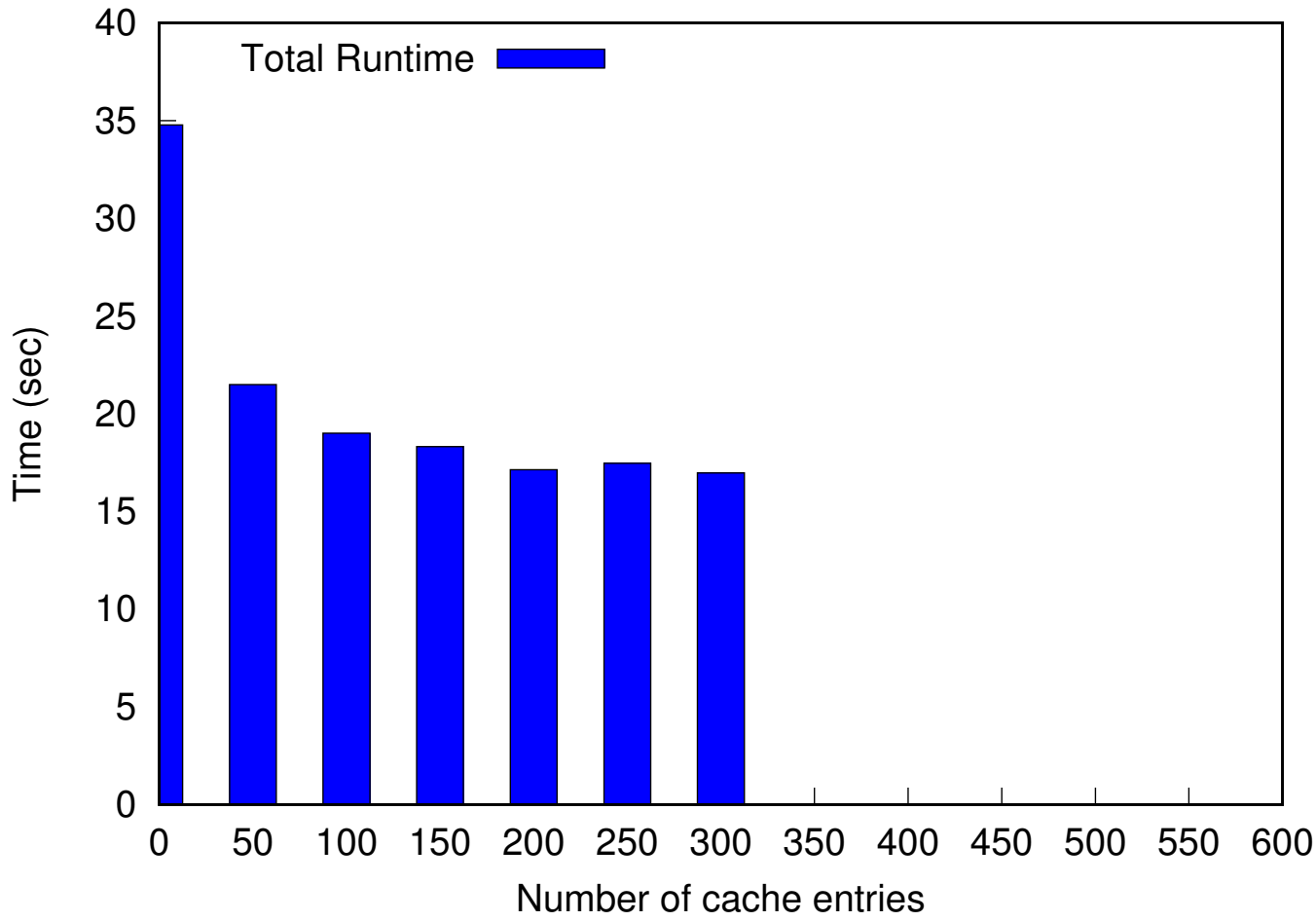
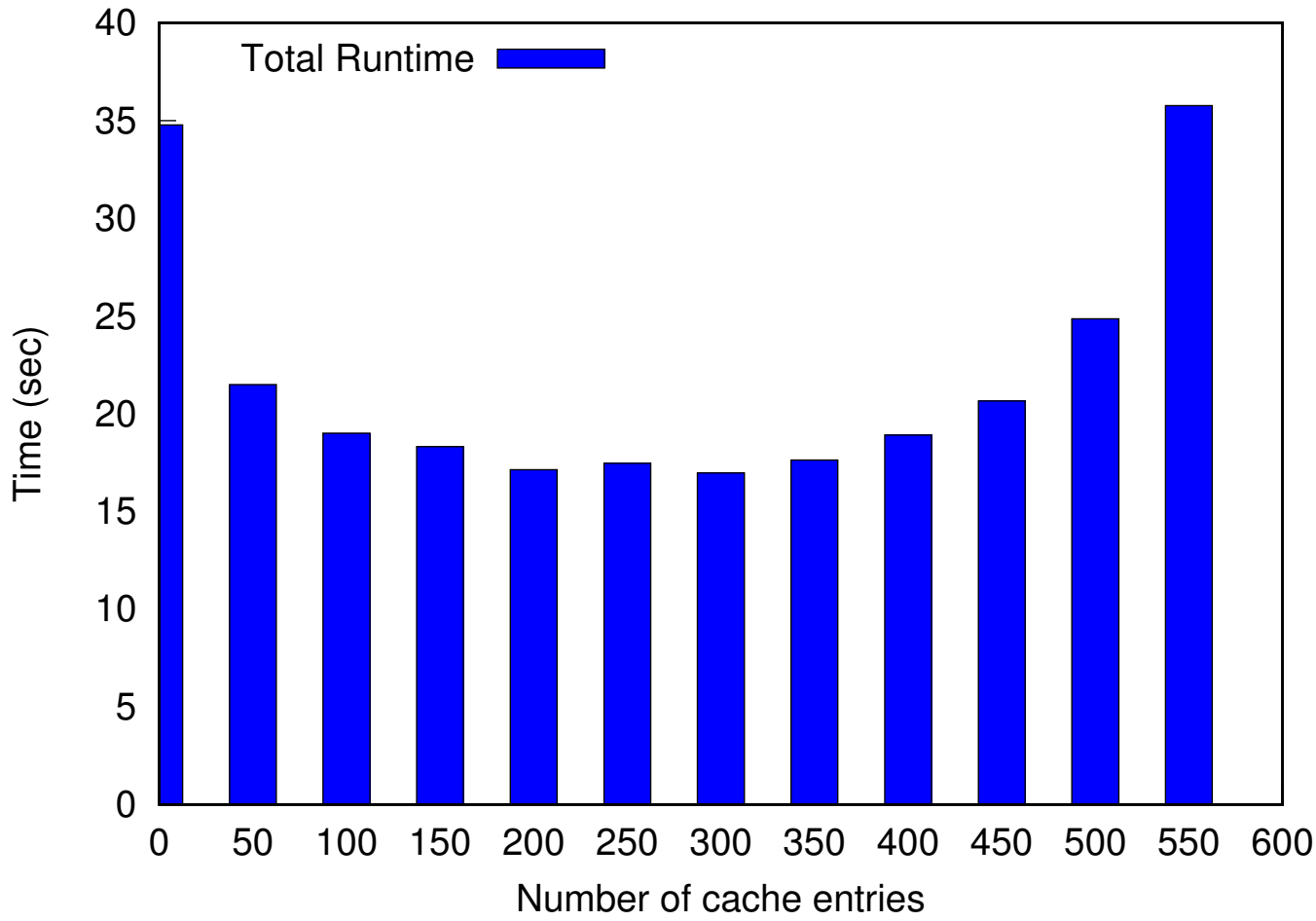
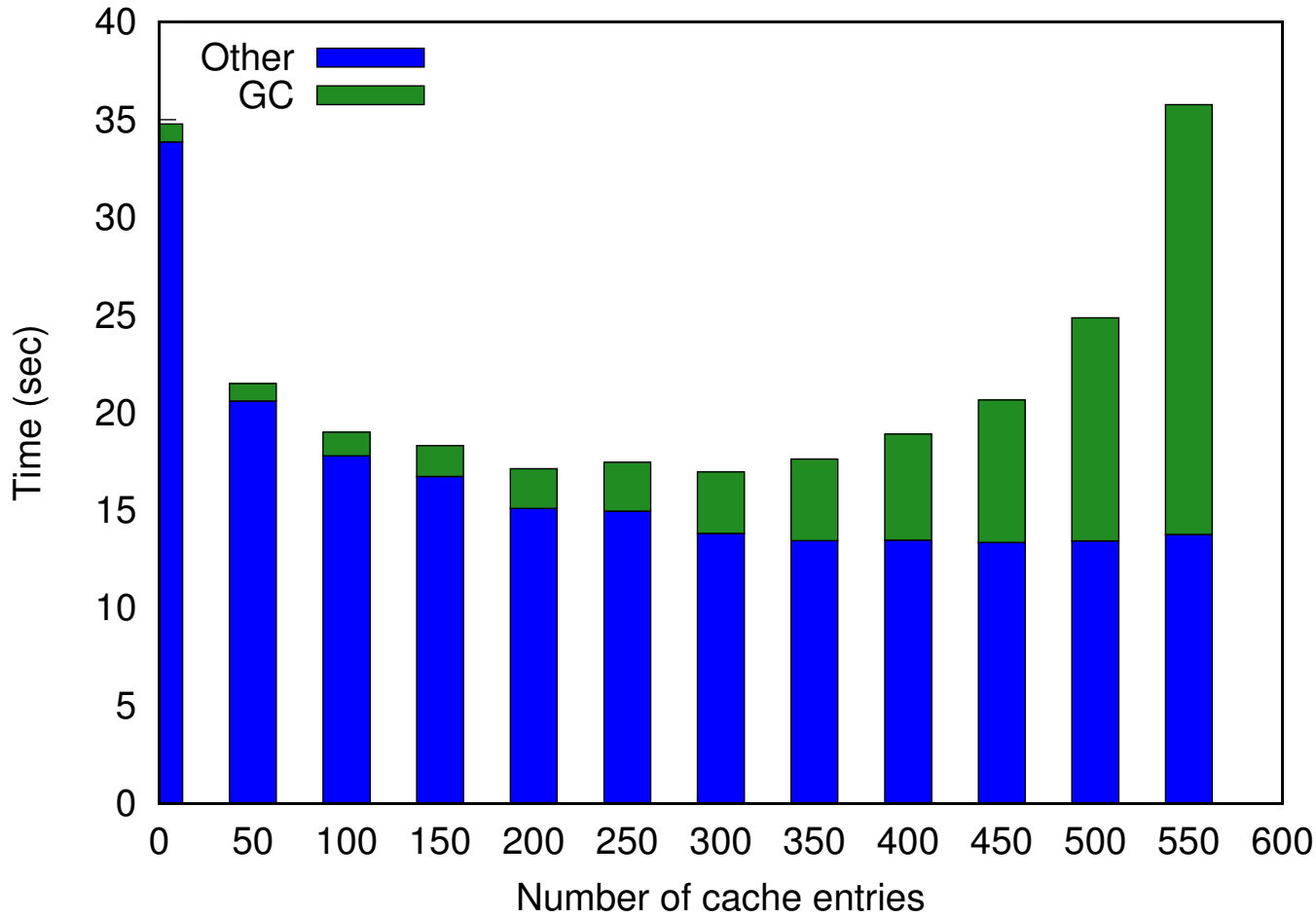


Caches are a space-time tradeoff?



Garbage collection dominates runtime.

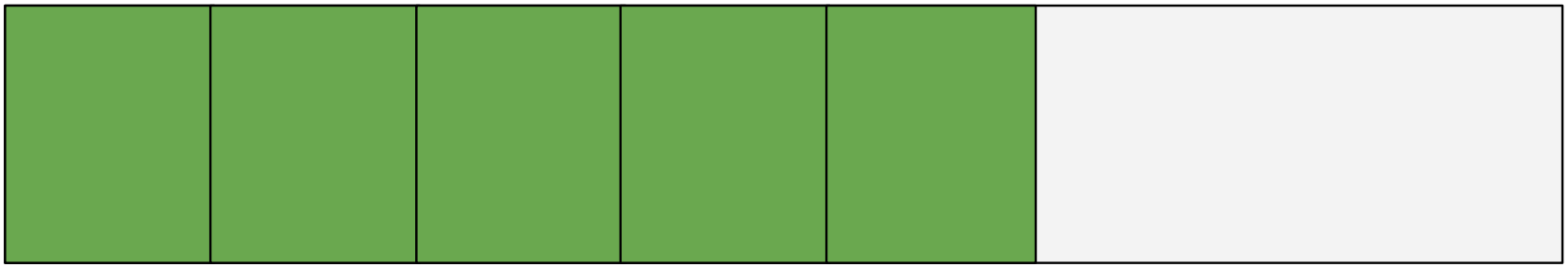


Perfect Cache Size

Elements can be too small.

- The cache can use more space.

Elements can be too big.



- The cache needs to use less space.

Evicted elements remain in memory until next GC.

