Hierarchical Real Time Garbage Collection

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  - Java programmers are accustomed to garbage collection.

- We would like to use real-time garbage collection (RTGC) - but sometimes performance is not good enough.

- Programmers may be forced to use some form of manual memory management instead (scoped memory, object pools, eventrons, reflexes).

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Interruptions from the collector are part of the real-time schedule.

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Following interruption, the time before the mutator gets to relinquish control from the collector should be small.

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For a given timeslice, the amount of time that the mutator is *guaranteed* to utilize, is maximized.

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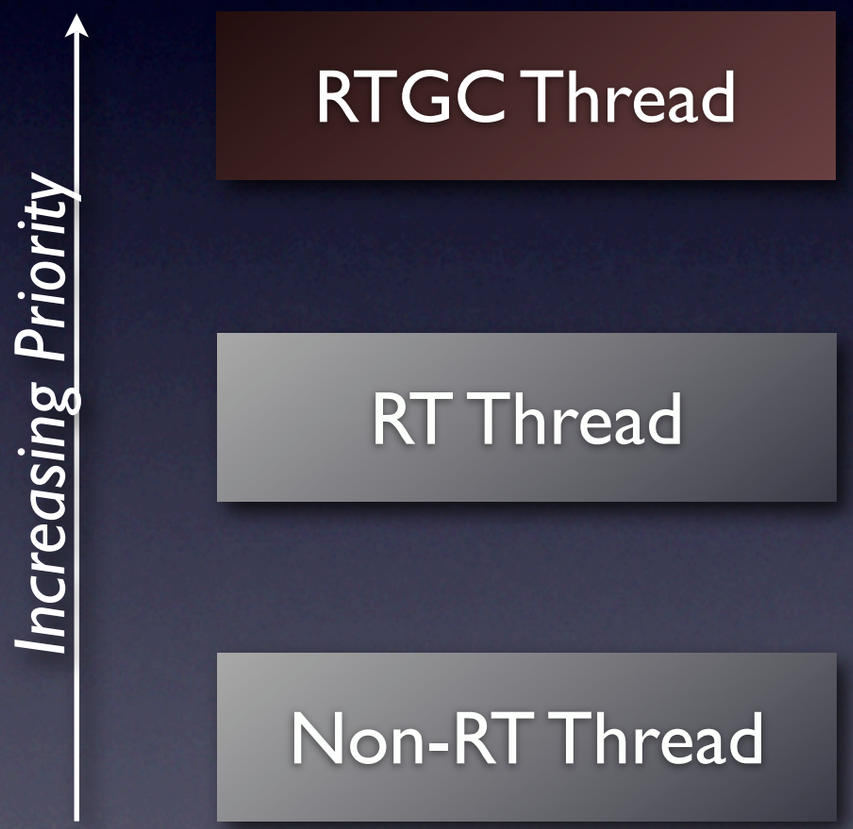
    - *RTGCs are not primarily designed to maximize overall application throughput!*
  - All RTGCs "interfere" with the mutator by either actively interrupting it (Metronome) or requiring it to occasionally yield (Henriksson).

The problem with “normal” RTGCs.



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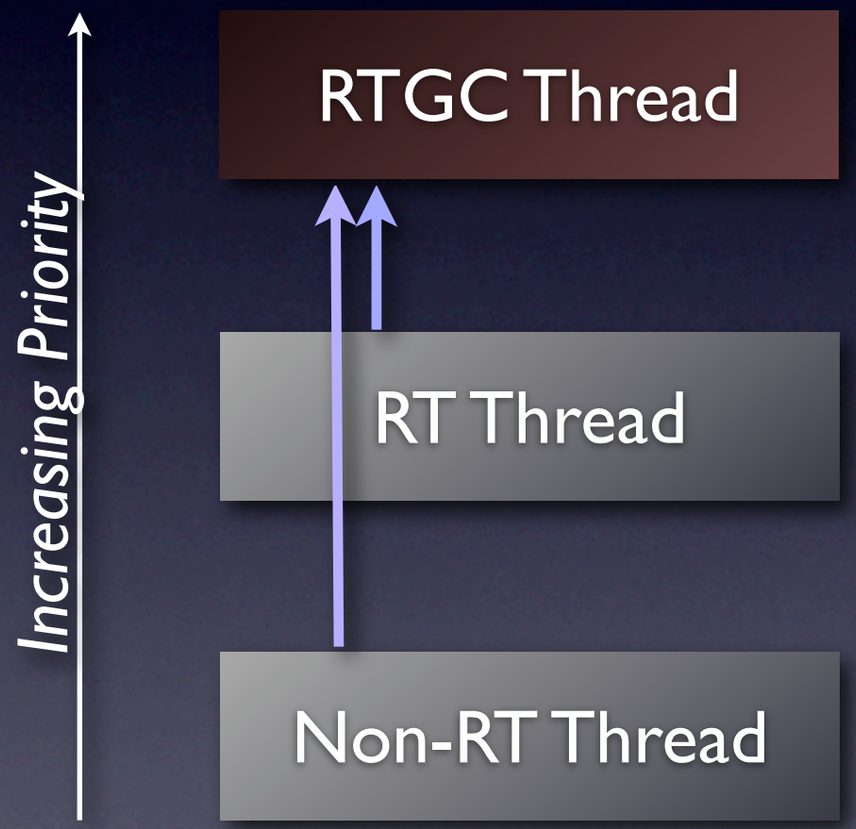
- The amount of interference from the RTGC is determined by the allocation rate of *all threads*, and the size of the *whole heap*.



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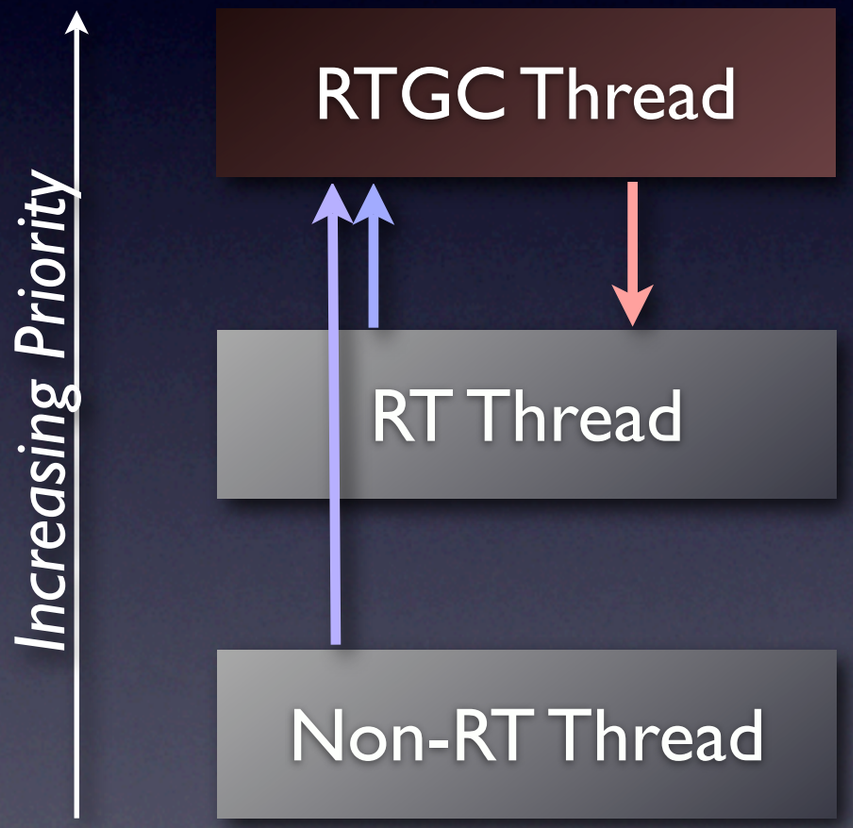
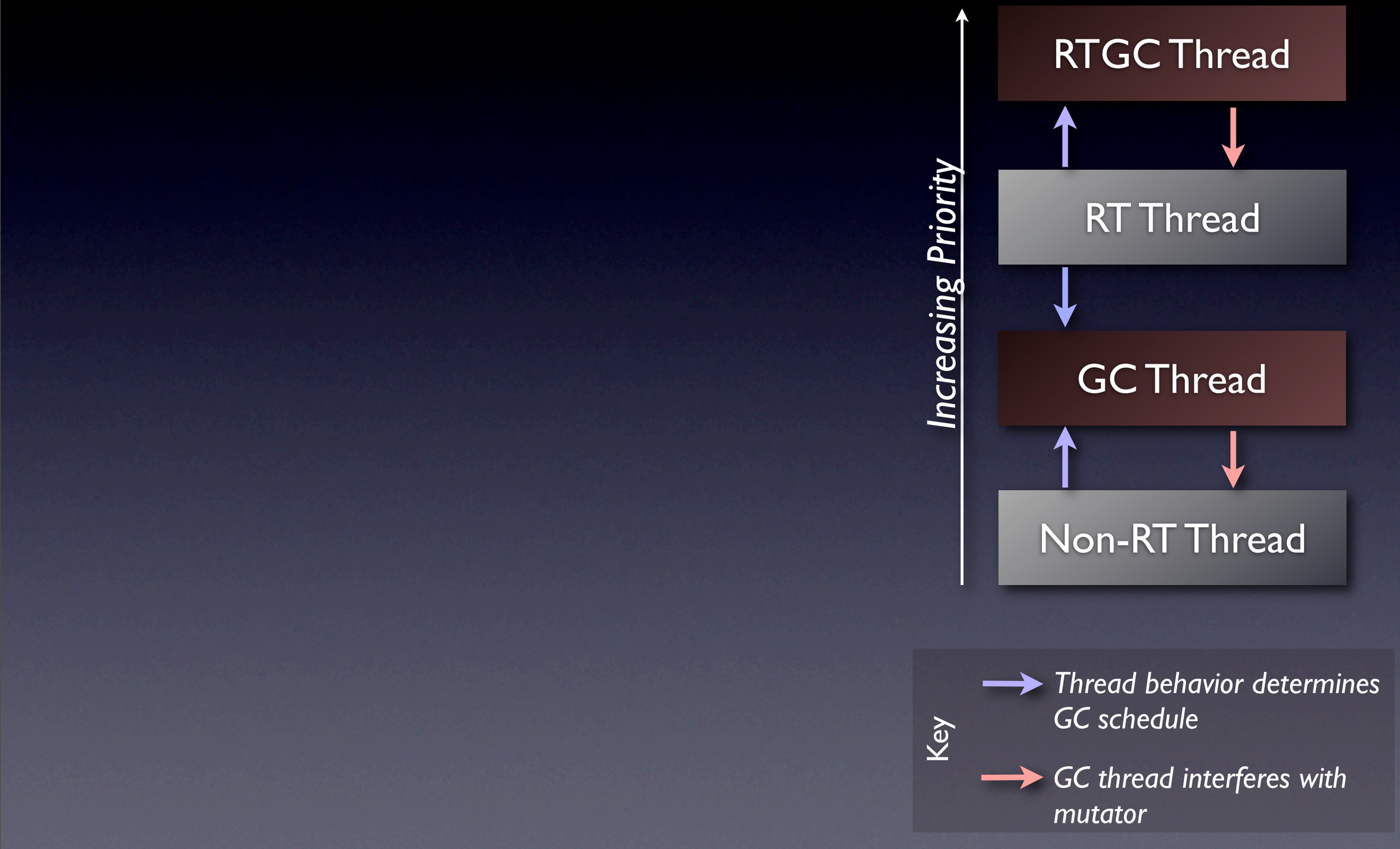
- The amount of interference from the RTGC is determined by the allocation rate of *all threads*, and the size of the *whole heap*.

- This leads to a kind of *priority inversion*: the heap usage of a non-real-time task may cause the GC to interfere with a real-time task.



- This problem affects all styles of RTGC (time-based, work-based, Henriksson-style).
- *It can be easily avoided if the part of the heap used by the real-time tasks is segregated from the part used by non-real-time tasks.*

Basic Strategy



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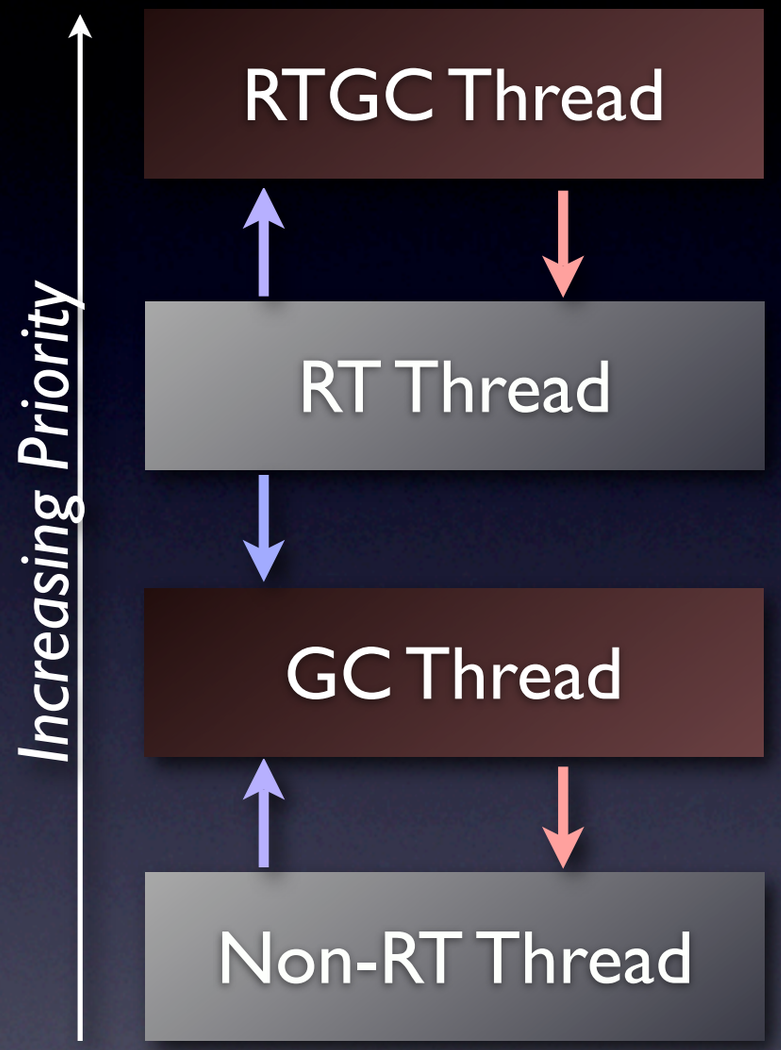

