Incremental GC
for Ruby interpreter

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2014

Very important year for me

10^{th} Anniversary

10th Anniversary

YARV development (2004/01-)

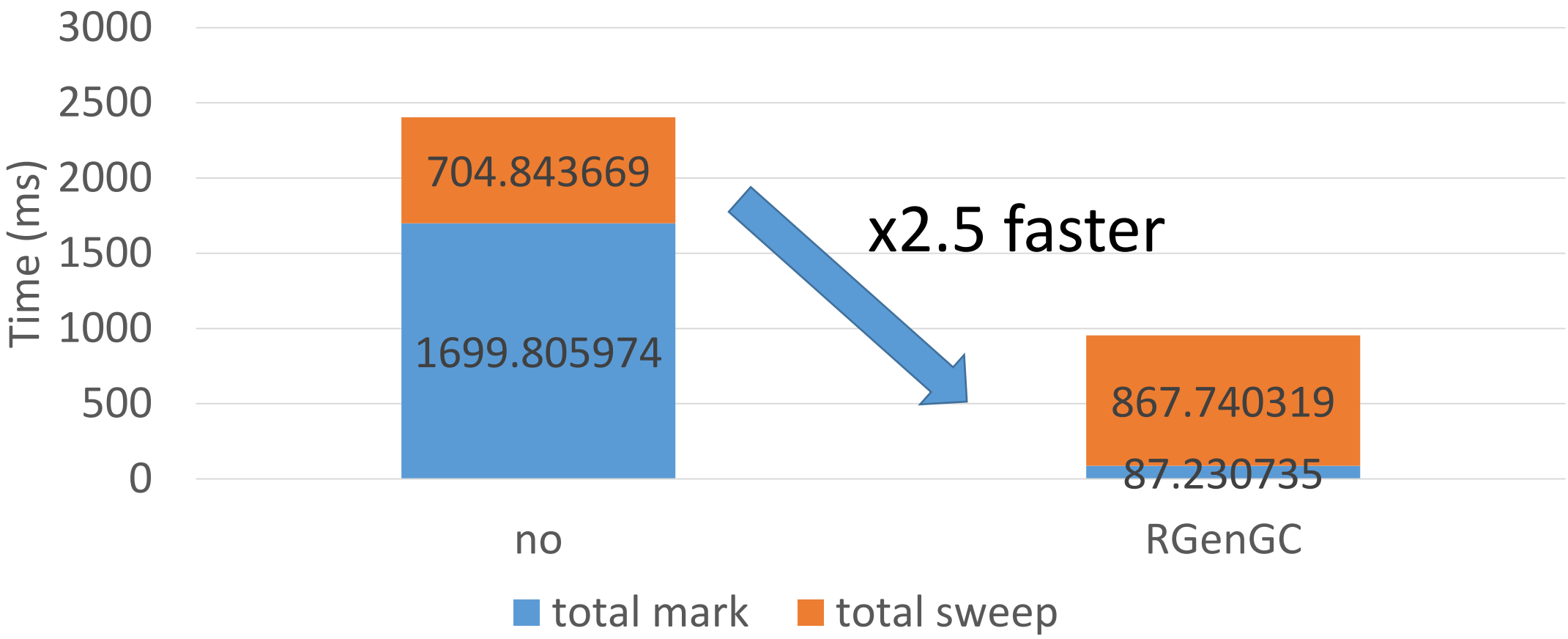
First presentation at RubyConf 2004

Garbage Collection Improvements

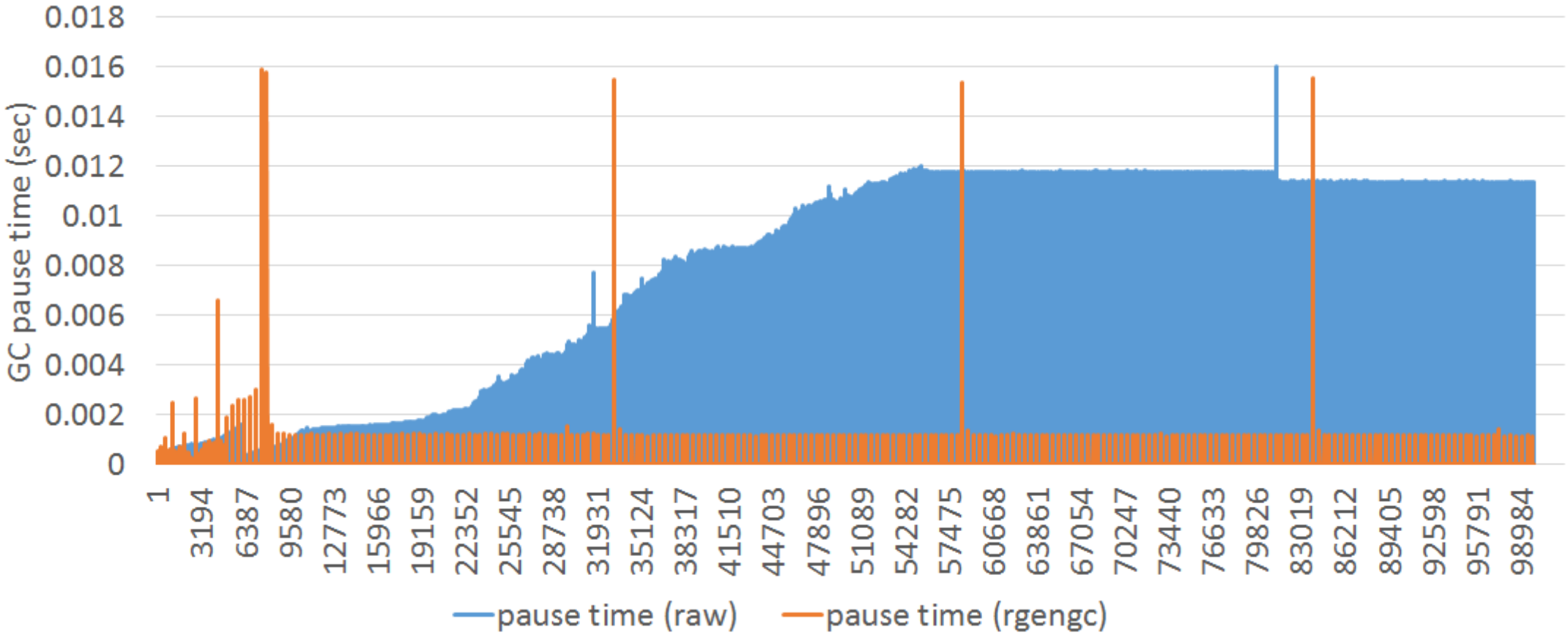
Good throughput and short pause time

Ruby 2.2 will be released soon.

RGenGC: Micro-benchmark



RGenGC: Pause time



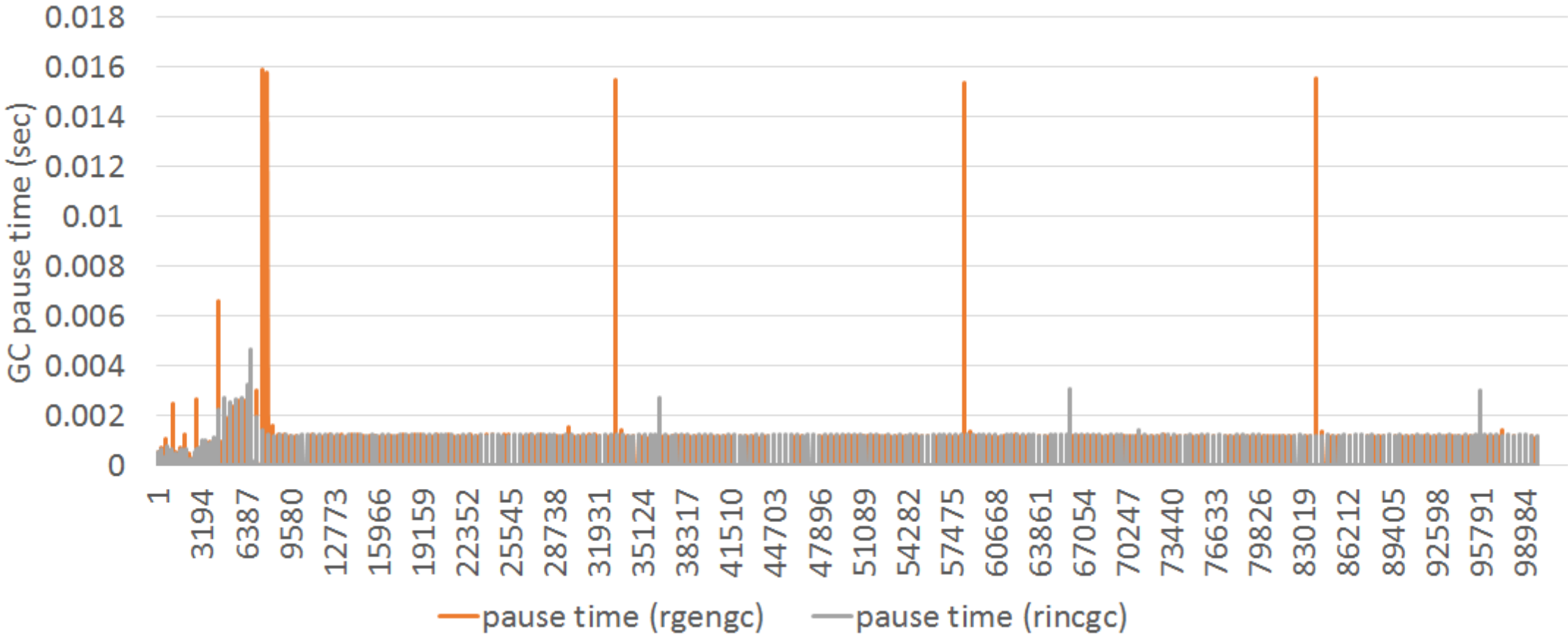
Today's topic

- Use incremental GC algorithm for major GC to reduce long pause time
- Ruby 2.2 will have it!!

Goal

	Before Ruby 2.1	Ruby 2.1 RGenGC	Incremental GC	Ruby 2.2 Gen+IncGC
Throughput	Low	High	Low	High
Pause time	Long	Long	Short	Short

Achievements: RGenGC+RincGC



Who am I?
Koichi Sasada as a Programmer

- CRuby committer since 2007/01
- Original YARV developer since 2004/01
- From Japan

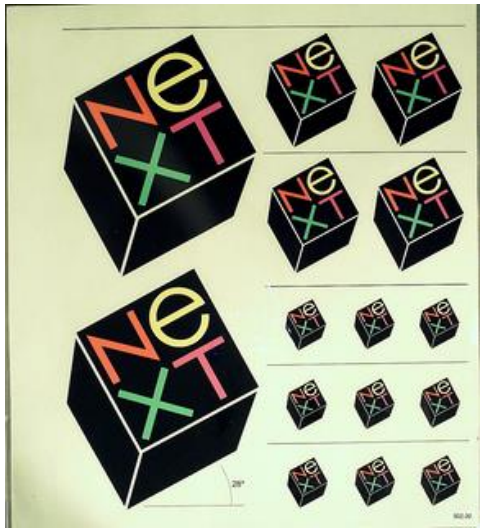
Who am I?
Koichi Sasada as a Employee

Who am I?
Koichi Sasada as a Employee

- A member of Matz team
  - Full-time CRuby developer
  - Working in Japan
  - Mission of our team is to improve “**QUALITY**” of CRuby interpreter

Upcoming Ruby 2.2

What's next?



http://www.flickr.com/photos/adafruit/8483990604

Ruby 2.2
Syntax

- No notable changes (maybe)

- Symbol key of Hash literal can be quoted
  - {“foo-bar”: baz}#=> {:”foo-bar” => baz}
    #=> not {“foo-bar” => baz} like JSON

TRAP: easy to misunderstand

Ruby 2.2
Classes and Methods

- Some methods are introduces
  - Kernel#itself
  - String#unicode_normalize
  - Etc.nprocessors
  - …

Ruby 2.2
Internal changes

- Remove obsolete C-APIs
- Hide internal definitions of data type

Ruby 2.2 Improvements

- Improve GC
  - Symbol GC
  - 4 ages generational GC
  - Incremental GC (today's topic)
- Improve the performance of keyword parameters
- Use frozen string literals if possible

Ruby 2.2
Symbol GC

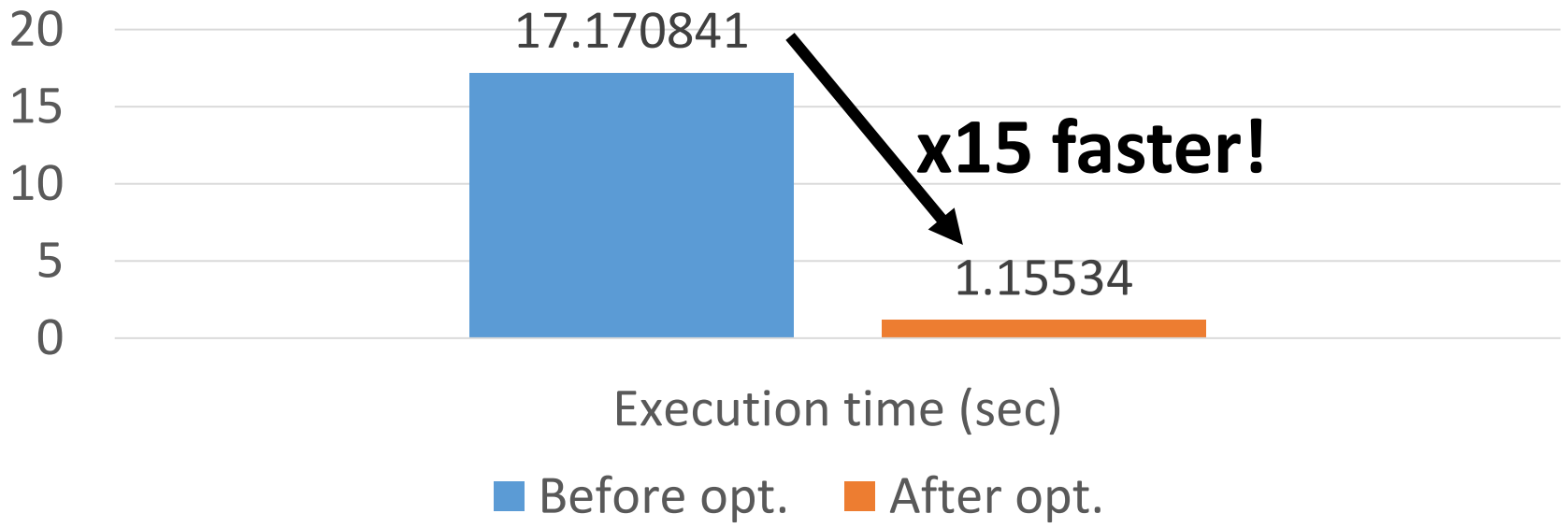
```
before = Symbol.all_symbols.size
1_000_000.times{|i| i.to_s.to_sym} # Make 1M symbols
after = Symbol.all_symbols.size; p [before, after]

# Ruby 2.1
#=> [2_378, 1_002_378] # not GCed ☹

# Ruby 2.2 (dev)
#=> [2_456, 2_456] # GCed! ☺
```