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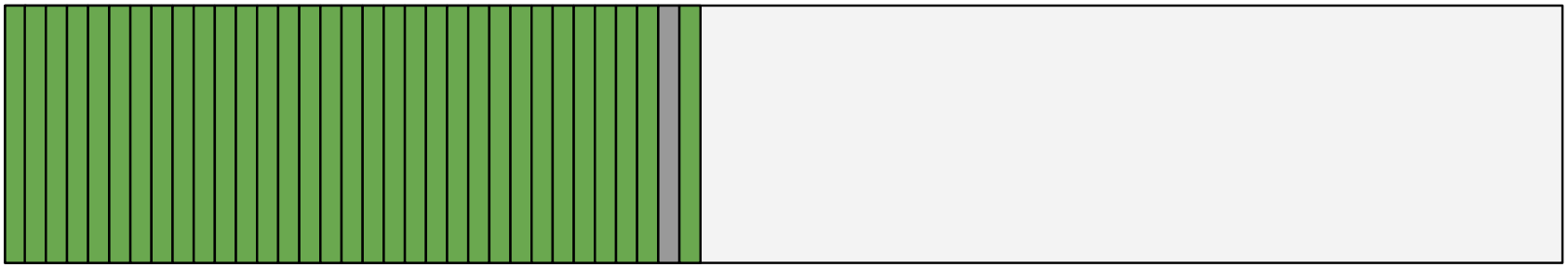

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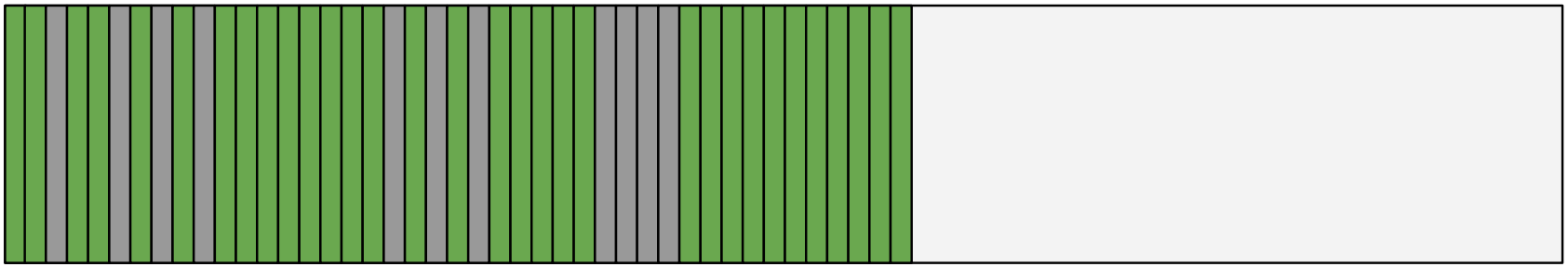

Problem

Can we . . .

- Keep the garbage collector from dominating program run time
- Handle entries of various sizes

Soft References

- Removed prior to an `OutOfMemory` exception
- JVMs can remove them during normal operation
  - Hotspot removes them over time in a Least-Recently-Used (LRU) order

All soft references are equal.

- All Soft References placed in a global queue
- Queue is cleared in an LRU policy over time
- Results in removal of cache values from cold code

Our Solution

Make the Garbage Collector aware of the cache and its contents

Our Solution

- Prioritized Garbage Collector
  - Separate the references into logical spaces with unique eviction policies
  - Compute how much memory each reference is responsible for
- Sache
  - Use the Prioritized Garbage Collector to limit the memory used by stored values

Prioritized Garbage Collection: Using PrioSpaces

```
//Specify memory limit in number of bytes...
PrioSpace<Tree> space = VM.getSpace(500);

//.. or percentage of heap
PrioSpace<Tree> space = VM.getSpace(0.6);
```

Register objects into a PrioSpace

```
Tree t;
PrioReference<T> ref = space.newReference(t);
```

Updates the reference's priority every use.

```
PrioReference<Tree> ref;
Tree t = ref.get();
/* Results in a call to
 * space.updateReference(t);
 */
```

Compare two PrioReferences

```
int compare(PrioReference<T> a,
            PrioReference<T> b);
```

- Determines the eviction policy of the space given by programmer

Compare two PrioReferences

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```

- Determines the eviction policy of the space given by programmer
- Determines the priority of a reference in the space
  - Higher priority $\rightarrow$ More likely to *not* be evicted

Prioritized Garbage Collection: Cleaning PrioSpaces

- For each `PrioSpace`, garbage collector calculates and stores the amount of memory used by strucures
- Garbage collector frees structures according to priority of the references

Sache (**S**pace **A**ware Ca**che**)

- User puts a limit on size of Sache in bytes
- Tell the prioritized garbage collector what values are in the cache and the order of eviction
  - Current eviction policy is LRU
- Measure the amount of memory used by these values during garbage collection
- If keeping a value means the Sache exceeds the size limit, evict that value

Sache: Interface

```
class Sache <K,V>
    extends HashMap<K, PrioReference<V>>
{
  protected int priority;
  protected PrioSpace<V> priospace;

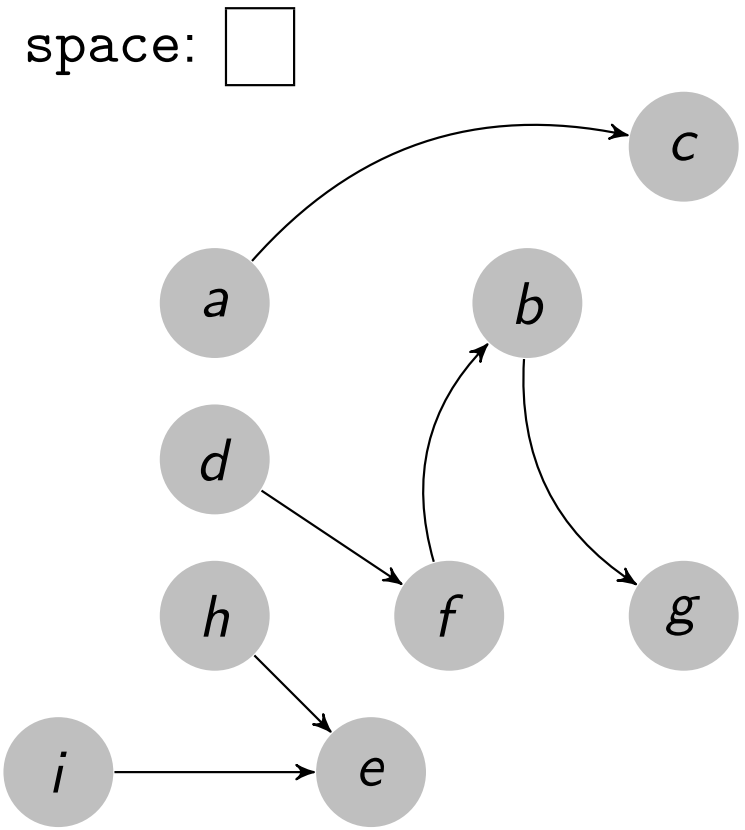
  public Sache(long maxSize);

  public boolean put(K key, V value);
  public V get(K key);
  public V remove(K key);

  private void update();
}
```

Sache: Using Sache

```
Sache map = new Sache(60);
map.put("1", d);
map.put("2", a);
map.put("3", h);
map.get("1");
//Garbage collection occurs
```



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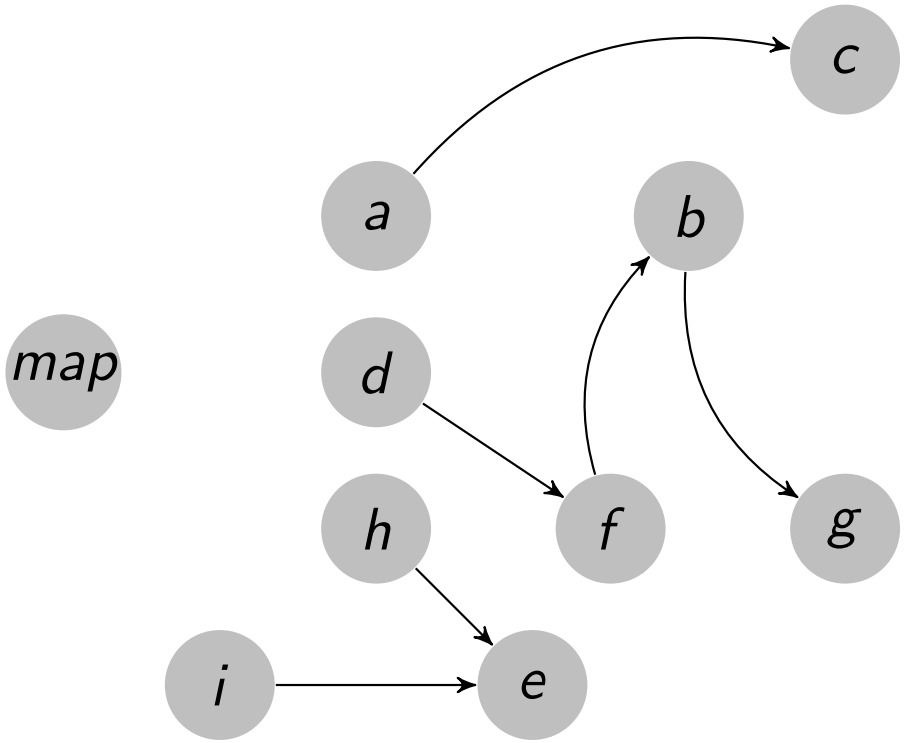

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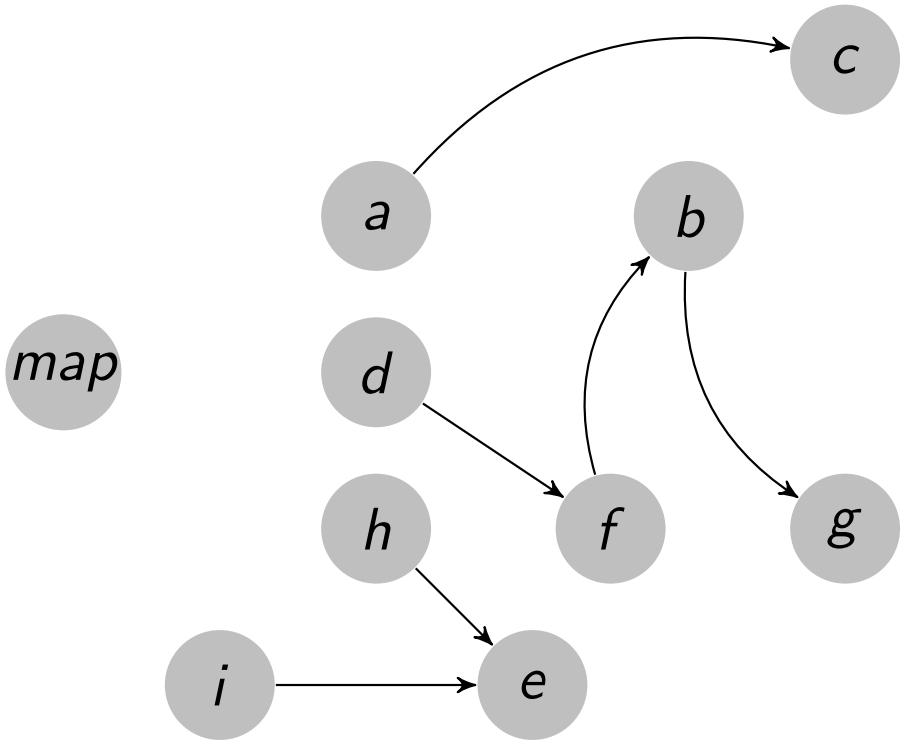

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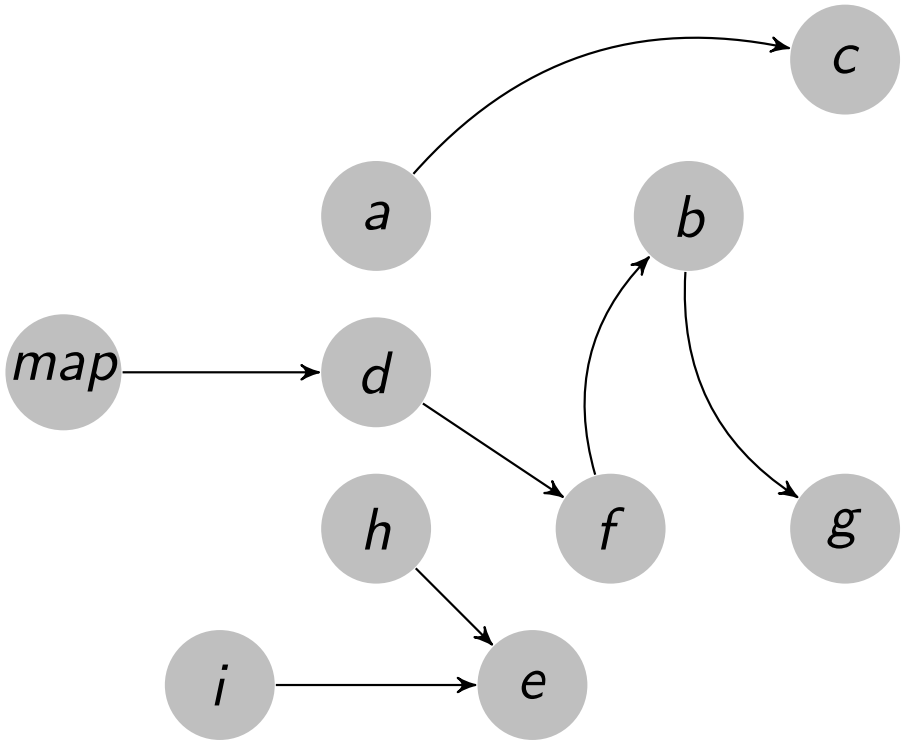

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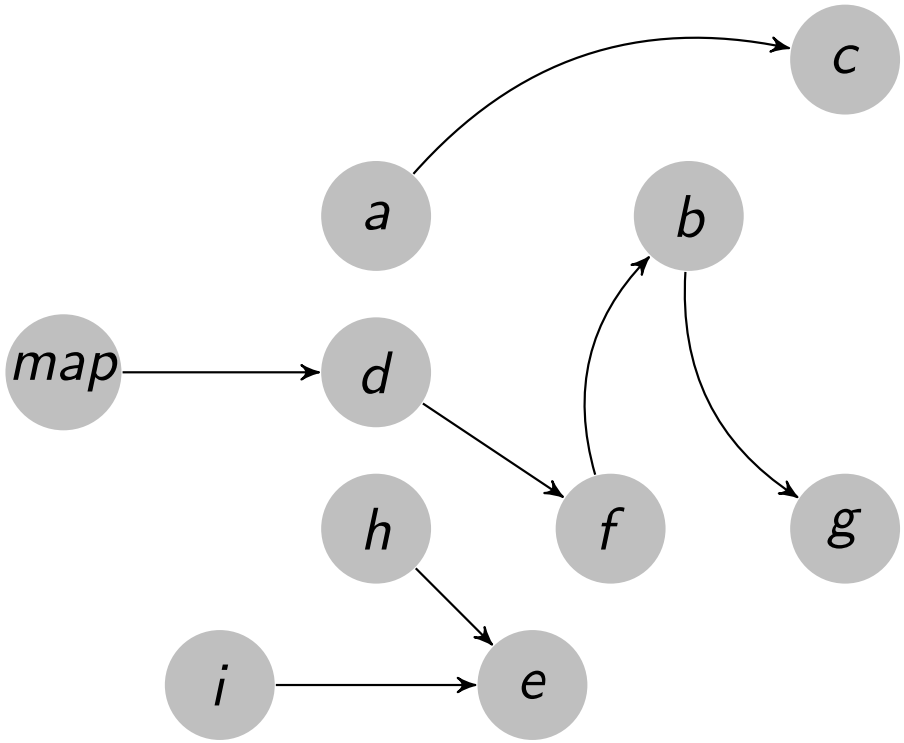

