Performance in the details: A way to make faster Ruby

Koichi Sasada

<ko1@heroku.com>

RailsClub 2015

A way to make faster Ruby

The only way I can find is:

Repeating a process.

A way to make faster Ruby: A process

1. Observe Ruby interpreter
2. Make assumption the reason of slowness
3. Consider ideas to overcome
4. Implement ideas
5. Measure the result
   - Bad/same performance → Goto 4, 3, 2 or 1
   - Good performance! → Commit it.

Koichi Sasada

A programmer from Japan

Koichi is a Programmer

- MRI committer since 2007/01
  - Original YARV developer since 2004/01
    - YARV: Yet Another RubyVM
    - Introduced into Ruby (MRI) 1.9.0 and later
  - Generational/incremental GC for 2.x

PROGRAMMING
Language

Koichi is an Employee

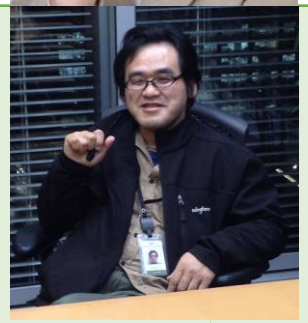
Koichi is a member of Heroku Matz team

Mission

Design Ruby language
and improve quality of MRI

Heroku employs three full time Ruby core developers in Japan named “Matz team”

Heroku Matz team

Matz		**Designer/director of Ruby**
Nobu		**Quite active committer**
Ko1		**Internal Hacker**