Ruby 2.2
Fast keyword parameters

```
# time of this program
def foo(k1: nil, k2: nil, k3: nil, k4: nil, k5: nil, k6: nil)
10_000_000.times{foo(k1: 1, k2: 2, k3: 3, k4: 4, k5: 5, k6: 6)}
```



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Break

Garbage collection

The automatic memory management

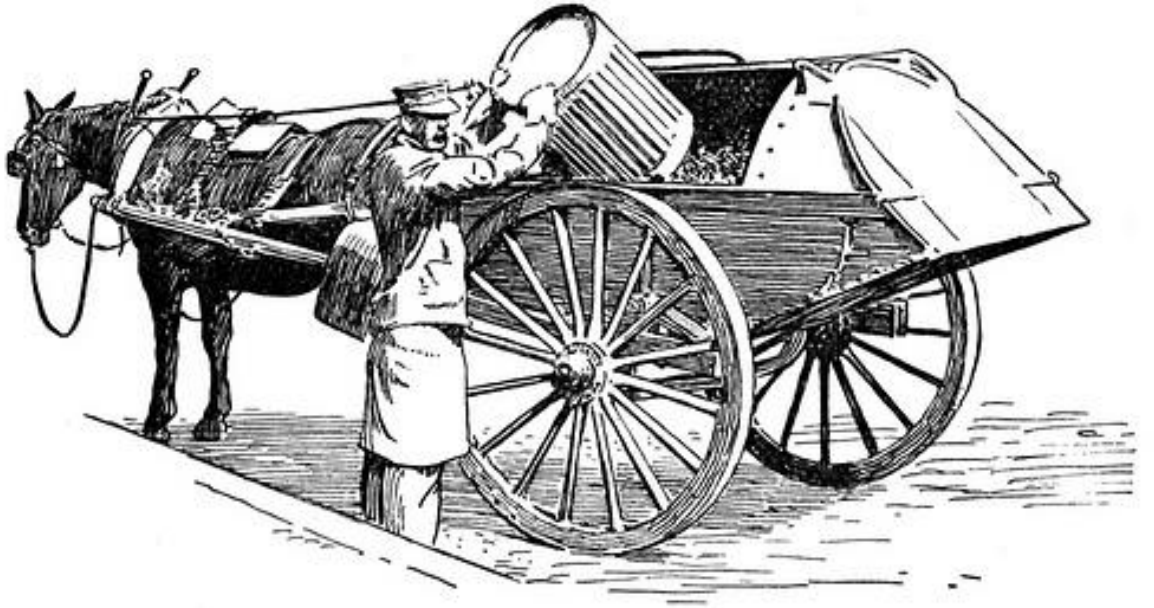


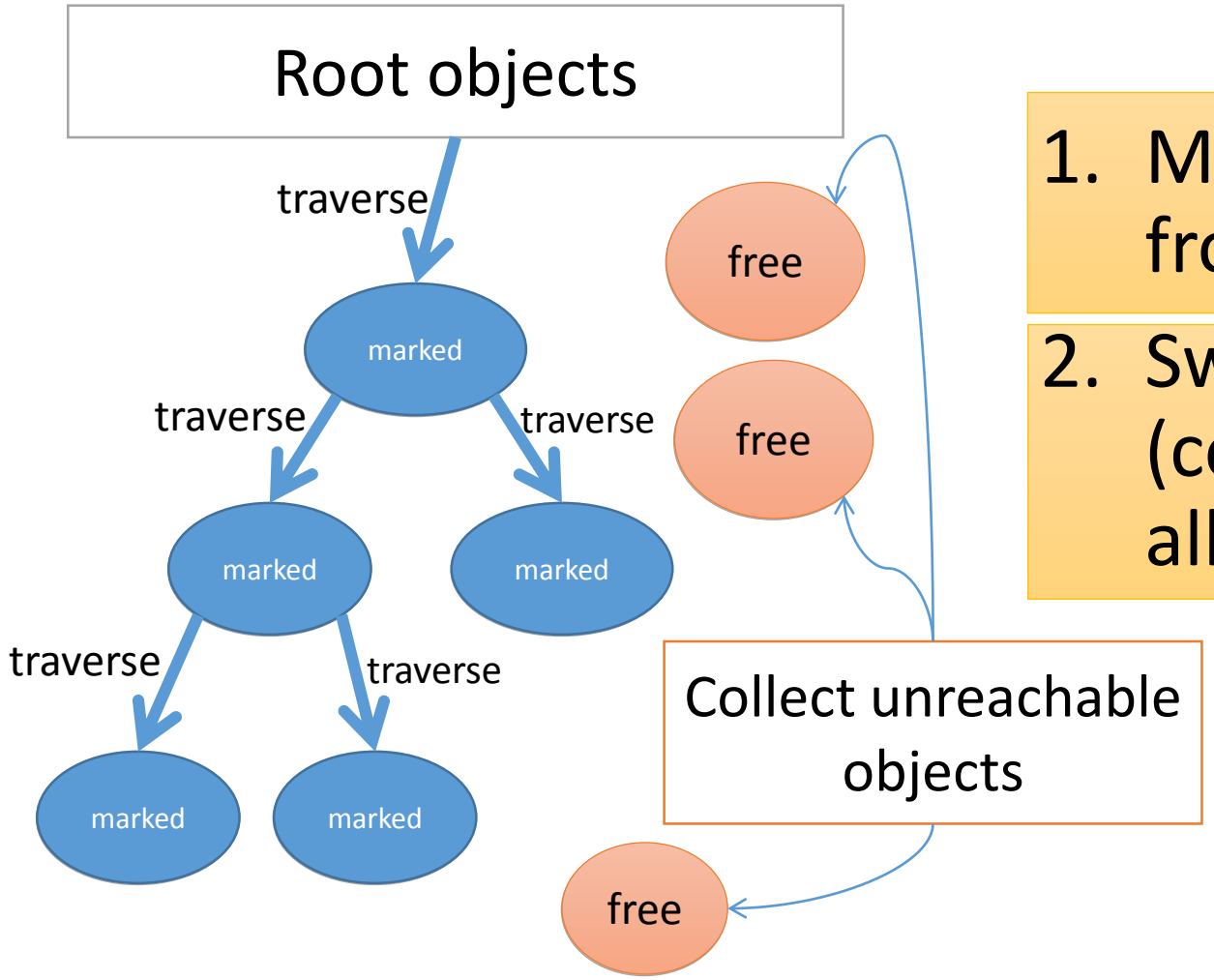
FIG. 109. — A GARBAGE COLLECTOR.

http://www.flickr.com/photos/circasassy/6817999189/

History of CRuby's GC

- 1993/12 Ruby 0.9: Conservative mark and sweep GC
  - Simple algorithm
  - Easy to implement C extensions
- 2011/10 Ruby 1.9.3: Lazy sweep
  - To reduce pause time on sweep
- 2013/02 Ruby 2.0: Bitmap marking
  - To make CoW friendly
- 2013/12 Ruby 2.1: RGenGC
  - To improve throughput

Since birth of Ruby
Simple Mark & Sweep

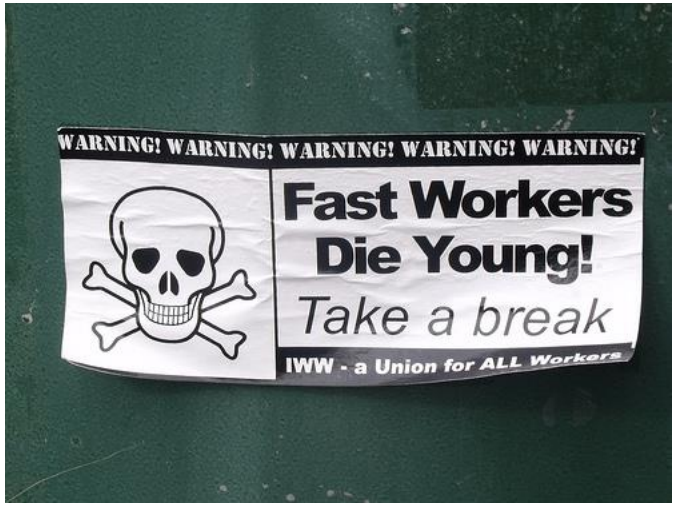


1. Mark reachable objects from root objects
2. Sweep ***unmarked*** objects (collection and de-allocation)

Since Ruby 2.1
RGenGC

- Weak generational hypothesis:

“Most objects die young”



http://www.flickr.com/photos/ell-r-brown/5026593710

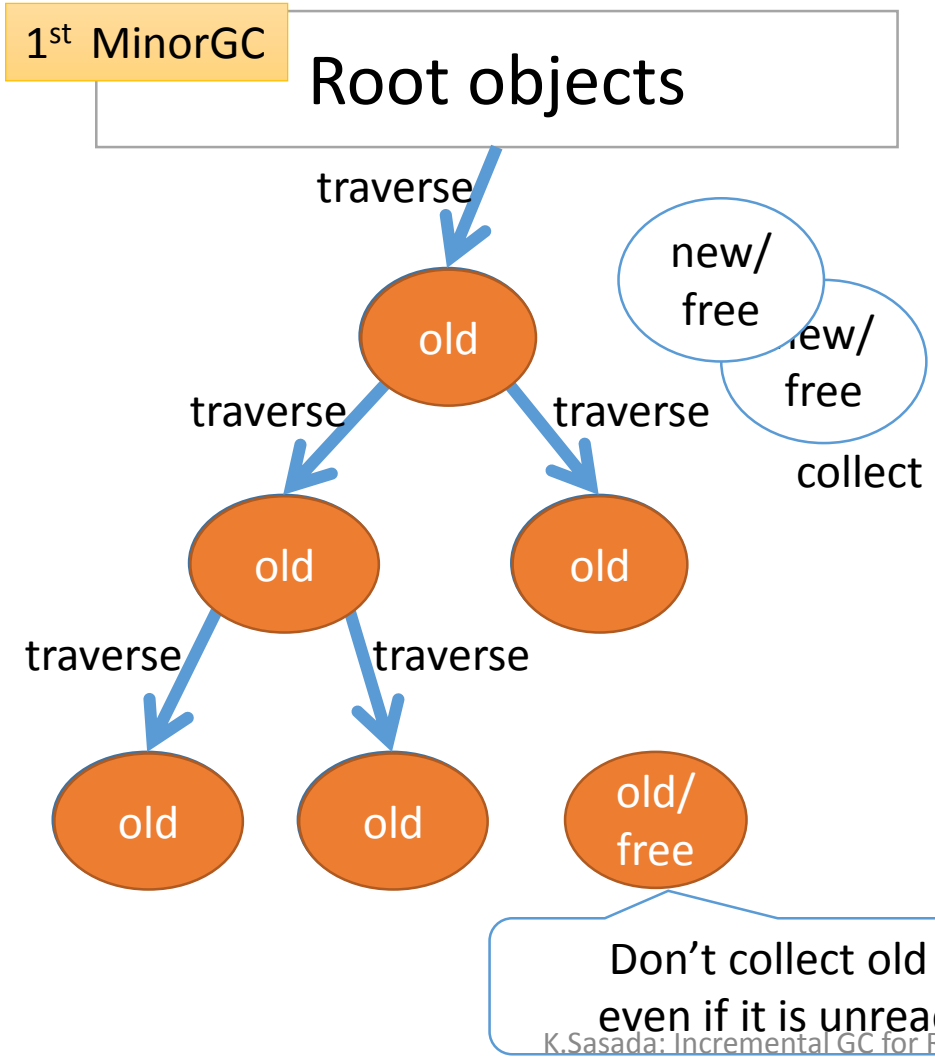
→ Concentrate reclamation effort only on the young objects

Since Ruby 2.1
RGenGC

- Separate young generations and old generations
  - Create objects as youngest generation
  - Promote to old generations after surviving GCs
- Many minor GC and rare major GC
  - Usually, GC on only young space (minor GC)
  - GC on both spaces if no memory (major/full GC)