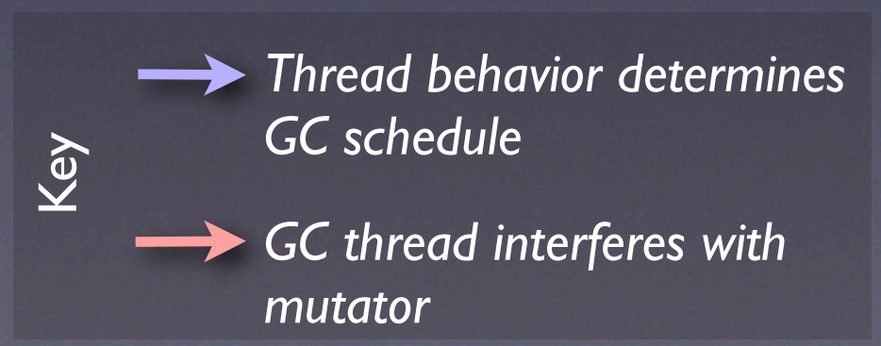

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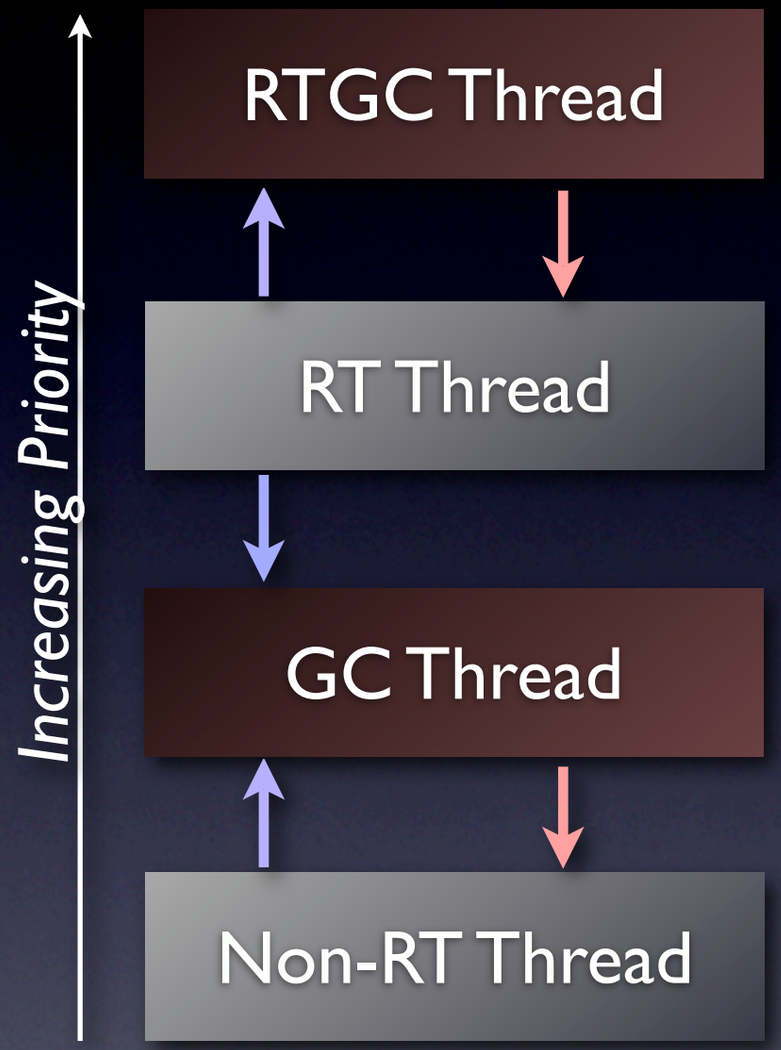

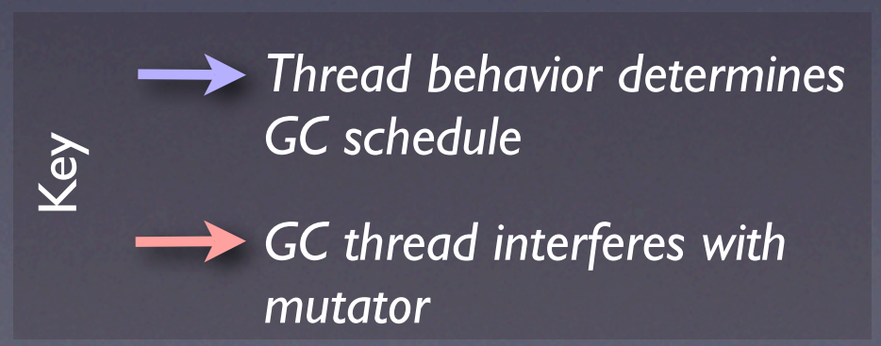

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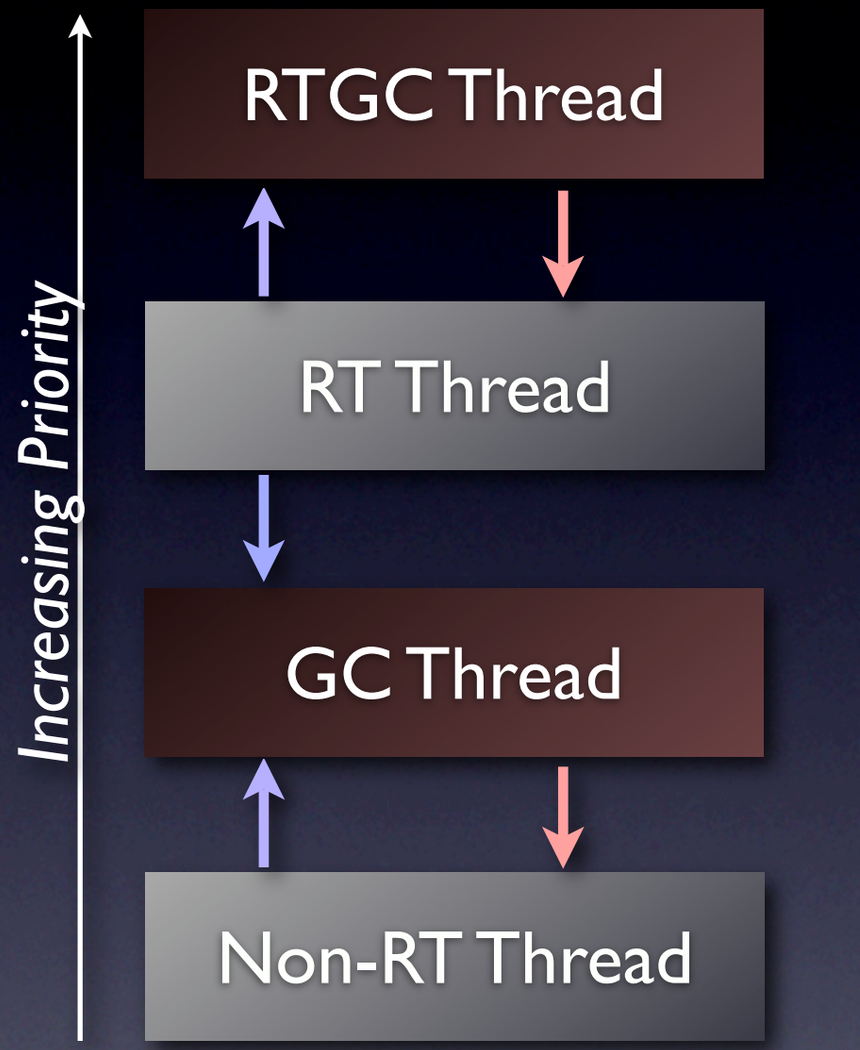
- The collector for the non-real-time heaplets never interferes with real-time tasks.



Basic Strategy

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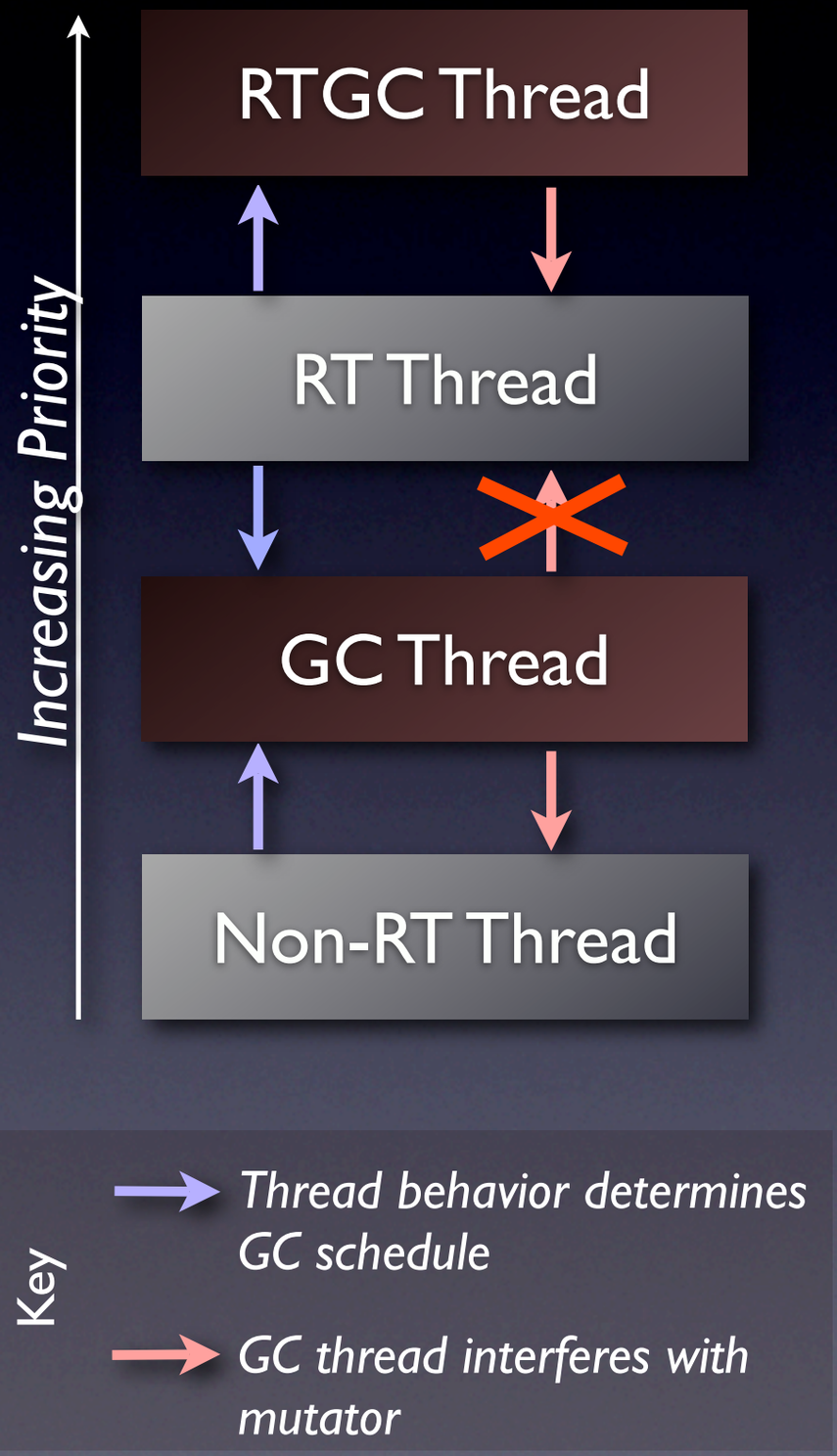
- Each heaplet gets its own collector thread.
- The collector for the non-real-time heaplets never interferes with real-time tasks.
- Thus - real-time code will not be affected by the footprint and allocation behavior of the non-real-time code.



What are heaplets?

- A "heaplet" is a user-specified heap partition, with a user-tuned RTGC thread.
- Any thread may use any heaplet for allocation at any time. The current allocation context is determined using an RTSJ-like API.
- Any thread may have references to objects in any heaplet.
- References between heaplets are allowed.