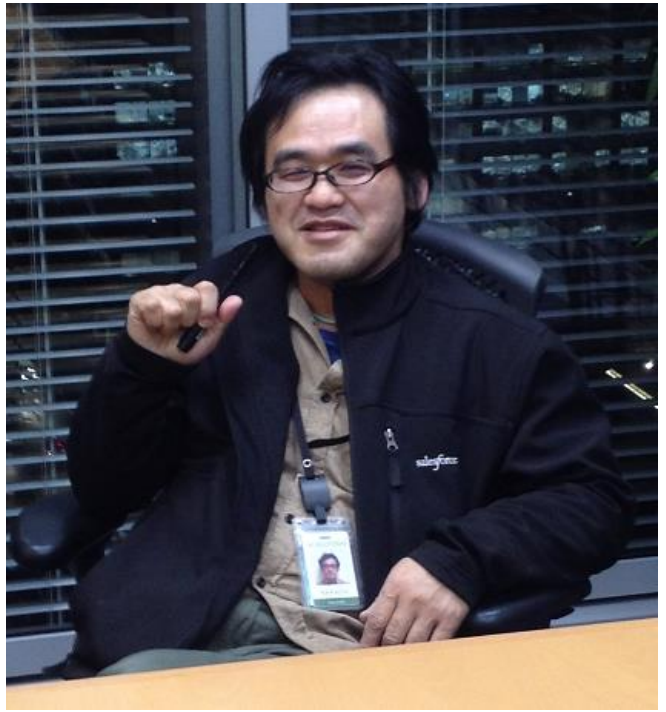
Matz
Title collector

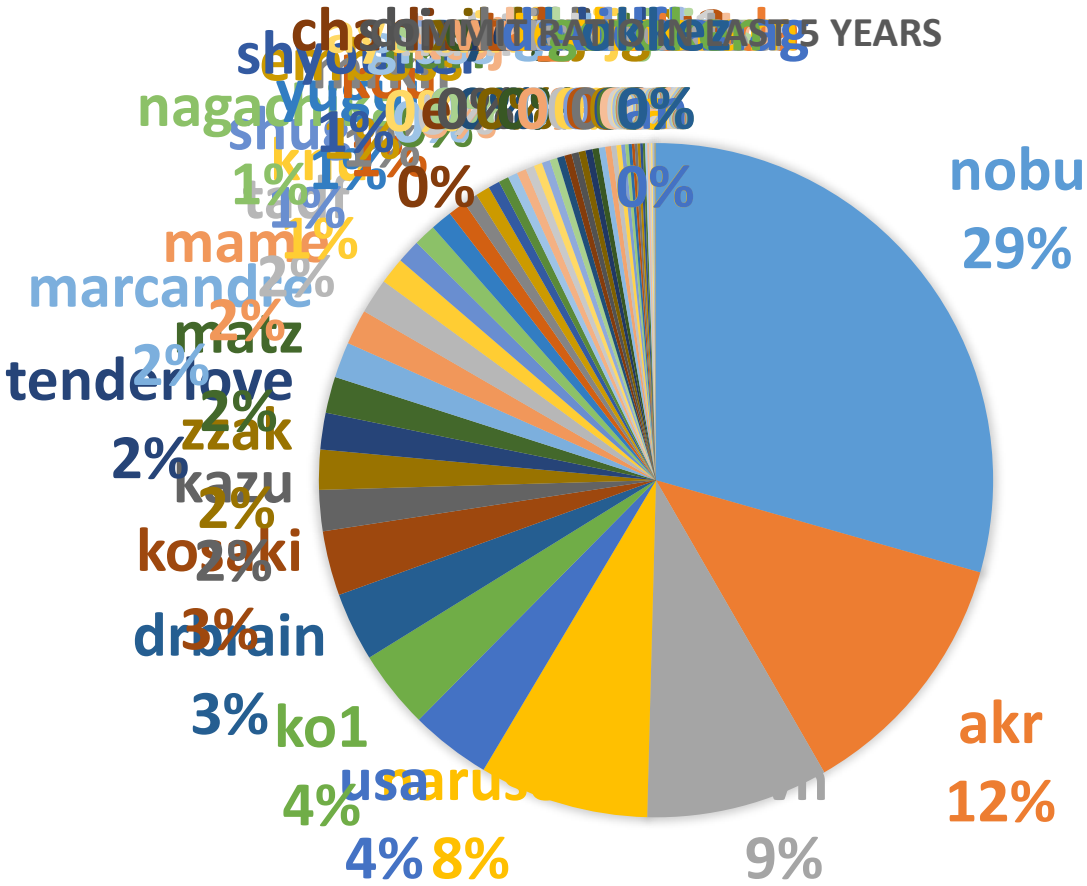
- He has so many (job) title
  - Chairman - Ruby Association
  - Fellow - NaCl
  - Chief architect, Ruby - Heroku
  - Research institute fellow – Rakuten
  - Chairman – NPO mruby Forum
  - Senior researcher – Kadokawa Ascii Research Lab
  - Visiting professor – Shimane University
  - Honorable citizen (living) – Matsue city
  - Honorable member – Nihon Ruby no Kai
  - …
- This margin is too narrow to contain