→ ***Improve total throughput***

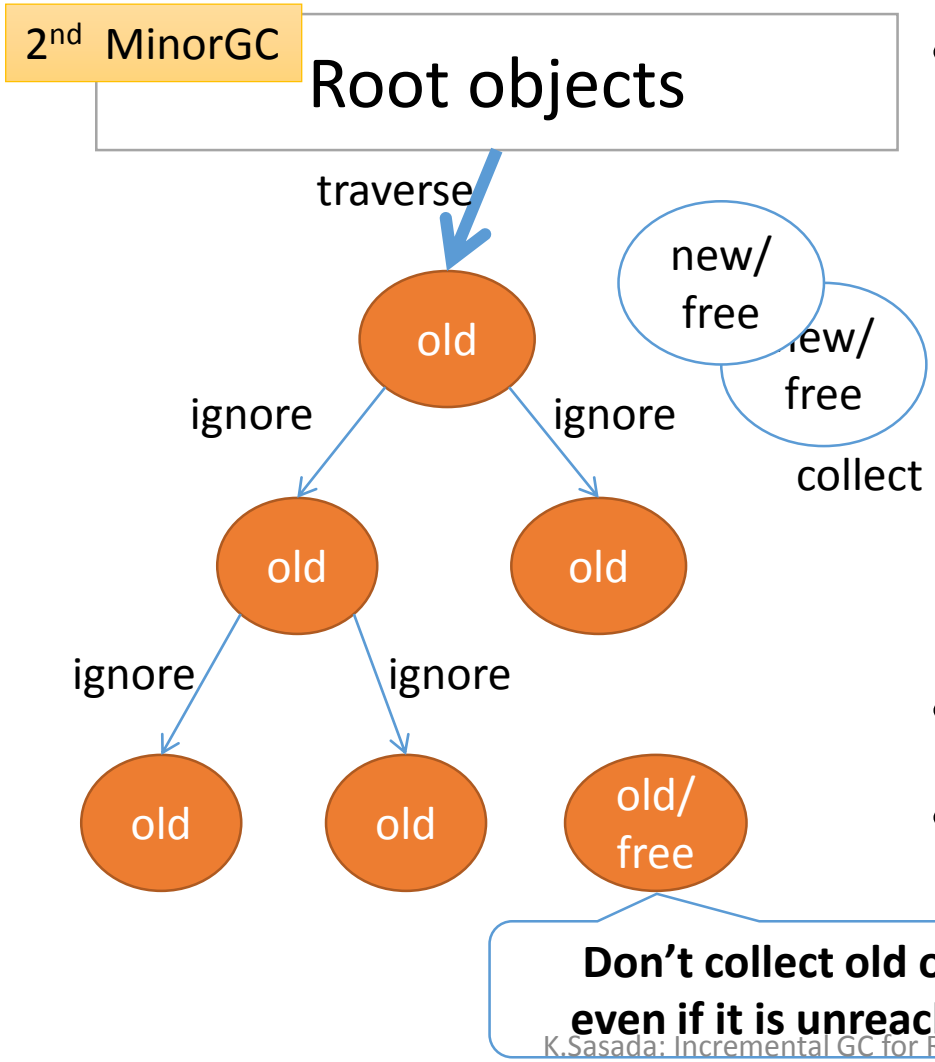
Since Ruby 2.1
RGenGC [Minor M&S GC]



- Mark reachable objects from root objects.
  - Mark and **promote to old generation**
  - Stop traversing after old objects

    → Reduce mark overhead
- Sweep not (marked or old) objects
- Can't collect Some unreachable objects

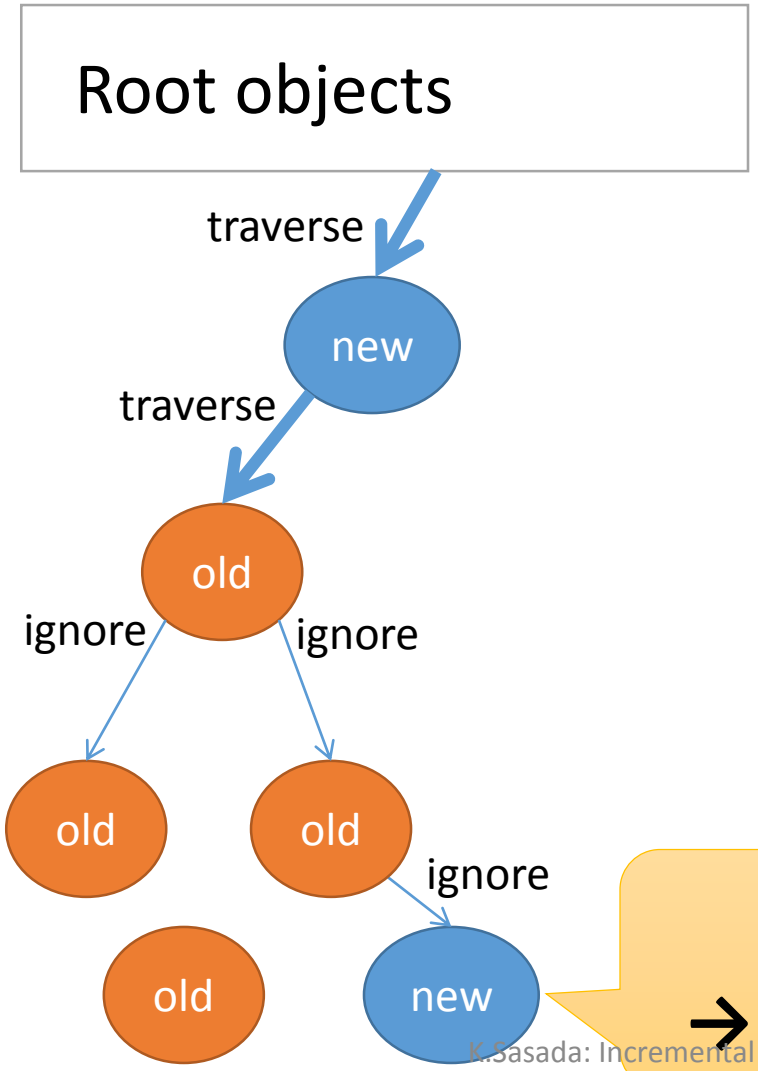
Since Ruby 2.1
RGenGC [Minor M&S GC]



- Mark reachable objects from root objects.
  - Mark and **promote to old generation**
  - **Assumption: "Old objects only refer old objects"**
  - Stop traversing after old objects

  → Reduce mark overhead
- Sweep not (marked or old) objects
- Can't collect Some unreachable objects

Since Ruby 2.1
RGenGC [Remember set]



- **Assumption: “Old objects only refer old objects”**
- However **old objects can refer young objects** by adding reference from old to new objects

→ Ignore traversal of old object

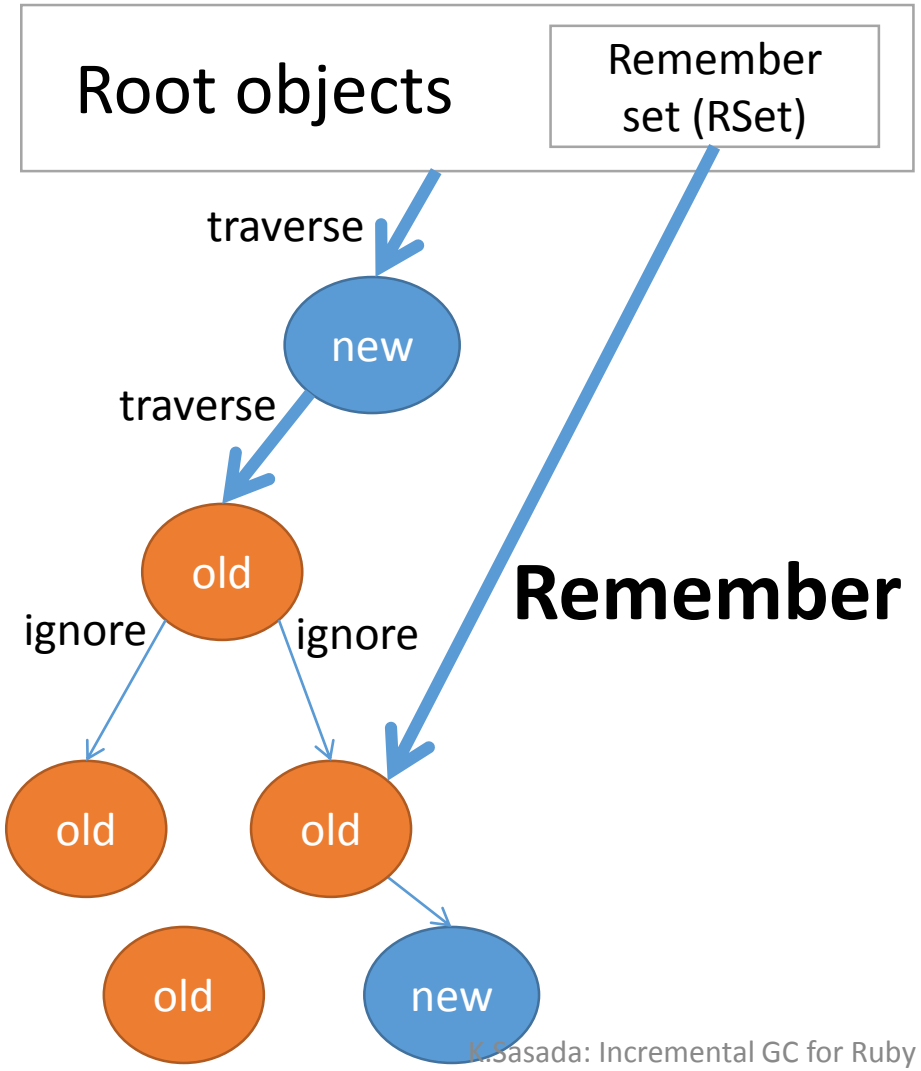
→ Minor GC causes marking leak!!

- Because minor GC ignores referenced objects by old objects

Can’t mark new object!

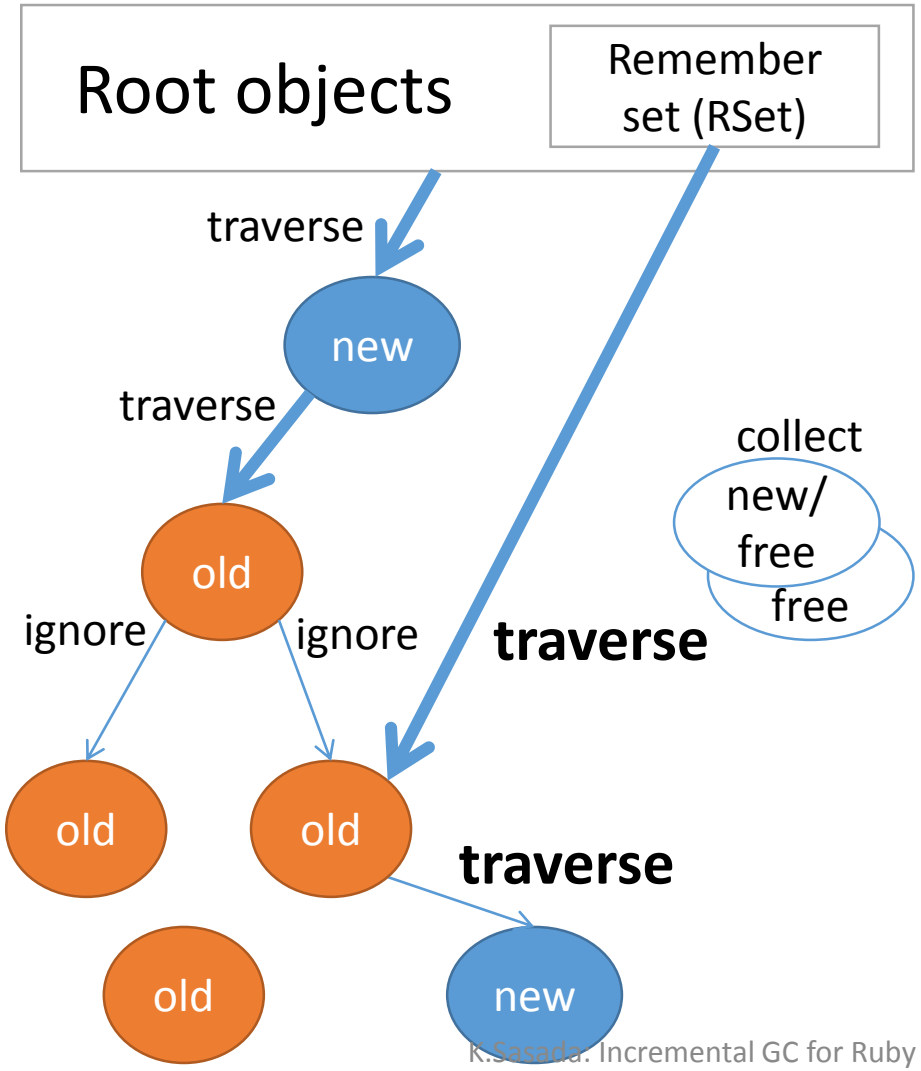
→ Sweeping living object! (Critical BUG)

Since Ruby 2.1
RGenGC [Remember set]



1. **Detect** creation of an [old->new] type reference
2. Add an [old object] into **Remember set (RSet)** if an old object refer new objects

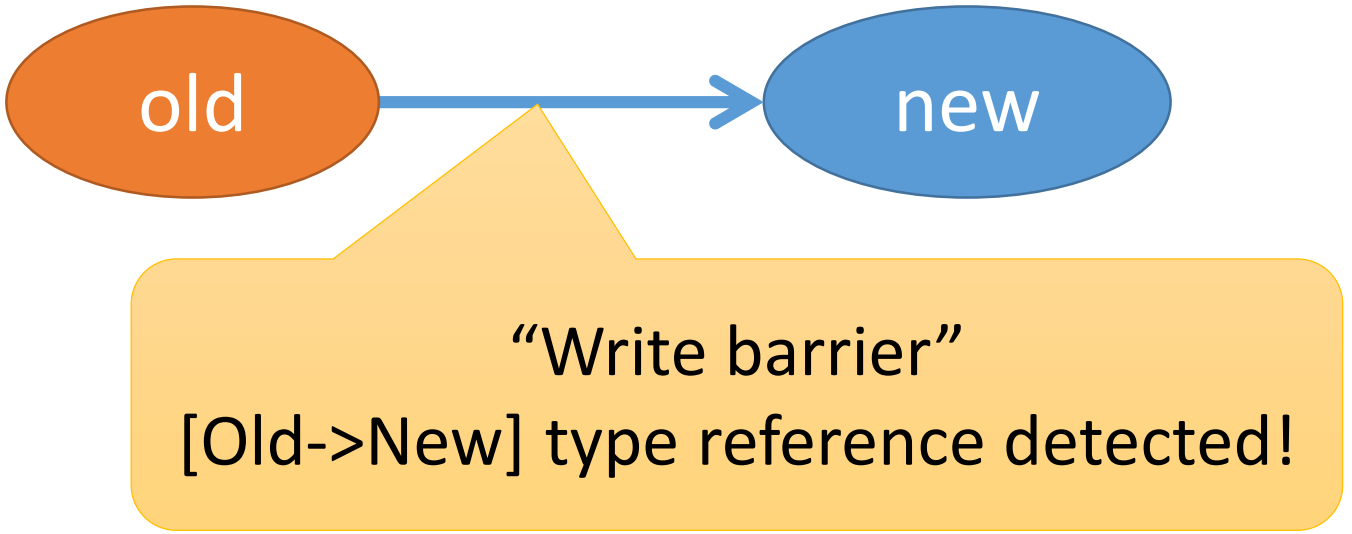
Since Ruby 2.1
RGenGC [Remember set]



1. Mark reachable objects from root objects
   - **<u>Remembered objects are also root objects</u>**
2. Sweep not (marked or old) objects