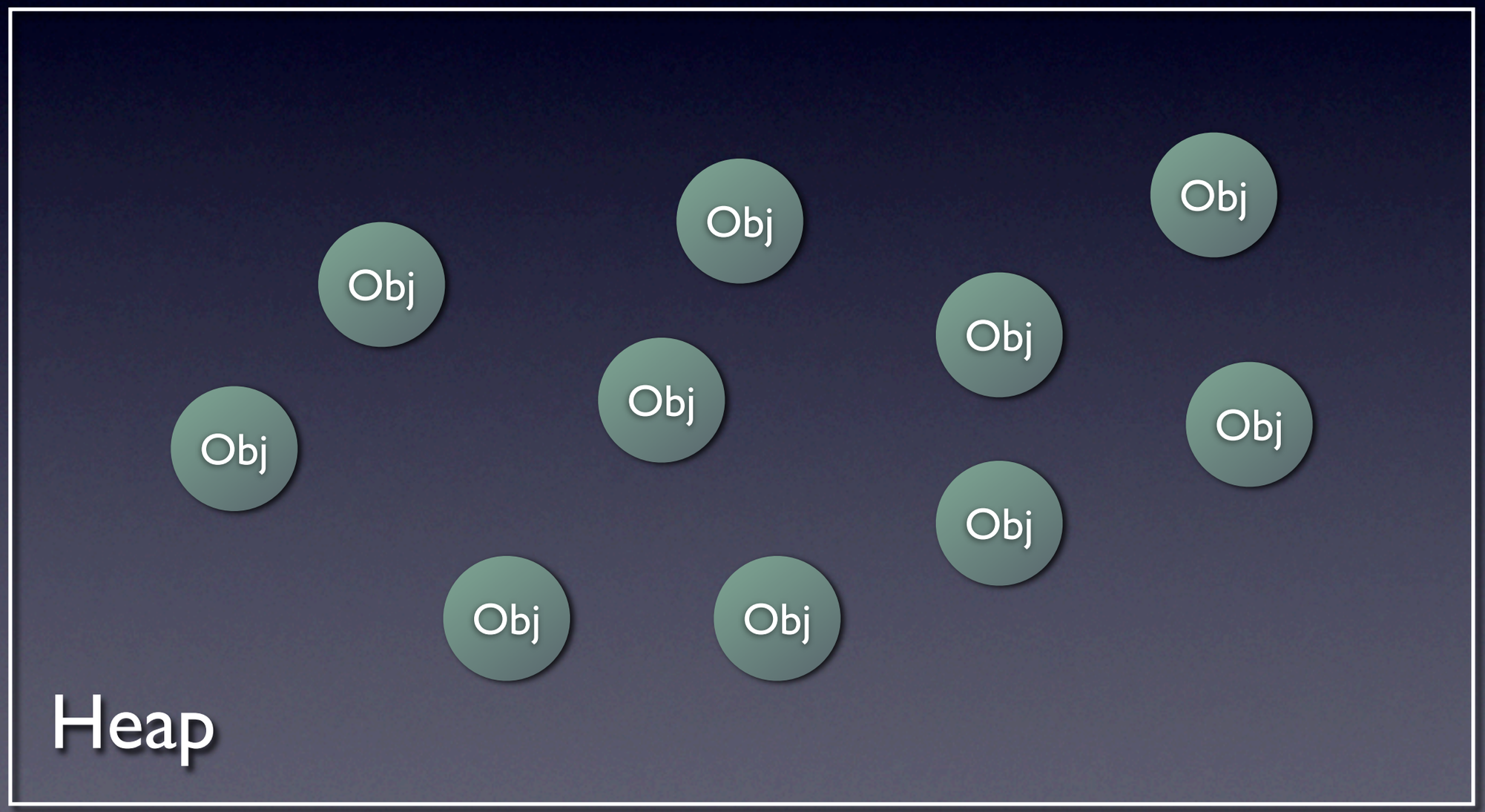
RTGC Example

Thread 1

Thread 2

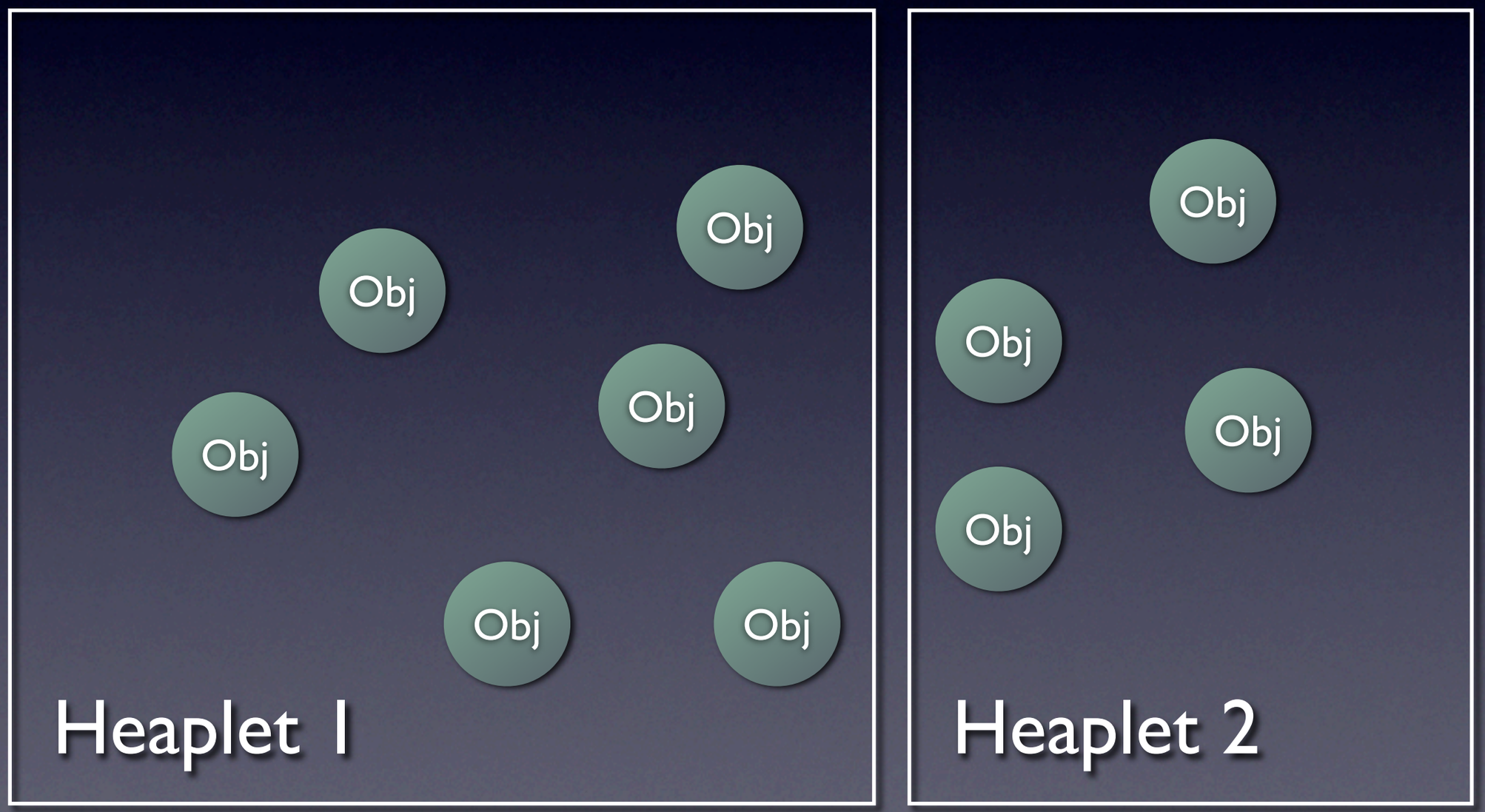
Thread 3

GC Thread



RTGC with Heaplets Example

Thread 1 | Thread 2 | Thread 3 | GC Thread | GC Thread



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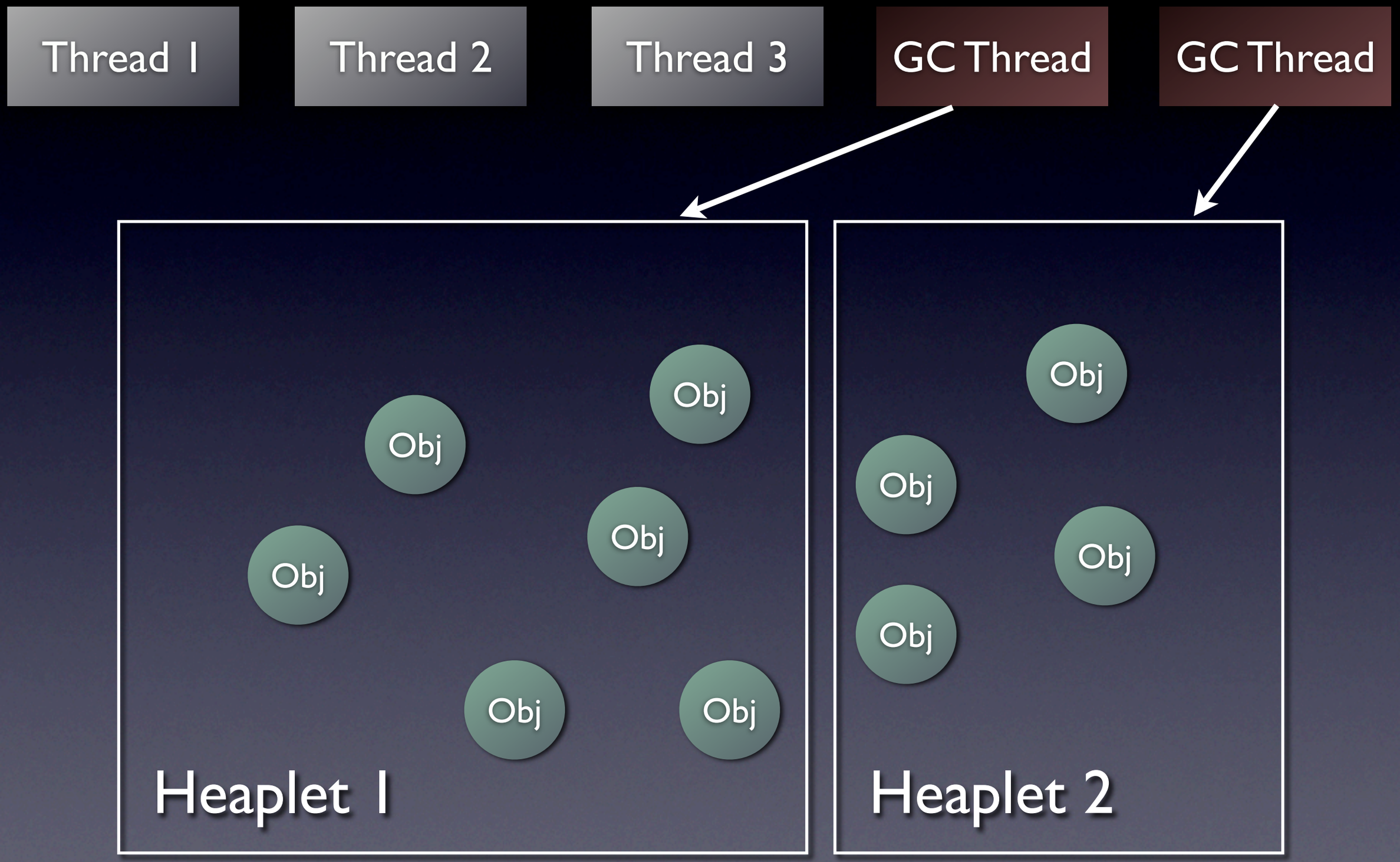

