Are Your V8 GC Logs Speaking to You?

About Me

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- *Joyee*
- Intern @ alinode ∈ AliCloud ∈ Alibaba Group

Background

- We provide **performance management services** to teams both inside and outside the group
- Alibaba is one of the largest companies in China that uses Node.js in production
  - Mostly driven by frontend devs

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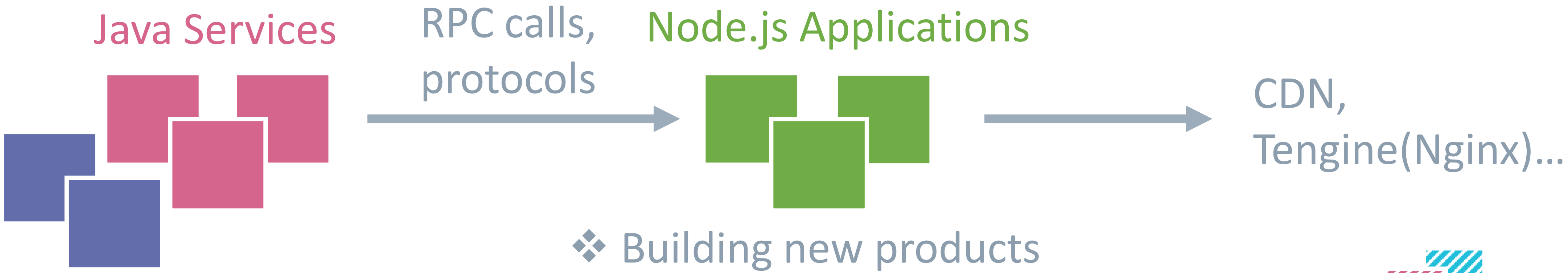


Java Services

RPC calls, protocols

Node.js Applications

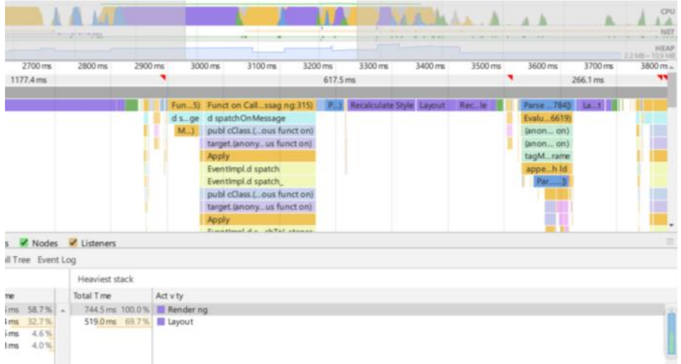
CDN, Tengine(Nginx)...

Distributed Systems (C++, Erlang, Java....)

- Building new products
- Refactoring old products(PHP/Java Web)
- Rapid iteration, better communication

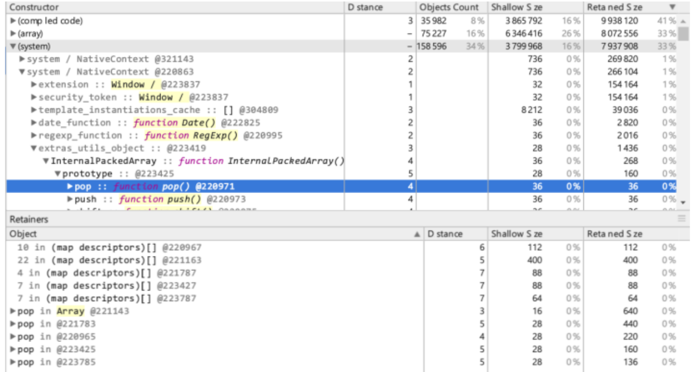
Background

- Java architects argue that Node.js is *not mature enough*
  - Lack of tooling for **monitoring and profiling**
- Java programmers *know* their VM and their GC. As for JS programmers, well…
  - Most come from a frontend dev background



CPU profile

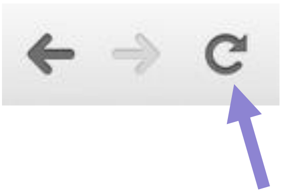
The pursuit of 60fps



```
Constructor                                     D stance  Objects Count   Shallow S ze       Reta ned S ze
▶(comp led code)                                     3    35 982    8 %   3 865 792   16 %   9 938 120   41 %
▶(array)                                             –    75 227   16 %   6 346 416   26 %   8 072 556   33 %
▼(system)                                            –   158 596   34 %   3 799 968   16 %   7 937 908   33 %
  ▶system / NativeContext @321143                    2                          736    0 %     269 820    1 %
  ▼system / NativeContext @220863                    2                          736    0 %     266 104    1 %
    ▶extension :: Window / @223837                   1                           32    0 %     154 164    1 %
    ▶security_token :: Window / @223837              1                           32    0 %     154 164    1 %
    ▶template_instantiations_cache :: [] @304809     3                        8 212    0 %      39 036    0 %
    ▶date_function :: function Date() @222825       2                           36    0 %       2 820    0 %
    ▶regexp_function :: function RegExp() @220995    2                           36    0 %       2 016    0 %
    ▼extras_utils_object :: @223419                  3                           28    0 %       1 436    0 %
      ▼InternalPackedArray :: function InternalPackedArray()  4                  36    0 %         268    0 %
        ▼prototype :: @223425                        5                           28    0 %         160    0 %
          ▶pop :: function pop() @220971             4                           36    0 %          36    0 %
          ▶push :: function push() @220973           4                           36    0 %          36    0 %
Retainers
Object                                        D stance   Shallow S ze       Reta ned S ze
  10 in (map descriptors)[] @220967                  6         112    0 %         112    0 %
  22 in (map descriptors)[] @221163                  5         400    0 %         400    0 %
  4 in (map descriptors)[] @221787                   7          88    0 %          88    0 %
  7 in (map descriptors)[] @223427                   7          88    0 %          88    0 %
  7 in (map descriptors)[] @223787                   7          64    0 %          64    0 %
▶pop in Array @221143                                3          16    0 %         640    0 %
▶pop in @221783                                      5          28    0 %         440    0 %
▶pop in @220965                                      4          28    0 %         220    0 %
▶pop in @223425                                      5          28    0 %         160    0 %
▶pop in @223785                                      5          28    0 %         136    0 %
```

HeapSnapshopts / HeapTimelines

you don't want to blow up your users' RAM



Click this!

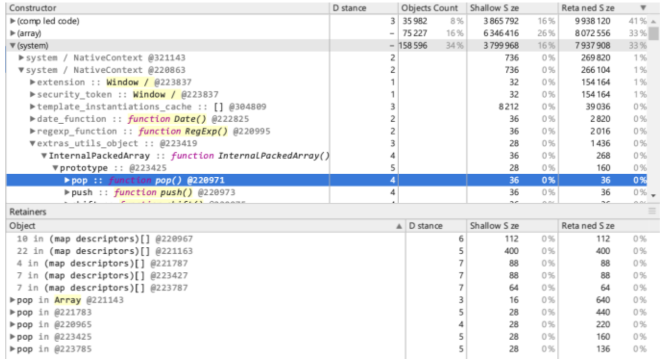
GC logs

Servers are long-running, clients are not

- V8 garbage collection logs are the least documented tools, not even available in devtools

What are V8 Garbage Collection logs good for?

- Combined with heap profiles, they can help you catch the culprit for memory leaks



```
Constructor                                          Distance  Objects Count      Shallow Size       Retained Size
▶(compiled code)                                            3  35 982     8 %     3 865 792   16 %   9 938 120   41 %
▶(array)                                                    –  75 227    16 %     6 346 416   26 %   8 072 556   33 %
▼(system)                                                   –  158 596   34 %     3 799 968   16 %   7 937 908   33 %
  ▶system / NativeContext @321143                           2                           736    0 %     269 820    1 %
  ▼system / NativeContext @220863                           2                           736    0 %     266 104    1 %
    ▶extension :: Window / @223837                          1                            32    0 %     154 164    1 %
    ▶security_token :: Window / @223837                     1                            32    0 %     154 164    1 %
    ▶template_instantiations_cache :: [] @304809            3                         8 212    0 %      39 036    0 %
    ▶date_function :: function Date() @222825               2                            36    0 %       2 820    0 %
    ▶regexp_function :: function RegExp() @220995           2                            36    0 %       2 016    0 %
    ▼extras_utils_object :: @223419                         3                            28    0 %       1 436    0 %
      ▼InternalPackedArray :: function InternalPackedArray() 4                           36    0 %         268    0 %
        ▼prototype :: @223425                               5                            28    0 %         160    0 %
          ▶pop :: function pop() @220971                    4                            36    0 %          36    0 %
          ▶push :: function push() @220973                  4                            36    0 %          36    0 %
Retainers
Object                                          ▲  Distance   Shallow Size       Retained Size
  10 in (map descriptors)[] @220967                       6          112    0 %        112    0 %
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  4 in (map descriptors)[] @221787                        7           88    0 %         88    0 %
  7 in (map descriptors)[] @223427                        7           88    0 %         88    0 %
  7 in (map descriptors)[] @223787                        7           64    0 %         64    0 %
▶pop in Array @221143                                     3           16    0 %        640    0 %
▶pop in @221783                                           5           28    0 %        440    0 %
▶pop in @220965                                           4           28    0 %        220    0 %
▶pop in @223425                                           5           28    0 %        160    0 %
▶pop in @223785                                           5           28    0 %        136    0 %
```
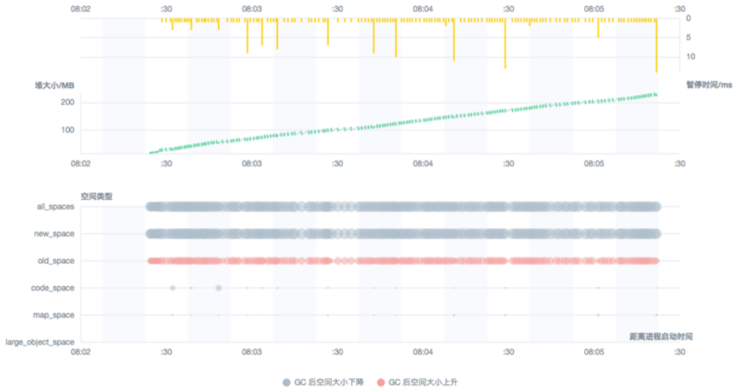