Since Ruby 2.1
RGenGC [Write barrier]

- To detect [old→new] type references, we need to insert **“Write-barrier”** into interpreter for all “Write” operation



Since Ruby 2.1
RGenGC: Challenge

- Trade-off of Speed and Compatibility
  - Introducing “Write barriers” completely is very hard
  - Can we achieve both **speed-up w/ GenGC** and **keeping compatibility?**

Since Ruby 2.1
RGenGC: Key idea

Introduce

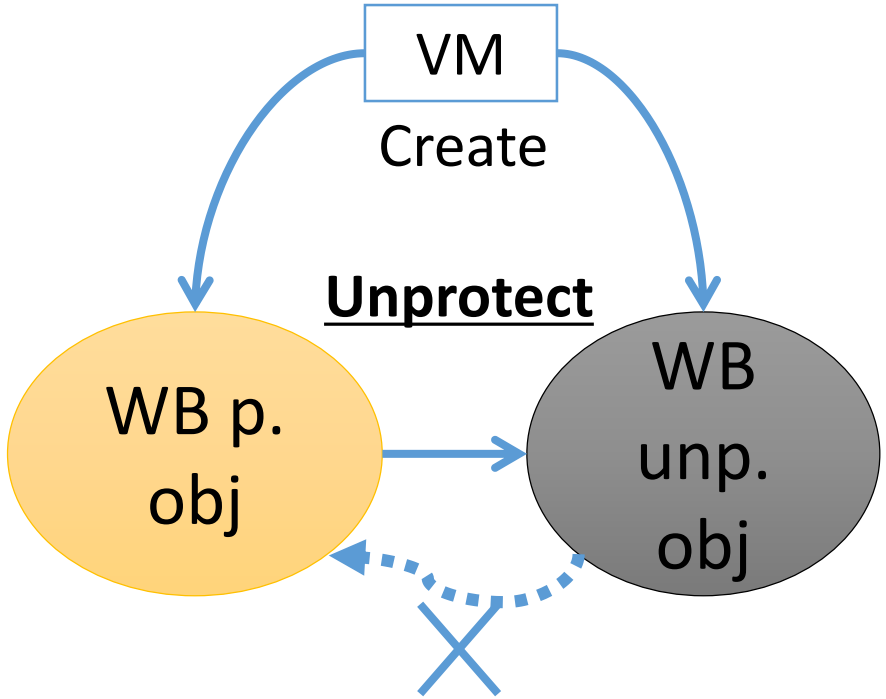
WB unprotected objects

Since Ruby 2.1
RGenGC: **Key idea**

- Separate objects into two types
  - WB protected objects
  - WB unprotected objects
- Decide this type at creation time
  - A class care about WB → WB protected object
  - A class don't care about WB → WB unprotected object

Since Ruby 2.1
RGenGC: **Key idea**

- Normal objects can be changed to WB unprotected objects
  - “WB unprotect operation”
  - C-exts which don’t care about WB, objects will be WB unprotected objects
  - Example
    - ptr = RARRAY_PTR(ary)
    - In this case, we can’t insert WB for ptr operation, so VM shade “ary”

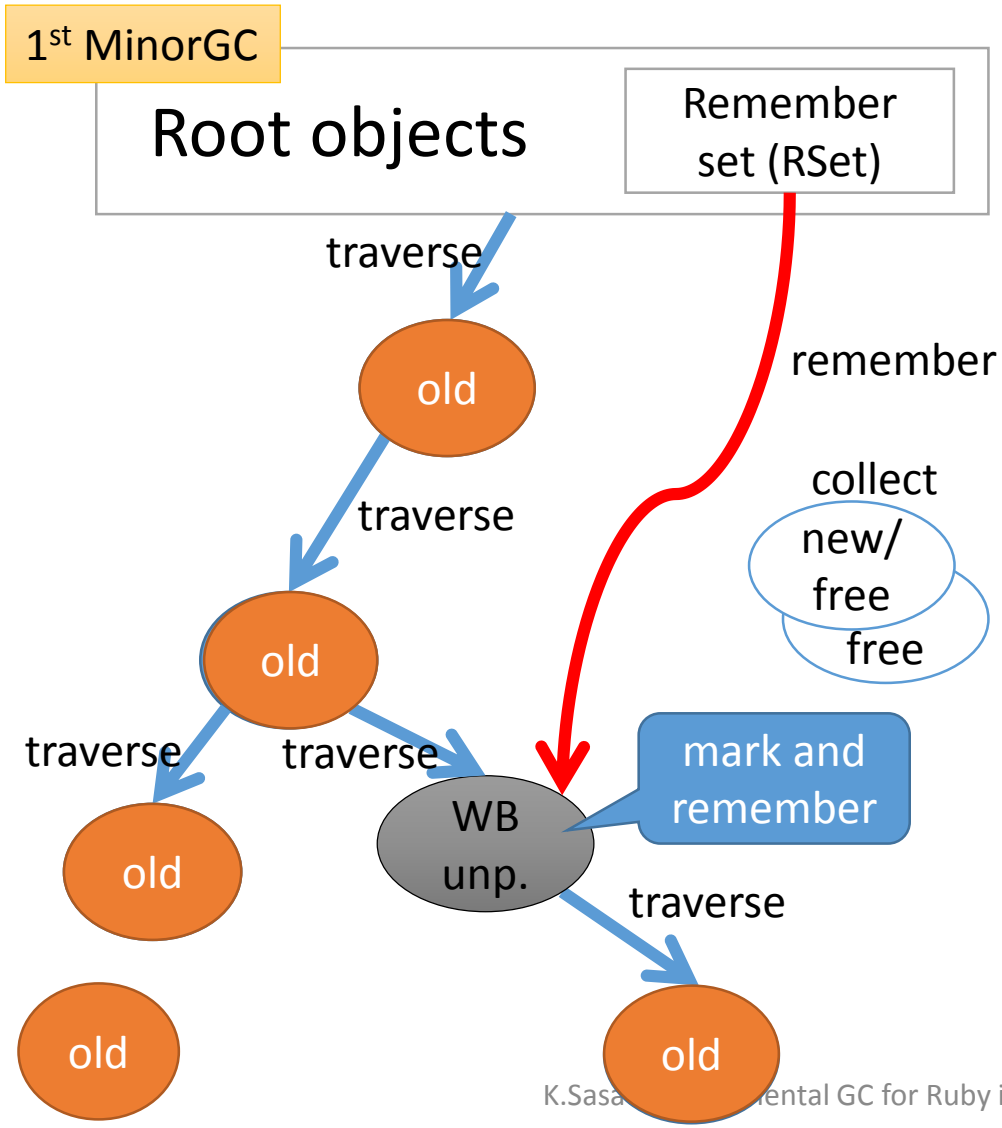


Now, WB unprotected object **can’t** change into WB p. object

Since Ruby 2.1
RGenGC: Rules

- Treat “WB unprotected objects” correctly
  - At Marking
  1. Don’t promote WB unprotected objects to old objects
  2. Remember WB unprotected objects pointed from old objects
  - At WB unprotect operation for old WB protected objects
  1. Demote objects
  2. Remember this unprotected objects

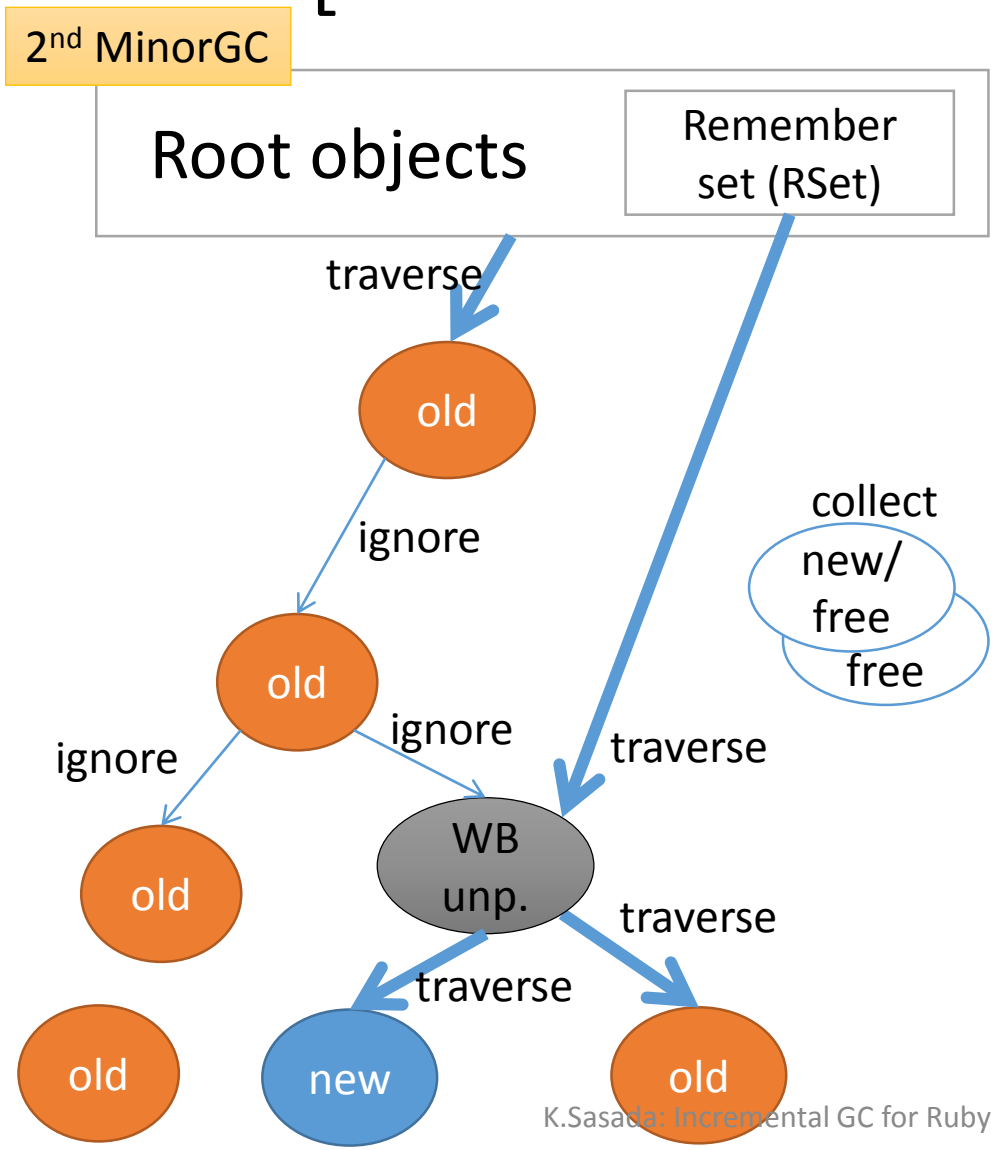
Since Ruby 2.1
RGenGC: [Minor M&S GC w/WB unp. objects]



- Mark reachable objects from root objects
  - Mark WB unprotected objects, and ***don't promote*** them to old gen objects
  - If WB unprotected objects **pointed from old objects**, then **remember this WB unprotected objects** by RSet.

    → Mark WB unprotected objects every minor GC!!

Since Ruby 2.1
RGenGC: [Minor M&S GC w/WB unp. objects]



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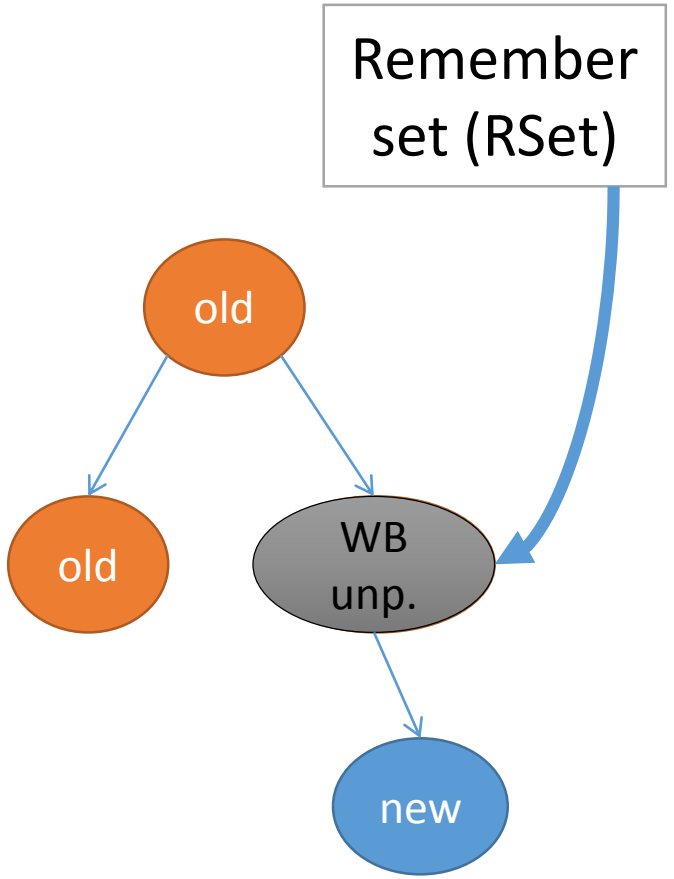
Since Ruby 2.1
RGenGC: [Unprotect operation]