Nobu
Great Patch monster

Ruby’s bug
|> Fix Ruby
|> Break Ruby
|> And Fix Ruby

Nobu
Patch monster

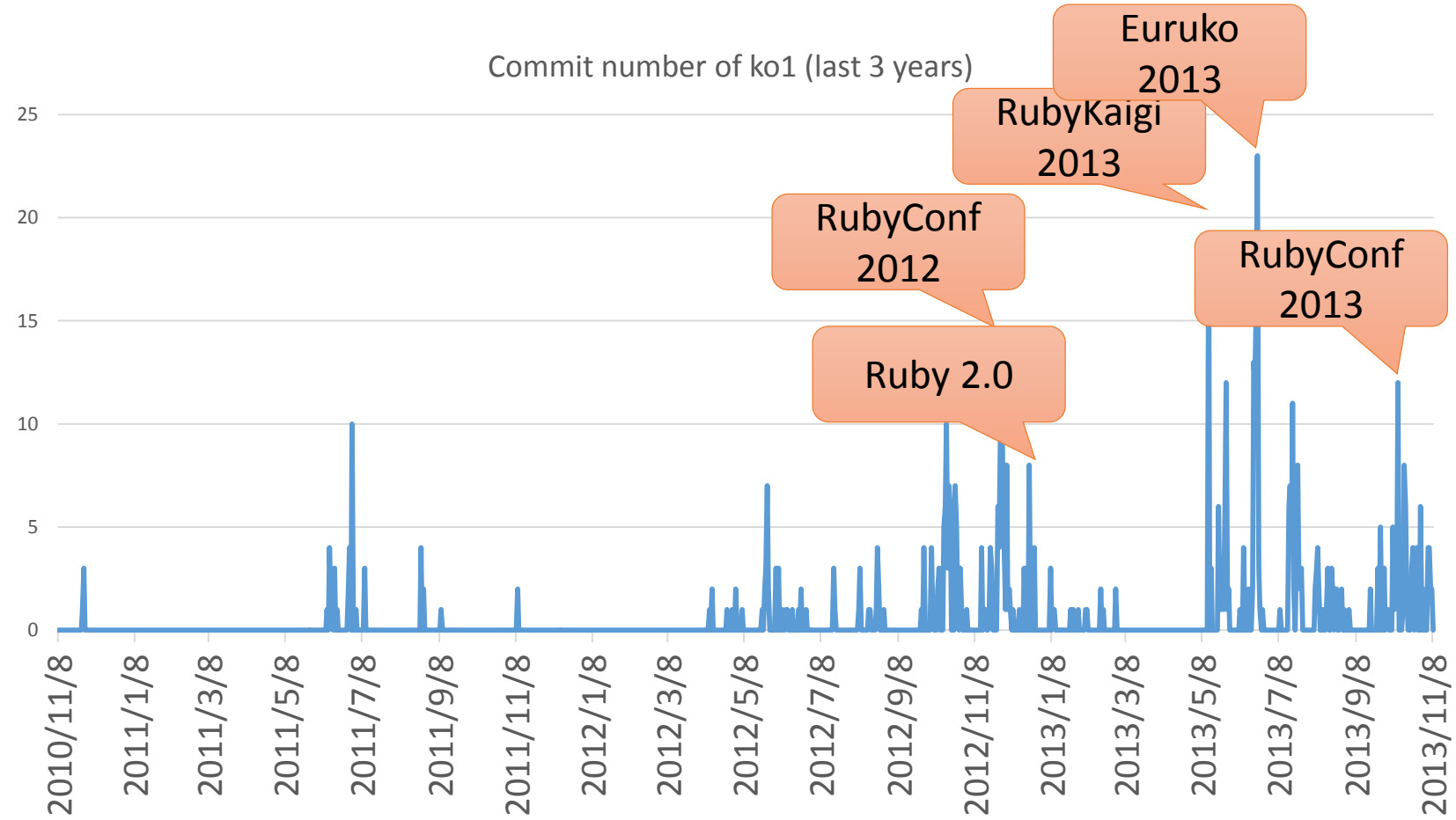




Commit count of MRI

Nobu
The Ruby Hero

Ko1
EDD developer



EDD: Event Driven Development

Heroku Matz team and Ruby core team
Recent achievement

Ruby 2.2

Current stable

Ruby 2.2
Syntax

- Symbol key of Hash literal can be quoted

```
{“foo-bar”: baz}
  #=> {:“foo-bar” => baz}
  #=> not {“foo-bar” => baz} like JSON
```

TRAP!!

Easy to misunderstand

(I wrote a wrong code, already…)

Ruby 2.2
Classes and Methods

- Some methods are introduces
  - Kernel#itself
  - String#unicode_normalize
  - Method#curry
  - Binding#receiver
  - Enumerable#slice_after, slice_before
  - File.birthtime
  - Etc.nprocessors
  - …

Ruby 2.2 Improvements

- Improve GC
  - Symbol GC
  - Incremental GC
  - Improved promotion algorithm
    - Young objects promote after 4 GCs
- Fast keyword parameters
- Use frozen string literals if possible