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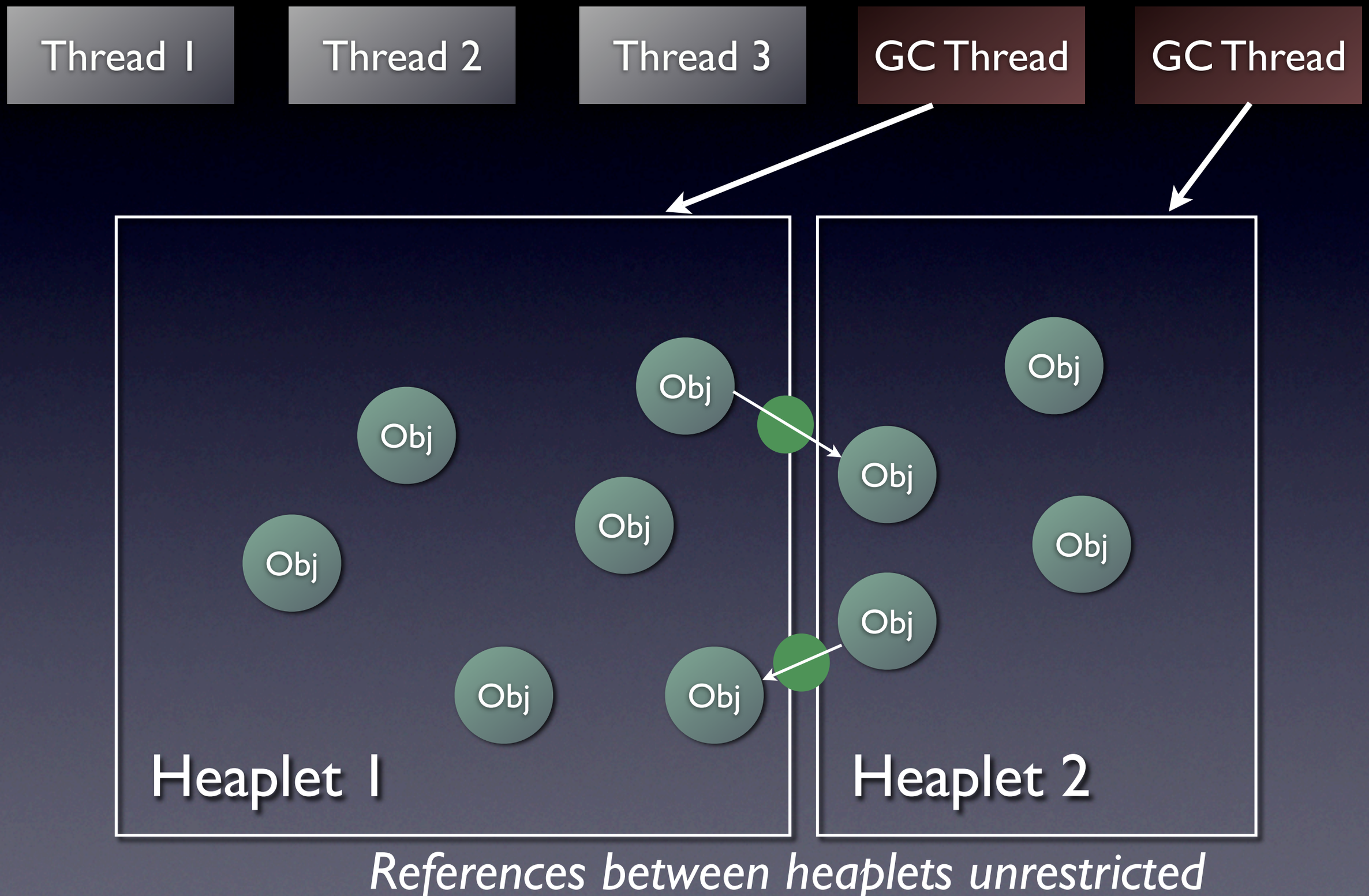
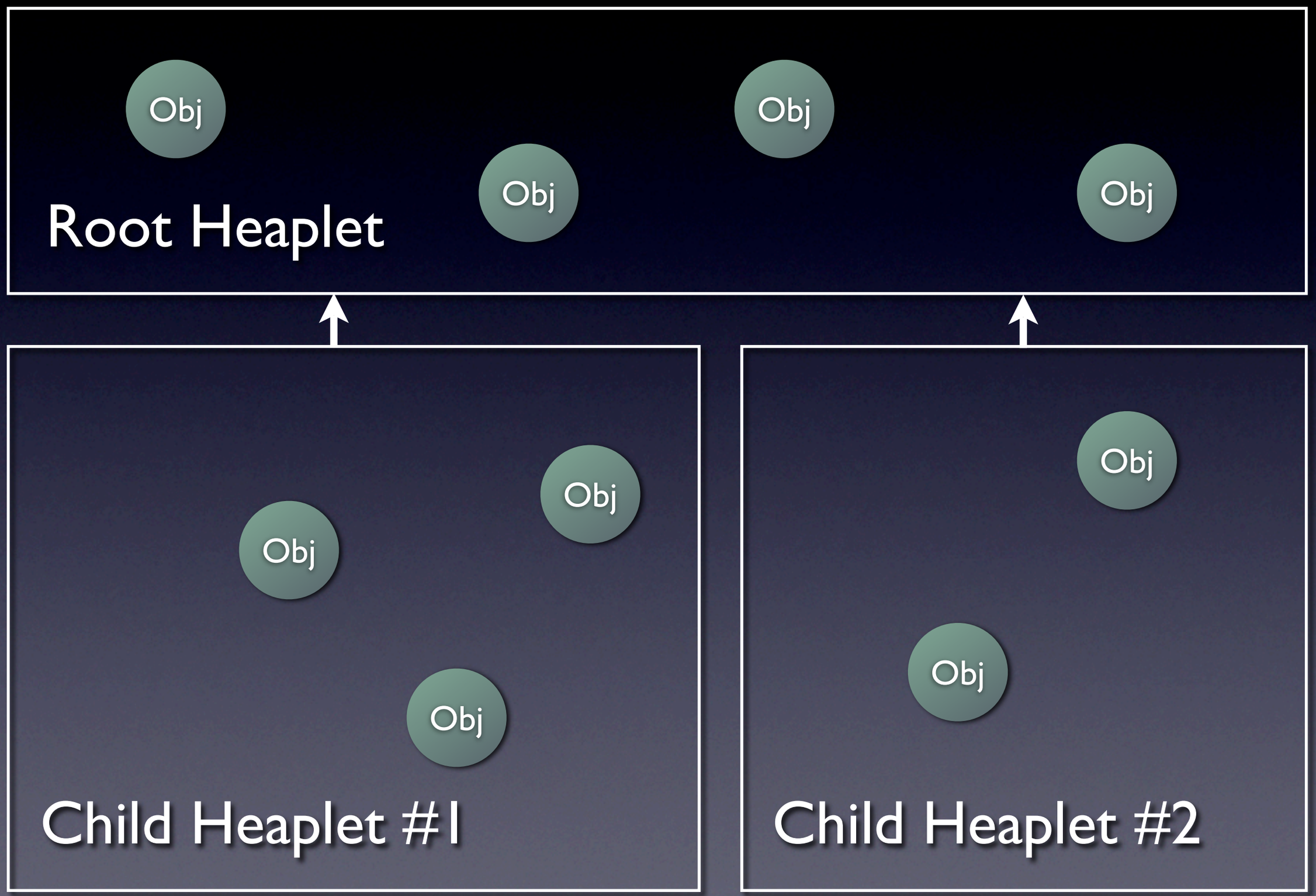


References between heaplets unrestricted

Heaplet Hierarchy

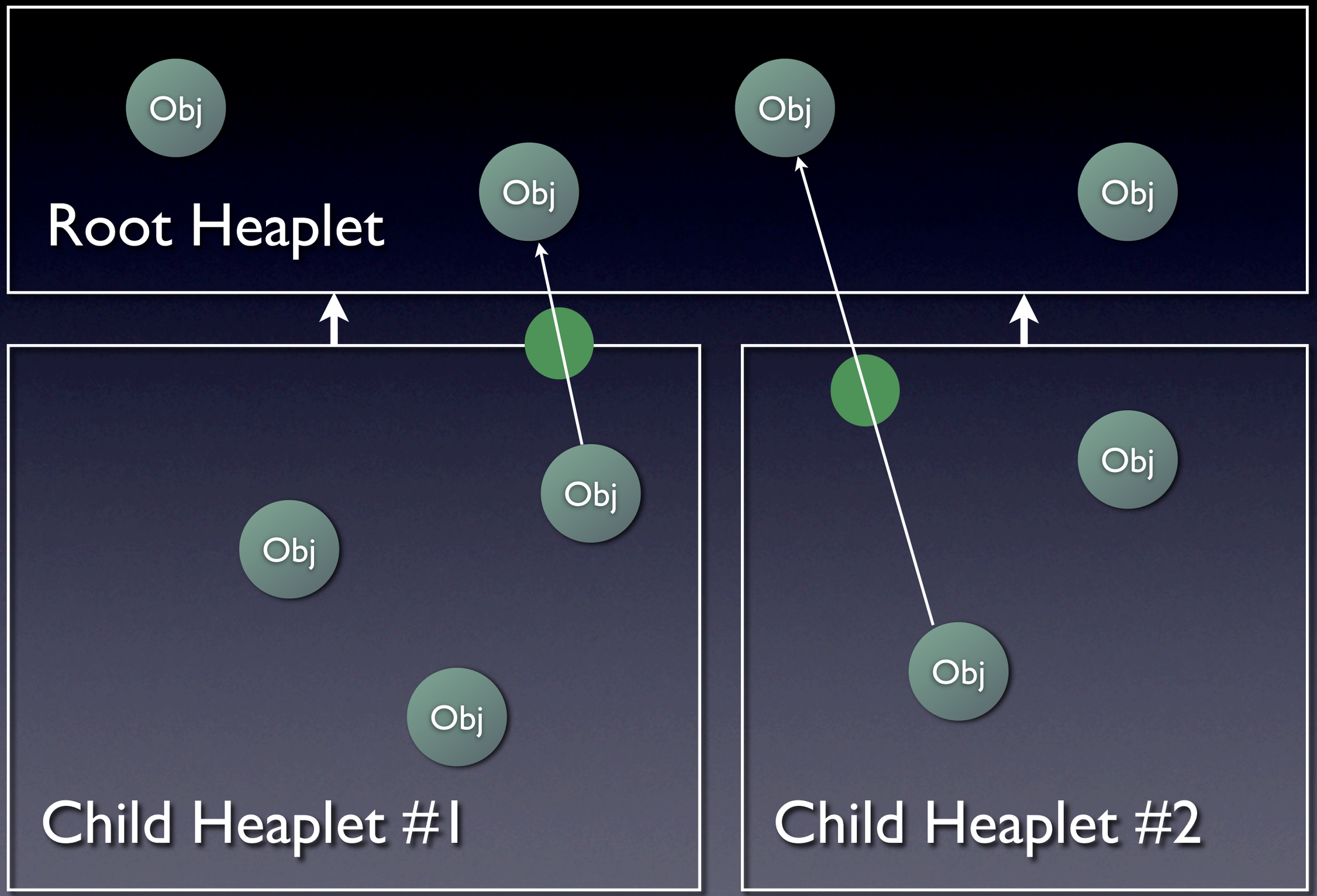
- We introduce a heaplet hierarchy to increase the performance of cross-heaplet references.
- A heaplet collector always scans child heaplets for references - thus, establishing new "up-hierarchy" references does not require barriers.
- Others cross-heaplet references are handled using a barrier and global cross-reference list ("cross-set").
  - Thus - establishing a cross-reference incurs a cost in both space and time.

Heaplet Hierarchy



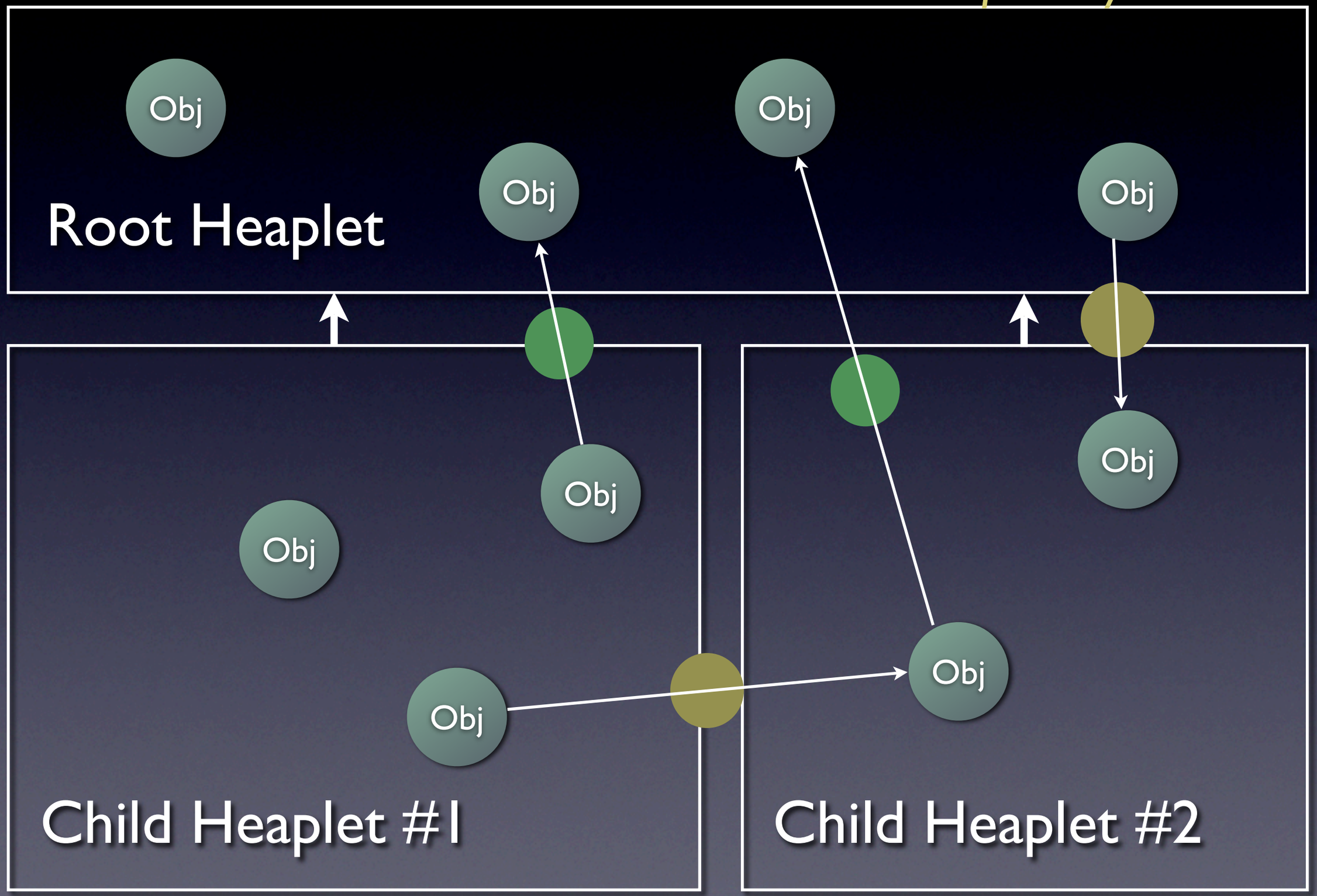
Heaplet Hierarchy

"up-references" are guaranteed fast



Heaplet Hierarchy

"up-references" are guaranteed fast
"cross-references" are allowed, but come with a penalty



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- Each heaplet gets its own collector, user-tuned for the allocation and footprint behavior of the heaplet.
- *Introducting heaplets into a correct program does not make it incorrect.*

The HRTGC Algorithm

- Each heaplet gets a Metronome-style mark-sweep collector.
- Each collector is scheduled like the Metronome - but with control of schedules extended to include phasing.
- Cycles of cross-heaplet references are handled using a global cycle collector. Because garbage cycles are rare, the cycle collector runs at a very low rate - in fact it runs at a *zero rate* in our benchmarks.

Implementation
and
Evaluation

- We use the OpenVM RTJVM and J2c ahead-of-time compiler on the Linux operating system.
  - HRTGC is implemented as a memory management configuration in the OVM.
- OVM already implements a Metronome-like RTGC, which we use as a baseline.

- Two real-time Java benchmarks were used for comparing regular RTGC and HRTGC:
  - RTZen, a 202 KLoC CORBA implementation from UC Irvine, and
  - CD, a 41 KLoC benchmark developed at Purdue.
- Both benchmarks were originally written to use RTSJ scoped memory. We have previously converted both to use our Metronome-like RTGC.
- For this evaluation, we again converted the benchmarks, this time to use heaplets.