Heapdump can tell you what is leaking, but they are sometimes too specific



GC logs can give you a bigger picture about what's going on, so you know where to look

- Help you verify that your fixes do fix your leaks

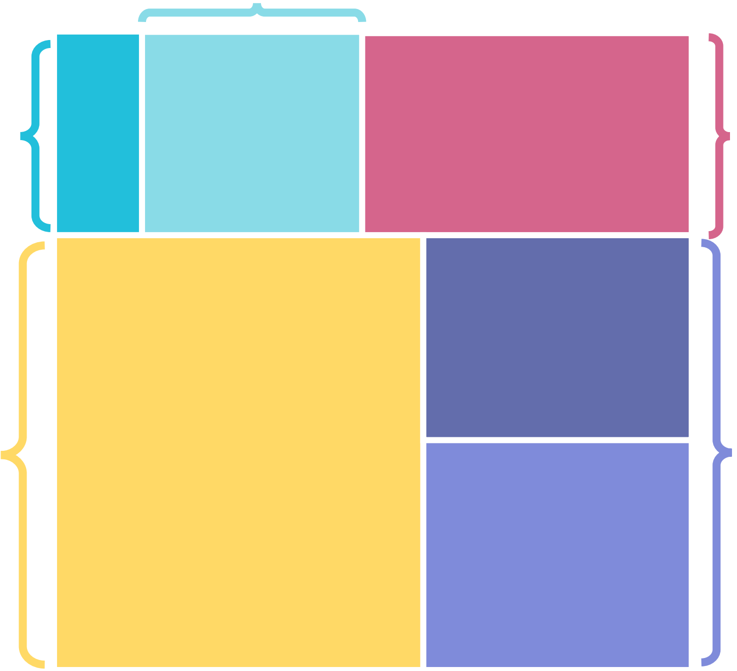
An introduction to V8 GC

- What is Garbage Collection(GC)?
  - Collect and free your objects(garbage) when you don’t need them anymore. That’s why you don’t need to manage the memory yourself in languages like JavaScript, Java, Ruby…
  - For ECMAScript/JavaScript, there are no specifications about it, everything is up to the implementation
- This talk is based on V8 4.5.103.35 (the one used by Node v4.x)
  - Node v6.x will use V8 5.x, which introduces a few improvements(mostly parallel stuff) and changes the GC log format a bit, but most of this talk still apply

An introduction to V8 GC

- Generational hypothesis
  - Most objects die young, others tend to live forever
- V8 GC Strategy
  - Generational: Young and Old
  - Accurate: Given a random word(always at least 4-byte aligned) in the memory, V8 can tell you if it’s a pointer or some data by looking at the last bit reserved as a tag
    - So V8 doesn’t have to scan the memory to be sure about this, which makes updating the pointers during GC fairly sufficient.
- GC is triggered by allocations(new or var most of the time) , when the memory allocated for a space is not enough
- In V8, Objects live on the heap, and the heap is divided into spaces

An introduction to V8 GC



Code Space

Executable code compiled by V8

Map Space

Metadata of hidden classes, pointed by objects

Large Object Space

Objects too large to fit into any other spaces.

Old Space

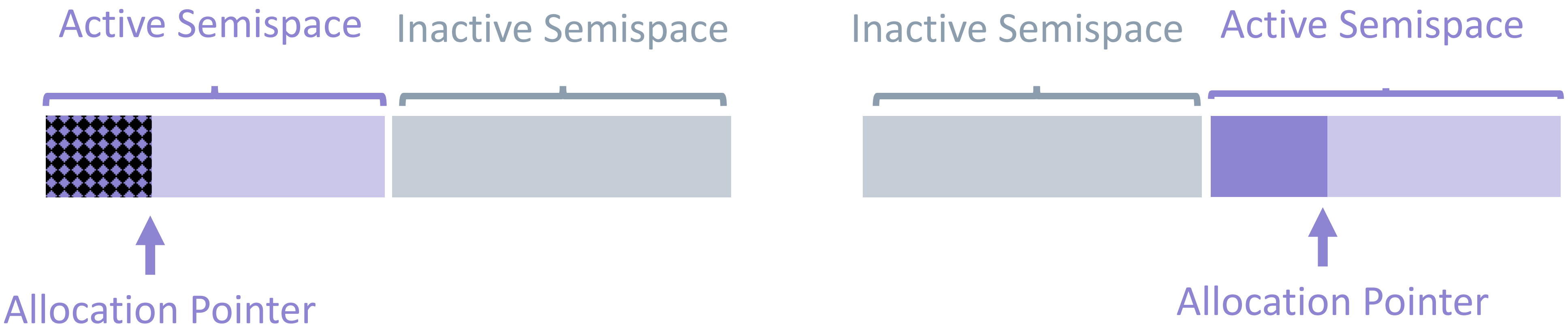
Objects survive more than two GCs in the new space

New Space

Divided in half, only one is active at a time. Most objects start and end their lives here.

An introduction to V8 GC

- New space: Scavenger
  - Implementation of Cheney's algorithm



- Old space
  - Mark-sweep/mark-compact
- *Oddly* similar to the early HotSpot JVM(designed by the same person)
- Further reading
  - http://alinode.aliyun.com/blog/14 (Chinese)
  - http://jayconrod.com/posts/55/a-tour-of-v8-garbage-collection (English)

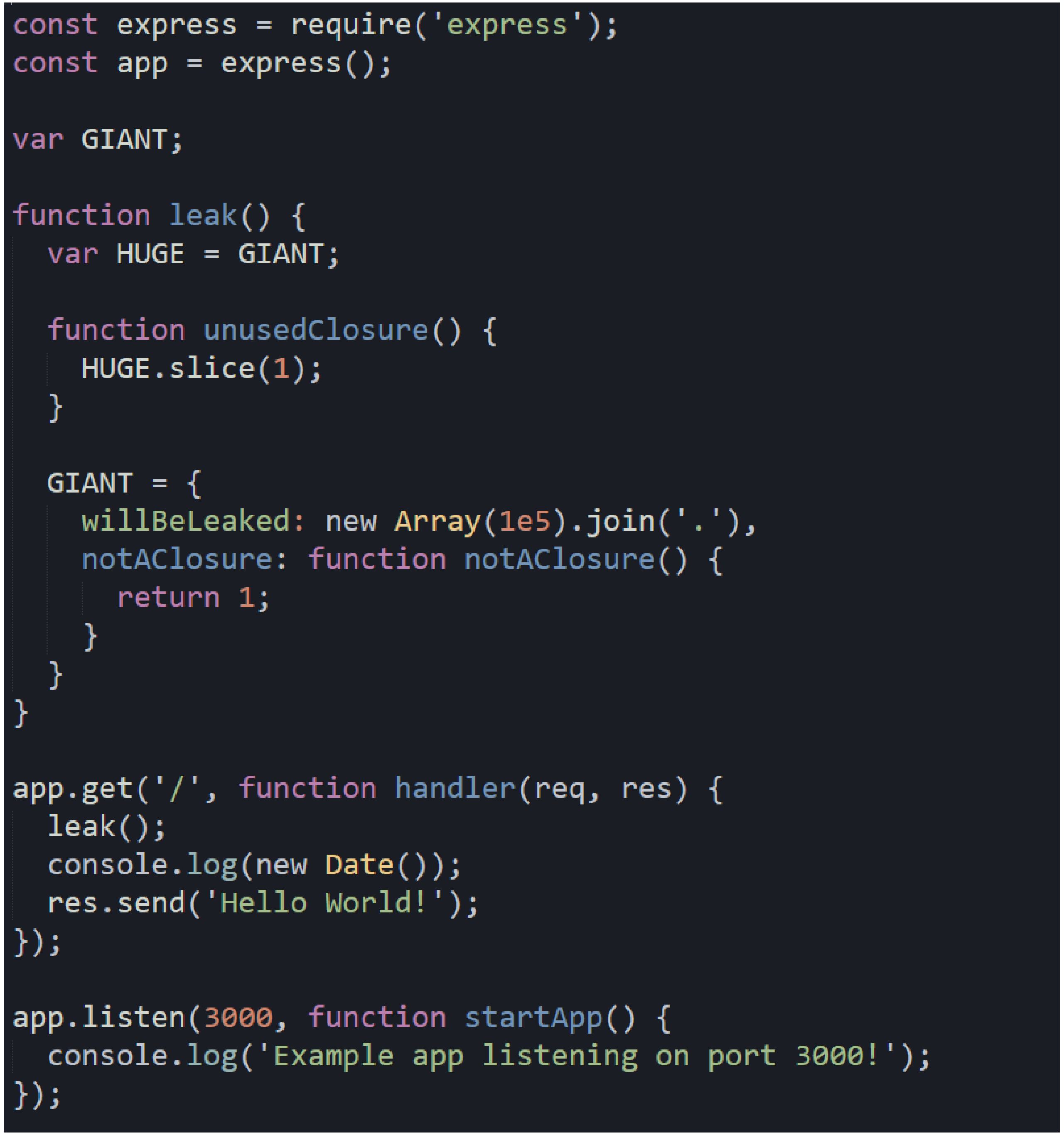
Getting started with V8 GC logs

- Plenty of options(`node --v8-options| grep gc`)
- We'll be focusing on
  - `--trace_gc`
  - `--trace_gc_nvp`
- Obviously you can't use these in production, even though it would be difficult to reproduce your problems offline
  - `v8.setFlagsFromString('--trace_gc')`
  - `v8.setFlagsFromString('--notrace_gc')`
  - Or use alinode to get them by clicking a button on our SAAS platform(wink wink)
- In case you do want to read the code
  - `deps/v8/src/heap`, start with `gc-tracer.cc`