Ruby 2.2
Symbol GC

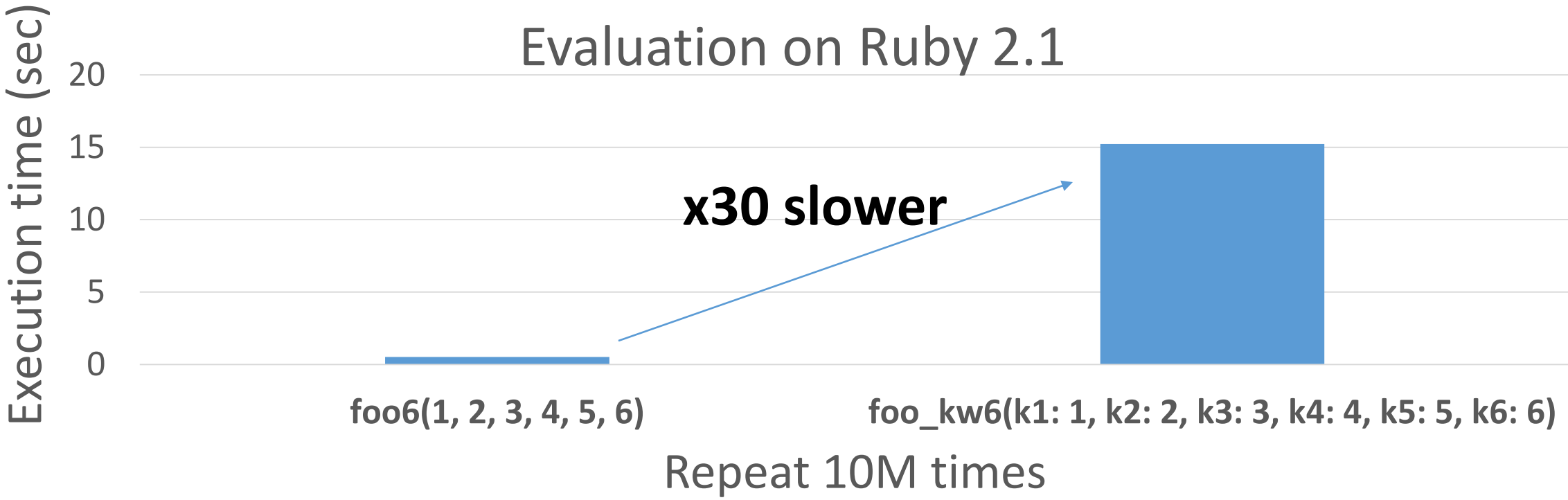
```
before = Symbol.all_symbols.size
1_000_000.times{|i| i.to_s.to_sym} # Make 1M symbols
after = Symbol.all_symbols.size; p [before, after]

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

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

Ruby 2.2
Symbol GC Issues history

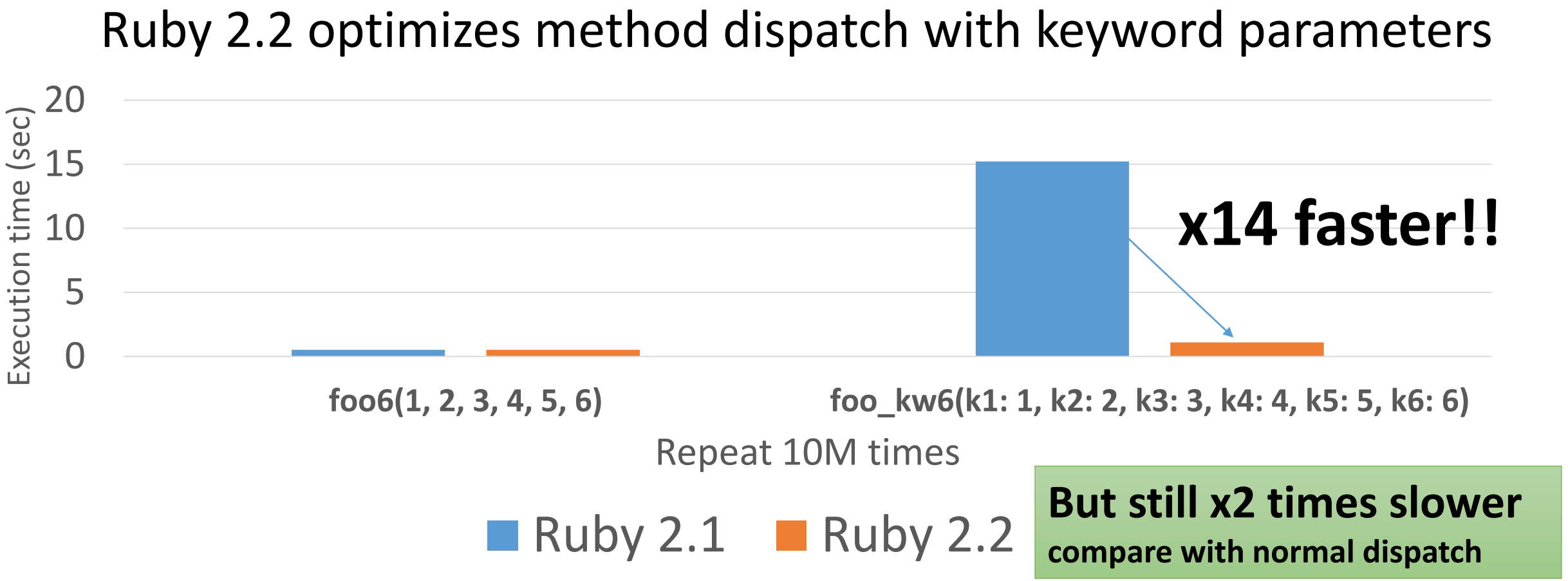
- **Ruby 2.2.0** has memory (object) leak problem
  - Symbols has corresponding String objects