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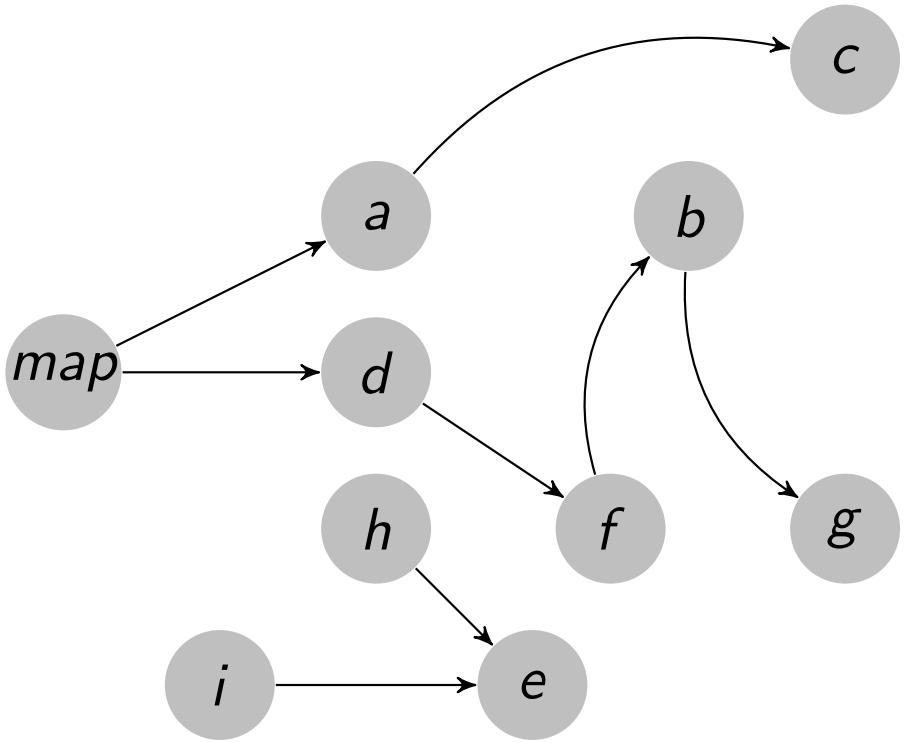

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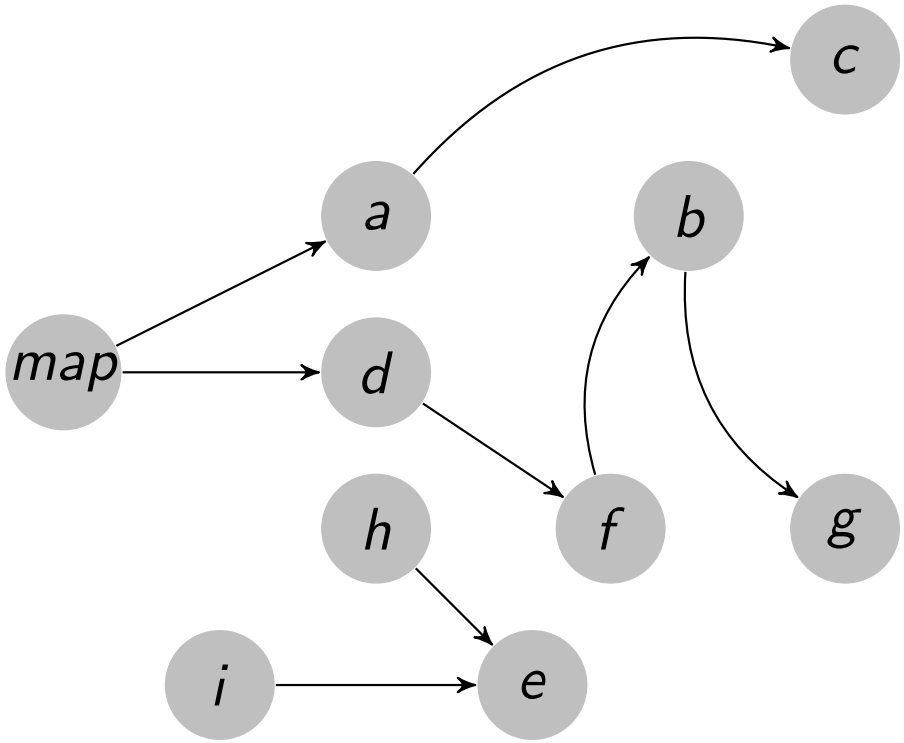

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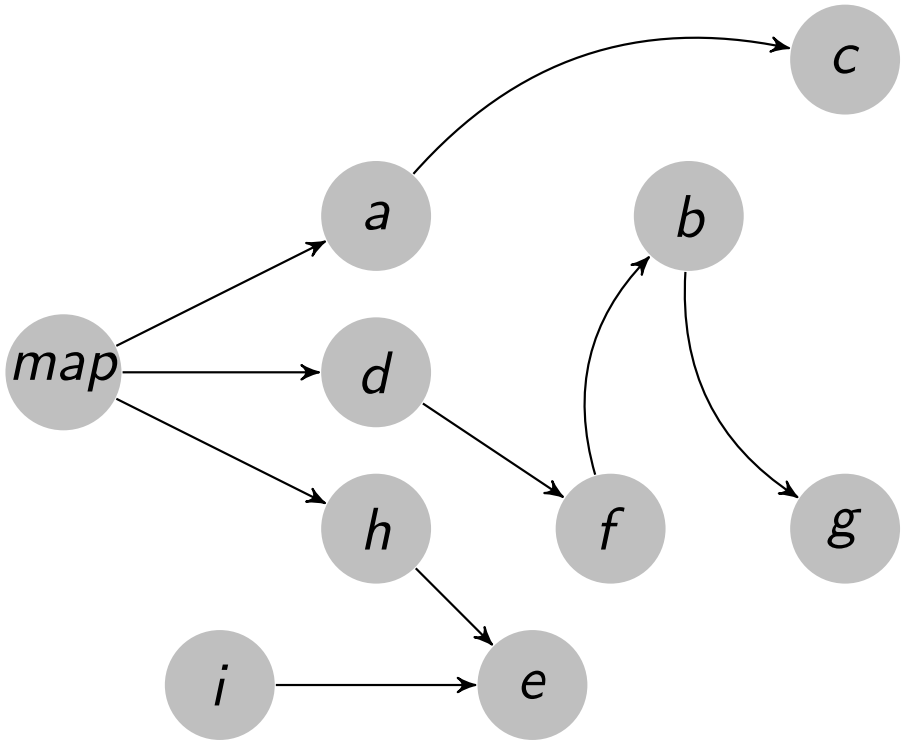

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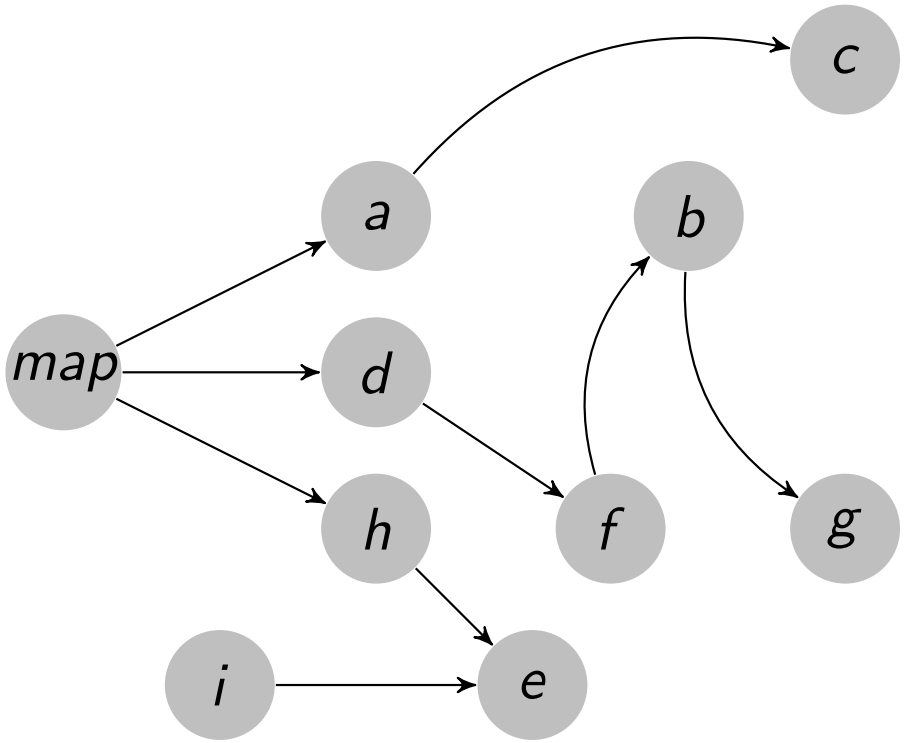

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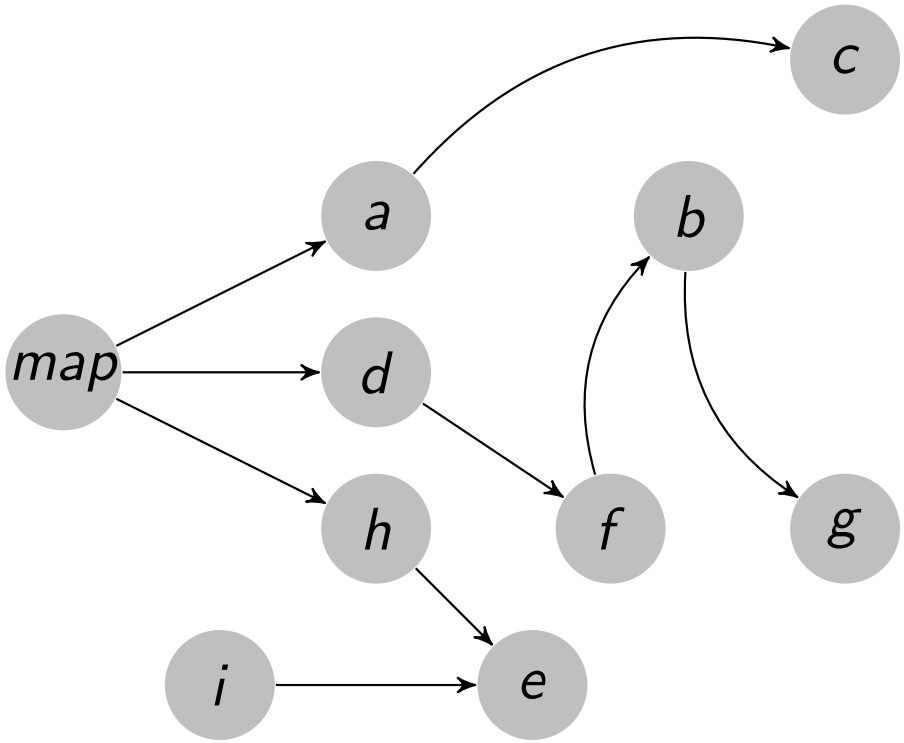

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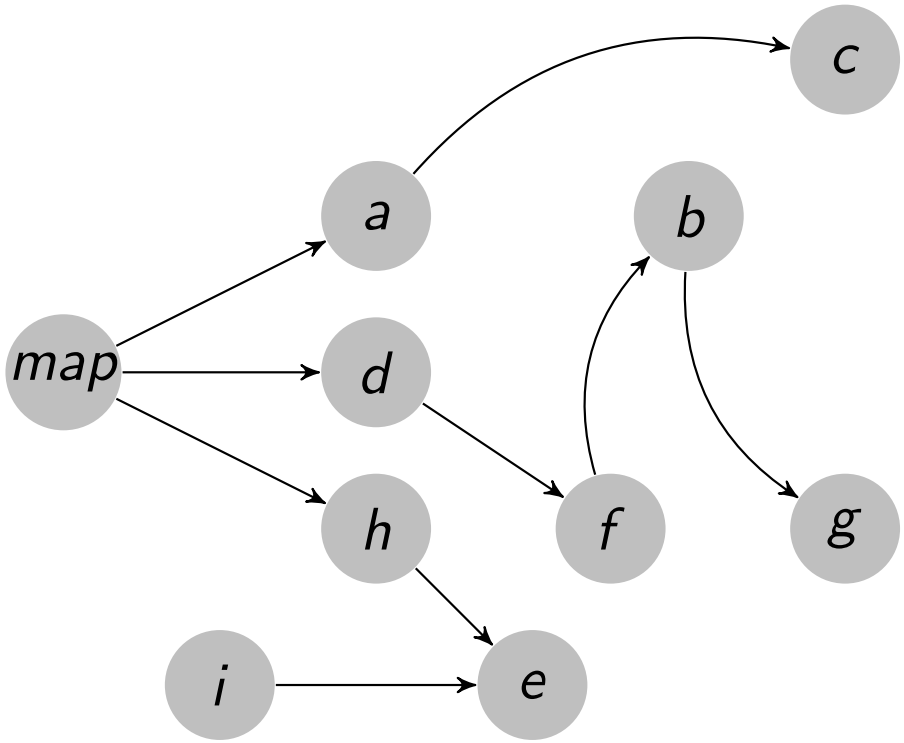