Demo Time

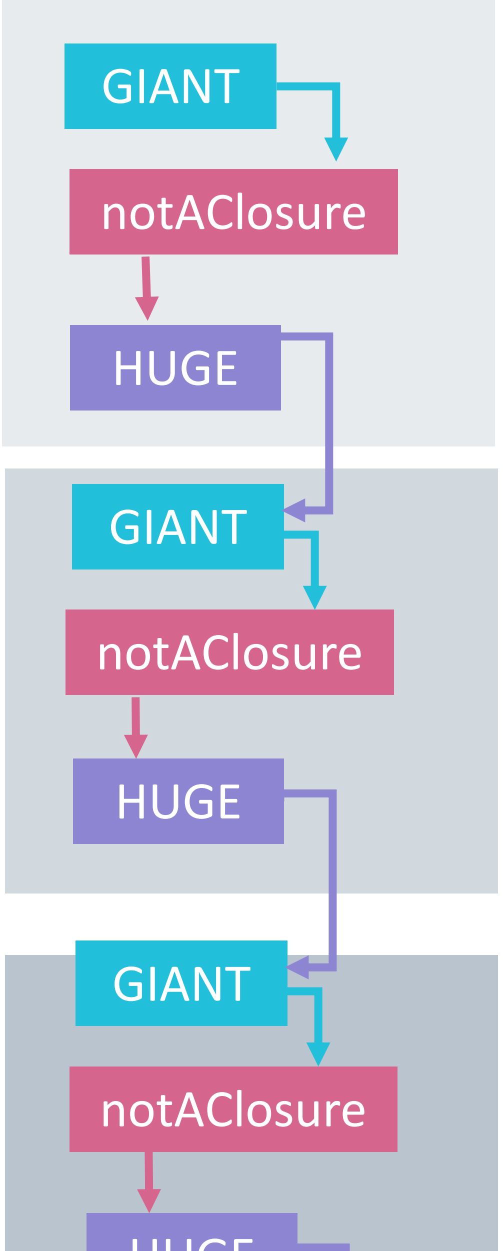
Leaks caused by closures

- Closures are created when declared, not when executed
- In V8, once there is any closure in the context, the context will be attached to every function, even for those who don't reference the context at all



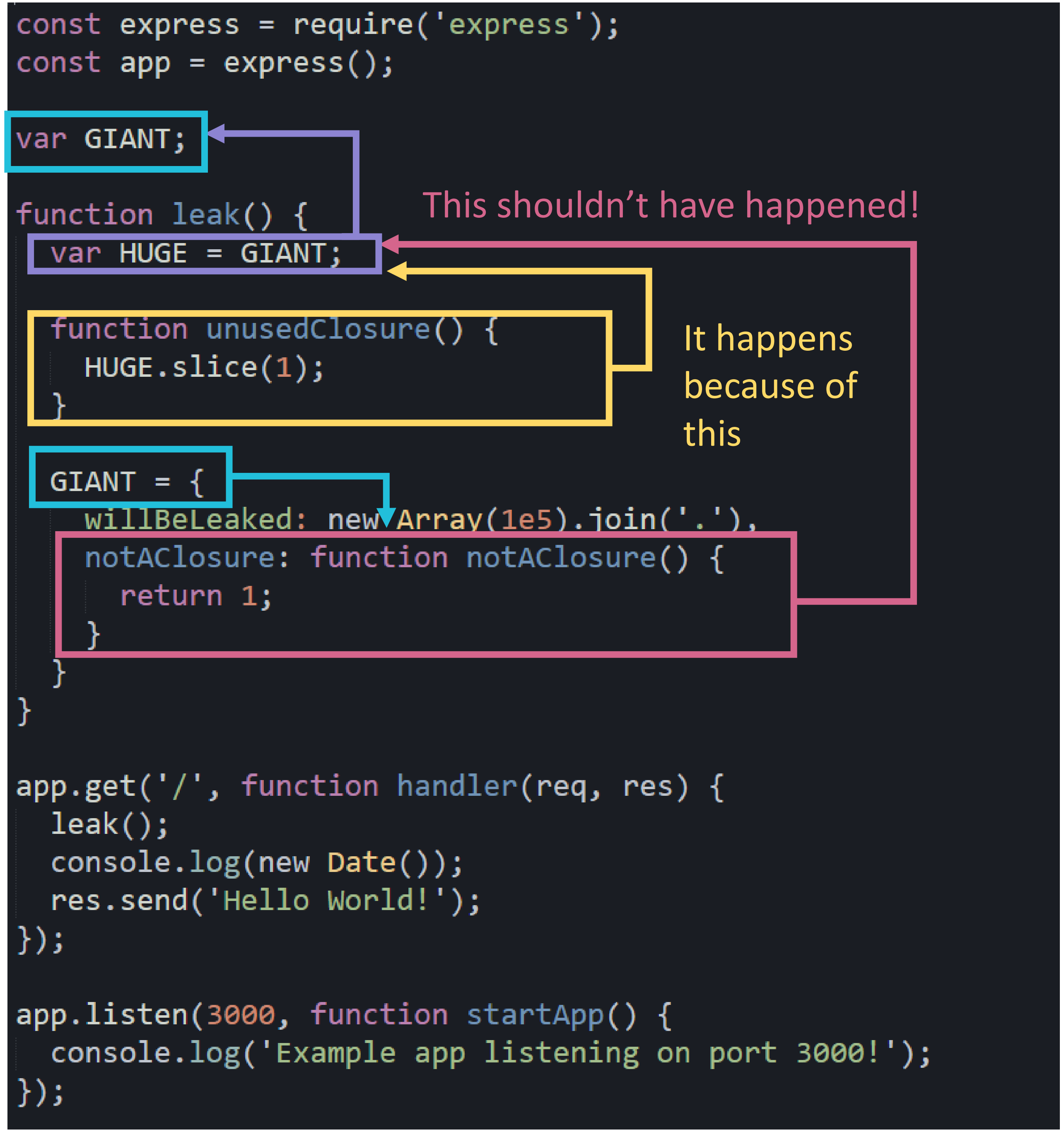
```
const express = require('express');
const app = express();

var GIANT;

function leak() {
  var HUGE = GIANT;

  function unusedClosure() {
    HUGE.slice(1);
  }

  GIANT = {
    willBeLeaked: new Array(1e5).join('.'),
    notAClosure: function notAClosure() {
      return 1;
    }
  }
}

app.get('/', function handler(req, res) {
  leak();
  console.log(new Date());
  res.send('Hello World!');
});

app.listen(3000, function startApp() {
  console.log('Example app listening on port 3000!');
});
```

Leaks caused by closures



Created in this call

Created in last call, but can't be GC'ed because they are referenced by the new ones

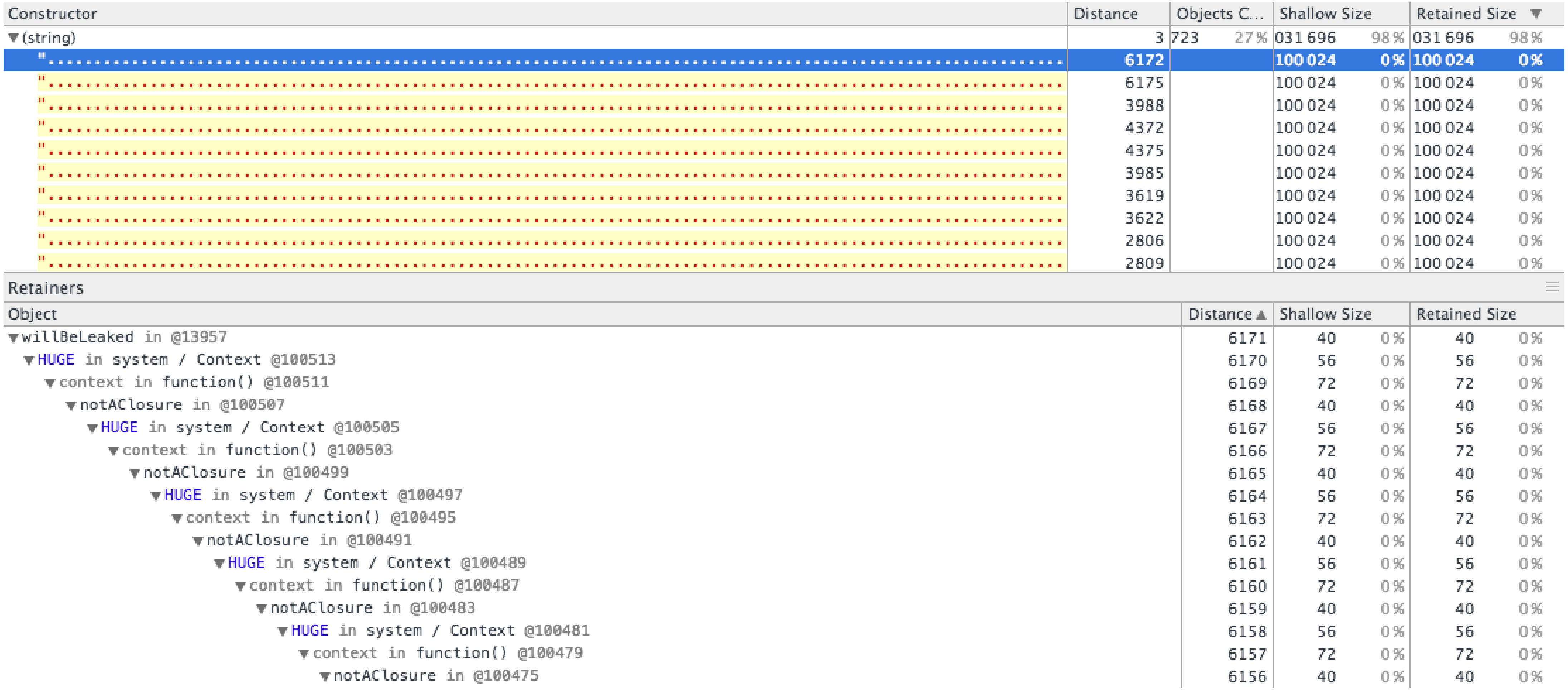


```
const express = require('express');
const app = express();

var GIANT;

function leak() {
  var HUGE = GIANT;

  function unusedClosure() {
    HUGE.slice(1);
  }

  GIANT = {
    willBeLeaked: new Array(1e5).join('.'),
    notAClosure: function notAClosure() {
      return 1;
    }
  }
}

app.get('/', function handler(req, res) {
  leak();
  console.log(new Date());
  res.send('Hello World!');
});

app.listen(3000, function startApp() {
  console.log('Example app listening on port 3000!');
});
```

This shouldn't have happened!