Conversion to use HRTGC

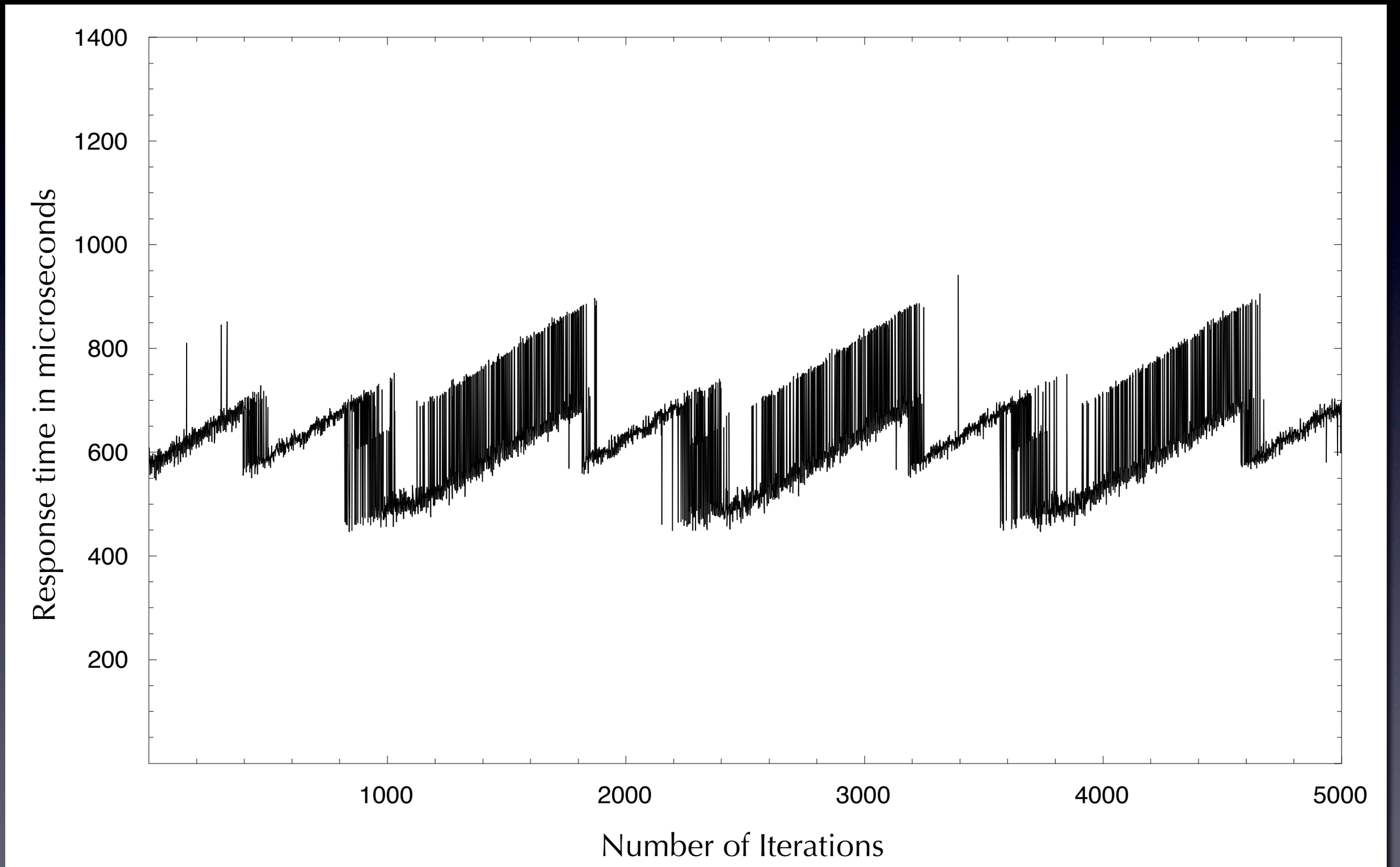
- Converting CD:
  - The CD use a producer-consumer pattern. We placed the producer and consumer in separate heaplets.
- Converting RTZen:
  - We place the core of Zen into its own heaplet.
  - The only changes were instrumentation in the main() method to create the ORB in our new heaplet.
  - *Thus, the Zen benchmark demonstrates not only the performance benefits of HRTGC, but the ease with which code can be refactored to use it effectively.*
- *Both benchmarks use 227_mtrt from SPECjvm98 as a noise maker.*

Measurements

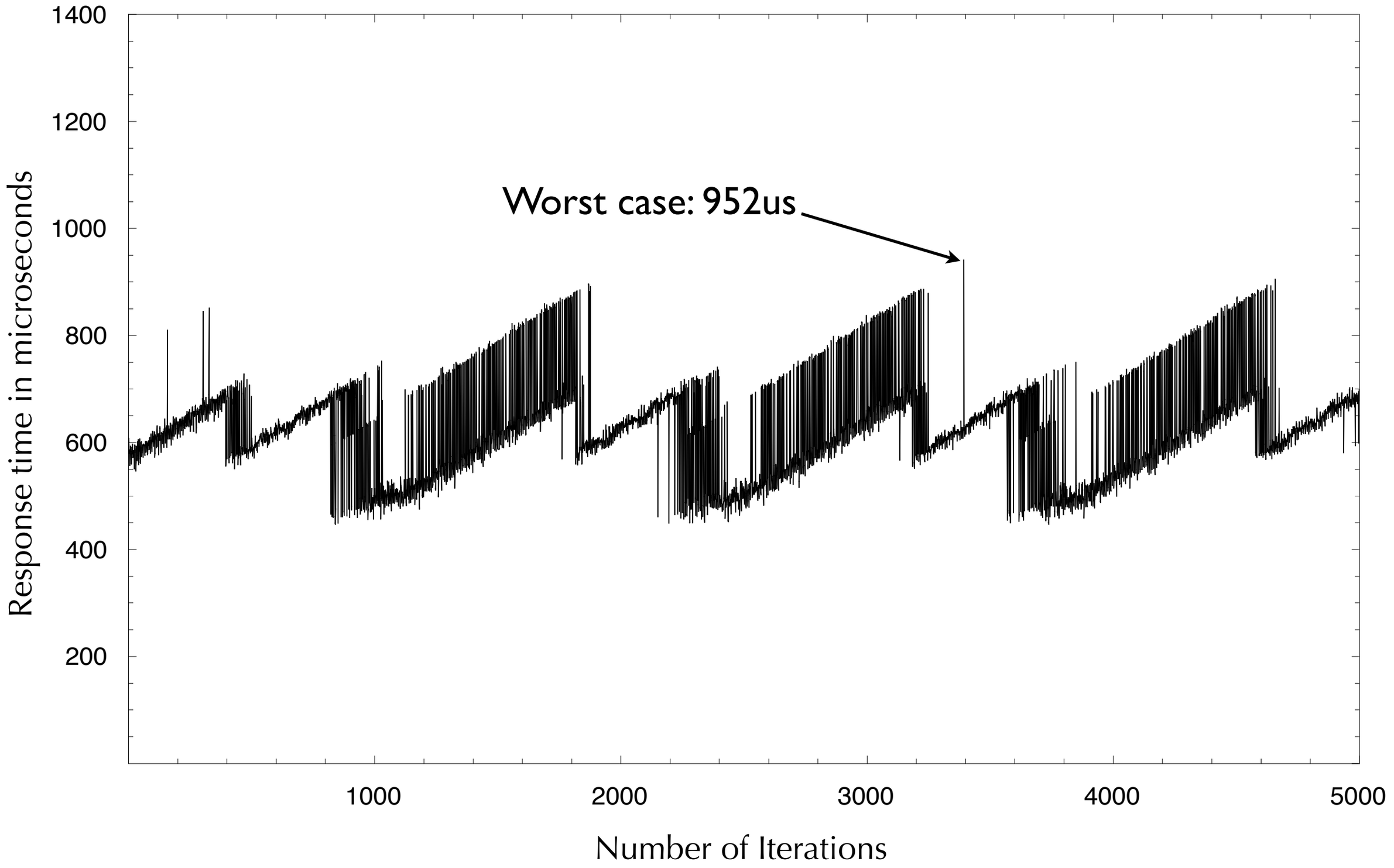
- We use a fixed total footprint for all configurations.
- The collector schedules are optimized for highest utilization while not allowing the memory usage to diverge.
- Both CD and RTZen are event-driven - thus, we record the total time required to handle each event - a quantity we call the *response time*.
- Additionally, we measure the *minimum mutator utilization* (MMU).