Prioritized GC: Measuring Sizes

- Mark entries in space
- Mark roots
- Depth-first search from roots
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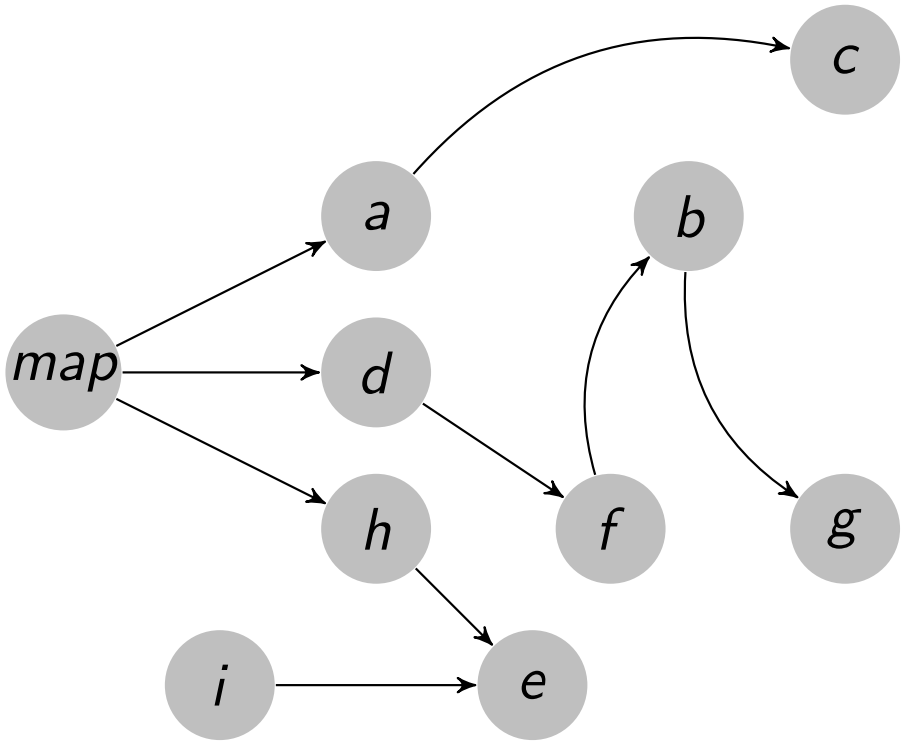

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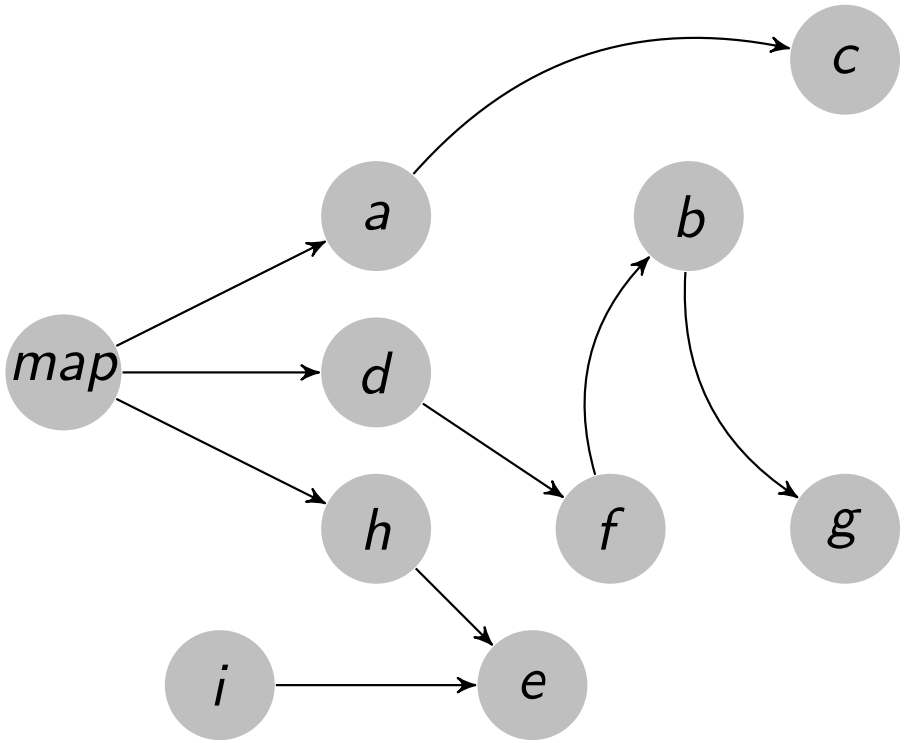

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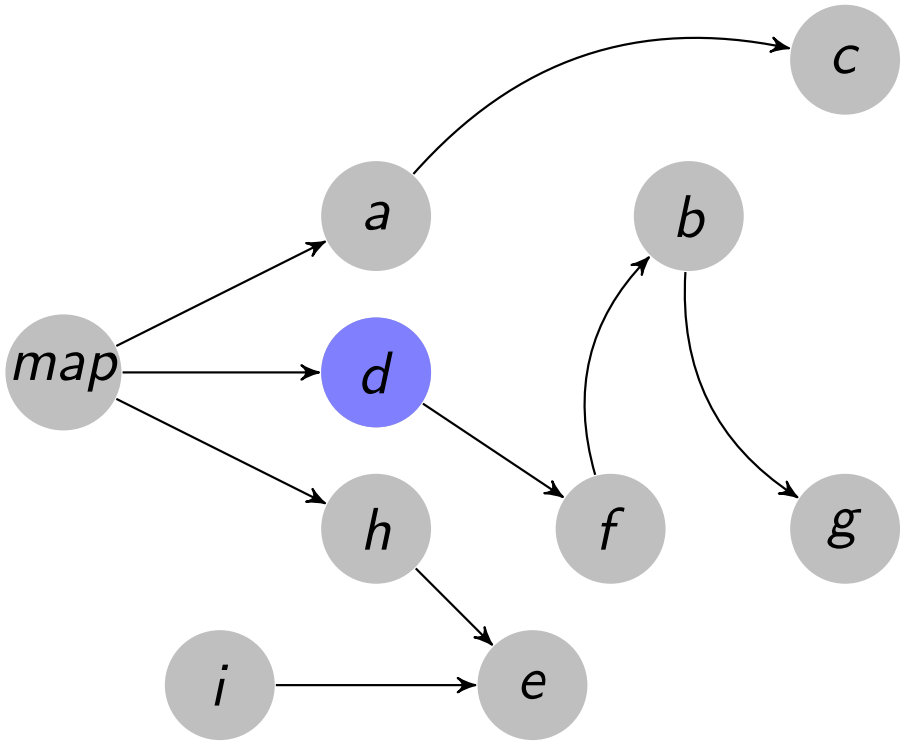

Marked by Mark Sweep

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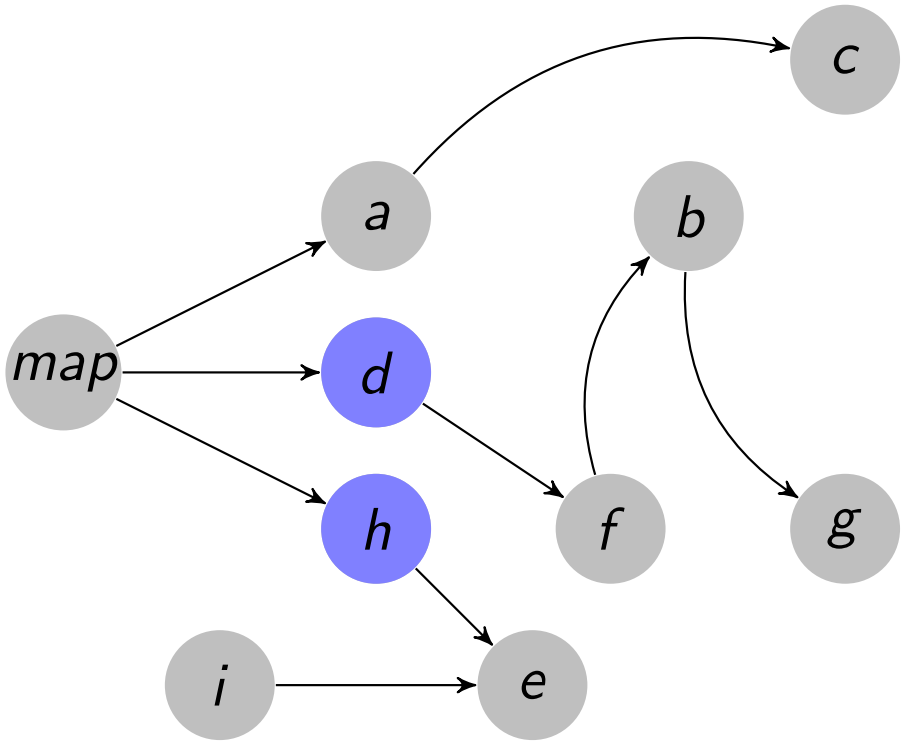

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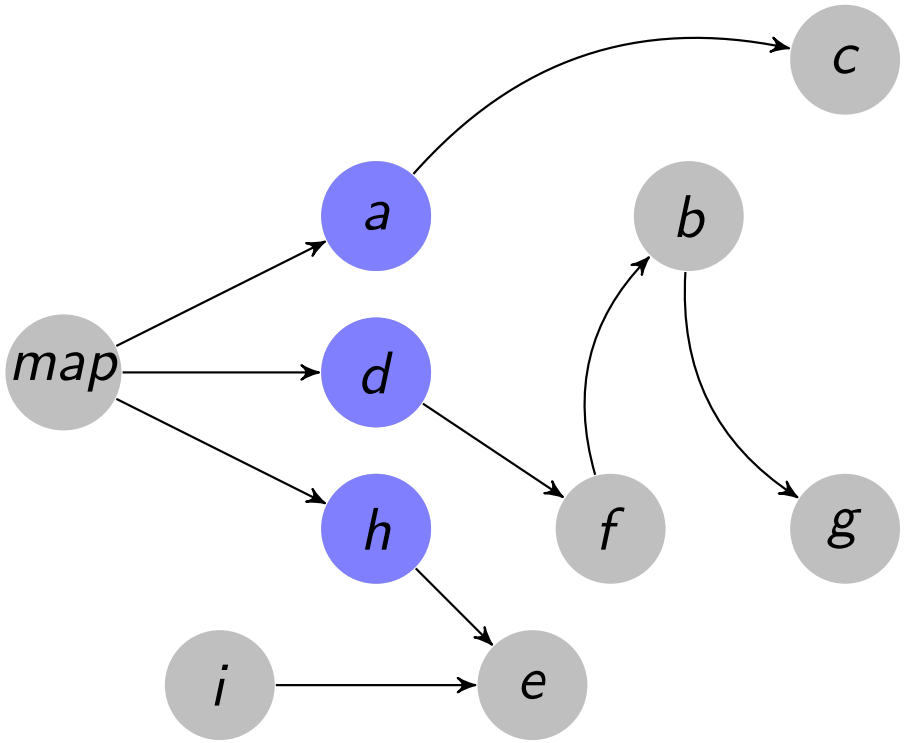

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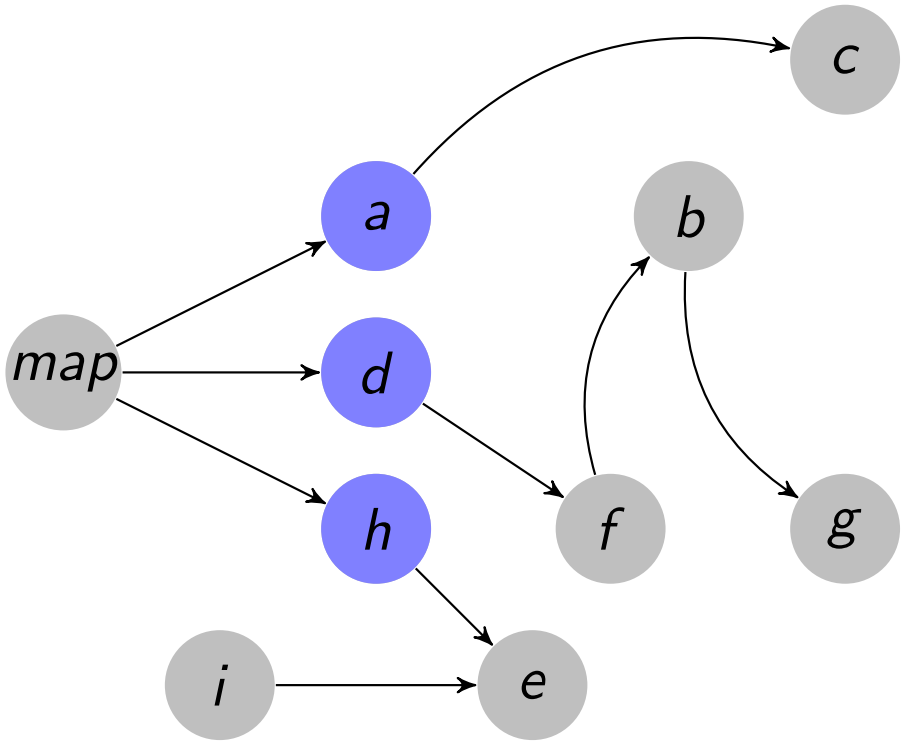

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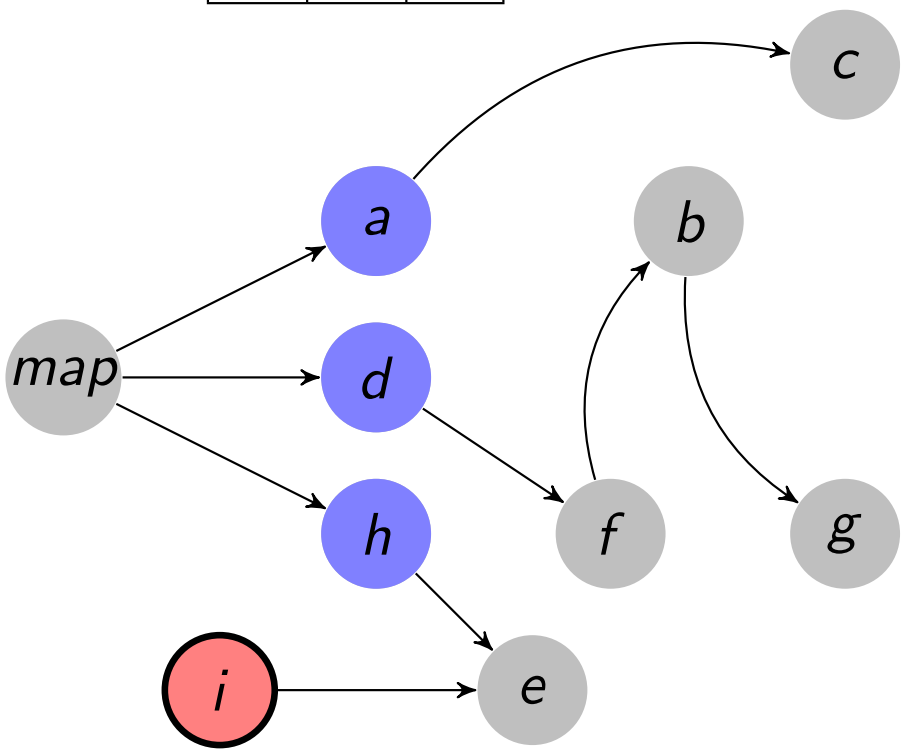