It happens because of this

Leaks caused by closures



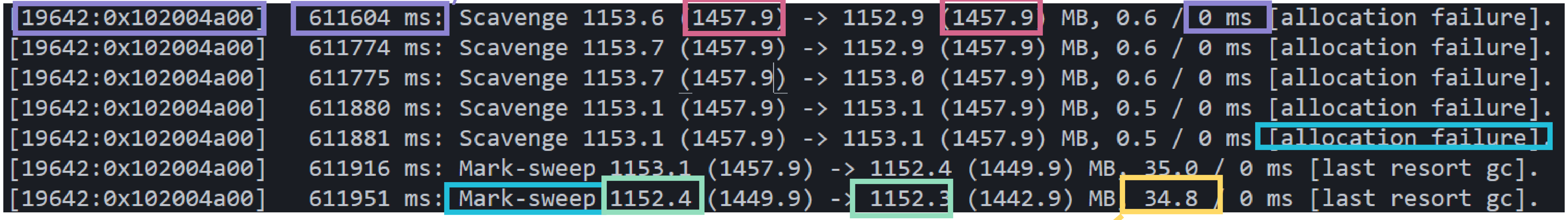
Constructor	Distance	Objects C...		Shallow Size		Retained Size ▼	
▼(string)	3	723	27 %	031 696	98 %	031 696	98 %
"..	6172			100 024	0 %	100 024	0 %
"..	6175			100 024	0 %	100 024	0 %
"..	3988			100 024	0 %	100 024	0 %
"..	4372			100 024	0 %	100 024	0 %
"..	4375			100 024	0 %	100 024	0 %
"..	3985			100 024	0 %	100 024	0 %
"..	3619			100 024	0 %	100 024	0 %
"..	3622			100 024	0 %	100 024	0 %
"..	2806			100 024	0 %	100 024	0 %
"..	2809			100 024	0 %	100 024	0 %

Retainers

Object	Distance ▲	Shallow Size		Retained Size	
▼willBeLeaked in @13957	6171	40	0 %	40	0 %
▼HUGE in system / Context @100513	6170	56	0 %	56	0 %
▼context in function() @100511	6169	72	0 %	72	0 %
▼notAClosure in @100507	6168	40	0 %	40	0 %
▼HUGE in system / Context @100505	6167	56	0 %	56	0 %
▼context in function() @100503	6166	72	0 %	72	0 %
▼notAClosure in @100499	6165	40	0 %	40	0 %
▼HUGE in system / Context @100497	6164	56	0 %	56	0 %
▼context in function() @100495	6163	72	0 %	72	0 %
▼notAClosure in @100491	6162	40	0 %	40	0 %
▼HUGE in system / Context @100489	6161	56	0 %	56	0 %
▼context in function() @100487	6160	72	0 %	72	0 %
▼notAClosure in @100483	6159	40	0 %	40	0 %
▼HUGE in system / Context @100481	6158	56	0 %	56	0 %
▼context in function() @100479	6157	72	0 %	72	0 %
▼notAClosure in @100475	6156	40	0 %	40	0 %

Leaks caused by closures

- --trace_gc (print one trace line following each garbage collection)



```
[19642:0x102004a00]   611604 ms: Scavenge 1153.6 (1457.9) -> 1152.9 (1457.9) MB, 0.6 / 0 ms [allocation failure].
[19642:0x102004a00]   611774 ms: Scavenge 1153.7 (1457.9) -> 1152.9 (1457.9) MB, 0.6 / 0 ms [allocation failure].
[19642:0x102004a00]   611775 ms: Scavenge 1153.7 (1457.9) -> 1153.0 (1457.9) MB, 0.6 / 0 ms [allocation failure].
[19642:0x102004a00]   611880 ms: Scavenge 1153.1 (1457.9) -> 1153.1 (1457.9) MB, 0.5 / 0 ms [allocation failure].
[19642:0x102004a00]   611881 ms: Scavenge 1153.1 (1457.9) -> 1153.1 (1457.9) MB, 0.5 / 0 ms [allocation failure].
[19642:0x102004a00]   611916 ms: Mark-sweep 1153.1 (1457.9) -> 1152.4 (1449.9) MB, 35.0 / 0 ms [last resort gc].
[19642:0x102004a00]   611951 ms: Mark-sweep 1152.4 (1449.9) -> 1152.3 (1442.9) MB, 34.8 / 0 ms [last resort gc].
```

PID:Address

The time since you start this VM

Size of memory allocated from OS

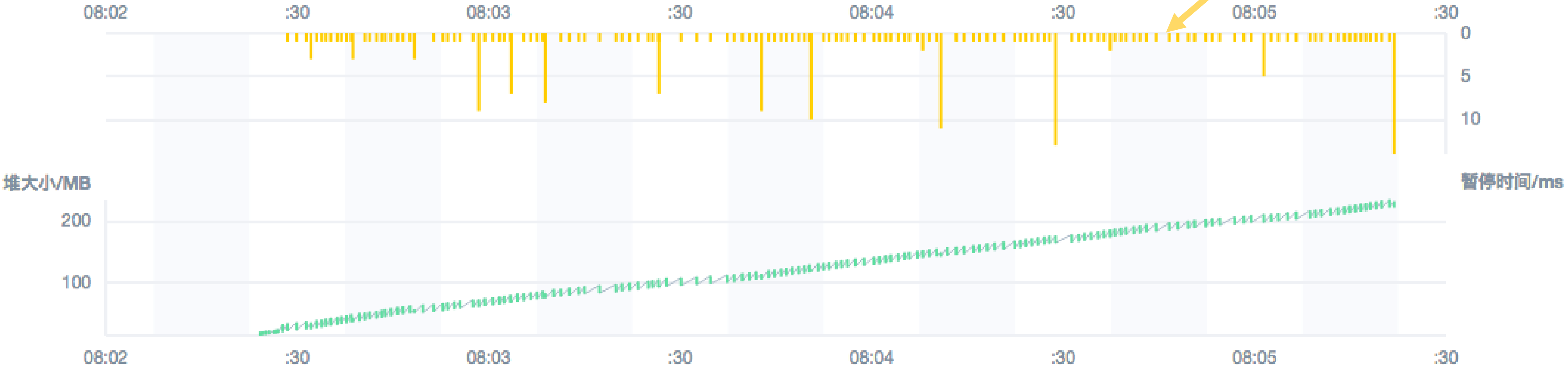
Spent on external memory

Type of GC

Size of all objects

Pause

Because the GC is triggered when there's not enough memory

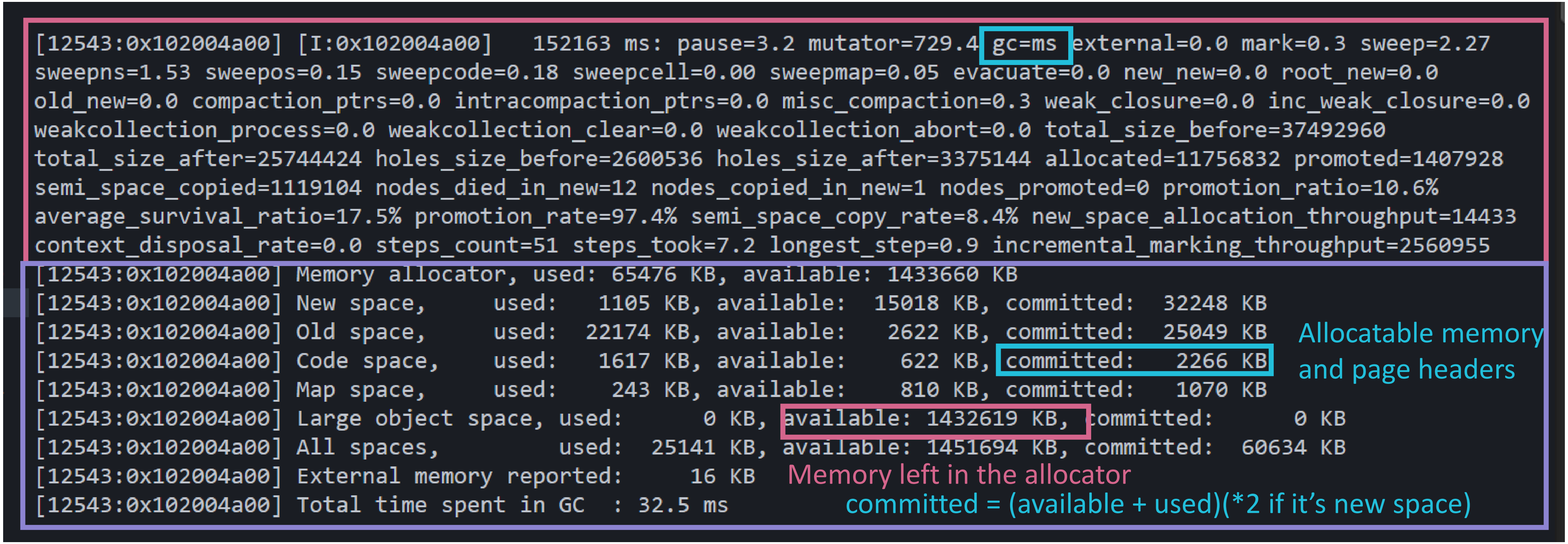


Leaks caused by closures

- --trace_gc_nvp (print one detailed trace line in name=value format after each garbage collection)