RTZen Response Time

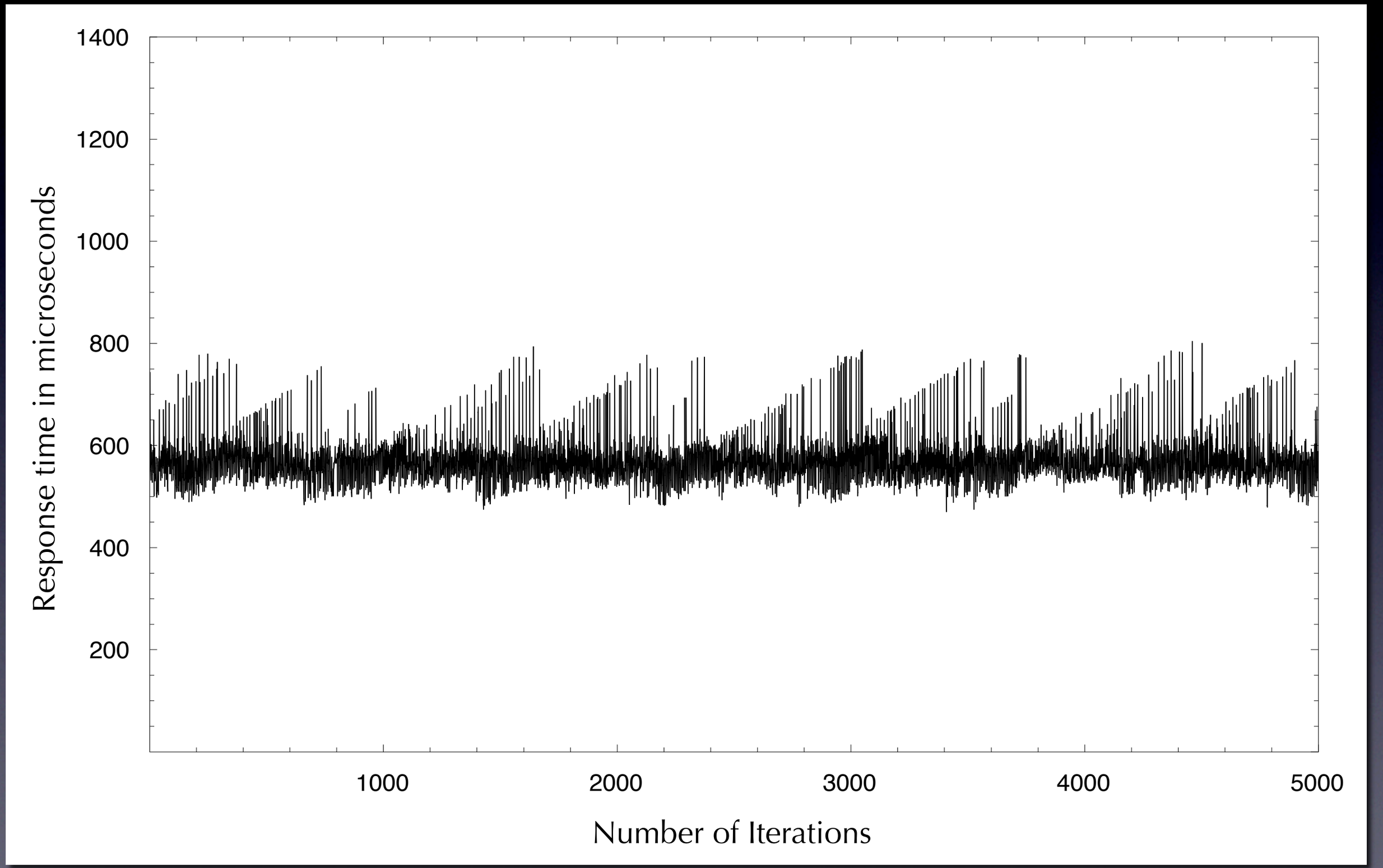
RTZen with RTGC



RTZen with RTGC



RTZen with HRTGC



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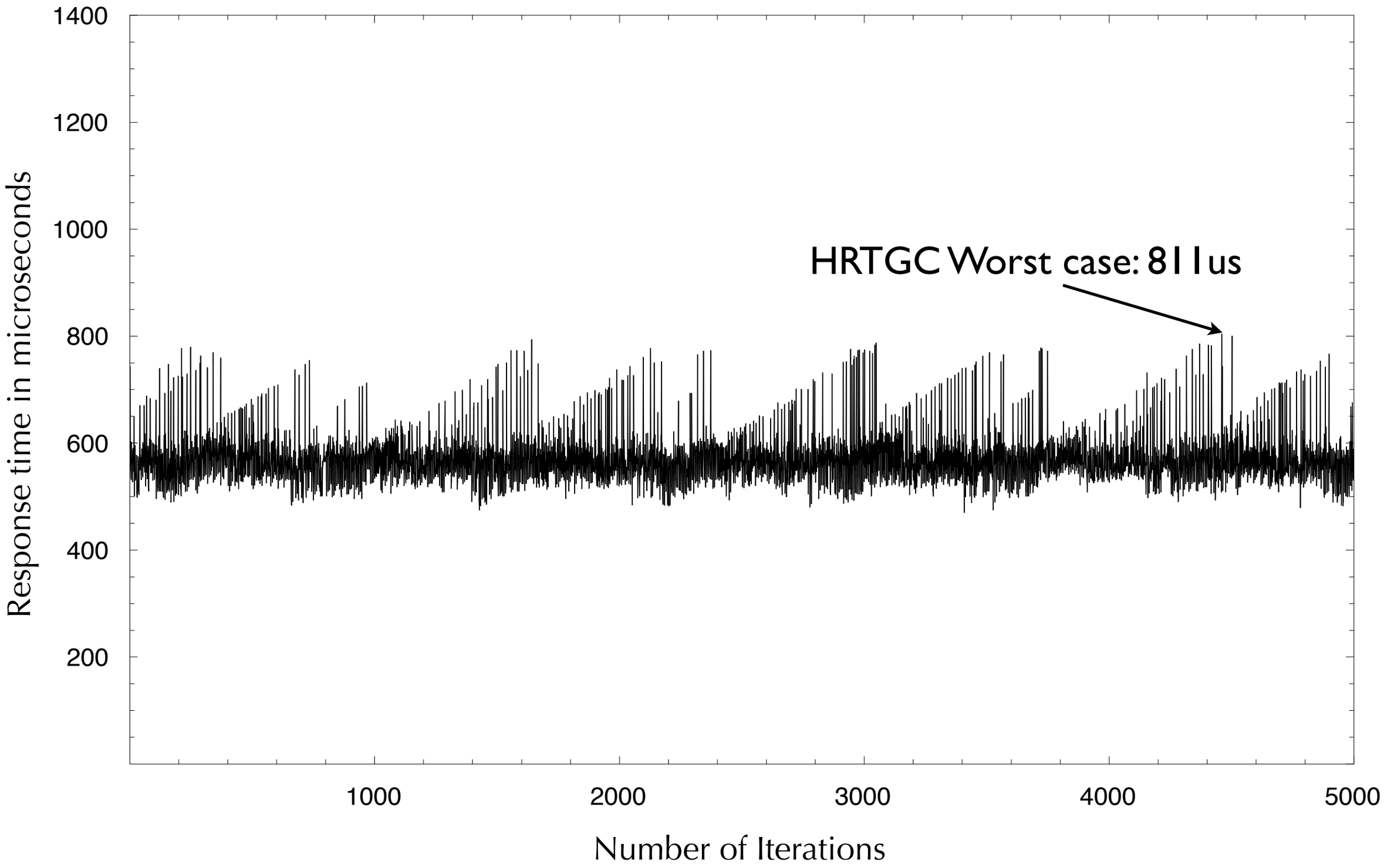

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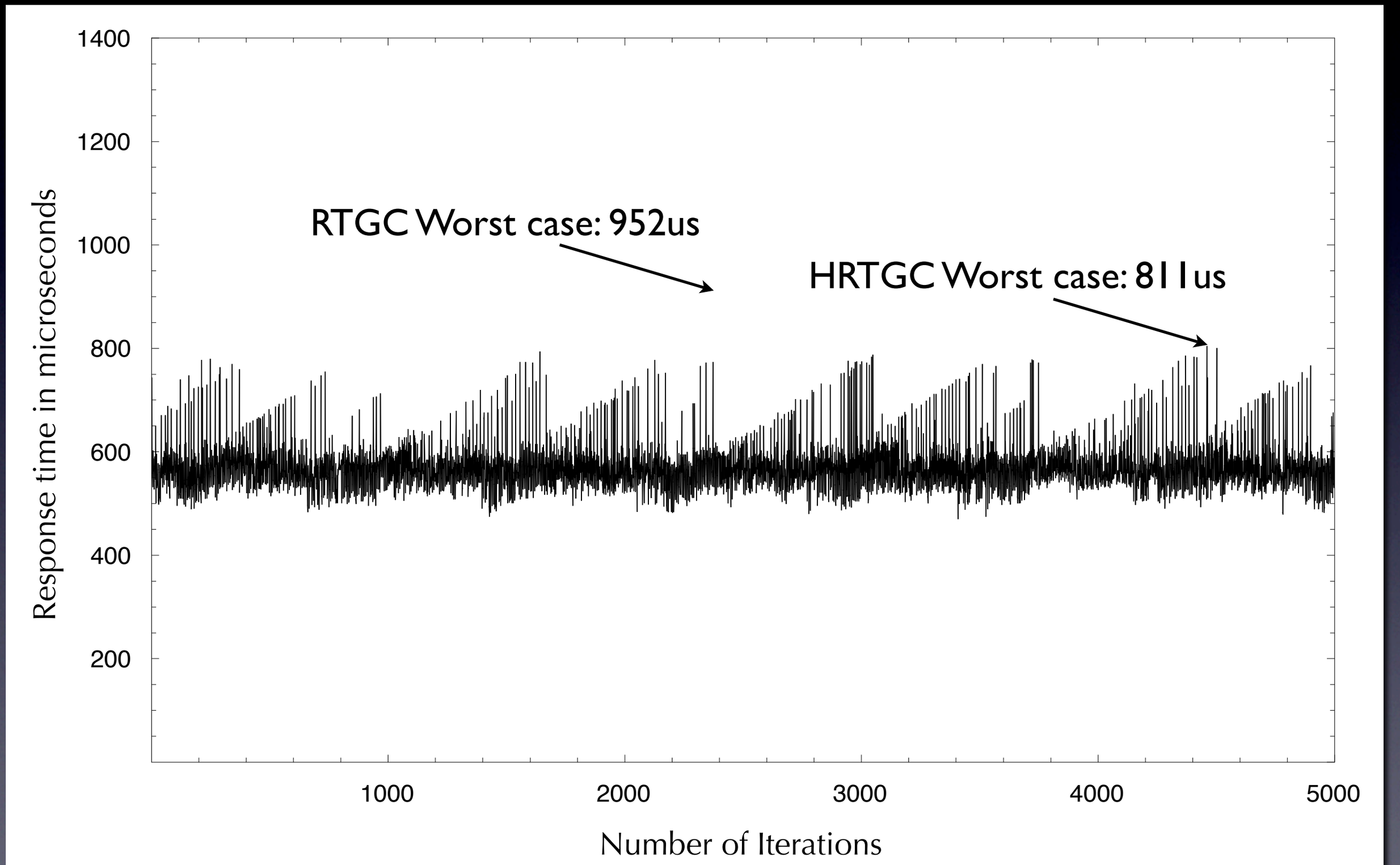

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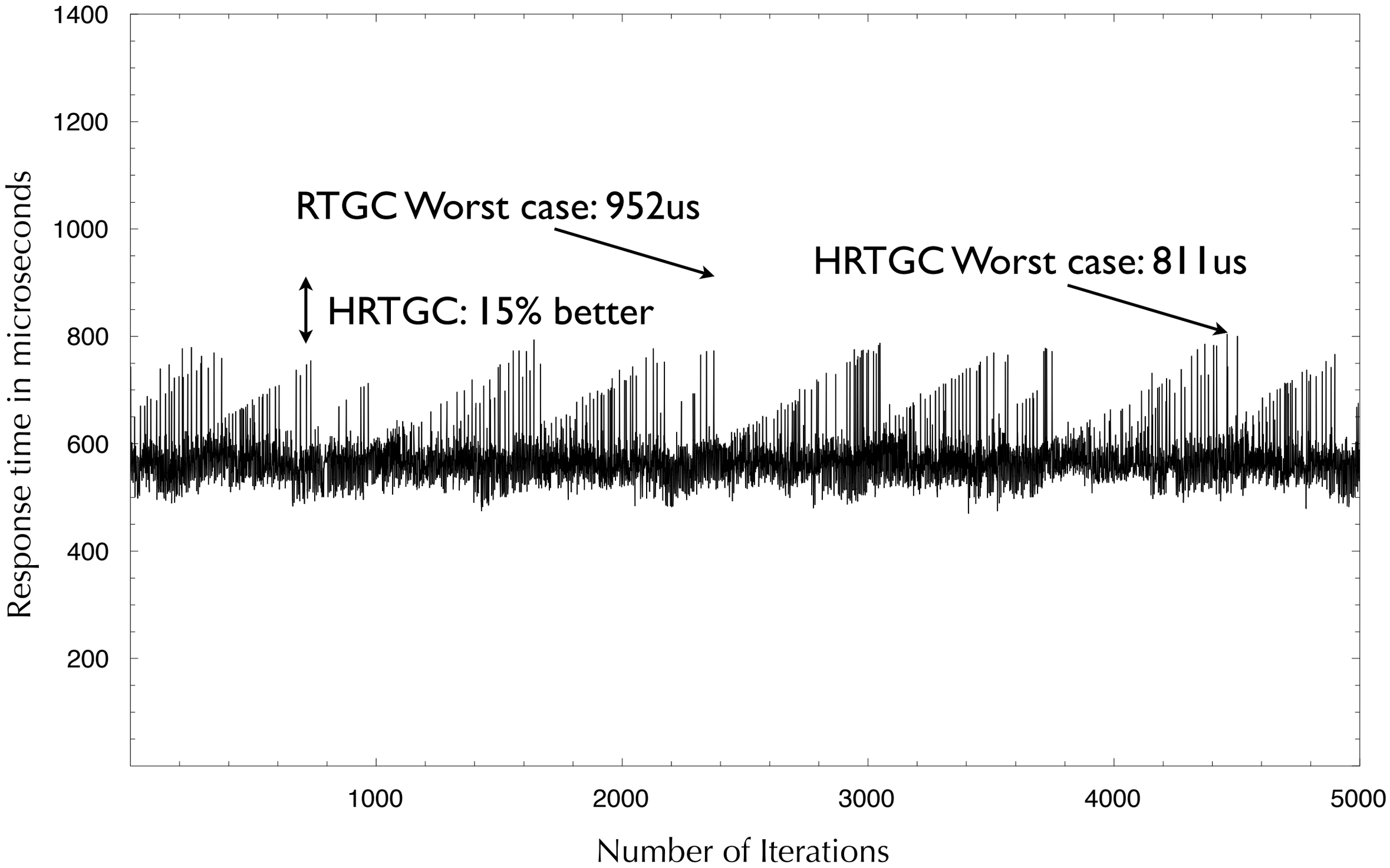
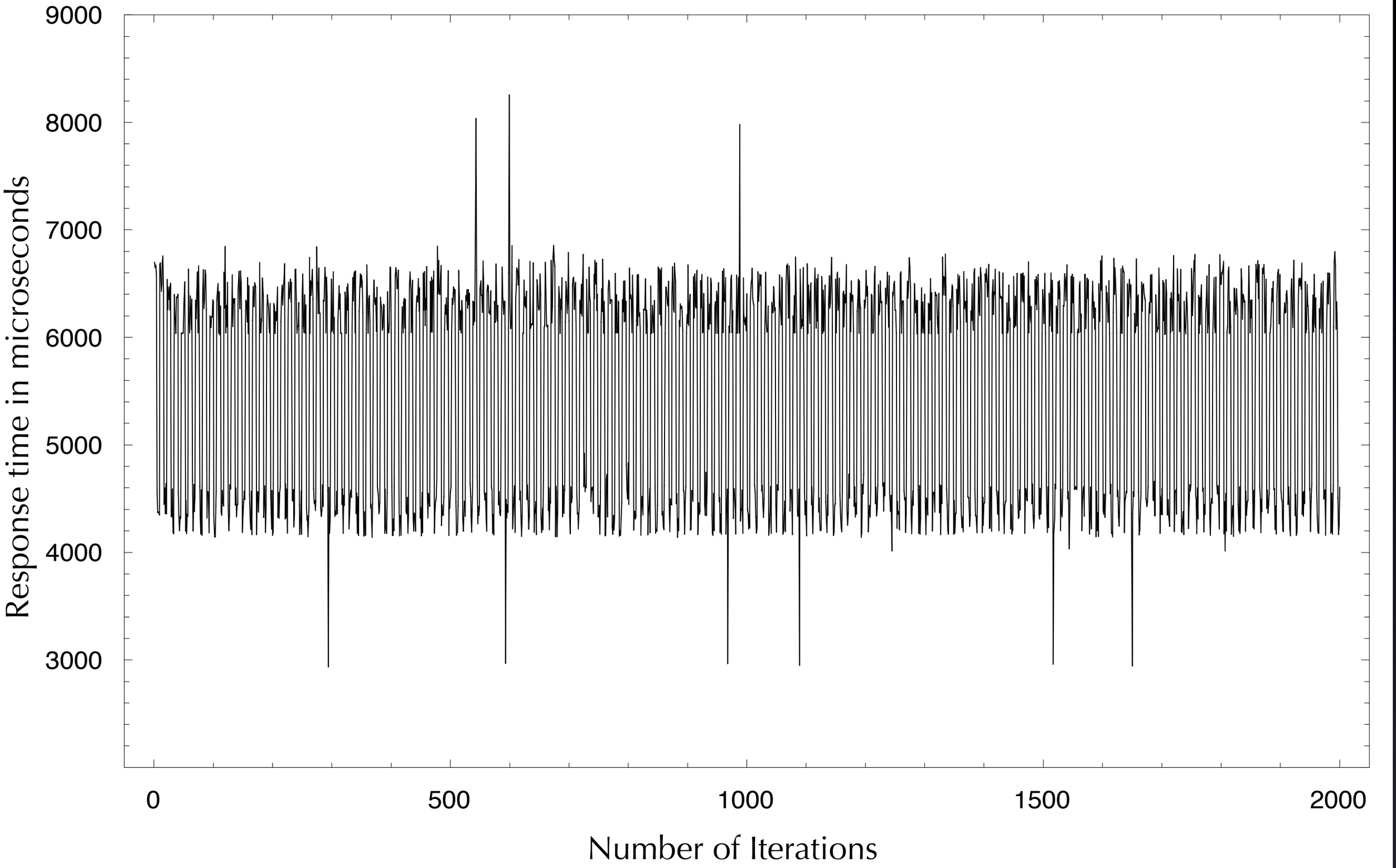
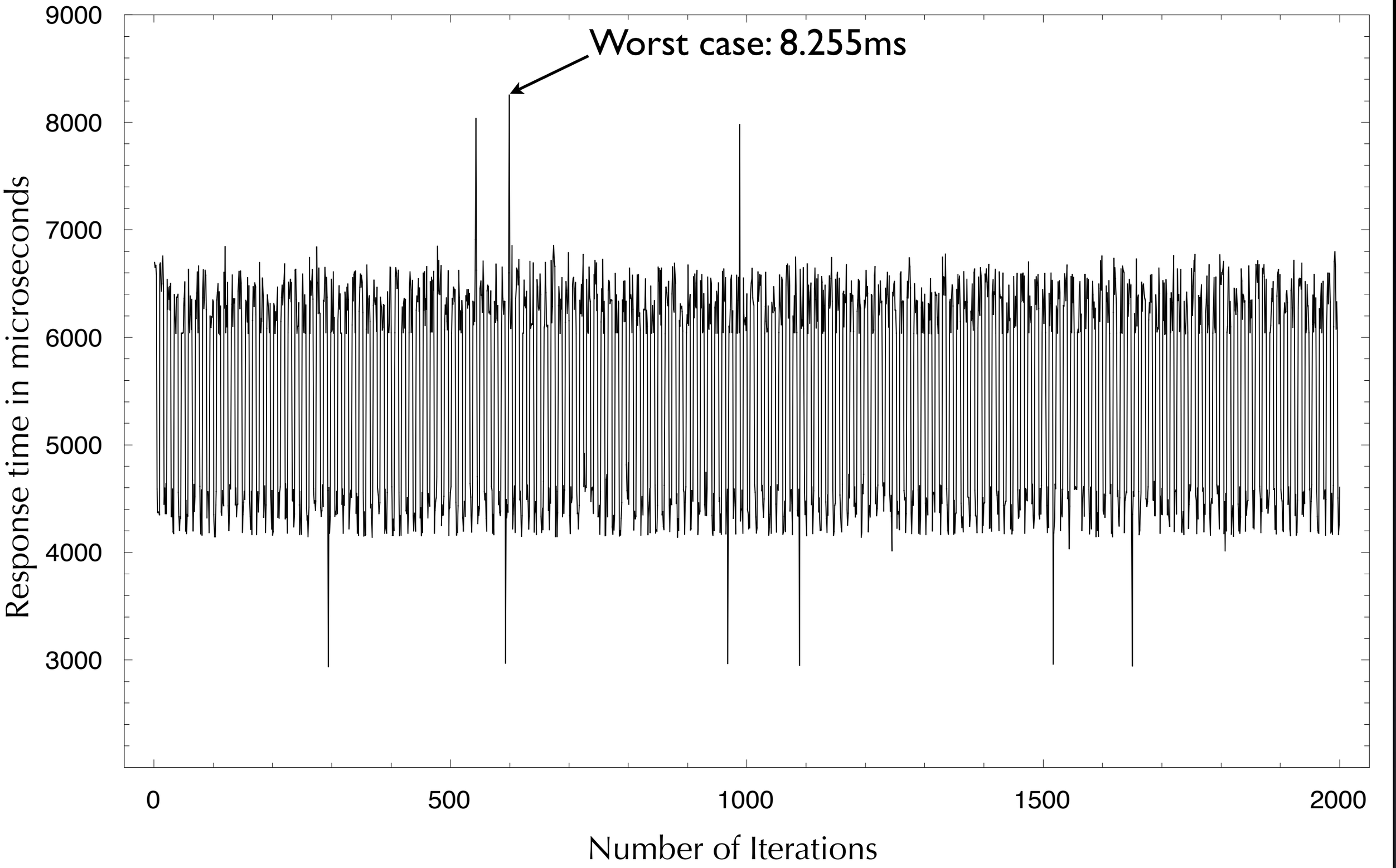