- Anytime Object can give up to keep write barriers

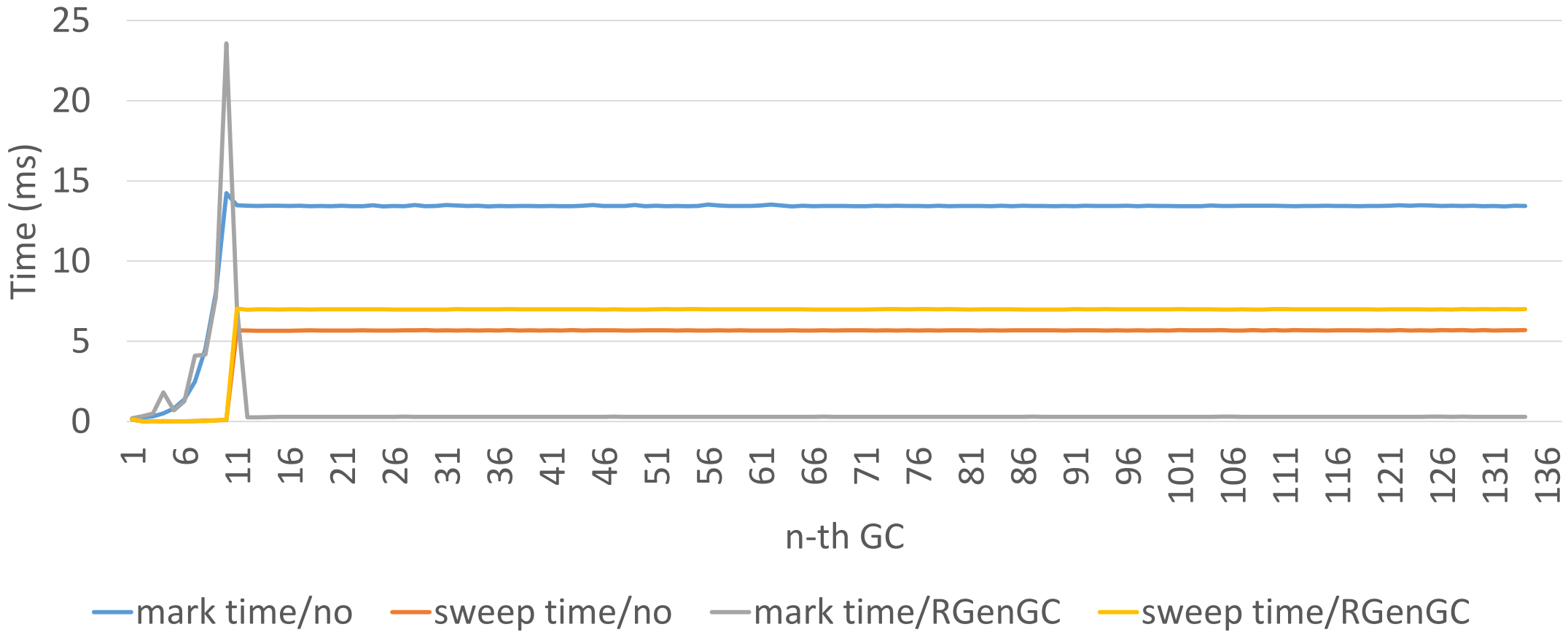
  → [Unprotect operation]

- Change old WB protected objects to WB unprotected objects
  - Example: RARRAY_PTR(ary)

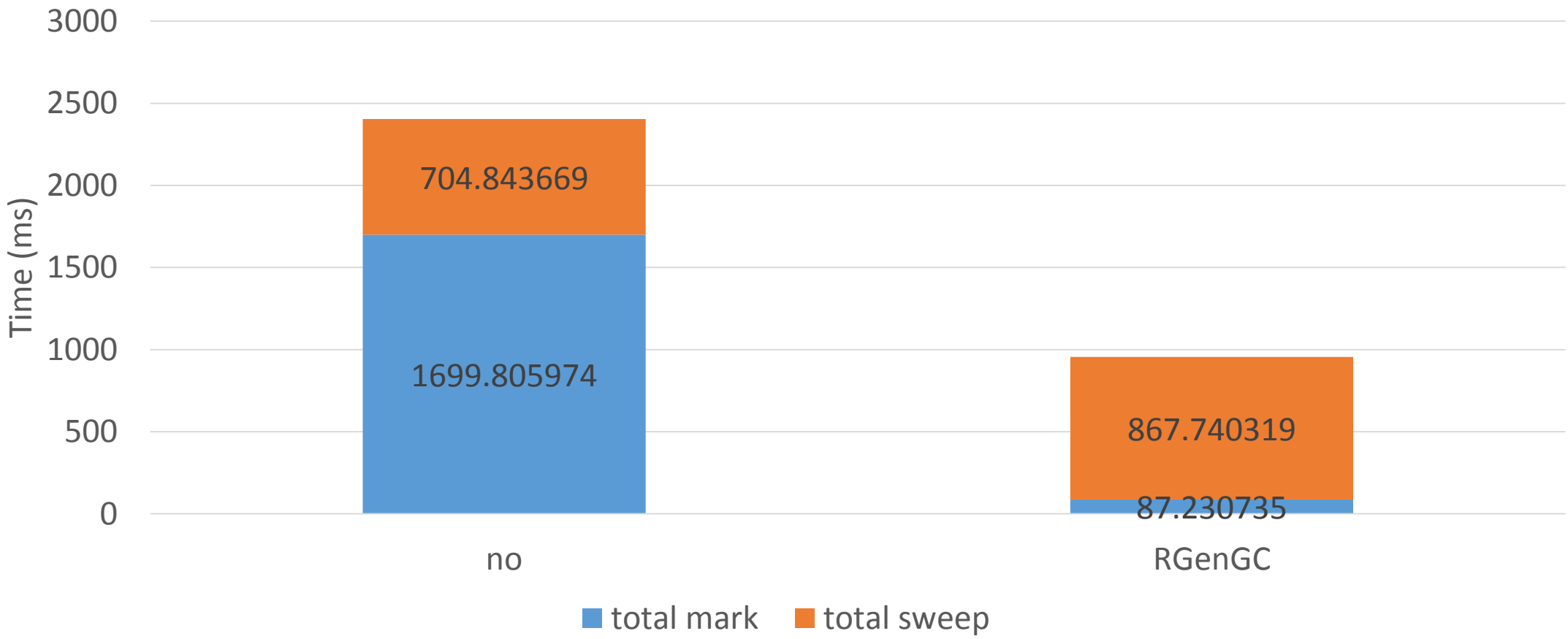
  (1) Demote object (old → new)