Name-value

Type of GC, ms=Mark-sweep/Mark-compact, s=Scavenger



```
[12543:0x102004a00] [I:0x102004a00]   152163 ms: pause=3.2 mutator=729.4 gc=ms external=0.0 mark=0.3 sweep=2.27
sweepns=1.53 sweepos=0.15 sweepcode=0.18 sweepcell=0.00 sweepmap=0.05 evacuate=0.0 new_new=0.0 root_new=0.0
old_new=0.0 compaction_ptrs=0.0 intracompaction_ptrs=0.0 misc_compaction=0.3 weak_closure=0.0 inc_weak_closure=0.0
weakcollection_process=0.0 weakcollection_clear=0.0 weakcollection_abort=0.0 total_size_before=37492960
total_size_after=25744424 holes_size_before=2600536 holes_size_after=3375144 allocated=11756832 promoted=1407928
semi_space_copied=1119104 nodes_died_in_new=12 nodes_copied_in_new=1 nodes_promoted=0 promotion_ratio=10.6%
average_survival_ratio=17.5% promotion_rate=97.4% semi_space_copy_rate=8.4% new_space_allocation_throughput=14433
context_disposal_rate=0.0 steps_count=51 steps_took=7.2 longest_step=0.9 incremental_marking_throughput=2560955
[12543:0x102004a00] Memory allocator, used: 65476 KB, available: 1433660 KB
[12543:0x102004a00] New space,     used:   1105 KB, available:  15018 KB, committed:  32248 KB
[12543:0x102004a00] Old space,     used:  22174 KB, available:   2622 KB, committed:  25049 KB
[12543:0x102004a00] Code space,    used:   1617 KB, available:    622 KB, committed:   2266 KB
[12543:0x102004a00] Map space,     used:    243 KB, available:    810 KB, committed:   1070 KB
[12543:0x102004a00] Large object space, used:      0 KB, available: 1432619 KB, committed:      0 KB
[12543:0x102004a00] All spaces,         used:  25141 KB, available: 1451694 KB, committed:  60634 KB
[12543:0x102004a00] External memory reported:     16 KB
[12543:0x102004a00] Total time spent in GC  : 32.5 ms
```

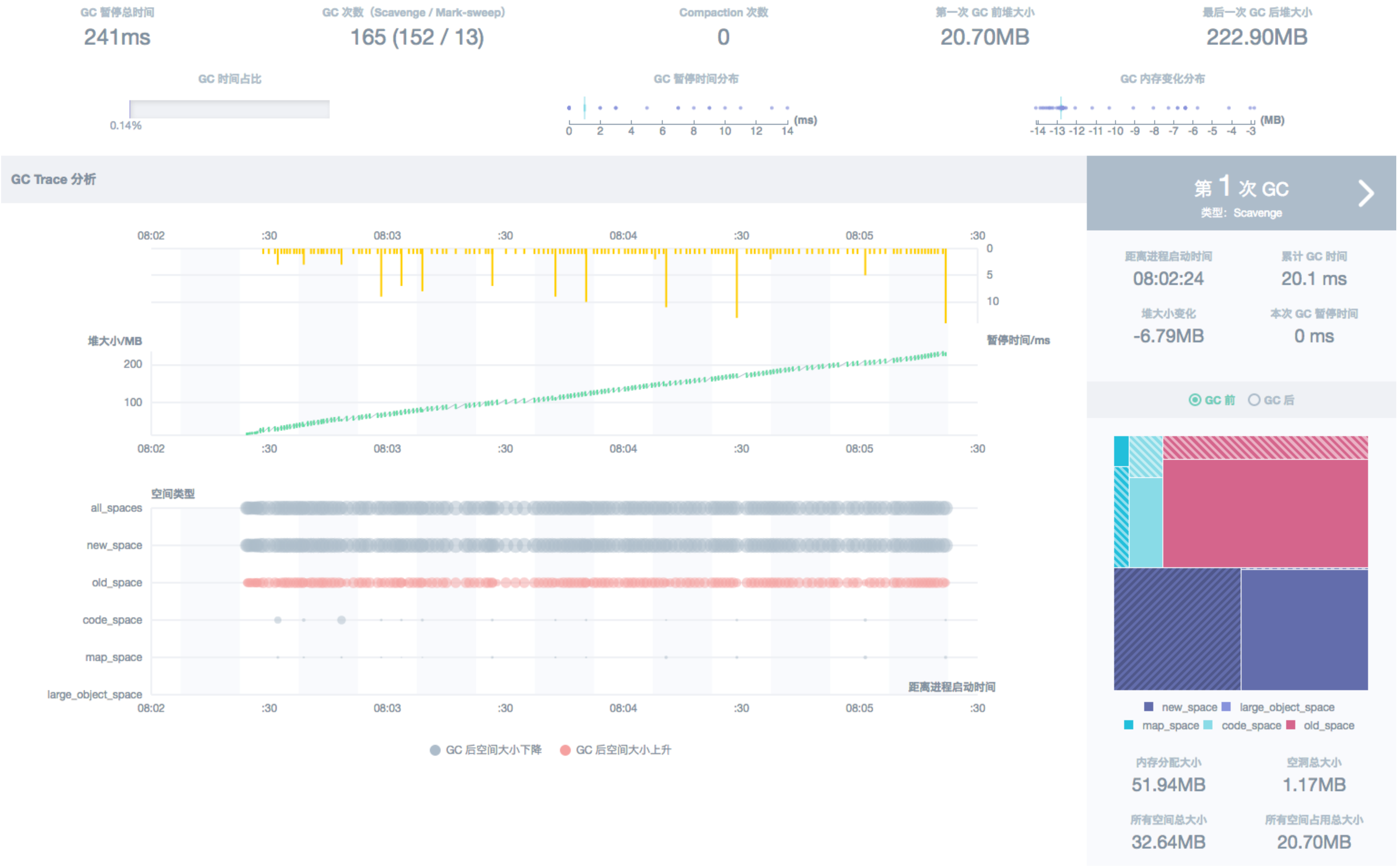
Allocatable memory and page headers

Memory left in the allocator

committed = (available + used)(*2 if it's new space)

Statistics of each space

Leaks caused by closures



GC 暂停总时间
241ms

GC 次数（Scavenge / Mark-sweep）
165 (152 / 13)

Compaction 次数
0

第一次 GC 前堆大小
20.70MB

最后一次 GC 后堆大小
222.90MB

GC 时间占比
0.14%

GC 暂停时间分布

GC 内存变化分布

GC Trace 分析

第 1 次 GC
类型：Scavenge

距离进程启动时间
08:02:24

累计 GC 时间
20.1 ms

堆大小变化
-6.79MB

本次 GC 暂停时间
0 ms

◉ GC 前 ○ GC 后

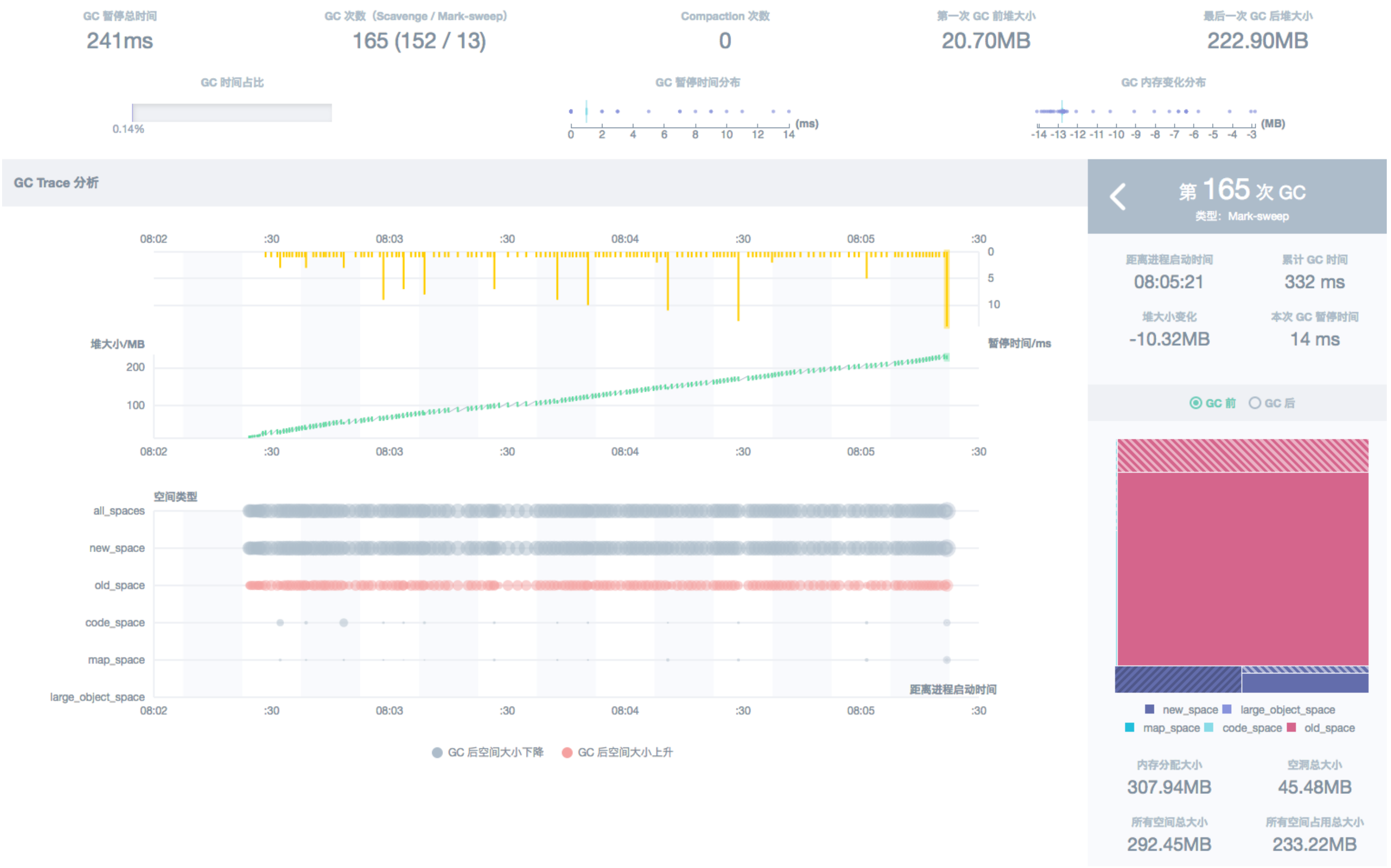
内存分配大小
51.94MB

空洞总大小
1.17MB

所有空间总大小
32.64MB

所有空间占用总大小
20.70MB

Leaks caused by closures



GC 暂停总时间
241ms

GC 次数（Scavenge / Mark-sweep）
165 (152 / 13)