  - Symbols are collected, but Strings are not collected! (leak)
- **Ruby 2.2.1** solved this problem!!
  - However, 2.2.1 also has problem (rarely you encounter BUG at **the end of process** **[Bug #10933]** ← not big issue, I want to believe)
- **Ruby 2.2.2** had solved [Bug #10933]!!
  - However, patch was forgot to introduce!!
- **Finally, Ruby 2.2.3 solved it!!**
  - **Please use newest version!!**

Ruby 2.2
Fast keyword parameters

“Keyword parameters” introduced in Ruby 2.0 is useful, but slow!!



Ruby 2.2
Fast keyword parameters



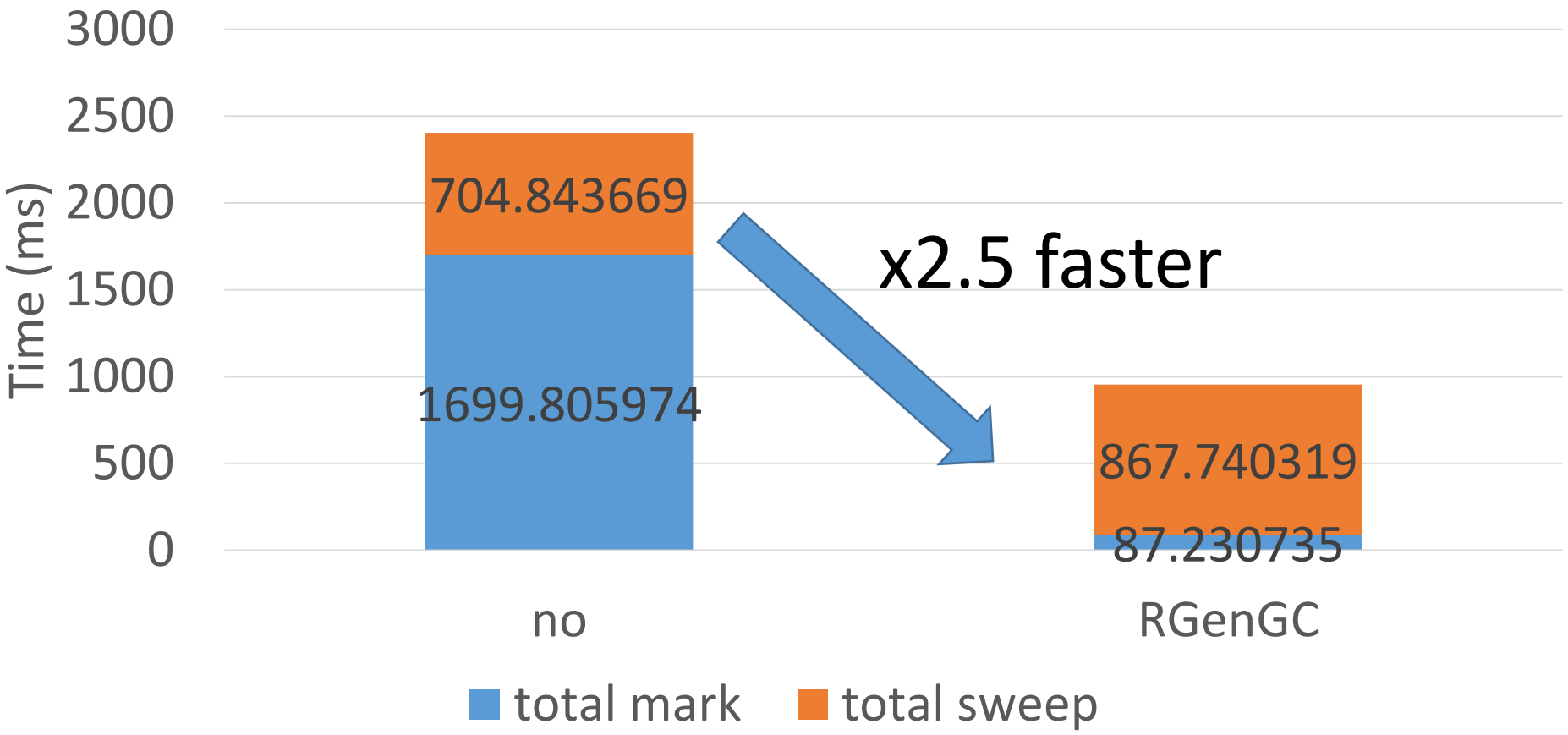
But still x2 times slower
compare with normal dispatch

Ruby 2.2
Incremental GC

Goal

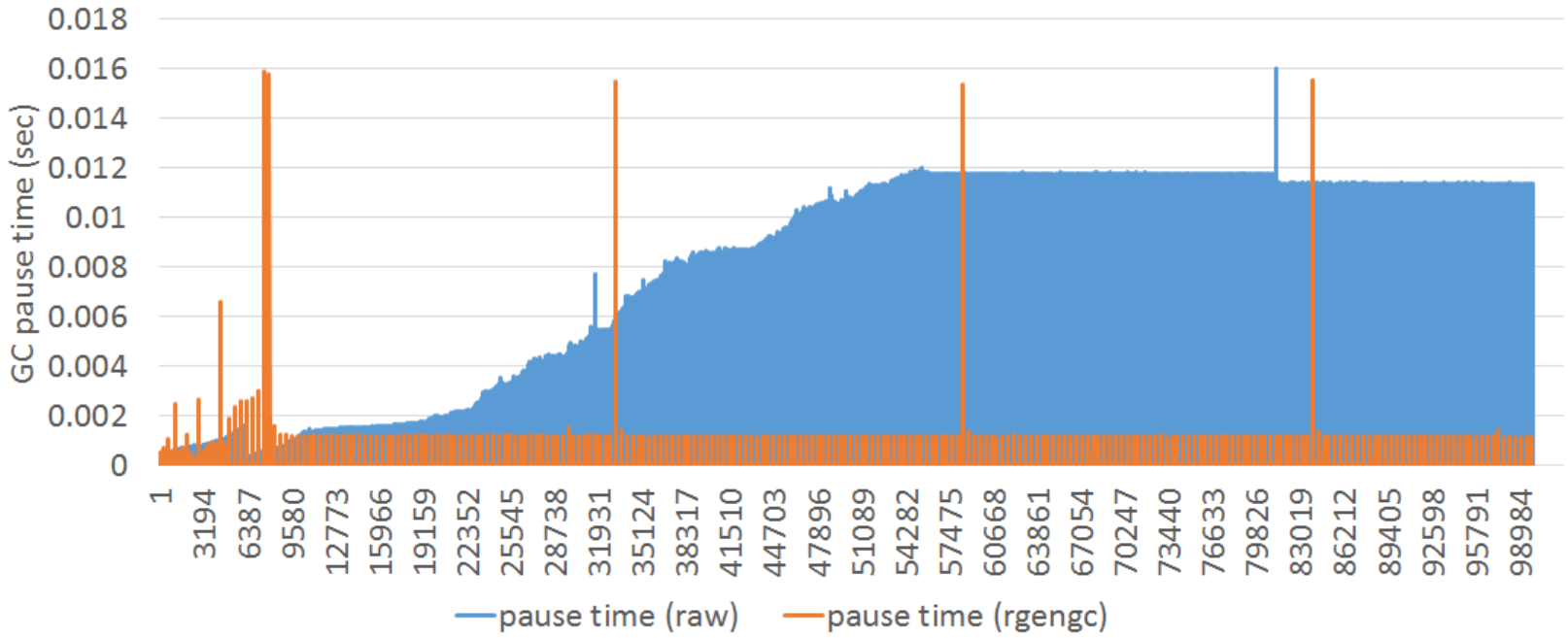
	Before Ruby 2.1	Ruby 2.1 RGenGC	Incremental GC	Ruby 2.2 Gen+IncGC
Throughput	Low	High	Low	High
Pause time	Long	Long	Short	Short

RGenGC from Ruby 2.1: Micro-benchmark



RGenGC from Ruby 2.1: Pause time

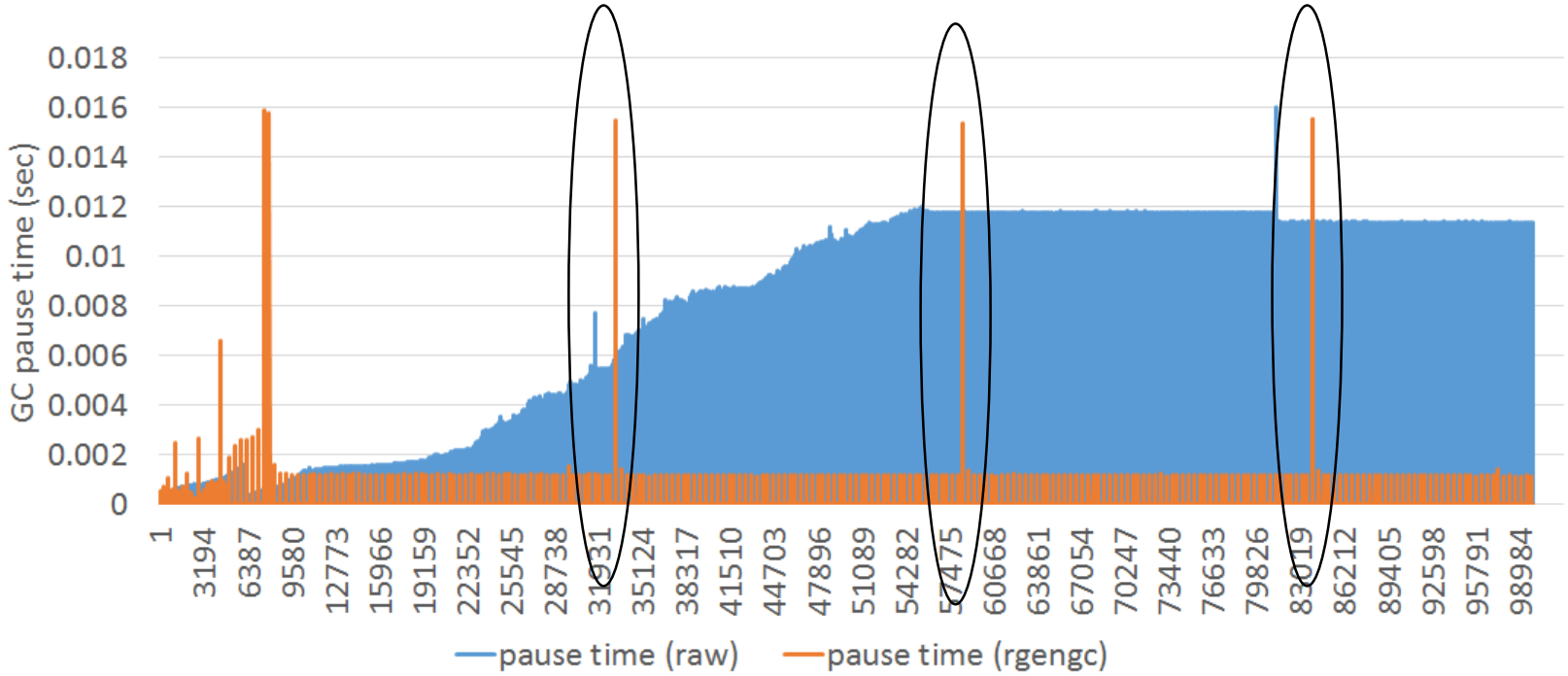
Most of cases, FASTER ☺



(w/o rgengc)