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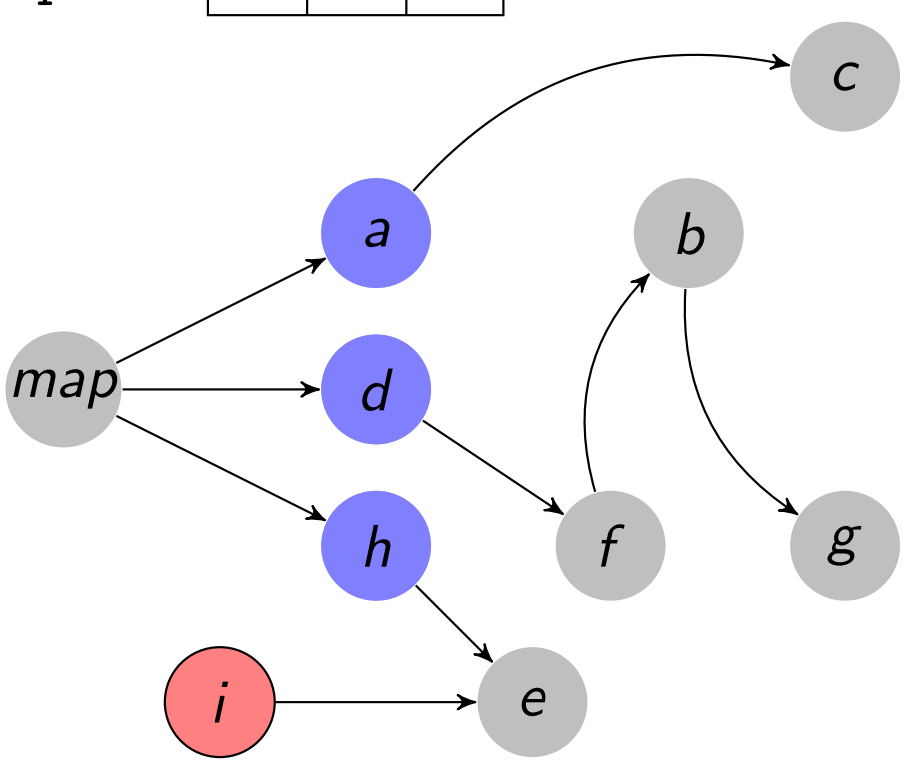

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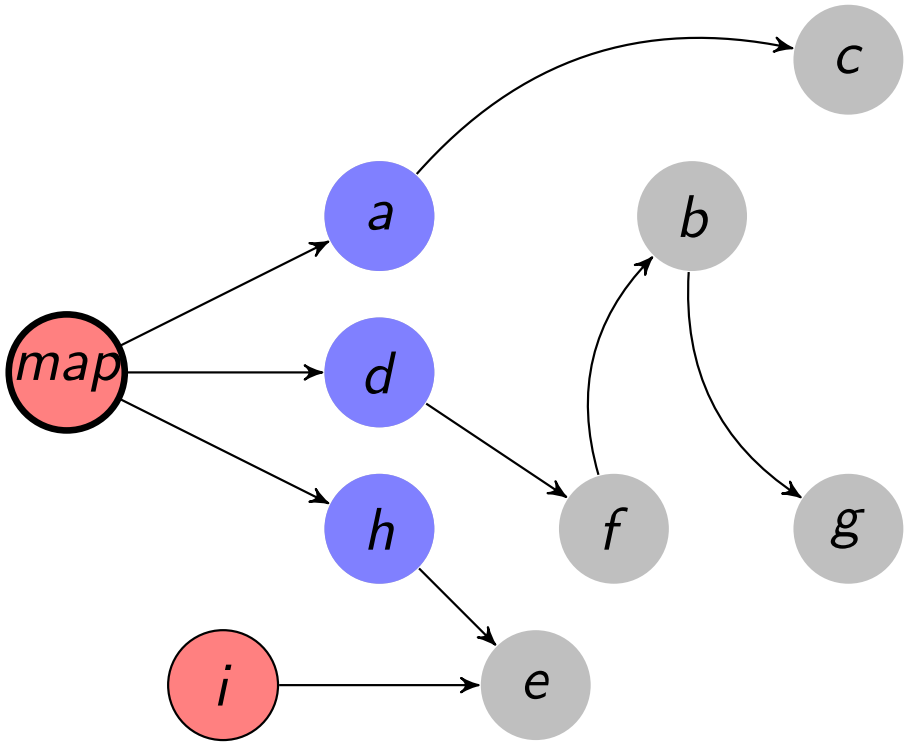
current-total = 0 bytes
space: | d | h | a |
```



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```
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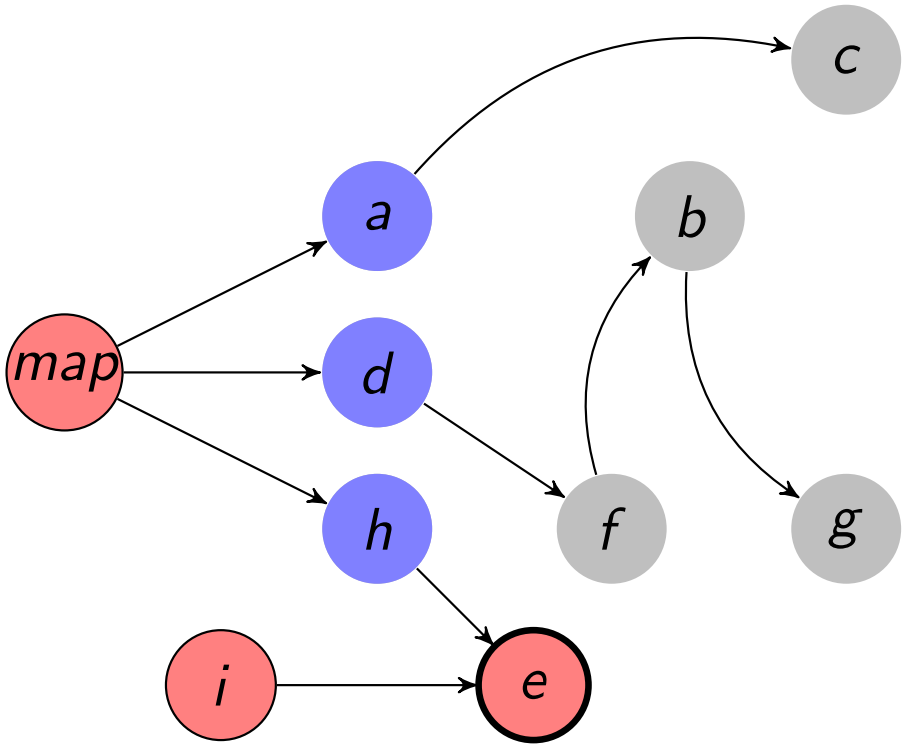
current-total = 0 bytes
space: | d | h | a |
```



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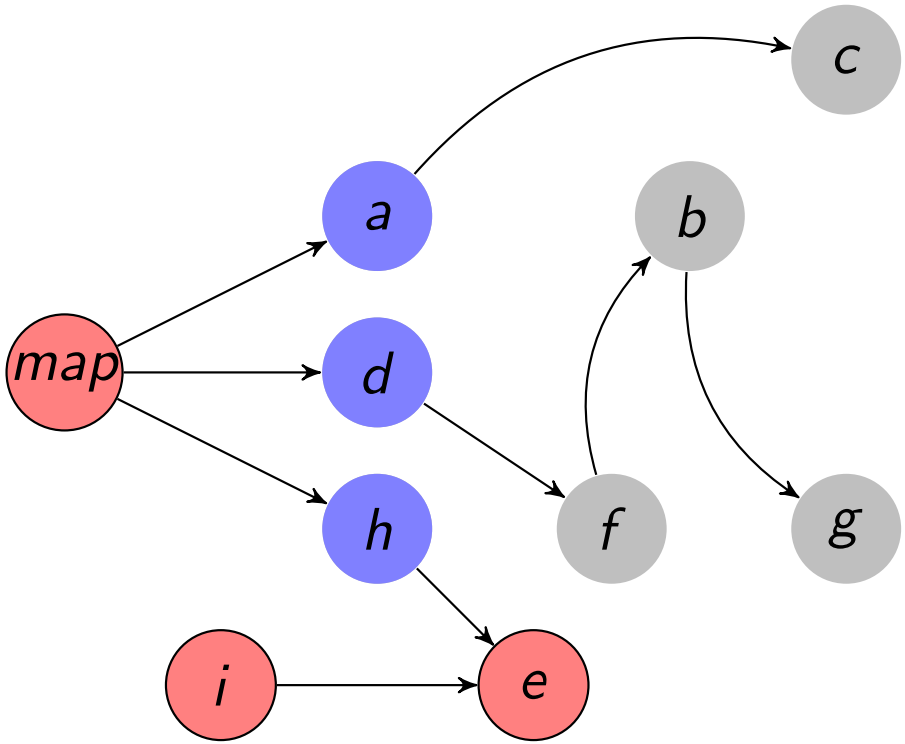
current-total = 0 bytes
space: | d | h | a |
```



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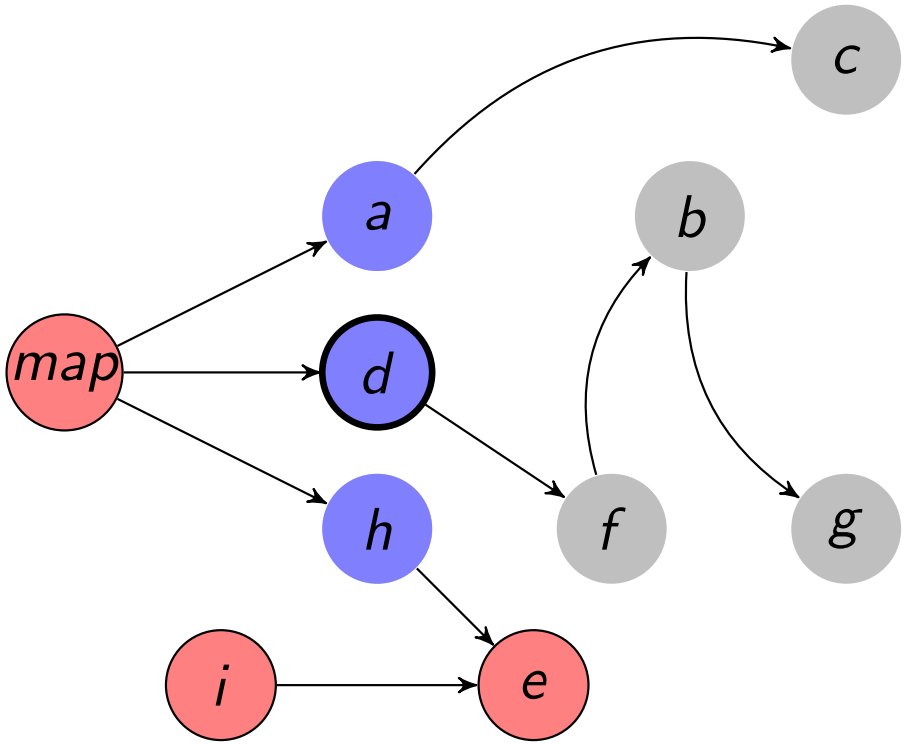
```
limit = 60 bytes
current-total = 12 bytes
space: | d | h | a |
```



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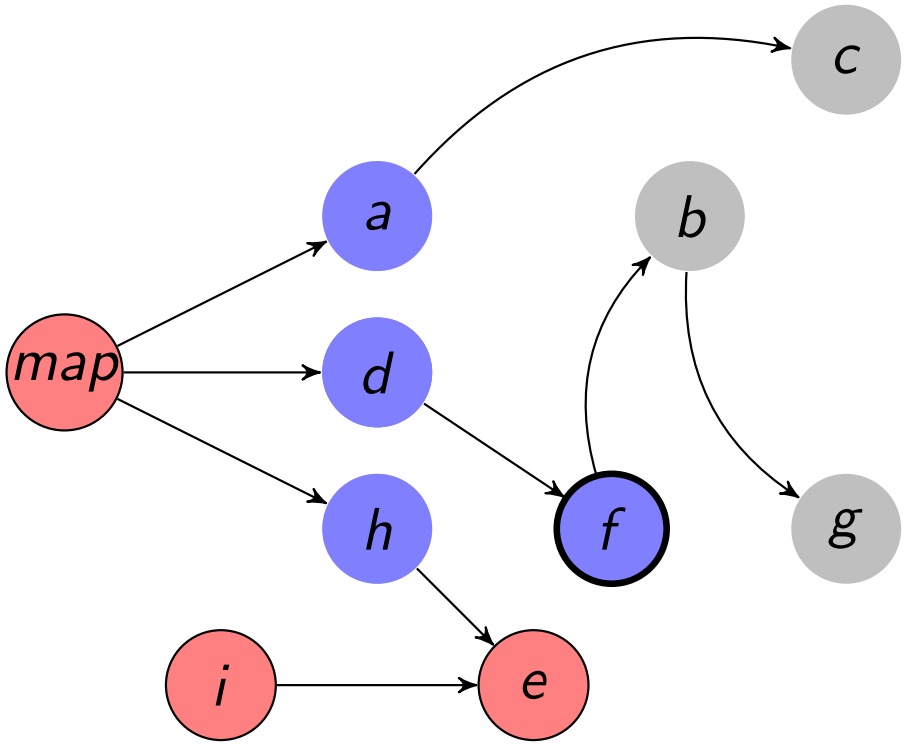
```
limit = 60 bytes
current-total = 24 bytes
space: | d | h | a |
```



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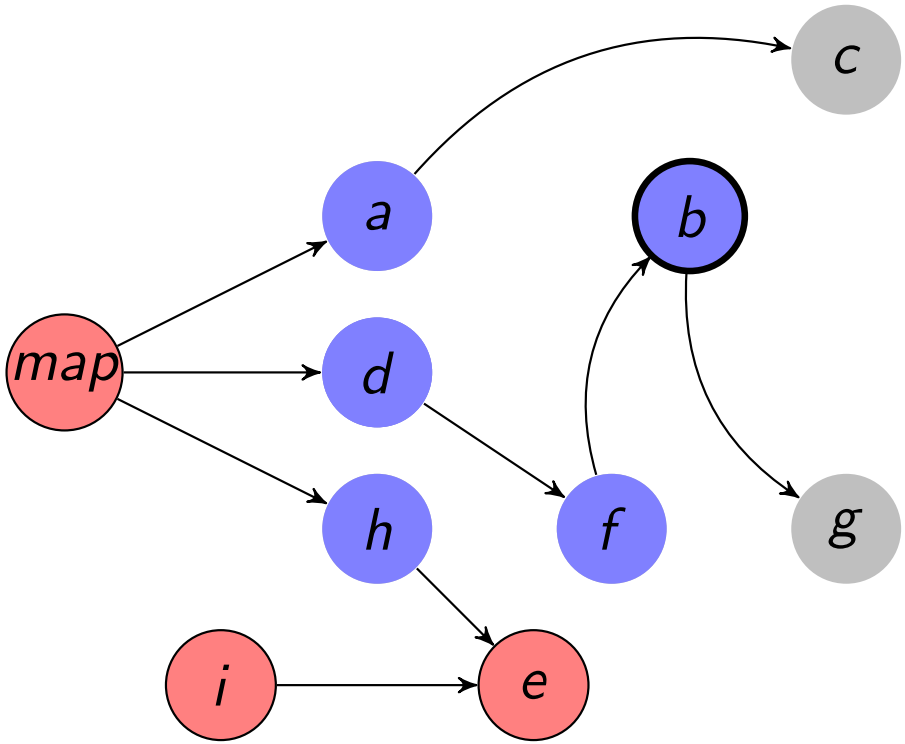
```
limit = 60 bytes
current-total = 36 bytes
space: | d | h | a |
```



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limit = 60 bytes
current-total = 48 bytes
space: | d | h | a |
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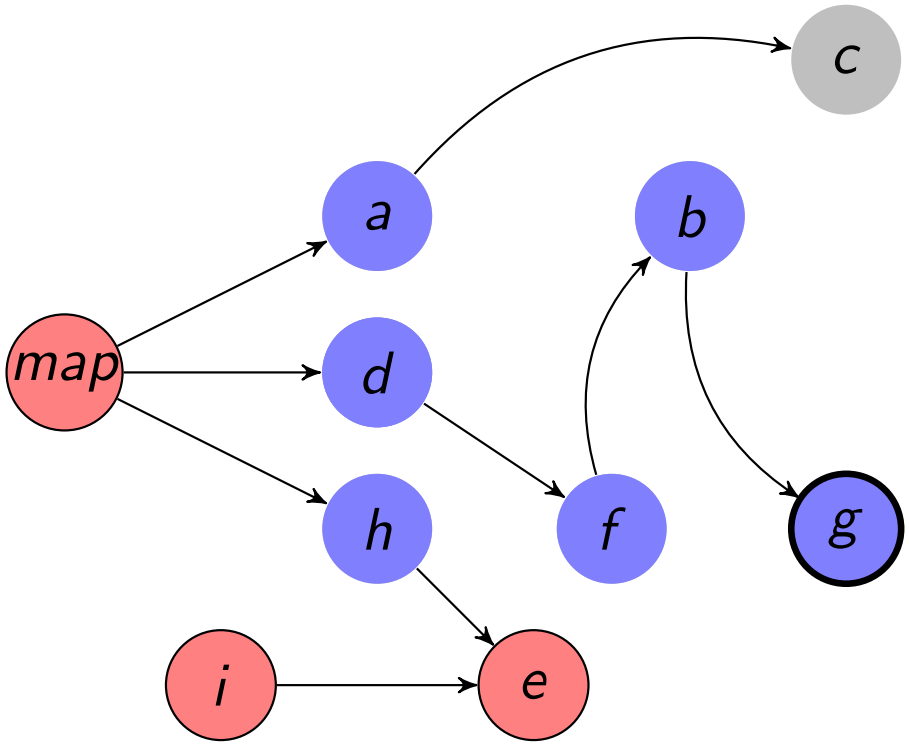

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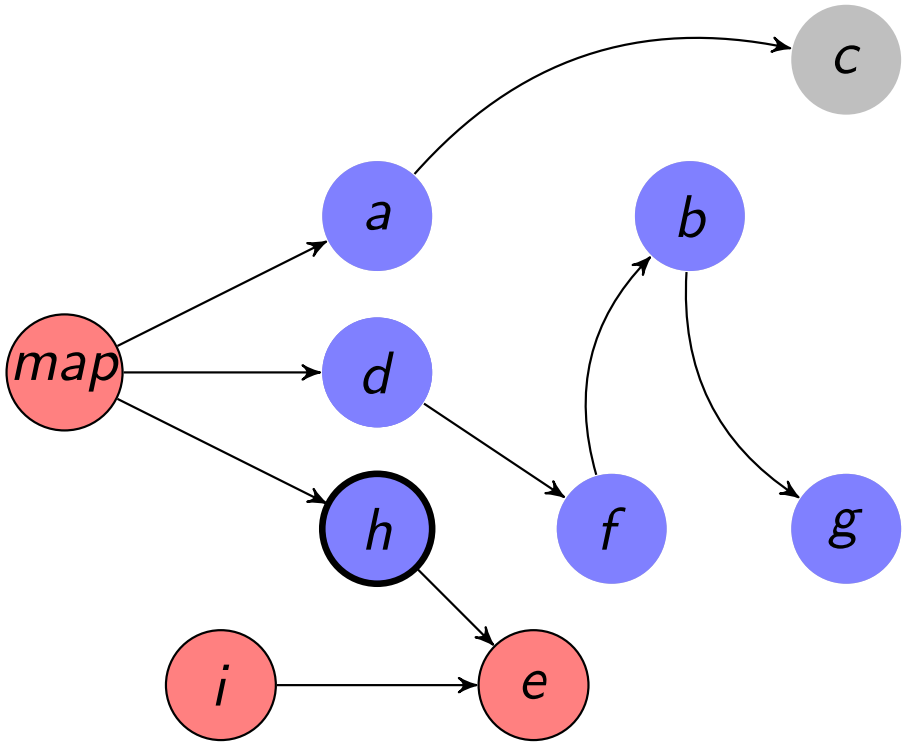
Prioritized GC: Measuring Sizes

- Mark entries in space
- Mark roots
- Depth-first search from roots
- Depth-first search from space entries
- Free all unmarked objects