Compaction 次数
0

第一次 GC 前堆大小
20.70MB

最后一次 GC 后堆大小
222.90MB

GC 时间占比
0.14%

GC Trace 分析

第 165 次 GC
类型：Mark-sweep

距离进程启动时间
08:05:21

累计 GC 时间
332 ms

堆大小变化
-10.32MB

本次 GC 暂停时间
14 ms

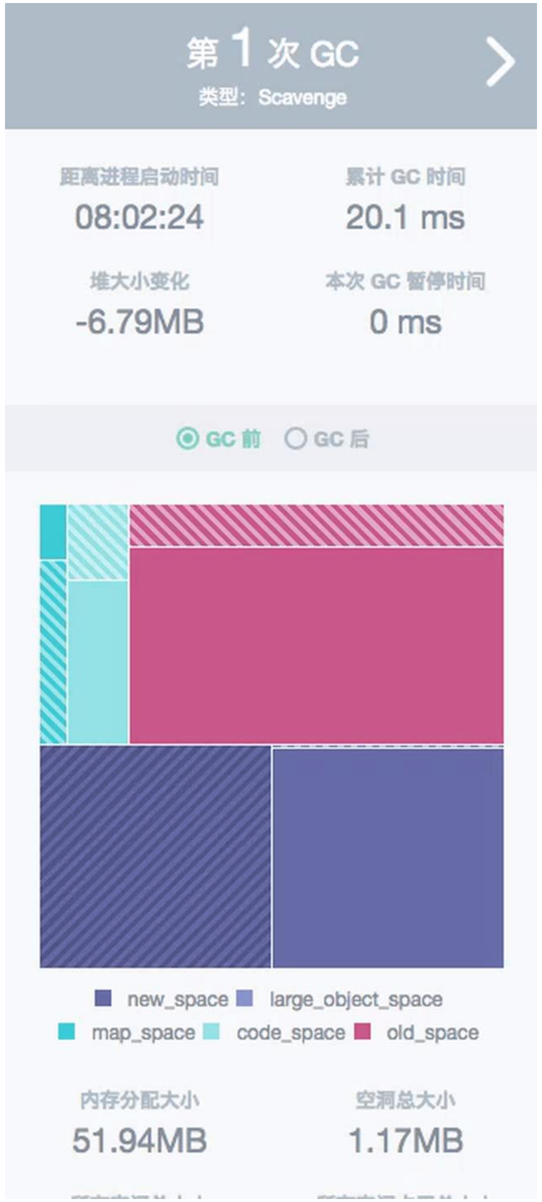
◉ GC 前 ○ GC 后

内存分配大小
307.94MB

空洞总大小
45.48MB

所有空间总大小
292.45MB

所有空间占用总大小
233.22MB



第 1 次 GC
类型：Scavenge

距离进程启动时间
08:02:24

累计 GC 时间
20.1 ms

堆大小变化
-6.79MB

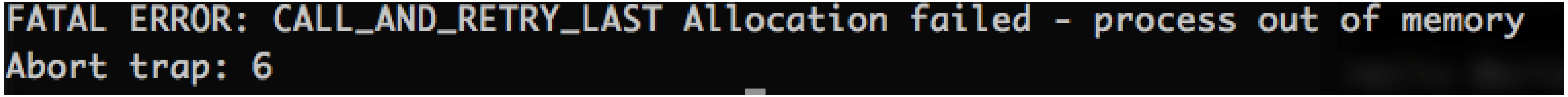
本次 GC 暂停时间
0 ms

◉ GC 前 ○ GC 后

内存分配大小
51.94MB

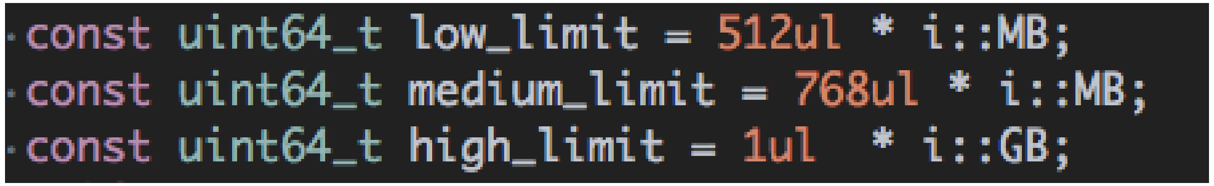
空洞总大小
1.17MB

Leaks caused by closures



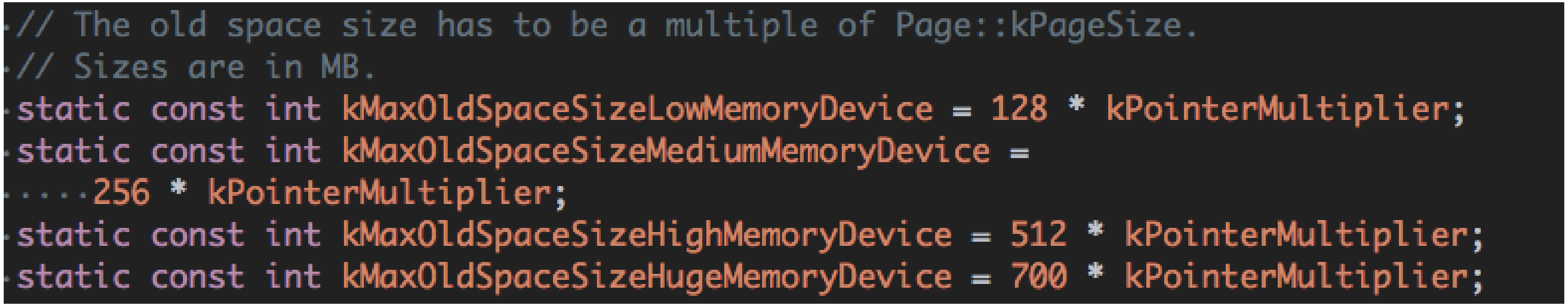
```
FATAL ERROR: CALL_AND_RETRY_LAST Allocation failed - process out of memory
Abort trap: 6
```

- ❖ deps/v8/src/api.cc: ResourceConstraints::ConfigureDefaults

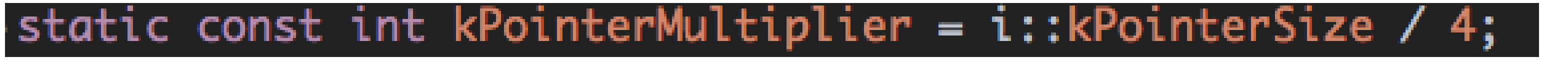


```
const uint64_t low_limit = 512ul * i::MB;
const uint64_t medium_limit = 768ul * i::MB;
const uint64_t high_limit = 1ul  * i::GB;
```

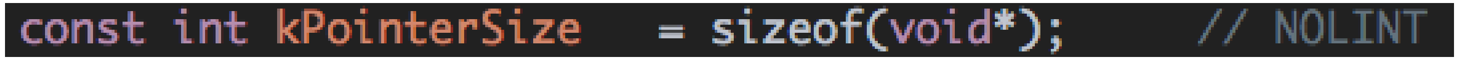
- ❖ deps/v8/src/heap/heap.h



```
// The old space size has to be a multiple of Page::kPageSize.
// Sizes are in MB.
static const int kMaxOldSpaceSizeLowMemoryDevice = 128 * kPointerMultiplier;
static const int kMaxOldSpaceSizeMediumMemoryDevice =
    256 * kPointerMultiplier;
static const int kMaxOldSpaceSizeHighMemoryDevice = 512 * kPointerMultiplier;
static const int kMaxOldSpaceSizeHugeMemoryDevice = 700 * kPointerMultiplier;
```

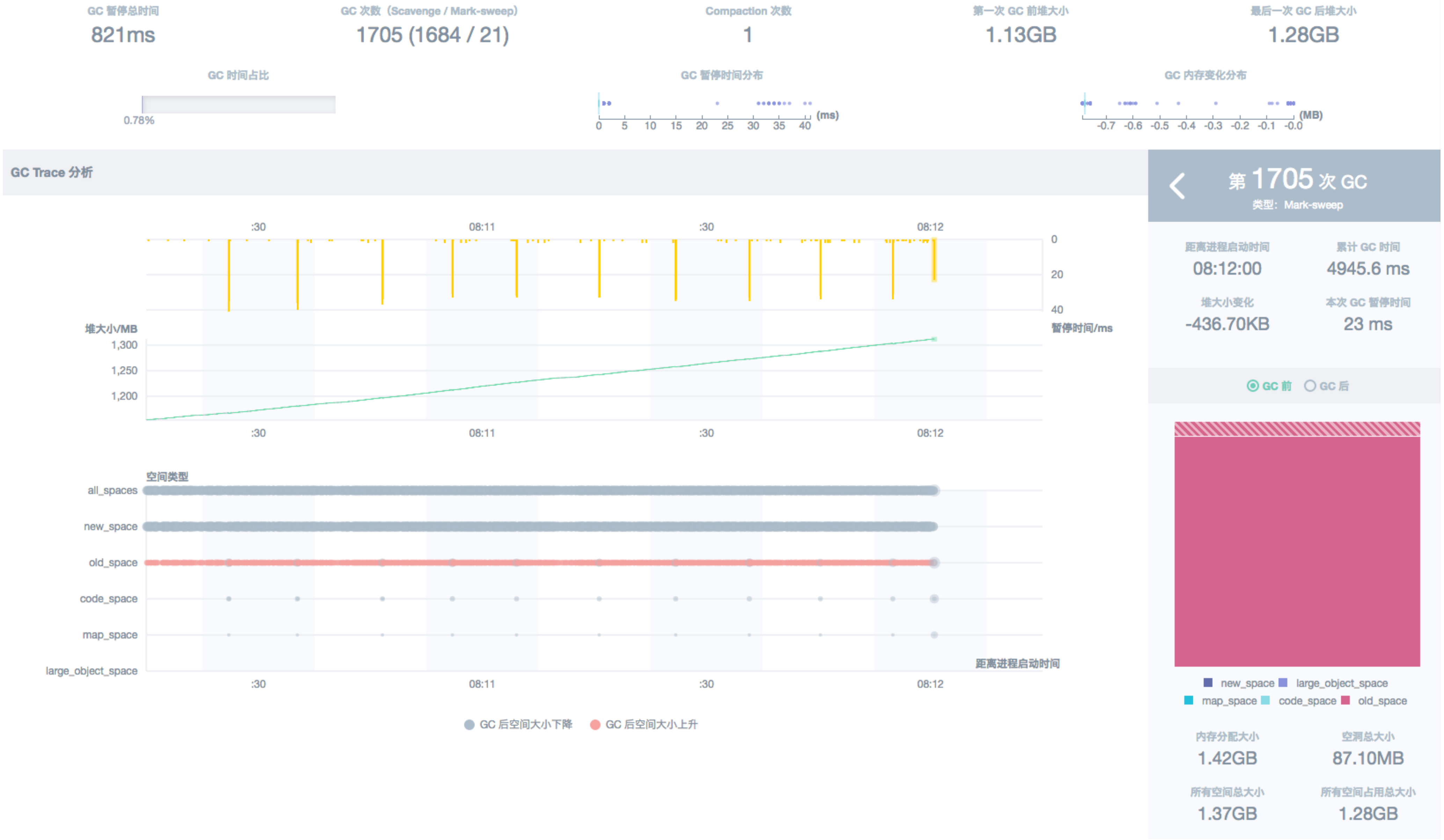


```
static const int kPointerMultiplier = i::kPointerSize / 4;
```



```
const int kPointerSize     = sizeof(void*);      // NOLINT
```