  (2) Register it to Remember Set

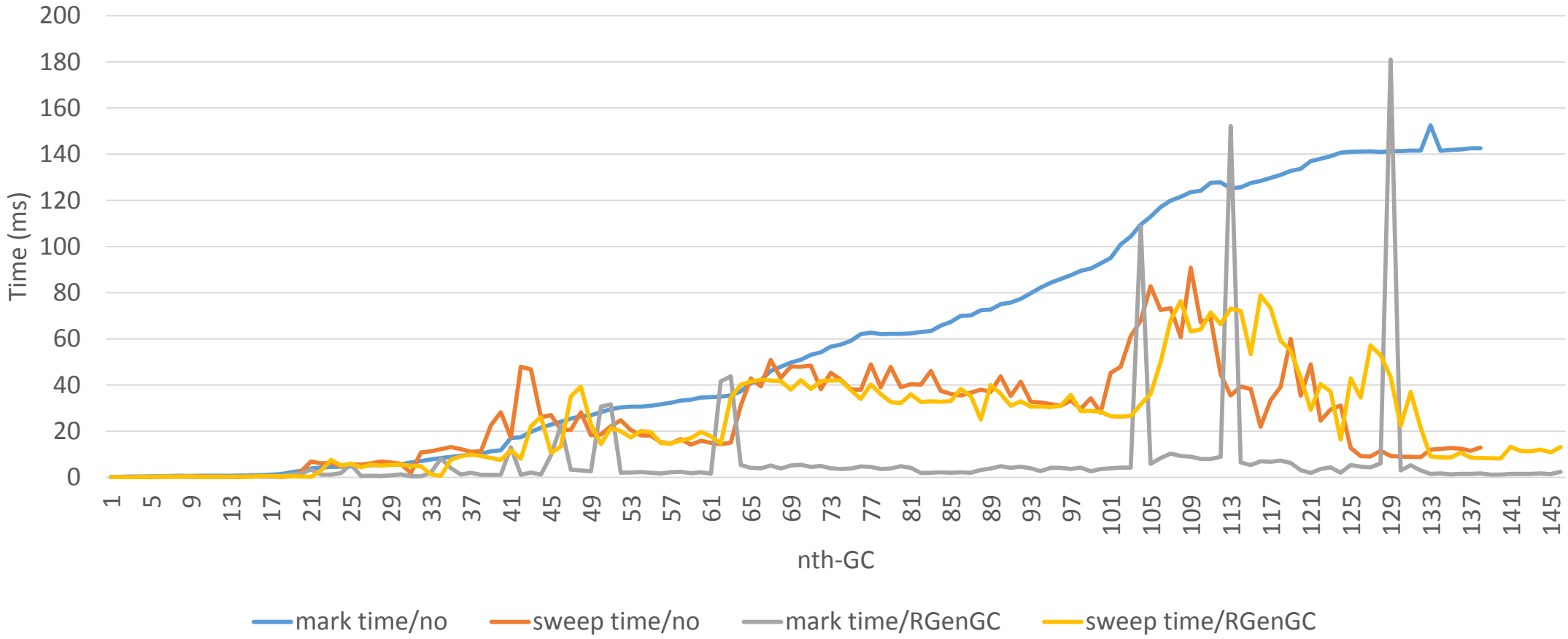
RGenGC: Micro-benchmark



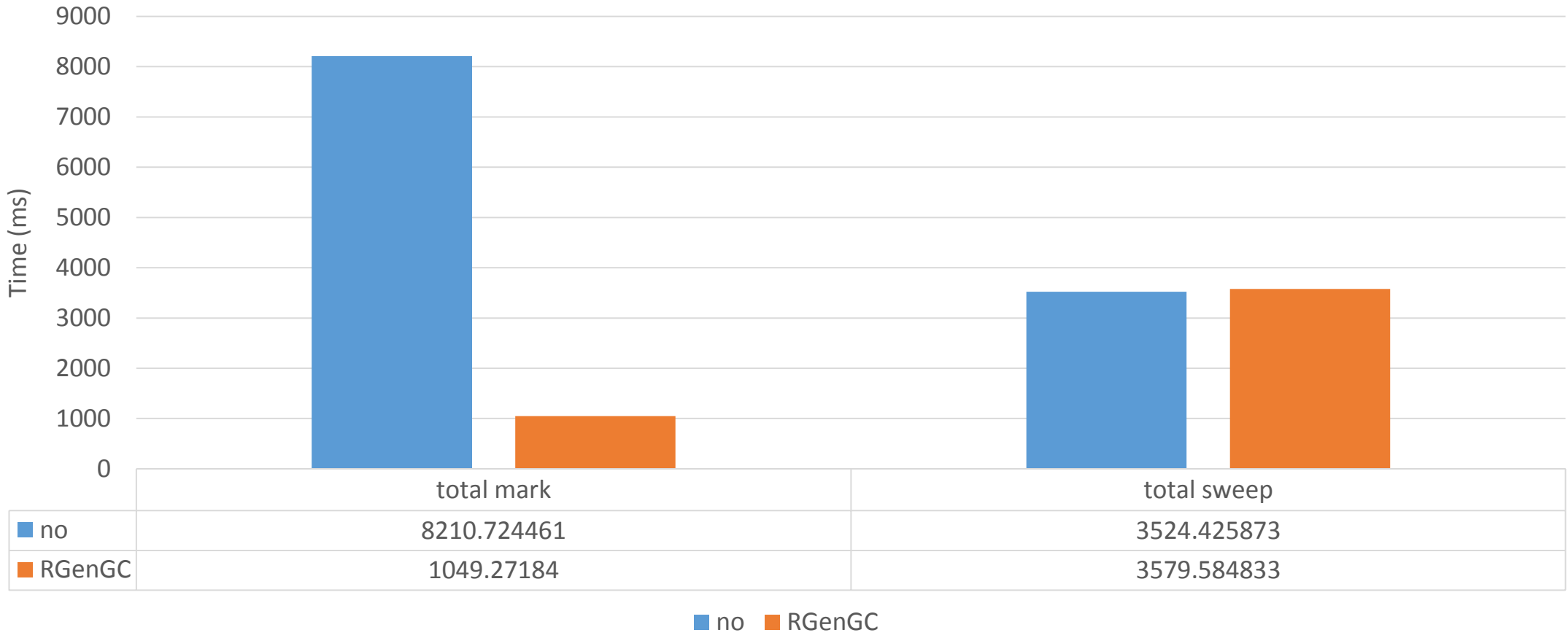
RGenGC: Micro-benchmark



RGenGC: Rdoc application

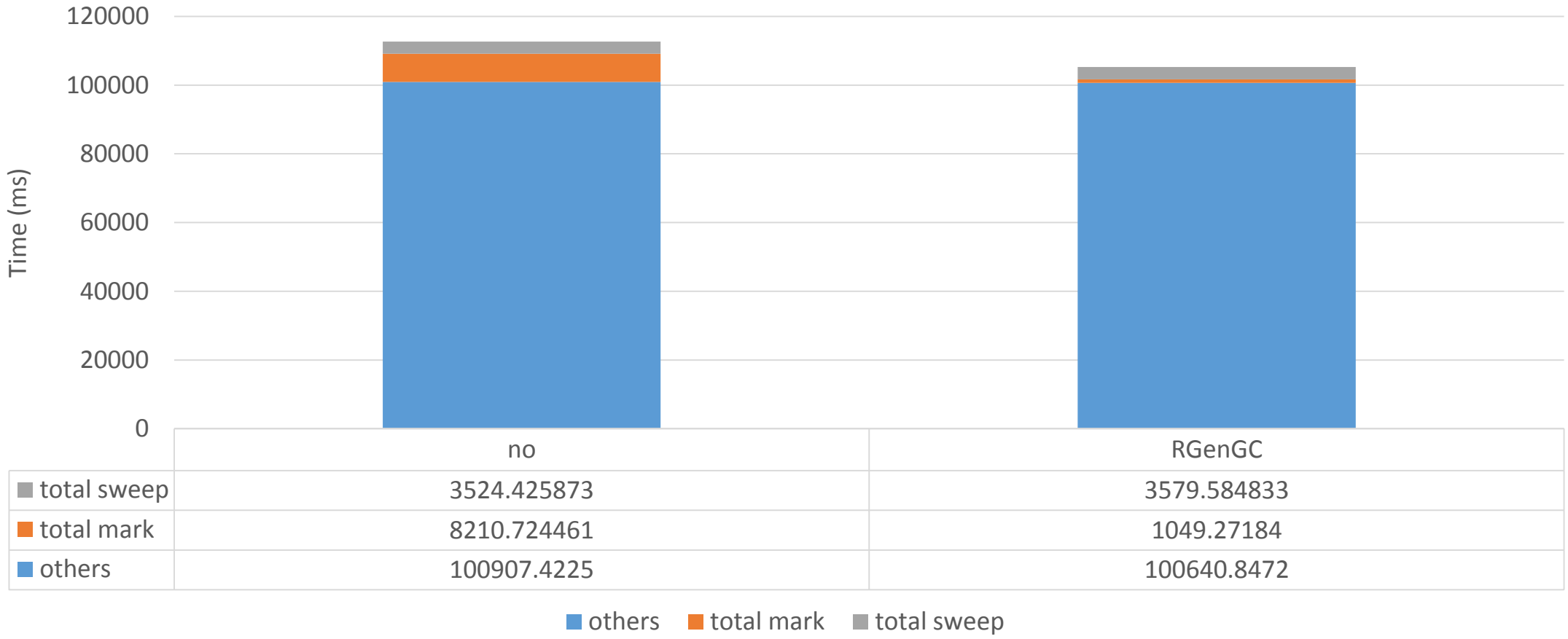


RGenGC: Rdoc application

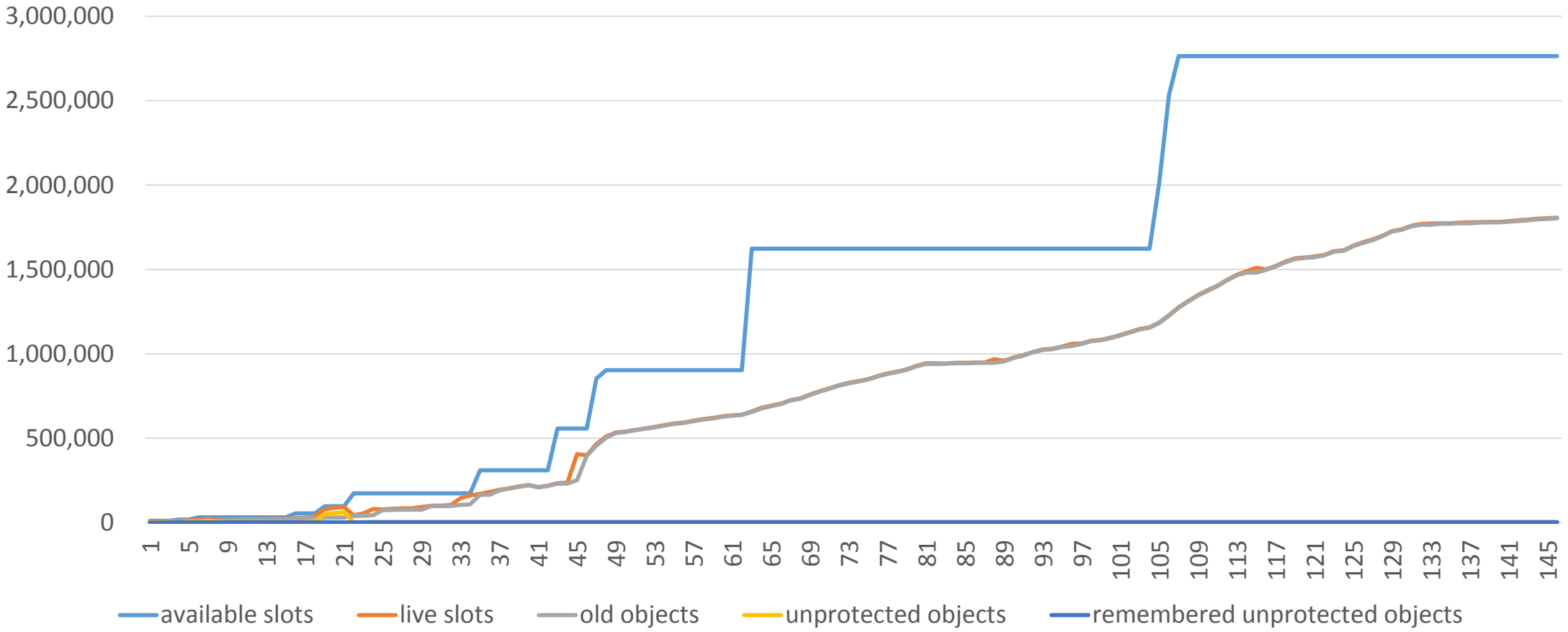


	total mark	total sweep
no	8210.724461	3524.425873
RGenGC	1049.27184	3579.584833

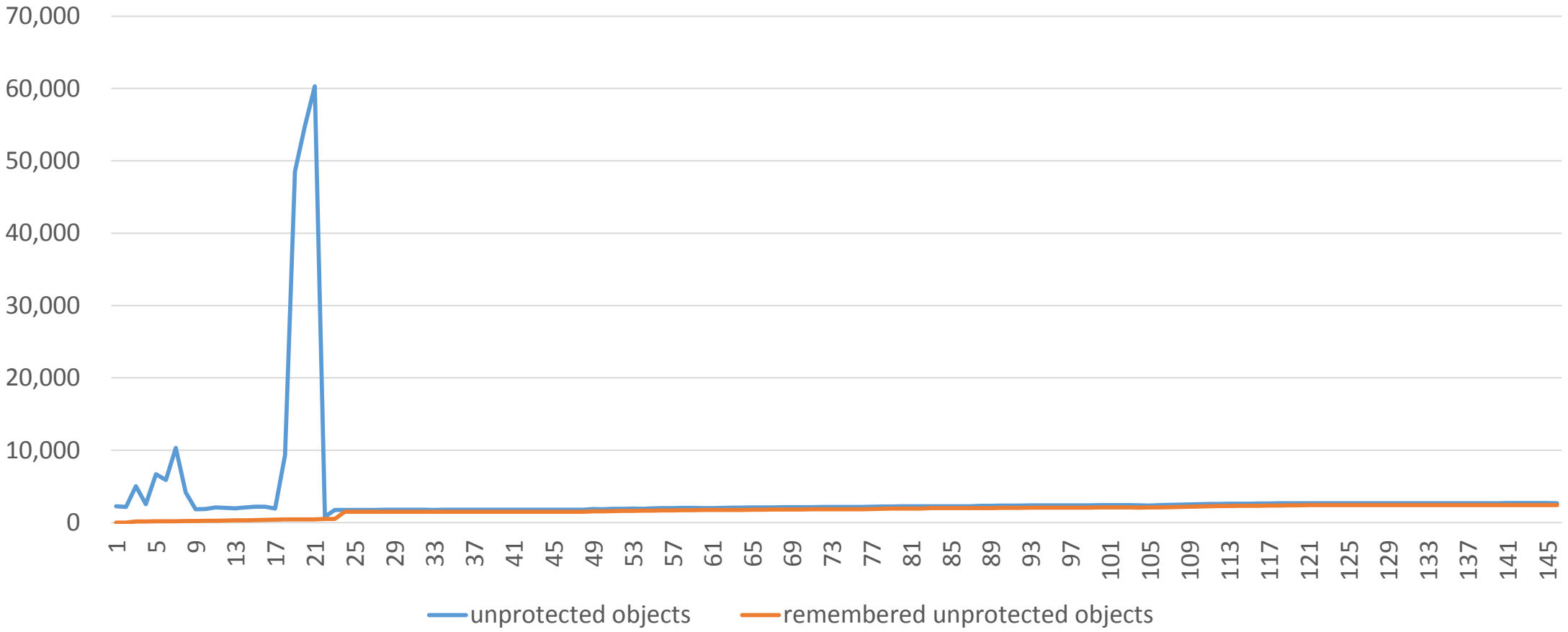
RGenGC: Rdoc application



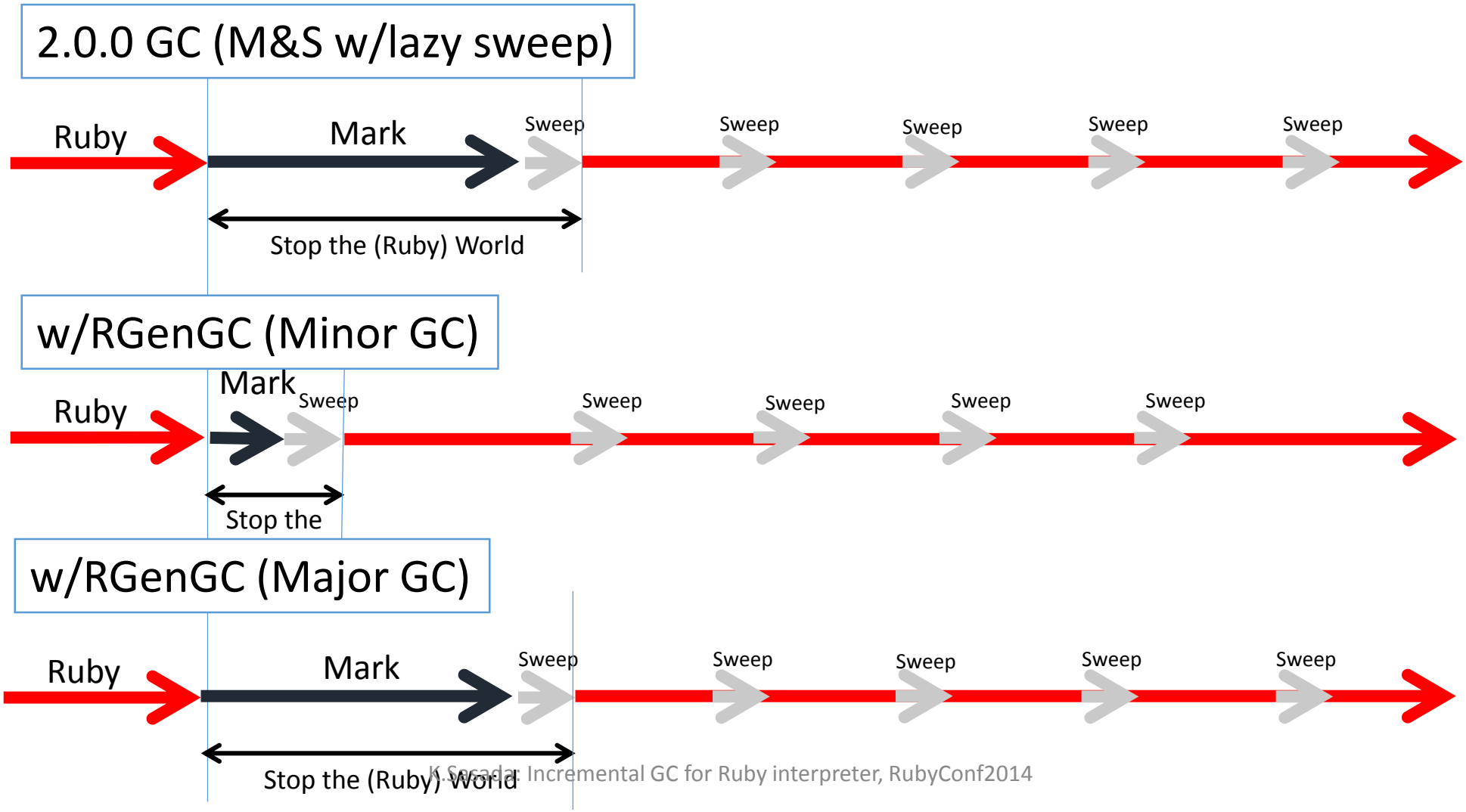
RGenGC: Rdoc application



RGenGC: Rdoc application



Since Ruby 2.1
RGenGC timing chart



Issue of RGenGC: Long pause time

☺ RGenGC achieves ***high throughput***

☺ Minor GC stops only ***short pause time***

☹ Major GC still stops ***long pause time***

→ ***Introducing Incremental GC for major GC***

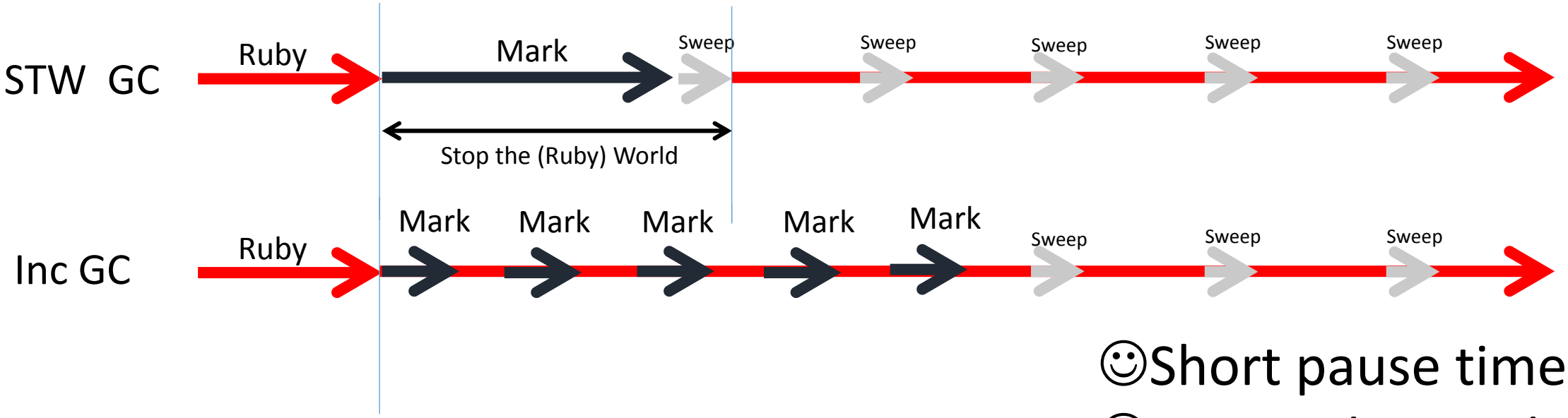
	Generational GC	Incremental GC	Gen+Inc GC
Throughput	**High**	**Low**	**High**
Pause time	**Long**	**Short**	**Short**

RincGC: Restricted Incremental GC algorithms

RincGC algorithm is implemented for Ruby 2.2.