```
limit = 60 bytes
current-total = 60 bytes
space: | d | h | a |
```



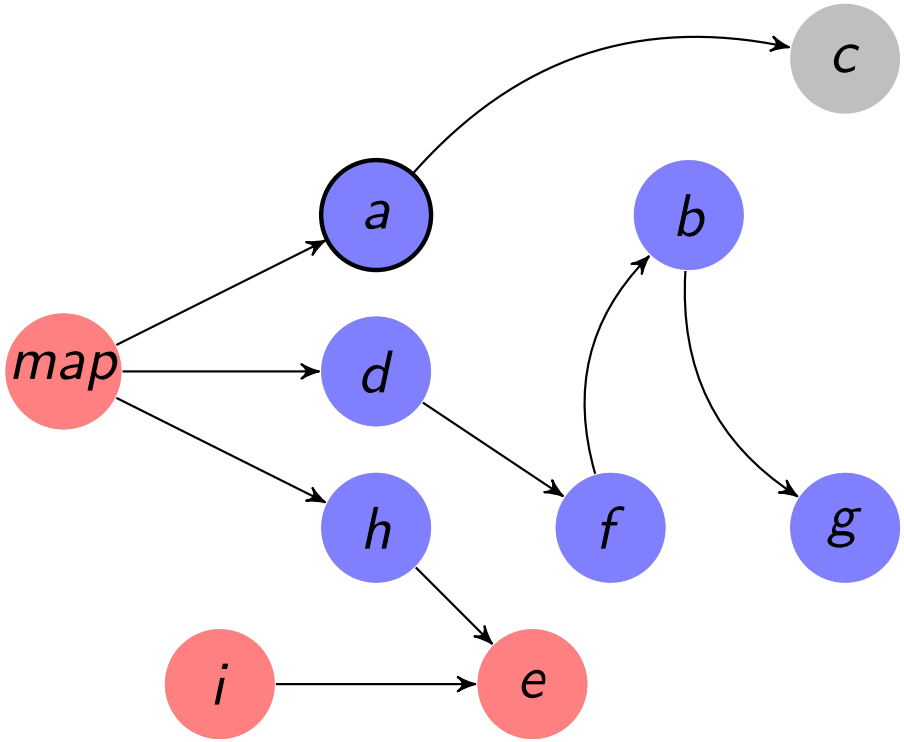
Marked by Mark Sweep

Marked by Prioritized GC

Prioritized GC: Eviction

- Mark entries in space
- Mark roots
- Depth-first search from roots
- Depth-first search from space entries
- Free all unmarked objects

```
limit = 60 bytes
current-total = 72 bytes
space: | d | h | a |
```



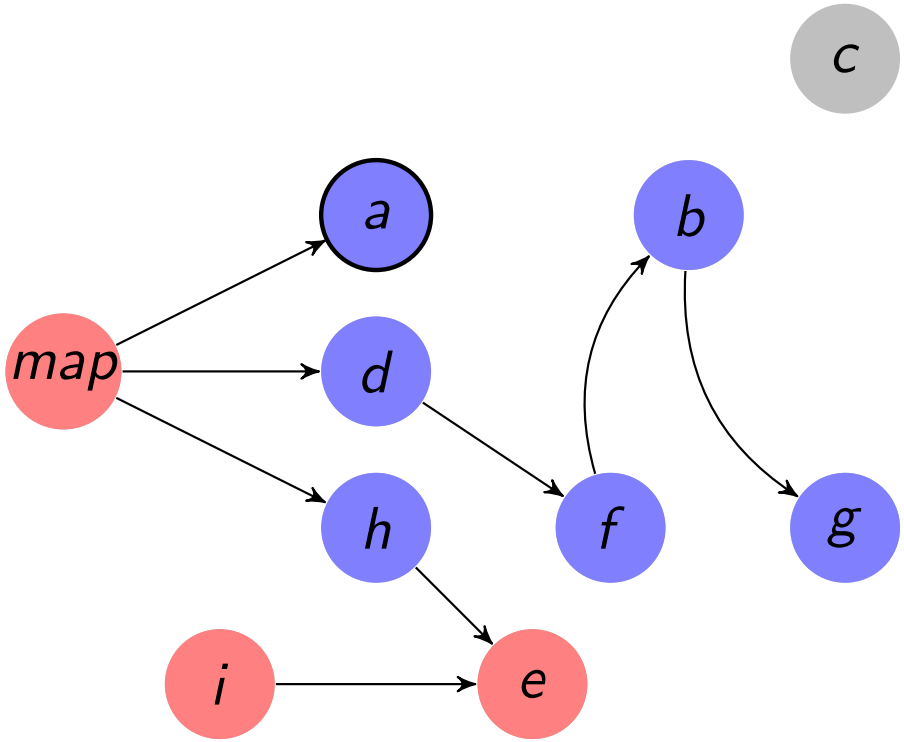
Marked by Mark Sweep

Marked by Prioritized GC

Prioritized GC: Eviction

- Mark entries in space
- Mark roots
- Depth-first search from roots
- Depth-first search from space entries
- Free all unmarked objects

```
limit = 60 bytes
current-total = 60 bytes
space: | d | h | a |
```



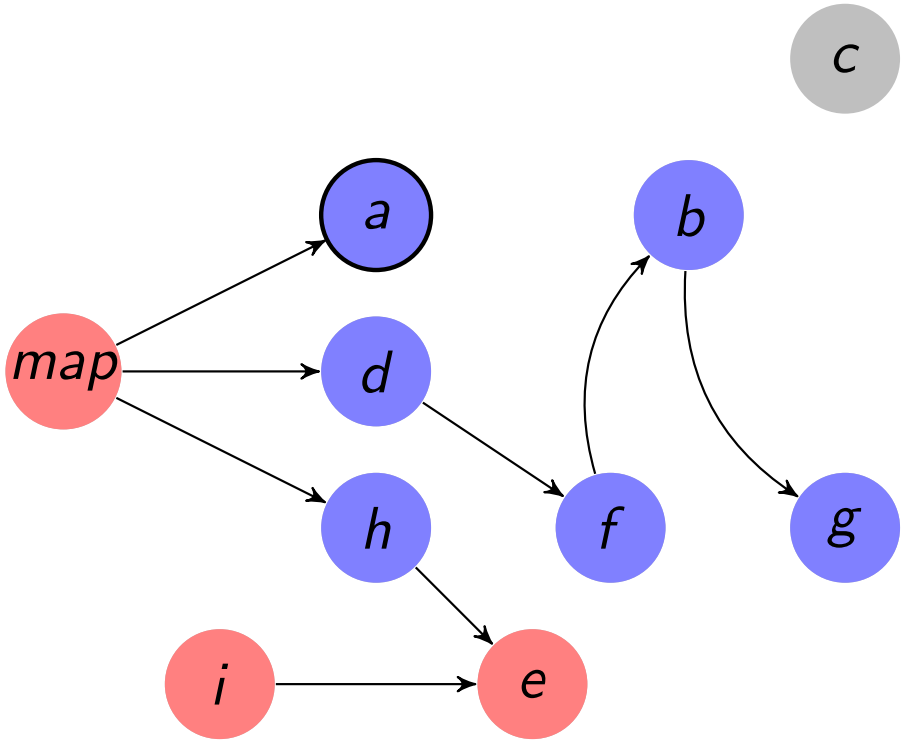
Marked by Mark Sweep

Marked by Prioritized GC

Prioritized GC: Eviction

- Mark entries in space
- Mark roots
- Depth-first search from roots
- Depth-first search from space entries
- Free all unmarked objects