Leaks caused by closures



GC 暂停总时间
821ms

GC 次数（Scavenge / Mark-sweep）
1705 (1684 / 21)

Compaction 次数
1

第一次 GC 前堆大小
1.13GB

最后一次 GC 后堆大小
1.28GB

GC 时间占比
0.78%

GC Trace 分析

第 1705 次 GC
类型：Mark-sweep

距离进程启动时间
08:12:00

累计 GC 时间
4945.6 ms

堆大小变化
-436.70KB

本次 GC 暂停时间
23 ms

◉ GC 前 ○ GC 后

内存分配大小
1.42GB

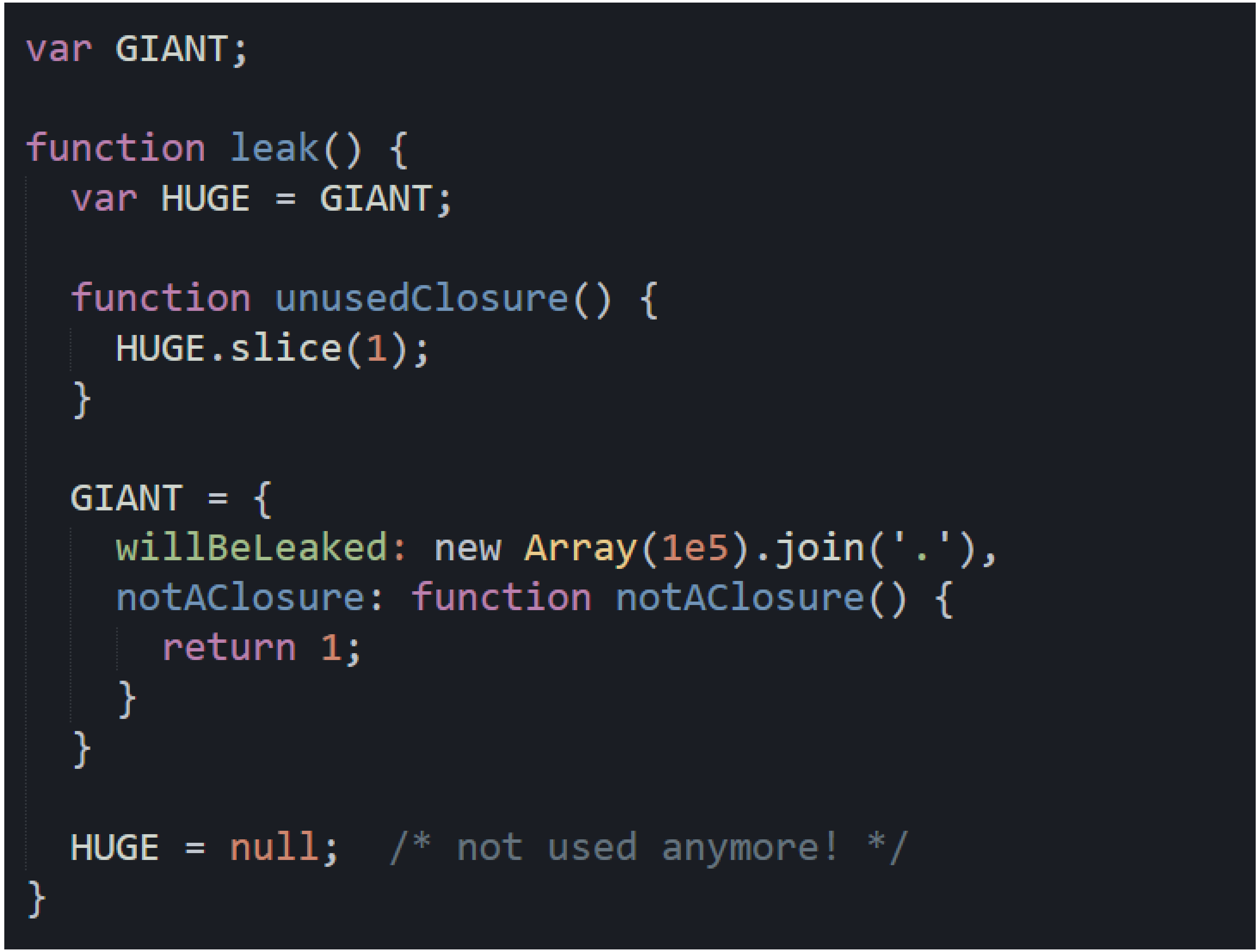
空洞总大小
87.10MB

所有空间总大小
1.37GB

所有空间占用总大小
1.28GB

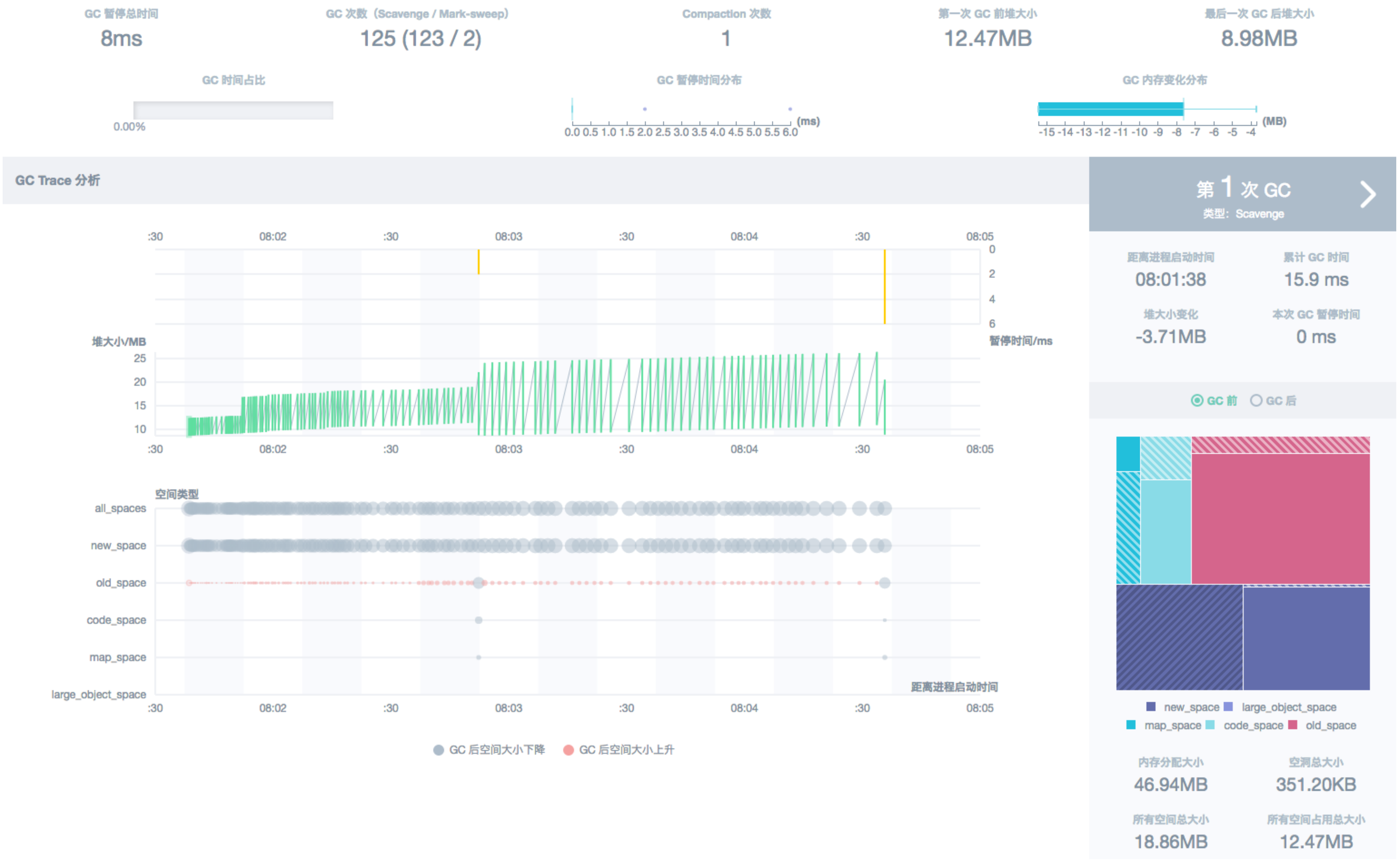
Solution #1: nullify your reference

- Cut off the reference to the old GIANT when you don’t need it anymore



```
var GIANT;

function leak() {
  var HUGE = GIANT;

  function unusedClosure() {
    HUGE.slice(1);
  }

  GIANT = {
    willBeLeaked: new Array(1e5).join('.'),
    notAClosure: function notAClosure() {
      return 1;
    }
  }

  HUGE = null;  /* not used anymore! */
}
```