Incremental GC
Well-known GC algorithm to reduce pause time

- Do GC steps incrementally
  - Interleaving with Ruby's execution (mutator) and GC process.
  - Lazy sweep is part of an incremental GC



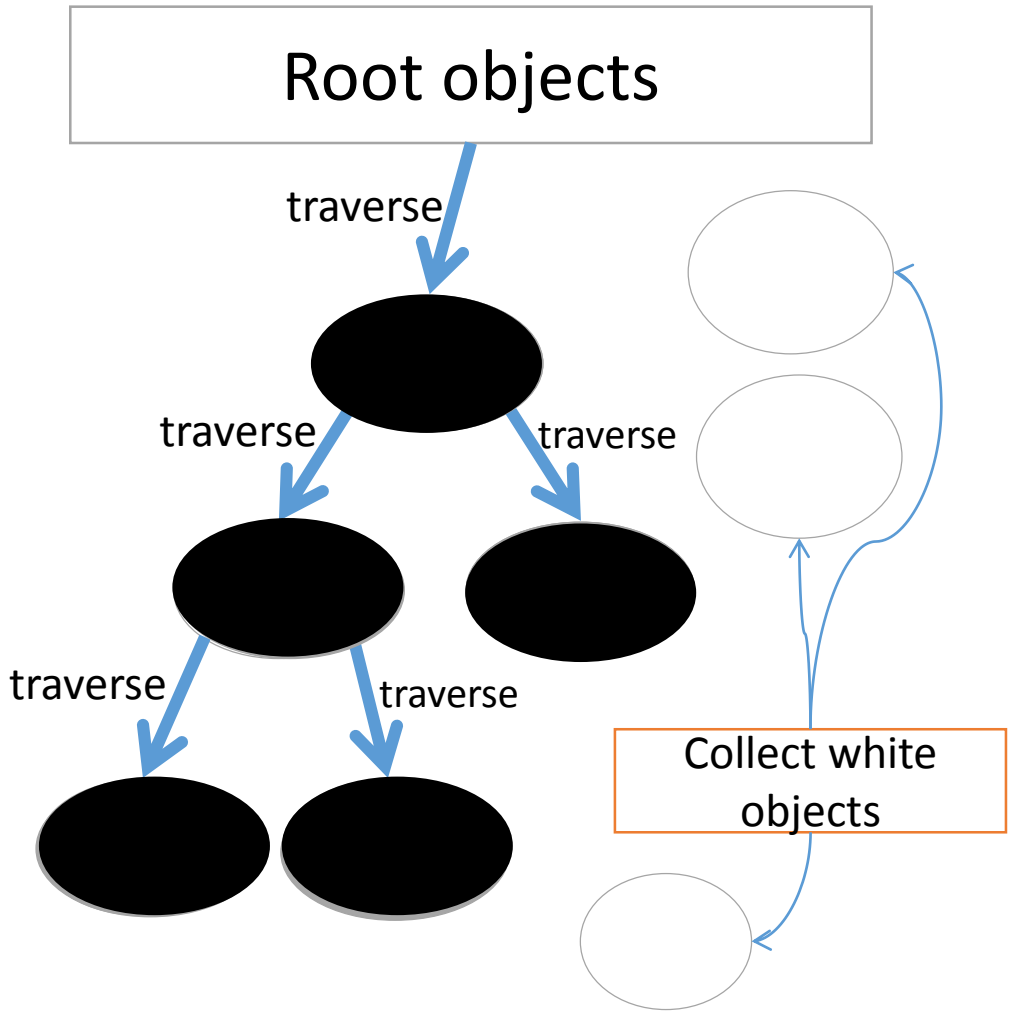
☺Short pause time

😐 No total time change

Terminology: Tri-color GC

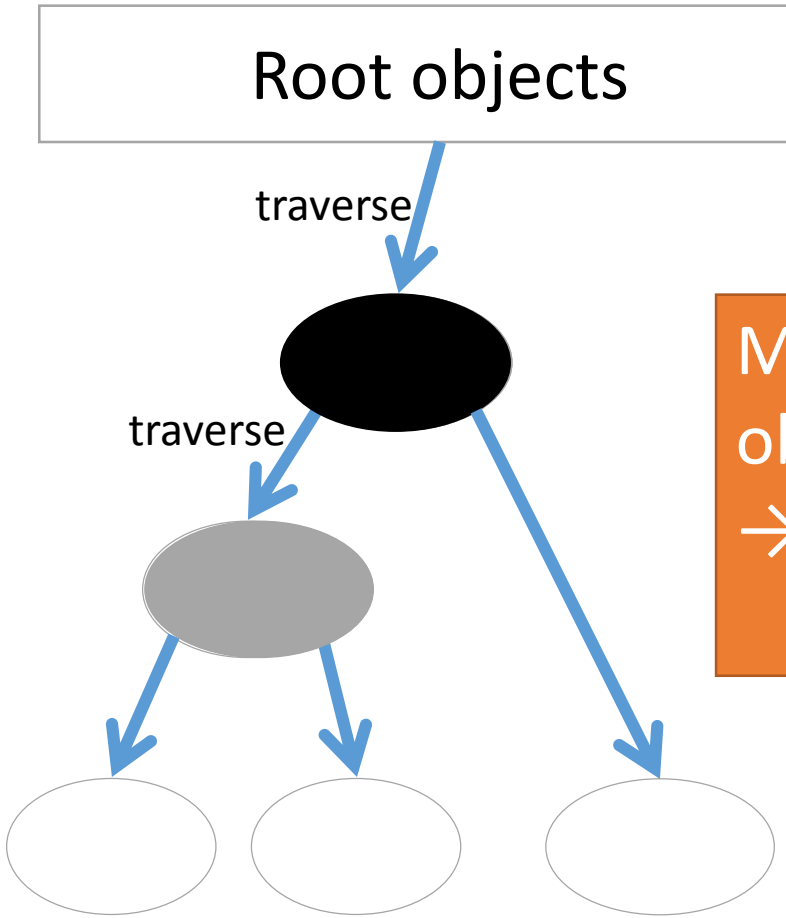
- Define three colors for objects
  - White objects is not traversed objects
  - Grey objects are marking objects
  - Black objects are marked objects

Incremental GC



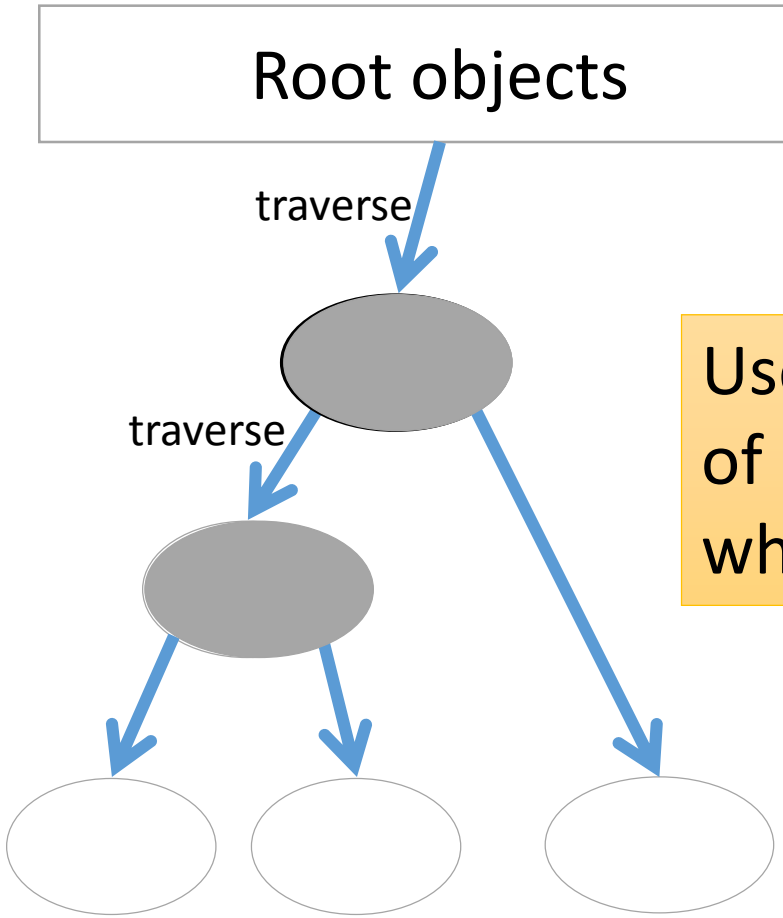
1. Color all objects “white”
2. Grey root objects
3. Choose a grey object and grey all reachable white objects, and black the chosen object (incremental marking)
4. Finish marking when no grey objects
5. Sweep white objects as ***unmarked*** objects

Incremental GC requires WBs



Mutator can add reference from a Black object to a white object!!
→ Mark miss!
No more traversal from black objects

Incremental GC requires WBs



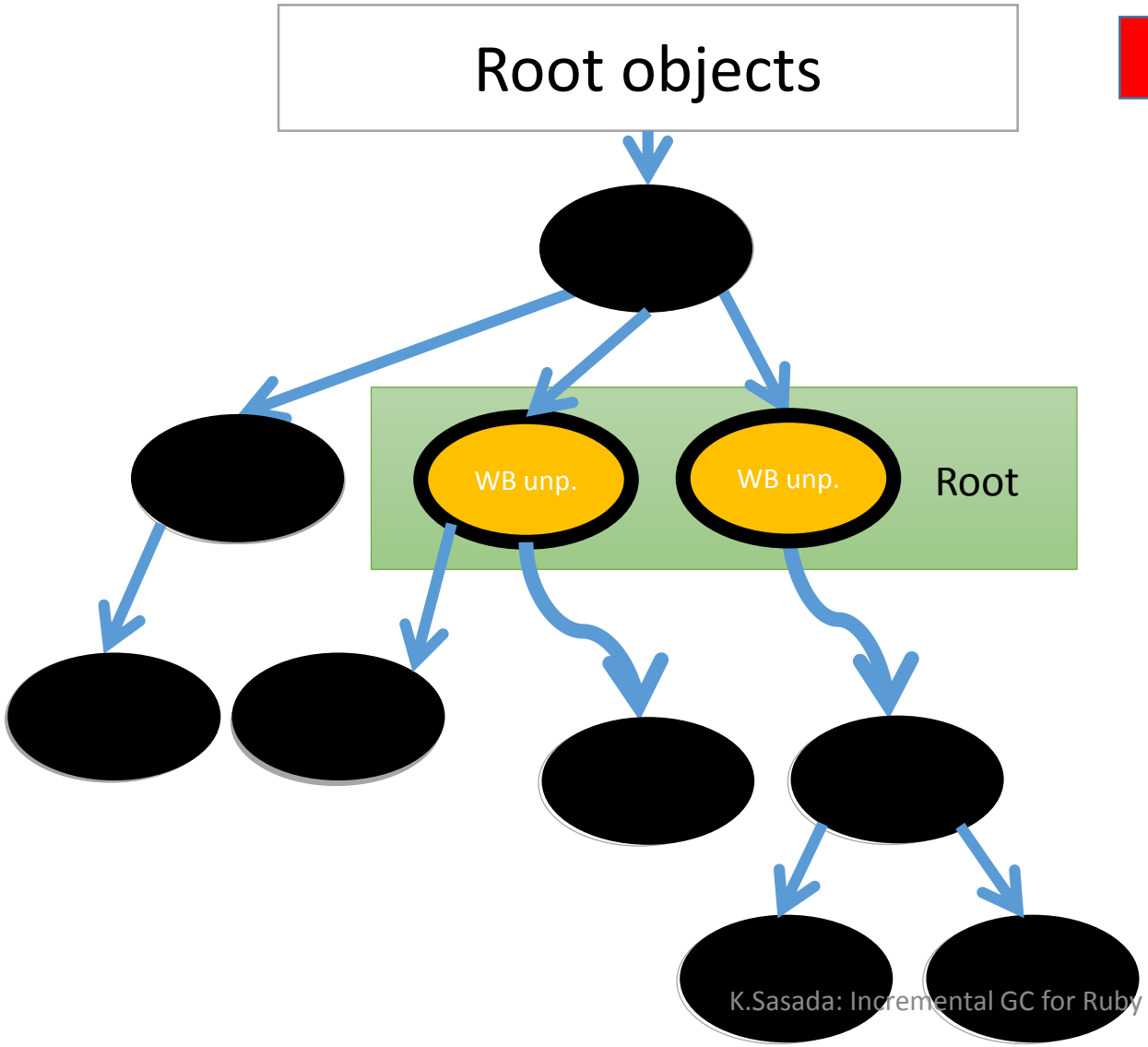
Use write barrier to detect an addition of references from black objects to white objects, and grey black objects

RincGC: Restricted Incremental GC using WB-unprotected objects

- Use WB unprotected objects like RGenGC
- Introducing a new rule: **“Scan all black WB unprotected objects at the end of incremental GC at once”**
  - WB unprotected objects can point white objects
  - Scan from **all** (“Black” **and** “WB unprotected objects”) at once (stop the world marking)

RincGC

Restricted Incremental GC
using WB-unprotected objects



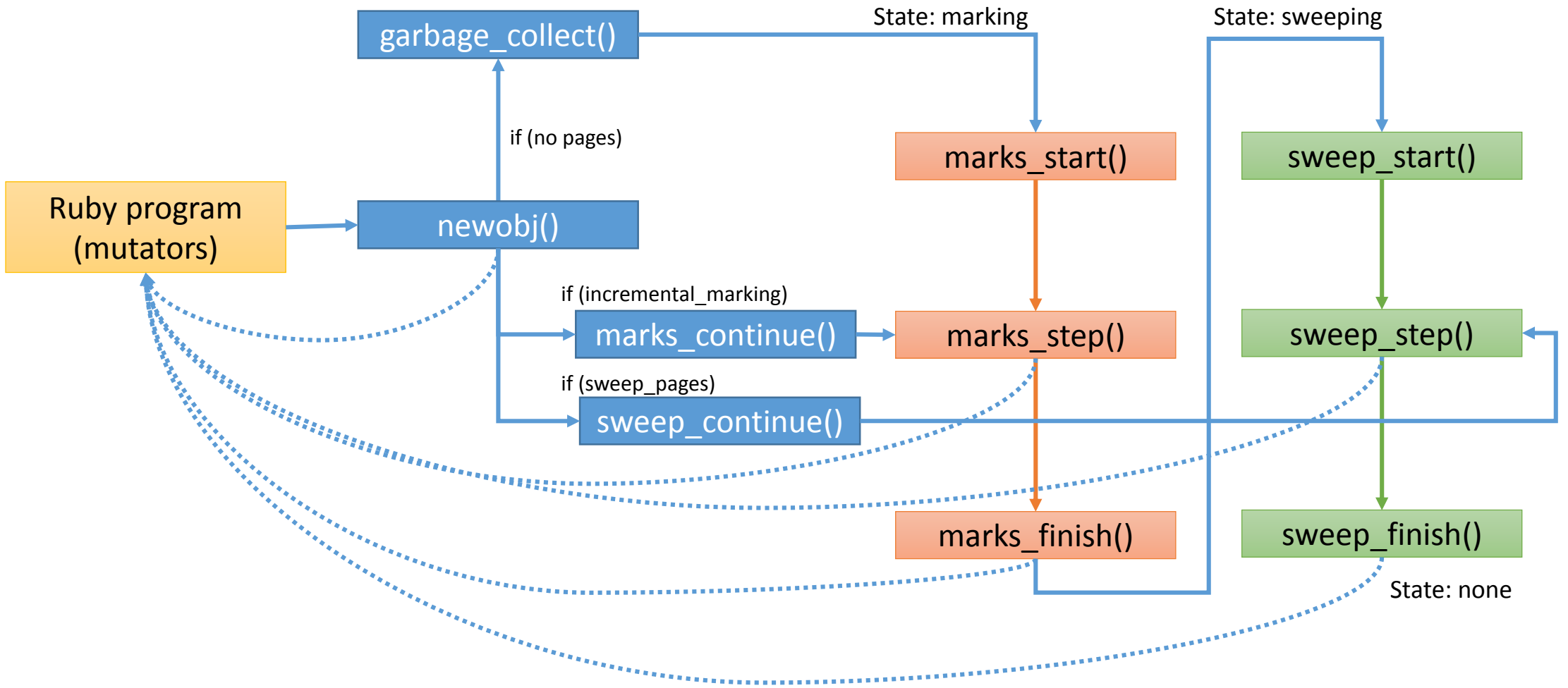
1. Color all objects “white”
2. Grey root objects
3. Choose a grey object and grey reachable white objects, and black the chosen object (incremental marking)
4. Finish marking when no grey objects
5. **Scan all black WB unprotected objects at once**
6. Sweep white objects as *unmarked* objects

RincGC: Discussion

- Long pause time than usual incremental GC step
  - This technique can introduce long pause time, relative to the number of WB unprotected objects at last. This is why this algorithm is named “Restricted”
  - Similar/shorter pause time than “Minor GC” of RGenGC.