CD Response Time

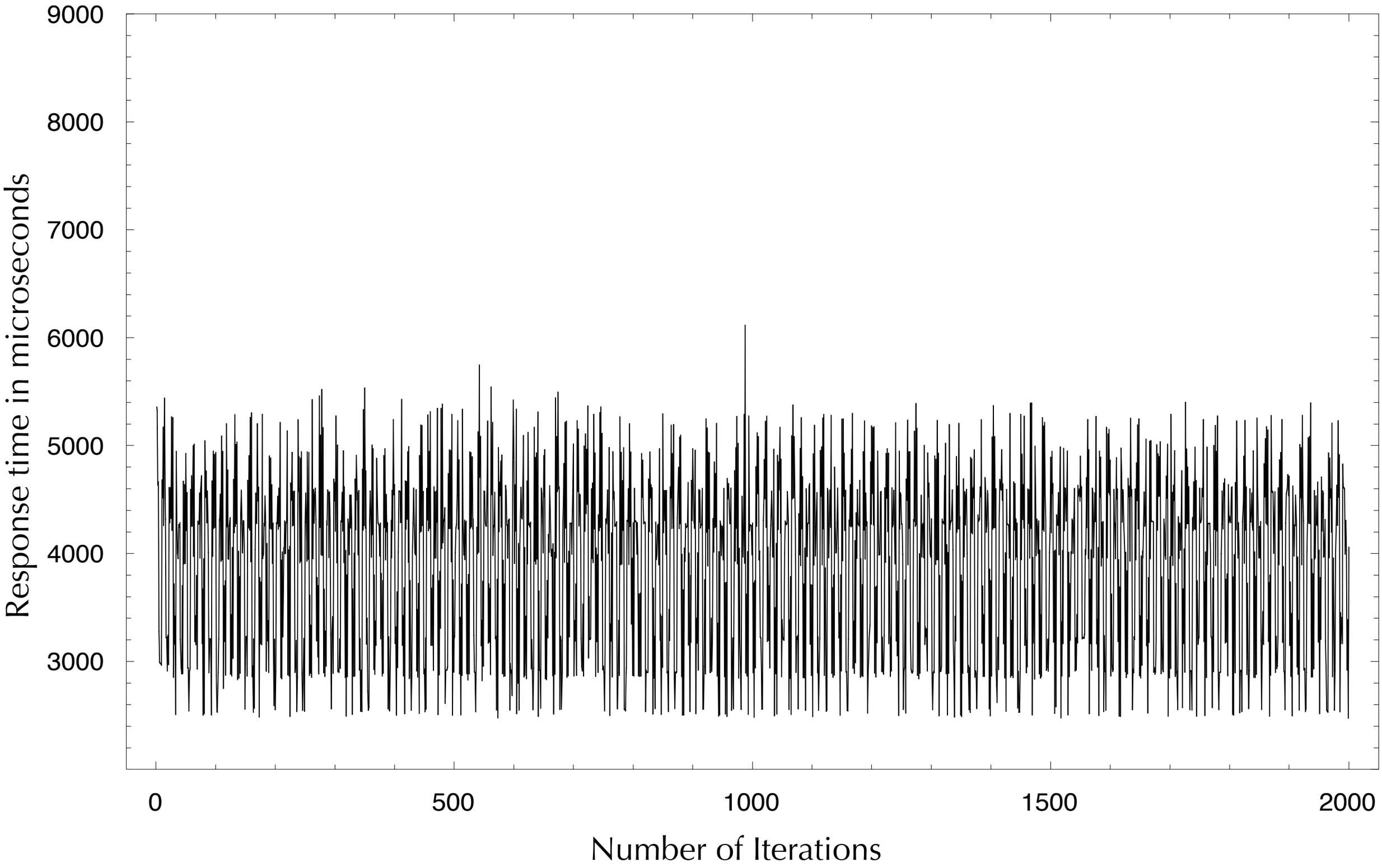
CD with RTGC


9000
8000
7000
6000
5000
4000
3000
Response time in microseconds
0
500
1000
1500
2000
Number of Iterations

CD with RTGC


Worst case: 8.255ms
9000
8000
7000
6000
5000
4000
3000
Response time in microseconds
0
500
1000
1500
2000
Number of Iterations

CD with HRTGC



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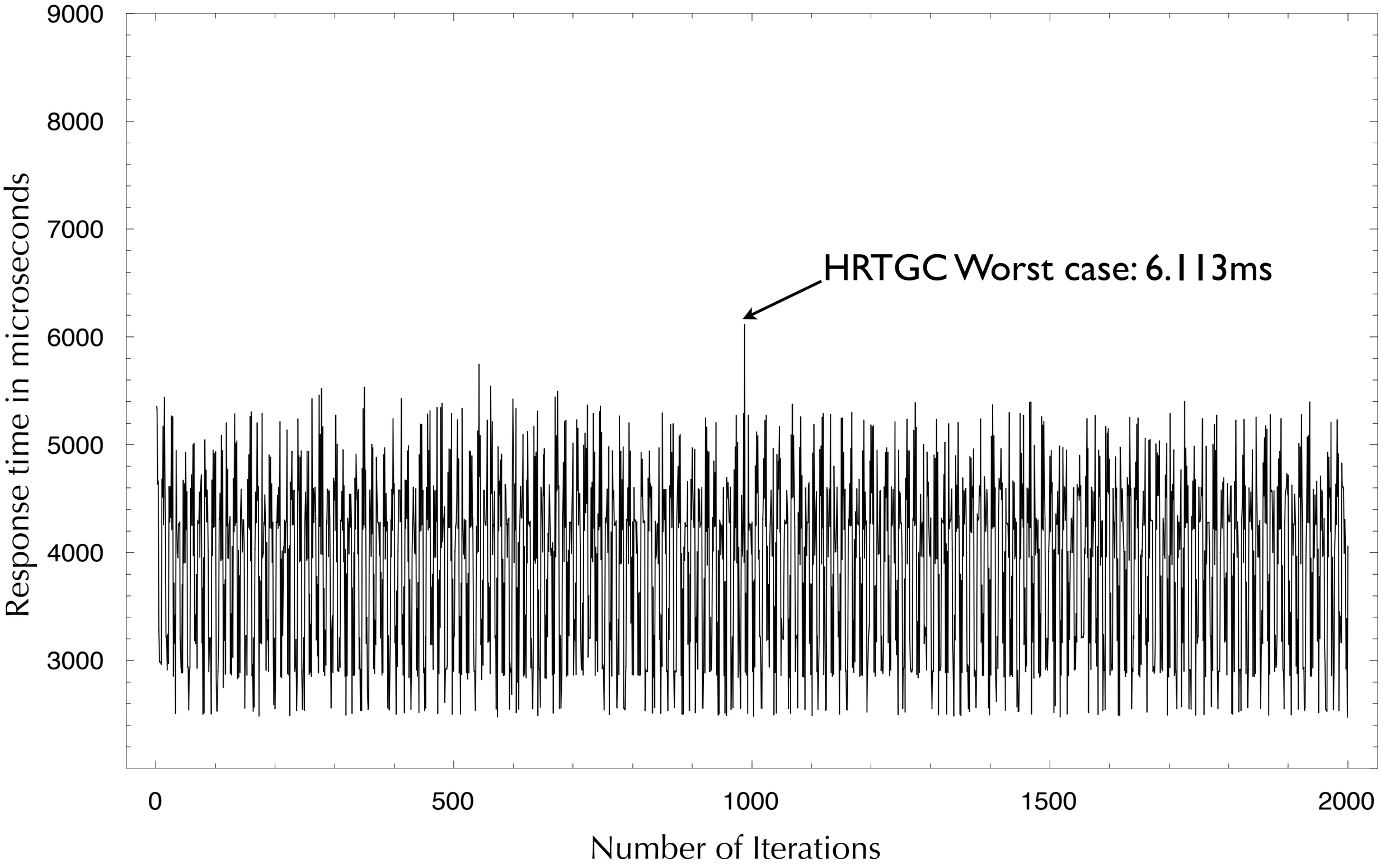

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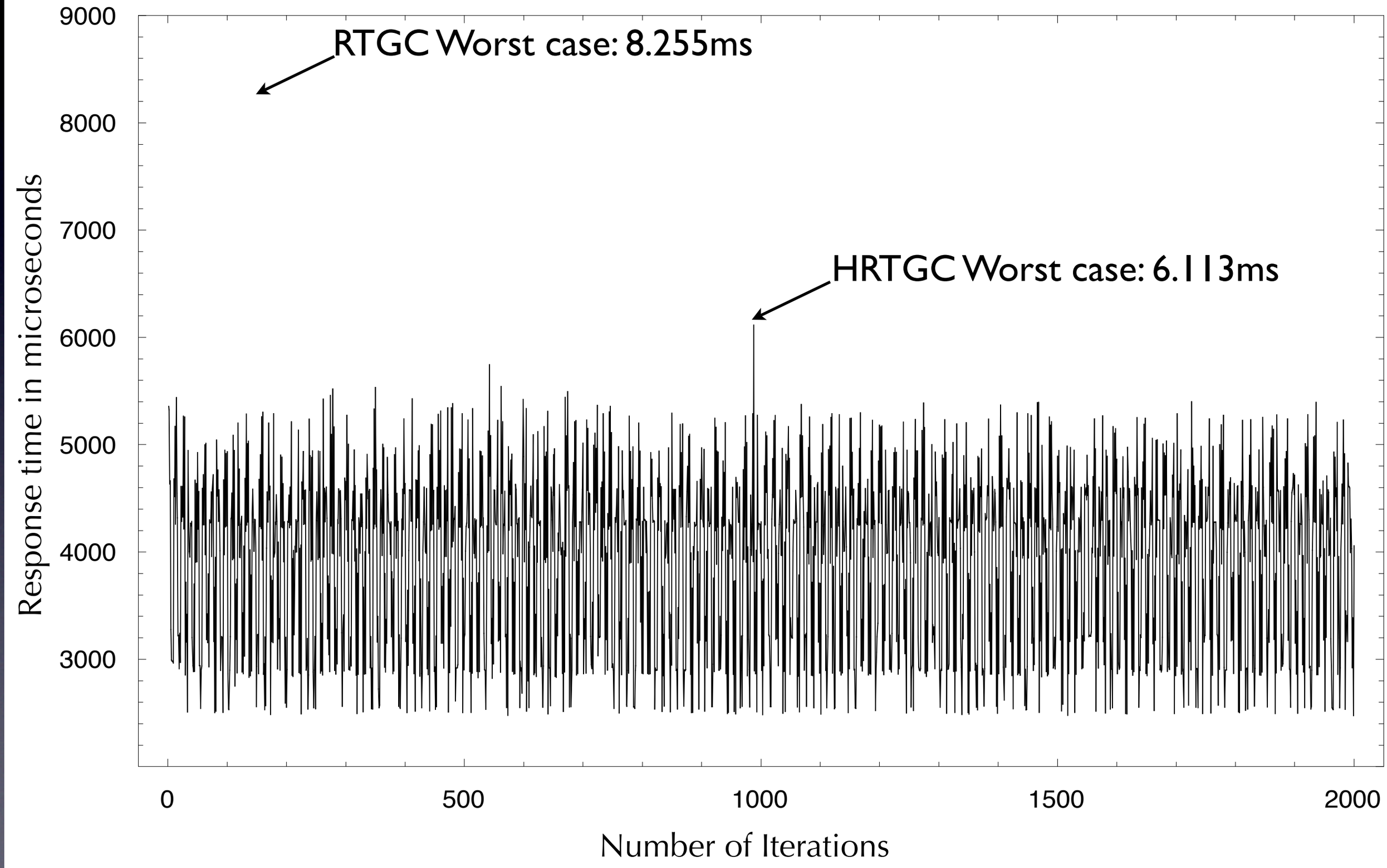