RGenGC from Ruby 2.1: Pause time

Several peaks ☹



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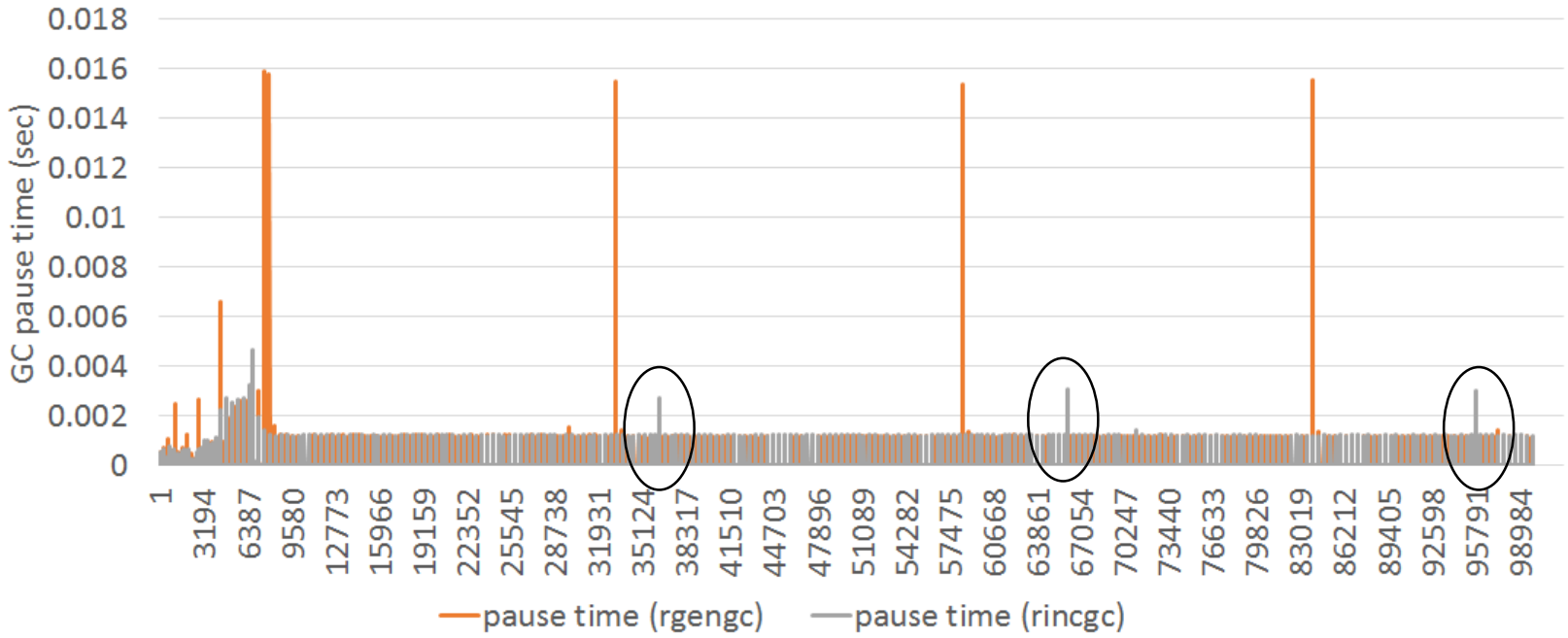
Ruby 2.2 Incremental GC

Short pause time ☺



Heroku Matz team and Ruby core team
Next target is

Ruby 2.3

Heroku Matz team and Ruby core team
Next target is

Ruby 2.3

No time to talk about it.

Please ask me later ☺

Performance in the details: A way to make faster Ruby

Ruby's components for users

Ruby (Rails) app

i gigantum umeris insidentes