Implementation

Ruby's implementation
State chart



Ruby's implementation
WB protected/unprotected

- Make popular class instances WB protected
  - String, Array, Hash, and so on
- Implement "unprotect operation" for Array and so on
- Remain WB unprotected objects
  - Difficult to insert WBs: a part of Module, Proc (local variables) and so on.
  - Minor features

Ruby's implementation
Data structure

- Introduce 2 bits age information to represent young and old objects
  - Age 0, 1, 2 is young object
  - Age 3 is old object
  - Surviving 1 GC increase one age
- Add 3 bits information for each objects (we already have mark bit)
  - WB unprotected bit
  - Long lived bit (old objects or remembered WB unprotected objects)
  - Remembered old object bit / Marking (Grey) bit
    - They can share 1 bit field because the former is used only at minor GC and the latter is used only at major GC (incremental GC)

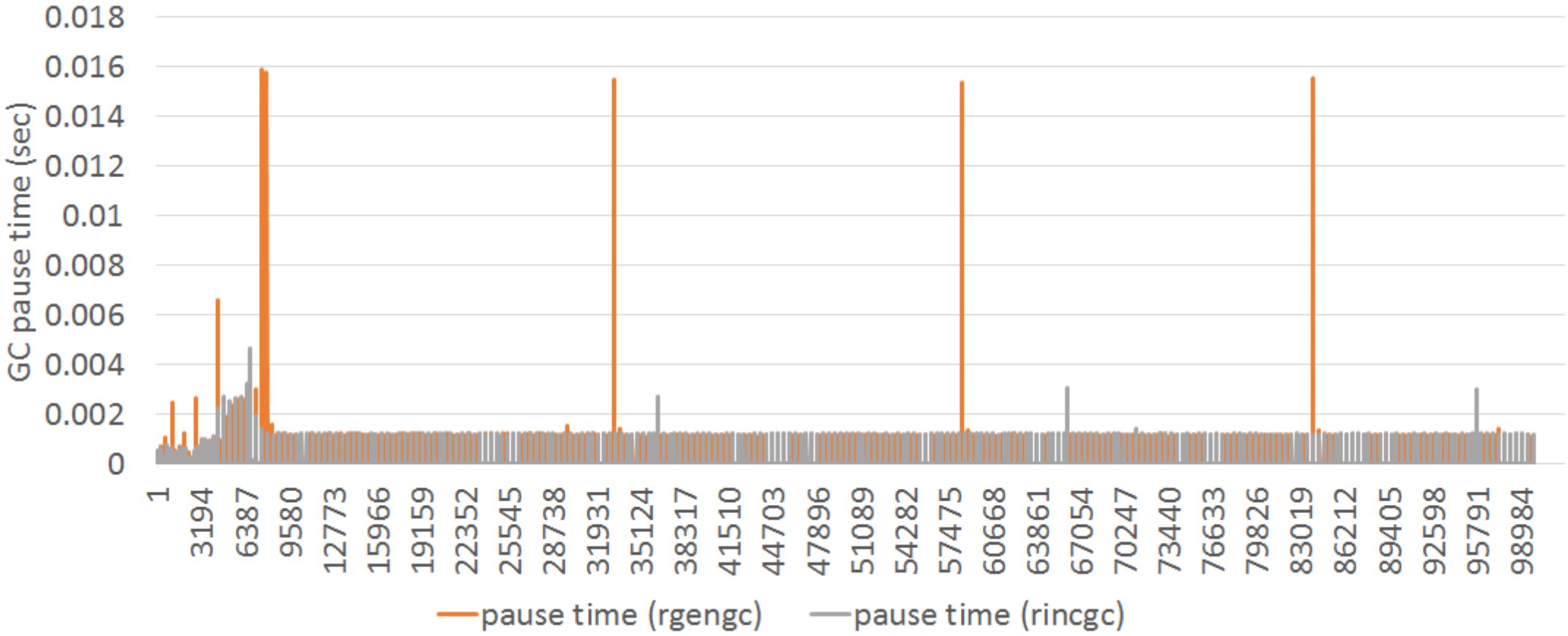
Ruby's implementation
Bitmap technique

- Each bits are managed by bitmap technique
  - Easy to mange remember set
  - Fast traversing
  - Easy to get a set
    - Remember set: (Remembered old object bitmap) | (Long lived bitmap & WB unp. Bitmap)
    - Living unprotected objects: (mark bitmap & WB unprotected bitmap)

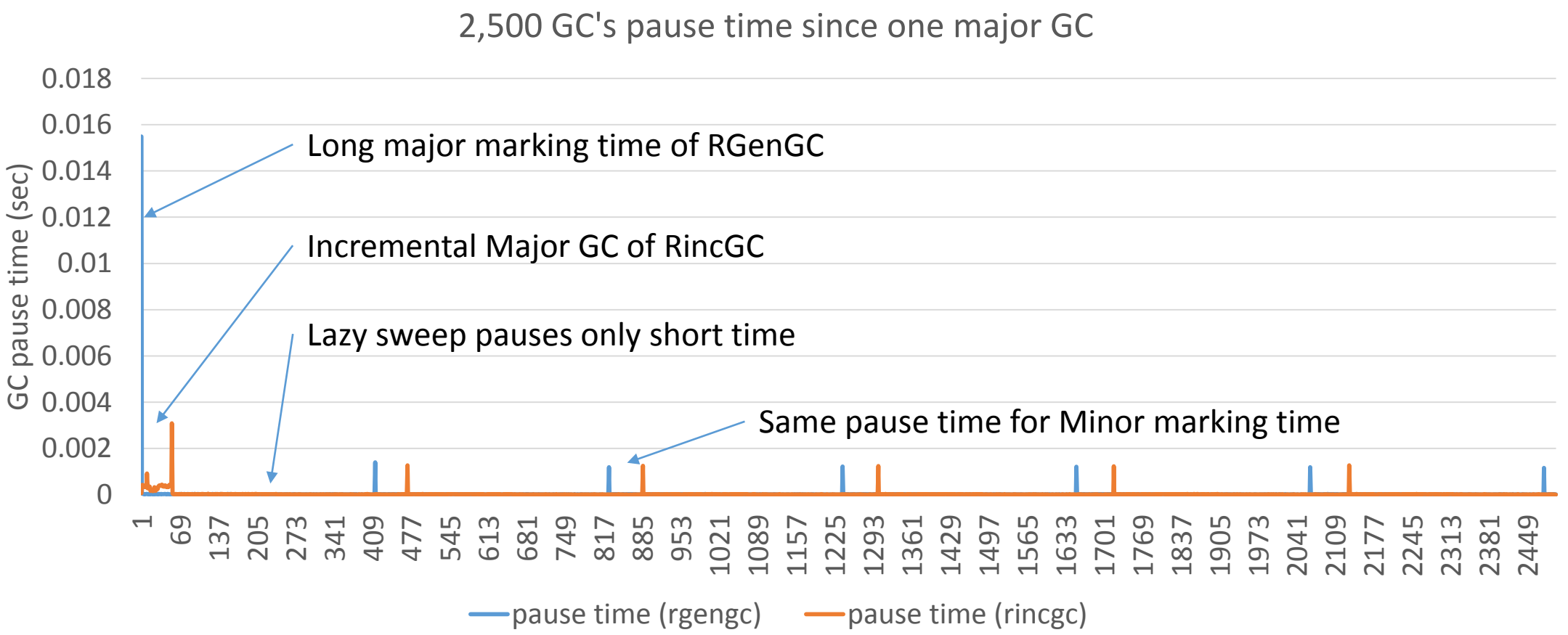
RincGC: Evaluation

- Measure pause times for <https://github.com/tenderlove/ko1-test-app> by Aaron Patterson

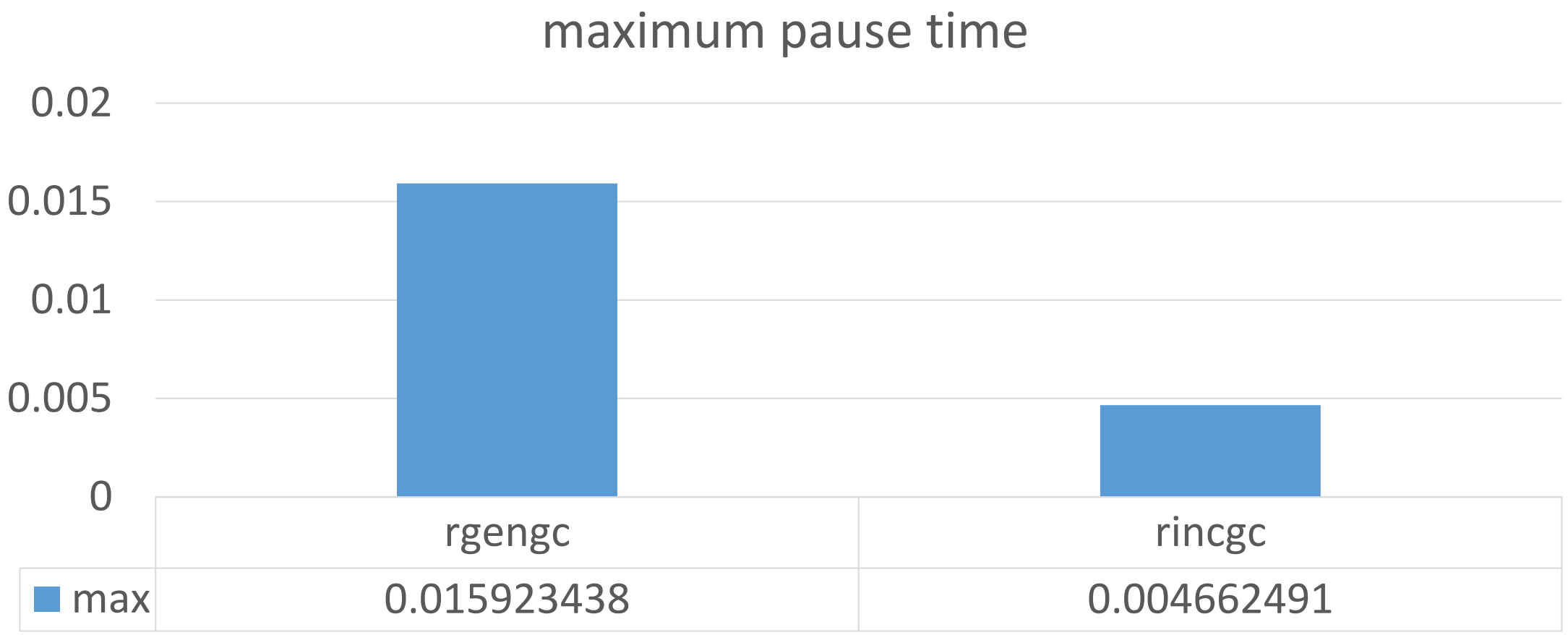
Evaluation


GC pause time (sec)
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
1
3194
6387
9580
12773
15966
19159
22352
25545
28738
31931
35124
38317
41510
44703
47896
51089
54282
57475
60668
63861
67054
70247
73440
76633
79826
83019
86212
89405
92598
95791
98984
pause time (rgengc)
pause time (rincgc)

Evaluation


2,500 GC's pause time since one major GC
GC pause time (sec)
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Long major marking time of RGenGC
Incremental Major GC of RincGC
Lazy sweep pauses only short time
Same pause time for Minor marking time
1
69
137
205
273
341
409
477
545
613
681
749
817
885
953
1021
1089
1157
1225
1293
1361
1429
1497
1565
1633
1701
1769
1837
1905
1973
2041
2109
2177
2245
2313
2381
2449
pause time (rgengc)
pause time (rincgc)

Evaluation


maximum pause time
0.02
0.015
0.01
0.005
0
rgengc
rincgc
max
0.015923438
0.004662491

NOTE: Incremental GC is not silver bullet

- Incremental GC does not guarantee improving your application's response time
  - Incremental GC does not reduce total GC time, so that a big task includes several major GC doesn't improve its response time.
  - Check GC counts with GC.stat(:major_gc_count) and GC.stat(:minor_gc_count) for each request.

Summary

- Introducing incremental GC algorithm into major GC to reduce long pause time
- Ruby 2.2 will have it!!

Goal

	Before Ruby 2.1	Ruby 2.1 RGenGC	Incremental GC	Ruby 2.2 Gen+IncGC
Throughput	Low	High	Low	High
Pause time	Long	Long	Short	Small

Thank you for your attention

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