```
limit = 60 bytes
current-total = 60 bytes
space: | d | h |
```



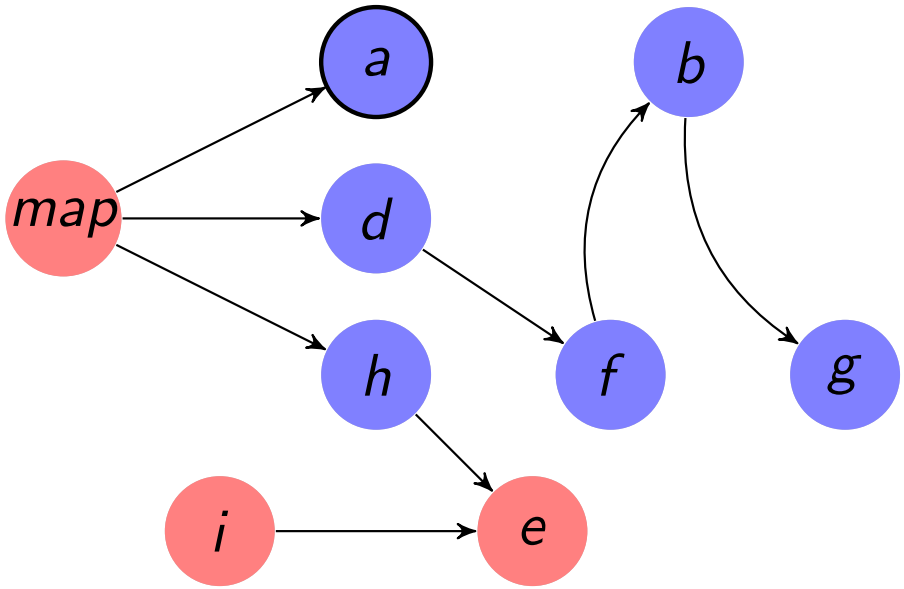
Marked by Mark Sweep

Marked by Prioritized GC

Prioritized GC: Sweep

- Mark entries in space
- Mark roots
- Depth-first search from roots
- Depth-first search from space entries
- Free all unmarked objects

```
limit = 60 bytes
current-total = 60 bytes
space: | d | h |
```



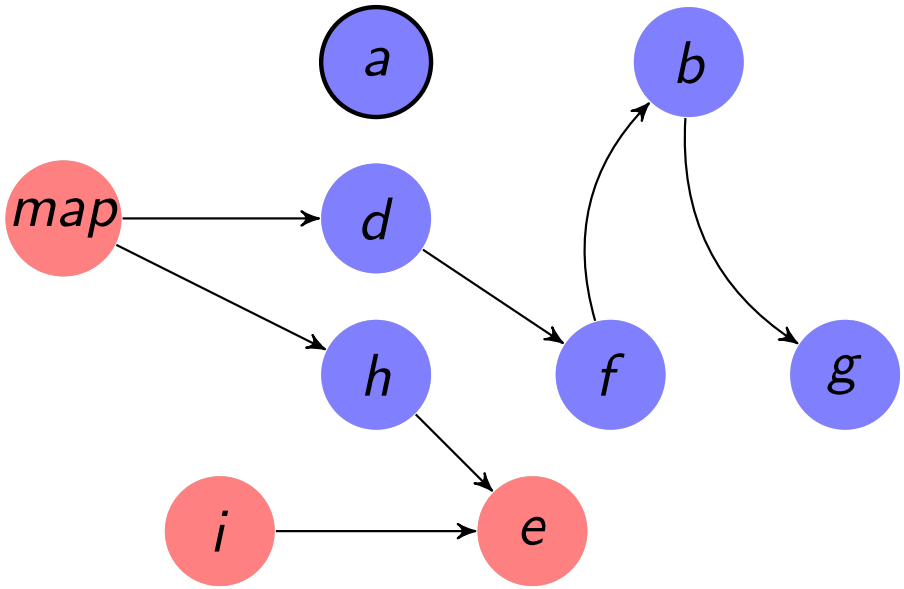
Marked by Mark Sweep

Marked by Prioritized GC

Sache evicts upon next access

- Mark entries in space
- Mark roots
- Depth-first search from roots
- Depth-first search from space entries
- Free all unmarked objects