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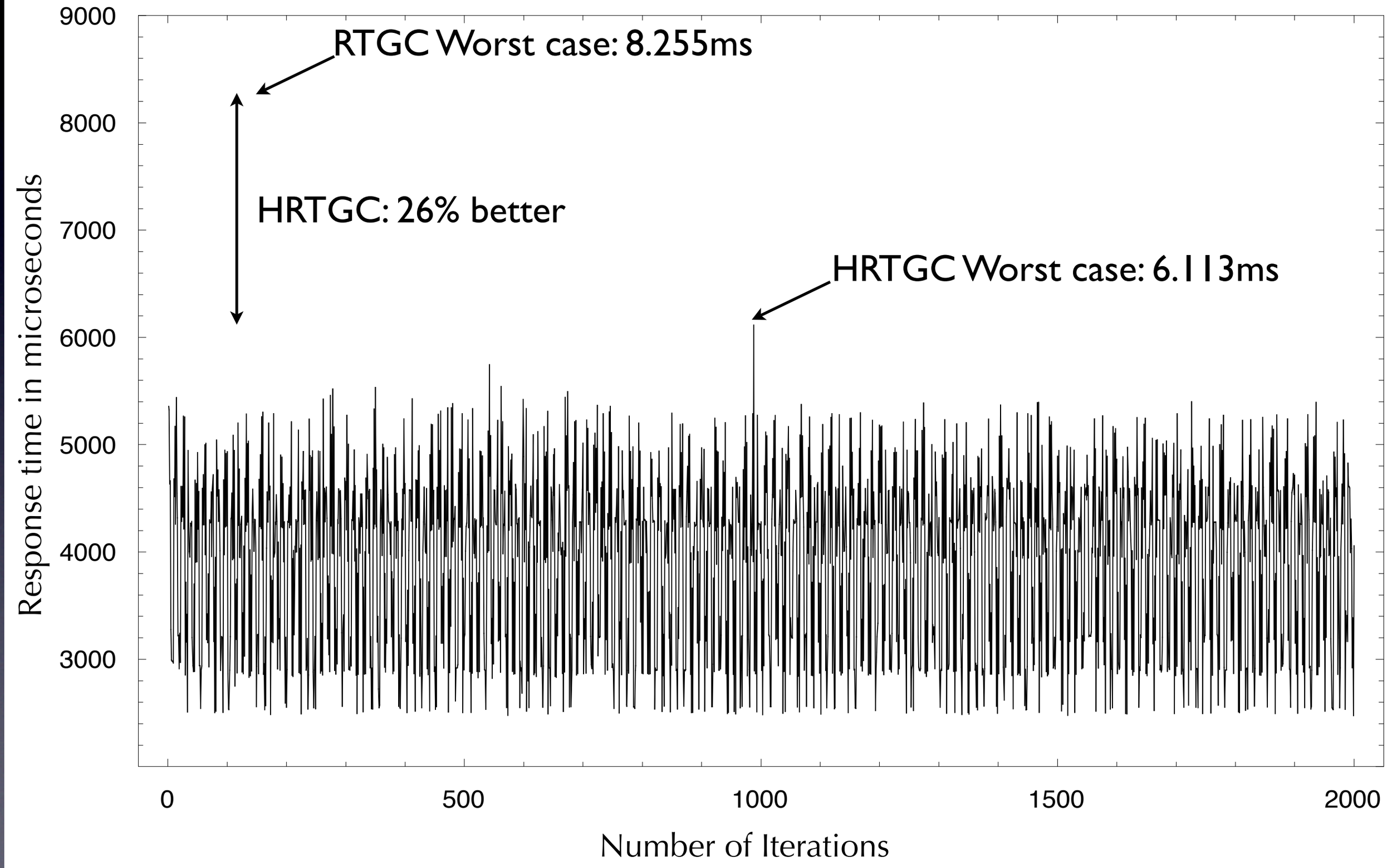


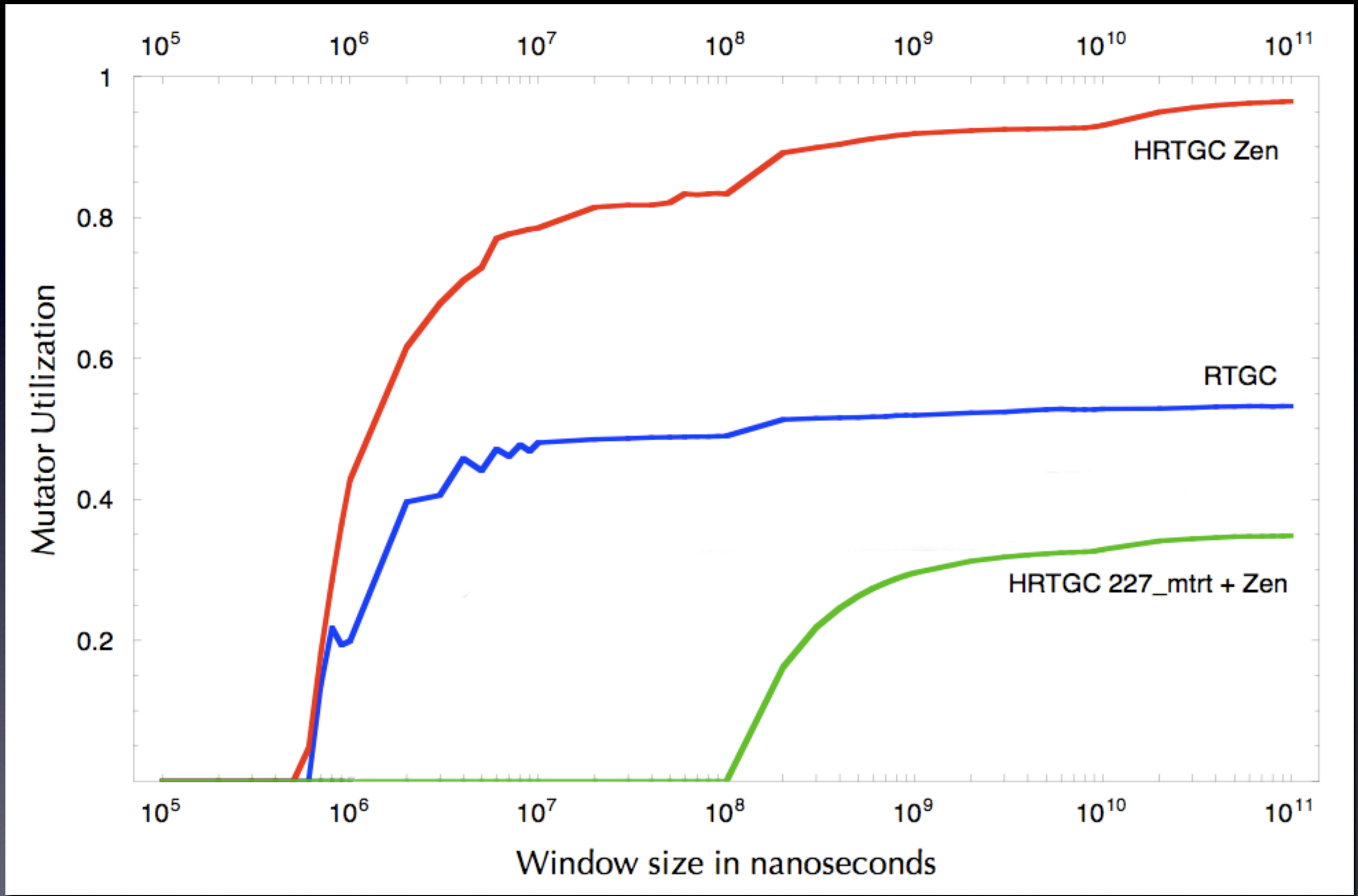
MMU

- *Minimum mutator utilization (MMU) shows the worst-case amount of time the mutator would get for a timeslice of a given length.*

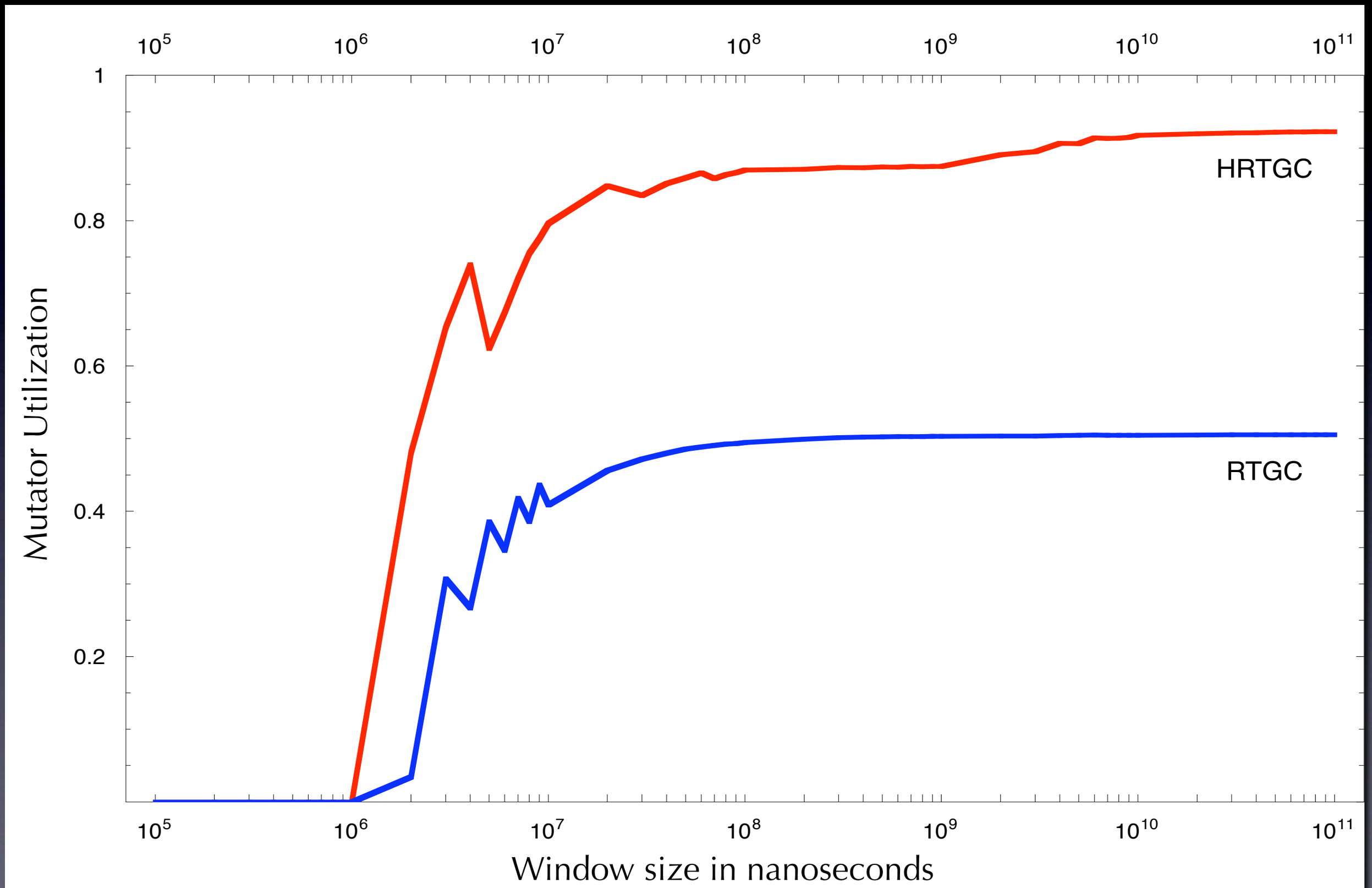
- Thus - MMU shows utilization (a number from 0 to 1, where 1 is better) versus timeslice size (in this case, in nanoseconds).

- We display MMU that has been empirically measured for our two benchmarks (RTZen and CD).

RTZen MMU


10^5
10^6
10^7
10^8
10^9
10^{10}
10^{11}
1
0.8
0.6
0.4
0.2
Mutator Utilization
HRTGC Zen
RTGC
HRTGC 227_mtrt + Zen
Window size in nanoseconds

CD MMU


10^5
10^6
10^7
10^8
10^9
10^{10}
10^{11}
1
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0.4
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Mutator Utilization
HRTGC
RTGC
Window size in nanoseconds

A more in-depth discussion of the algorithm, and the results, is found in the paper.

Questions/Comments