Solution #1: nullify your reference



GC 暂停总时间
8ms

GC 次数（Scavenge / Mark-sweep）
125 (123 / 2)

Compaction 次数
1

第一次 GC 前堆大小
12.47MB

最后一次 GC 后堆大小
8.98MB

GC 时间占比
0.00%

GC 暂停时间分布

GC 内存变化分布

GC Trace 分析

第 1 次 GC
类型：Scavenge

距离进程启动时间
08:01:38

累计 GC 时间
15.9 ms

堆大小变化
-3.71MB

本次 GC 暂停时间
0 ms

◉ GC 前 ○ GC 后

内存分配大小
46.94MB

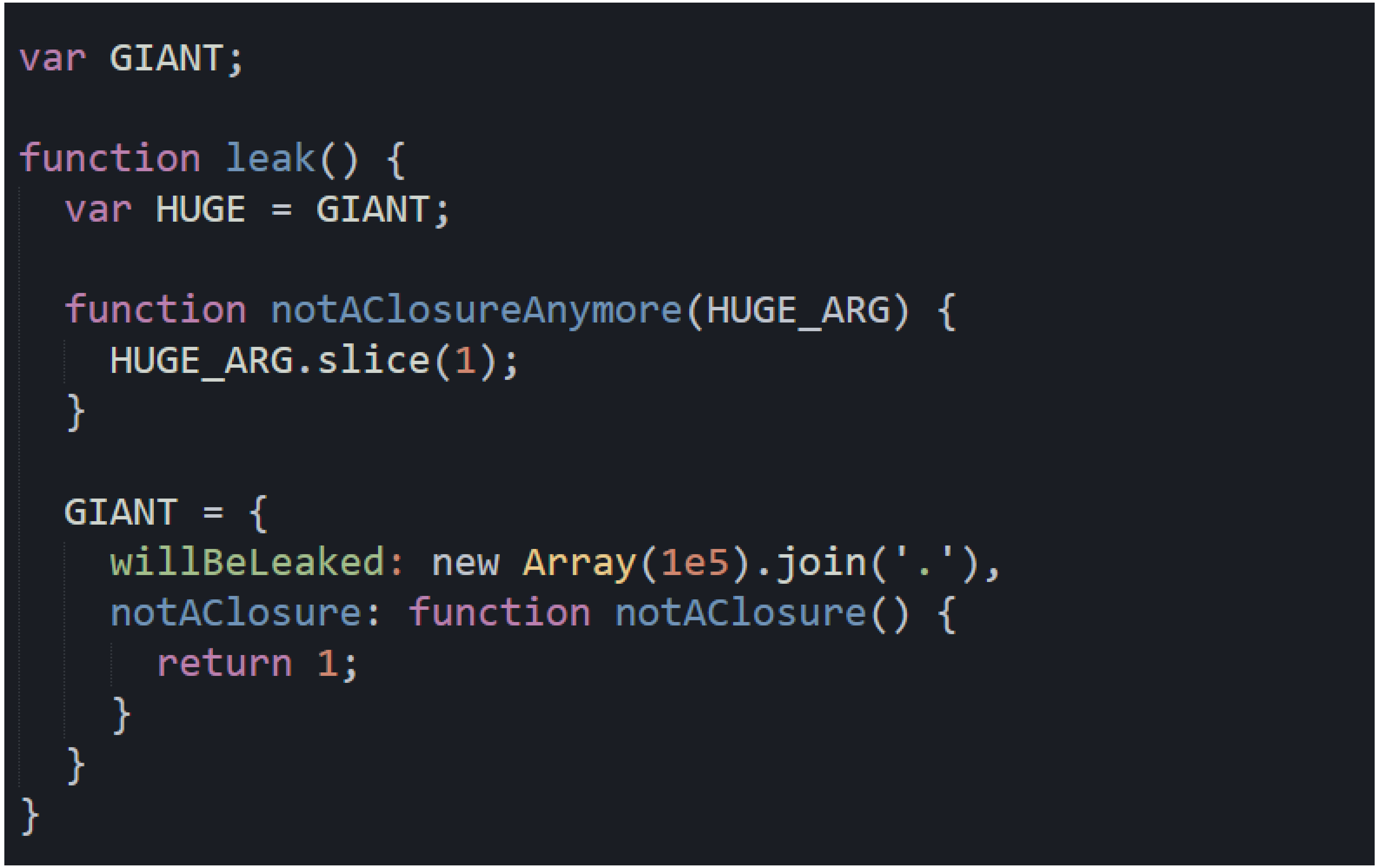
空洞总大小
351.20KB

所有空间总大小
18.86MB

所有空间占用总大小
12.47MB

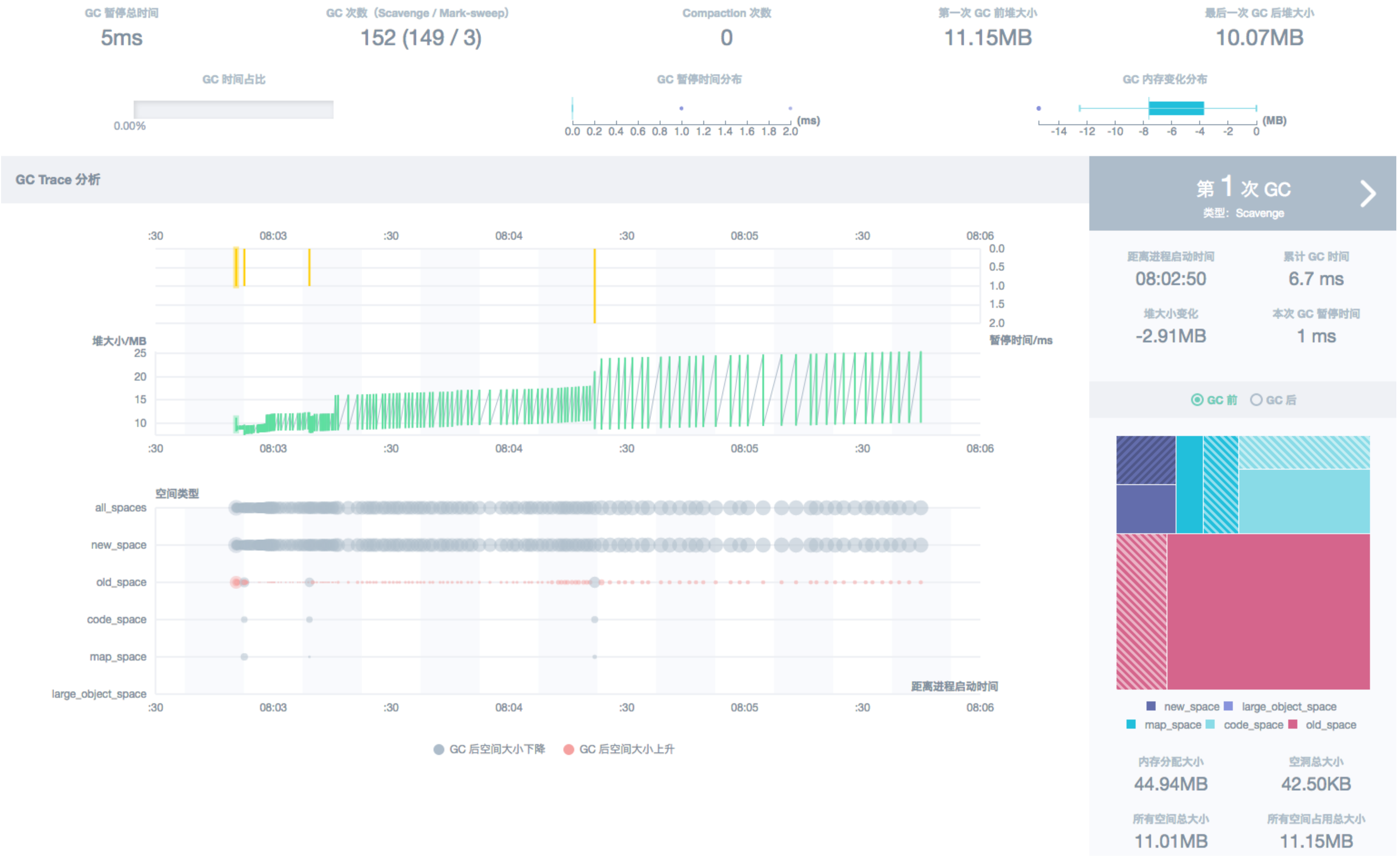
Solution #2: passing parameters

- Avoid closure like a plague



```
var GIANT;

function leak() {
  var HUGE = GIANT;

  function notAClosureAnymore(HUGE_ARG) {
    HUGE_ARG.slice(1);
  }

  GIANT = {
    willBeLeaked: new Array(1e5).join('.'),
    notAClosure: function notAClosure() {
      return 1;
    }
  }
}
```

Solution #2: passing parameters



GC 暂停总时间
5ms

GC 次数（Scavenge / Mark-sweep）
152 (149 / 3)

Compaction 次数
0

第一次 GC 前堆大小
11.15MB

最后一次 GC 后堆大小
10.07MB

GC 时间占比
0.00%

GC Trace 分析

第 1 次 GC
类型：Scavenge

距离进程启动时间
08:02:50

累计 GC 时间
6.7 ms

堆大小变化
-2.91MB

本次 GC 暂停时间
1 ms

◉ GC 前 ○ GC 后

内存分配大小
44.94MB

空洞总大小
42.50KB

所有空间总大小
11.01MB

所有空间占用总大小
11.15MB

Questions?

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