```
limit = 60 bytes
current-total = 60 bytes
space: | d | h |
```



Marked by Mark Sweep

Marked by Prioritized GC

Experiments: Traces Used

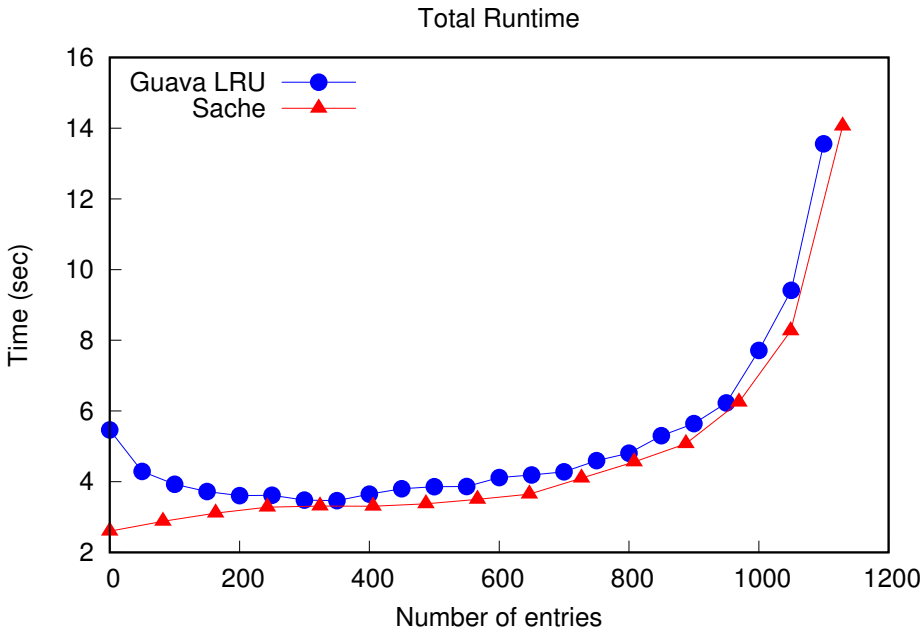
- Traces are list of (string, int) pairs
- string: unique string identifier
- int: size of structure to create
  - drawn from a predetermined range
- Request sequence follows Pareto distribution[1]

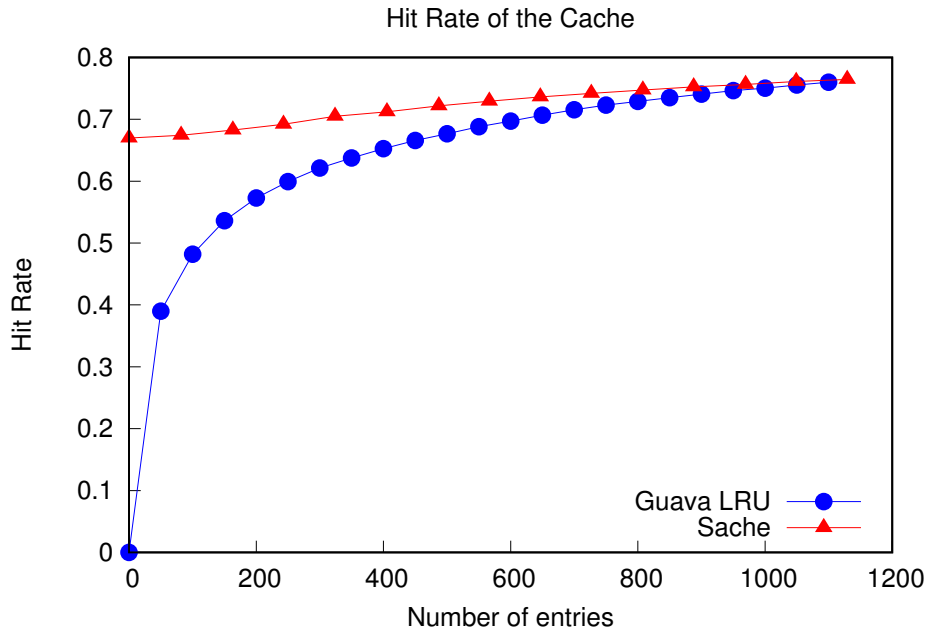
[1] C. Cunha, A. Bestavros, and M. Crovella. Characteristics of www client-based traces. Technical report, Boston, MA, USA, 1995.

Experiments

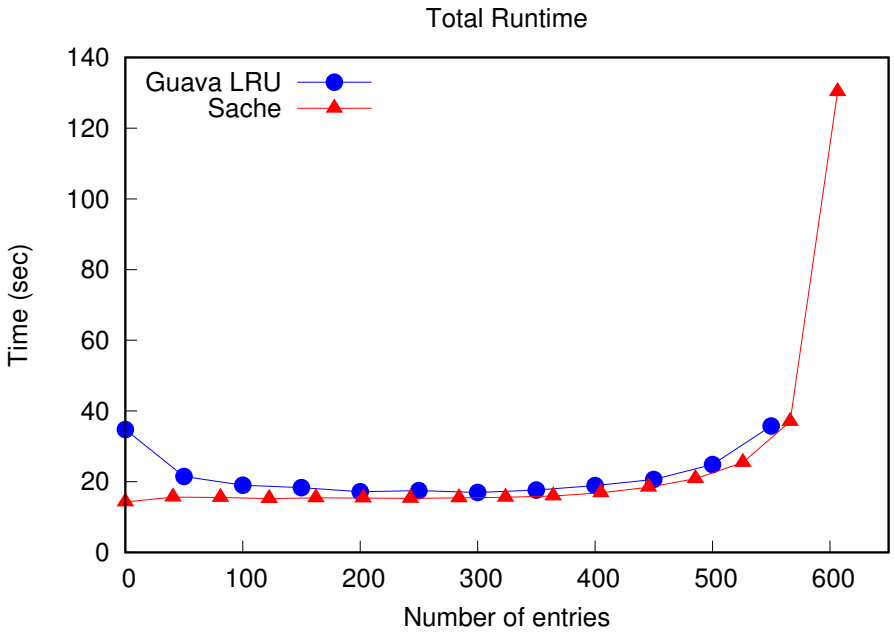
- Trace driven
  - Program reads requests: (string, int) pairs
  - Program looks the string up in the cache
  - If the read fails, create and store a tree of the requested size in the cache
- Change the cache used
  - Google Guava with LRU policy at fixed sizes
  - Sache at fixed sizes
- Implemented Prioritized GC in Jikes Research Virtual Machine

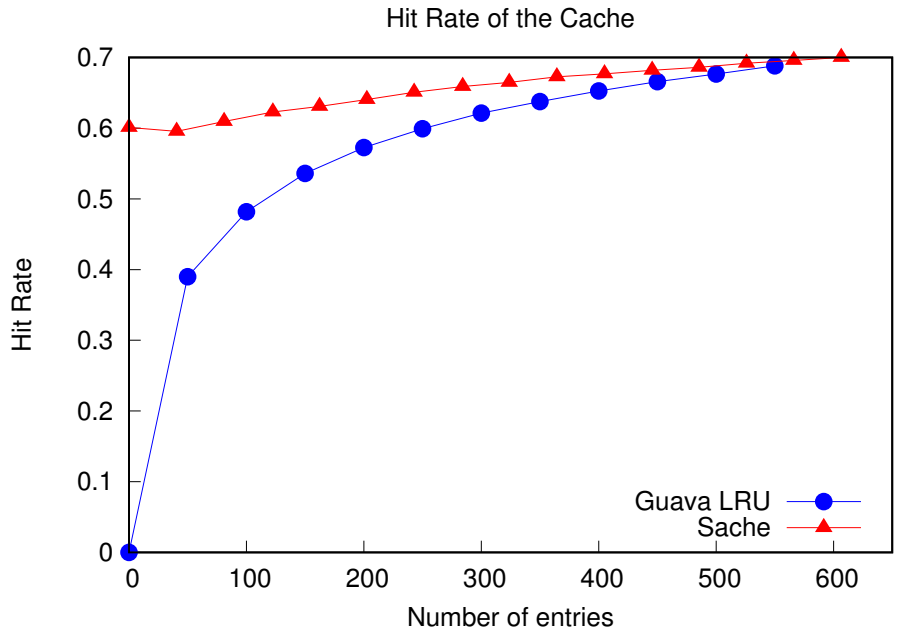
Results: Workloads (50KB – 100KB)





Results: Workloads (100KB – 200KB)





Our Solution: Sache (**S**pace **A**ware Ca**che**)

- User puts a limit on size of Sache in bytes
- Tell the garbage collector what values are in the cache
- Measure the size of these values during garbage collection
- If keeping a value means the Sache exceeds its size limit, evict that value

Our Solution: Adaptive Sache (**S**pace **A**ware Ca**che**)

- ~~User puts a limit on size of Sache in bytes~~
- Tell the garbage collector what values are in the cache
- Each collection, calculate limit on size of Sache in bytes
- Measure the size of these values during garbage collection
- If keeping a value means the Sache exceeds its size limit, evict that value

Adaptive Sache: Calculating Size Limits

Adaptive Sache: Calculating Size Limits

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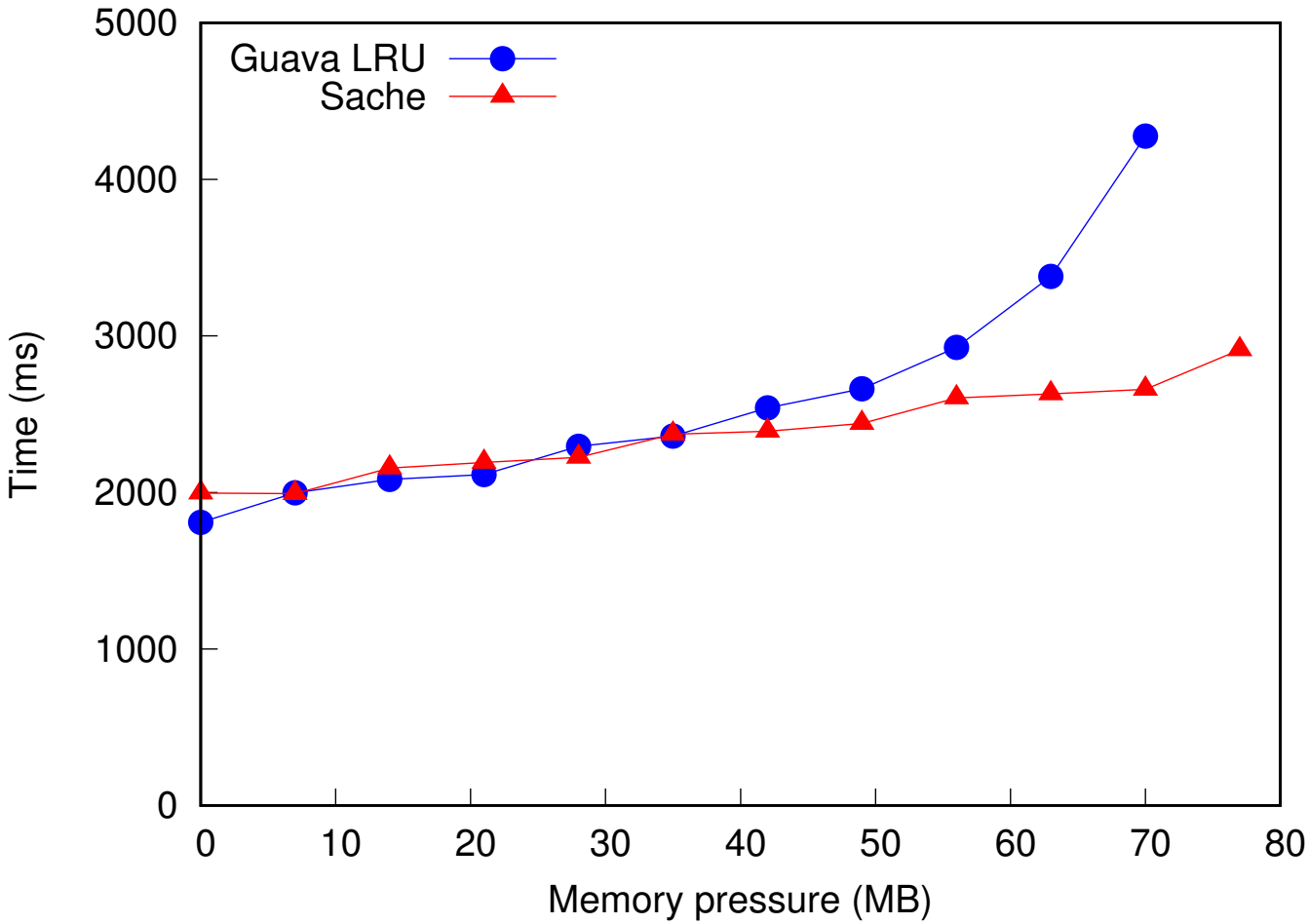
Adaptive Sache: Calculating Size Limits

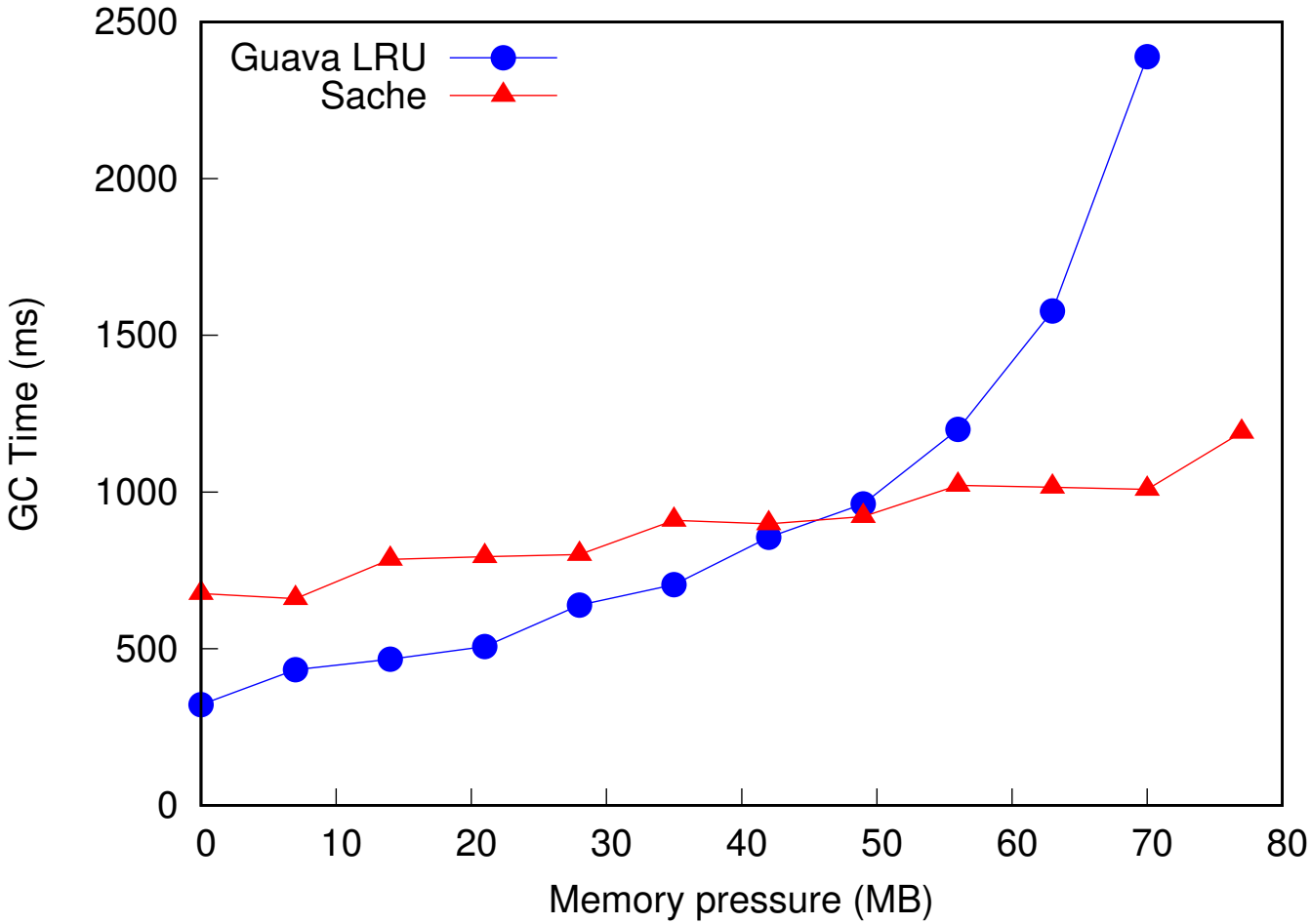
Experiments: Memory Pressure

- Trace driven
  - Use the workload with sizes in 50KB – 100KB range
  - After a third of requests read, increase memory pressure
  - After another third, decrease memory pressure
- Change the cache used
  - Google Guava with LRU policy fixed at 350 entries
  - Adaptive Sache with reserve of 50%

Results: Pressured Workload Trace: Total Run Time

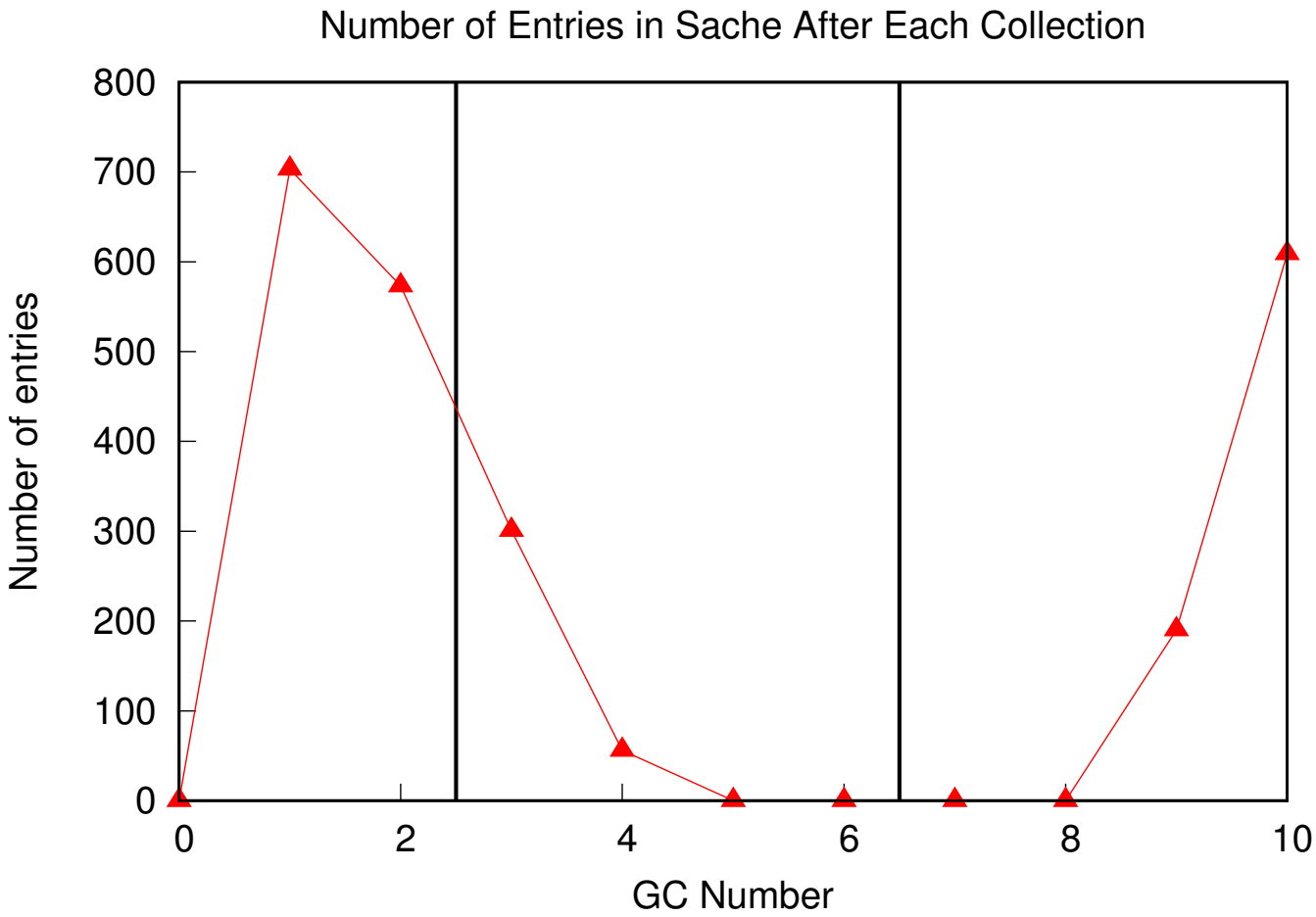


Results: Pressured Workload Trace: Total GC Time



Results: Adaptive Sache on Pressured Workload Trace

Add lines to note when memory pressure starts and ends



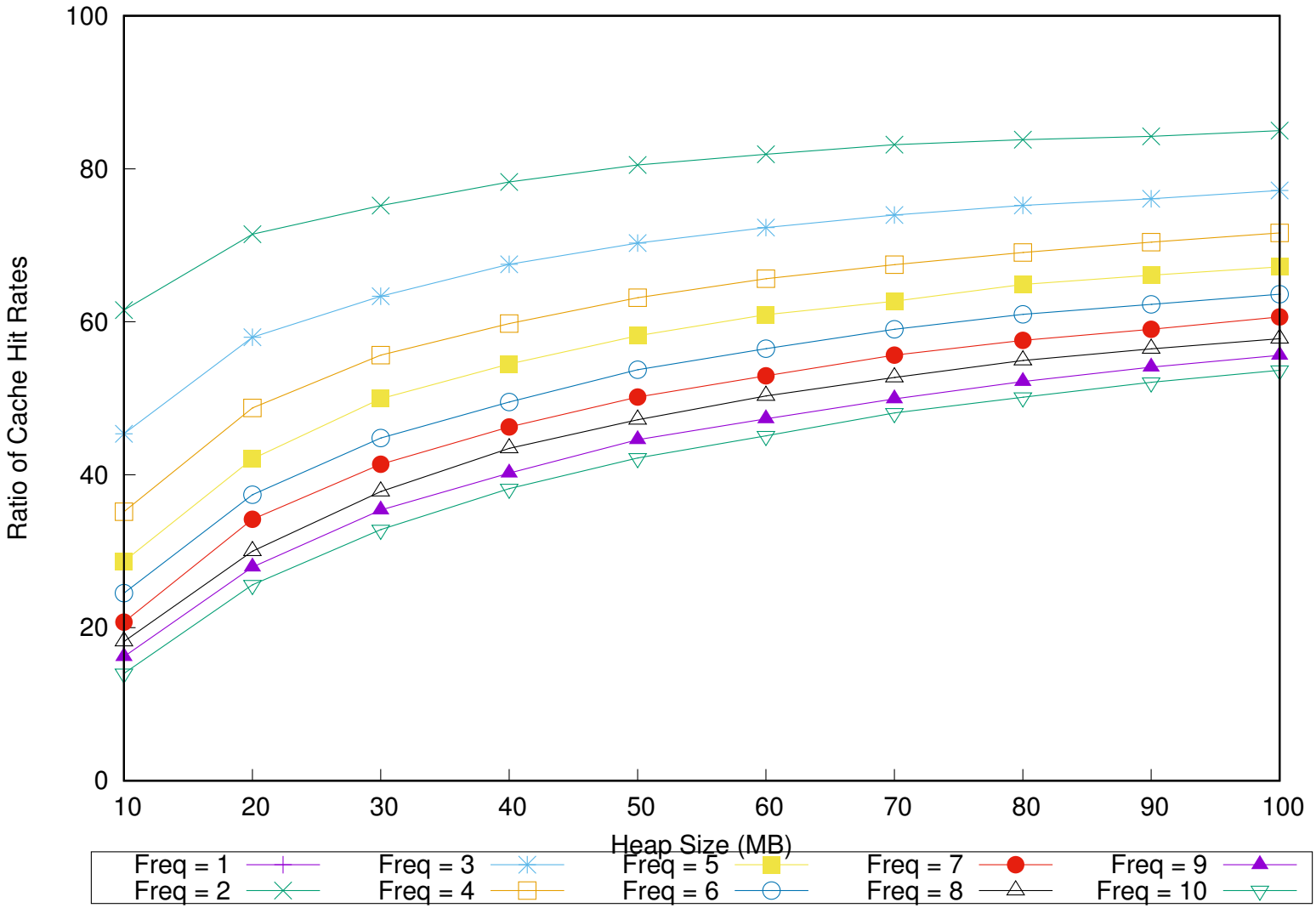
Conclusion

- Prioritized Garbage Collector allows programmers to handle references in application-specific ways
- Sache uses the Prioritized Garbage Collector to enforce memory limits
- Sache can adapt its size to memory pressure, improving robustness

Questions?

Backups

Saches and SoftReference Caches: Hotspot



Saches and SoftReference Caches: Sache