Standing on the shoulders of giants

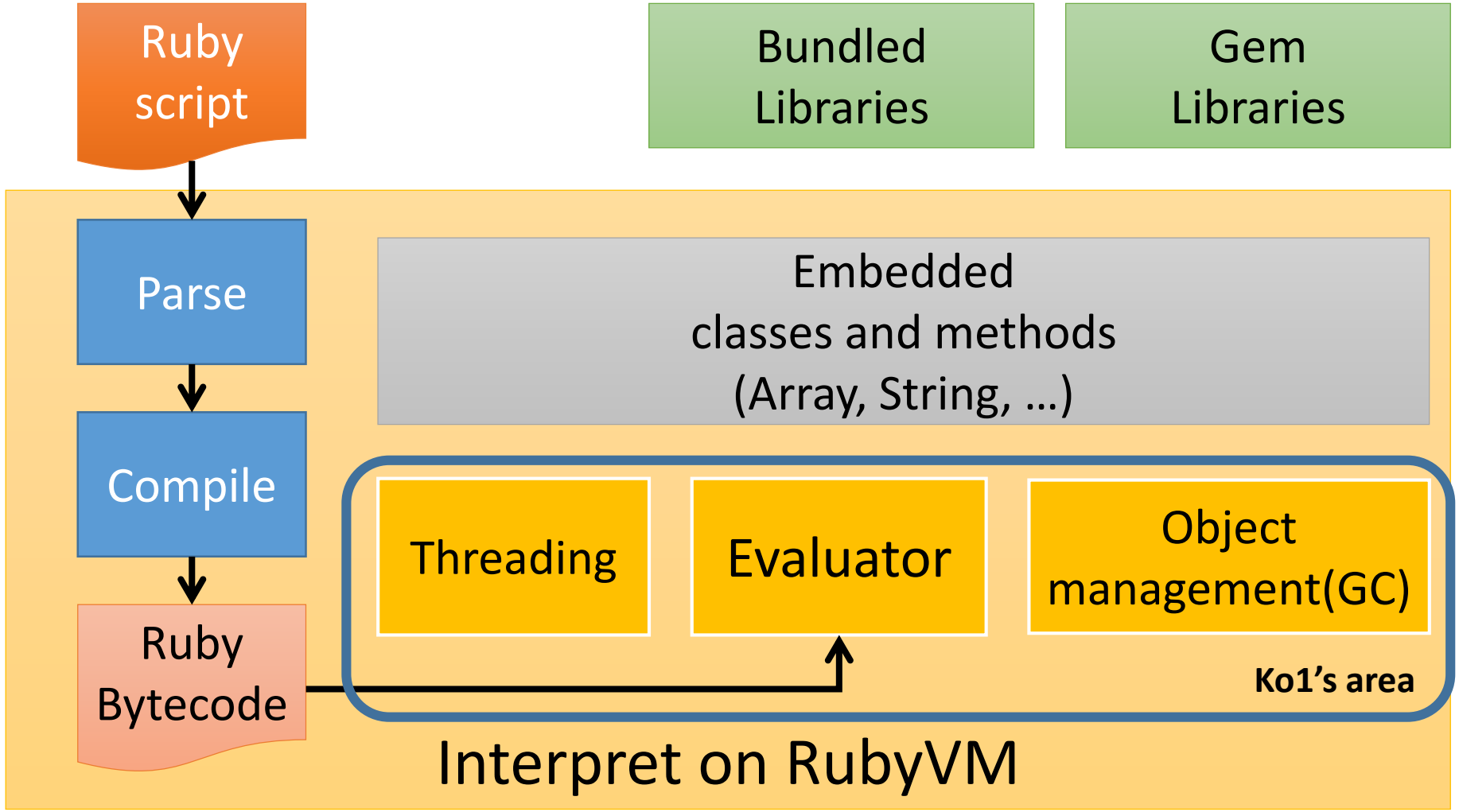
So many gems

such as Rails, pry, thin, … and so on.

RubyGems/Bundler

Ruby interpreter

Ruby's components from core developer's perspective



Basic flow to make faster Ruby

1. Observe Ruby interpreter
2. Make assumption the reason of slowness
3. Consider ideas to overcome
4. Implement ideas
5. Measure the result
   - Bad/same performance → Goto 4, 3, 2 or 1
   - Good performance! → Commit it.

Basic weapons to overcome issues

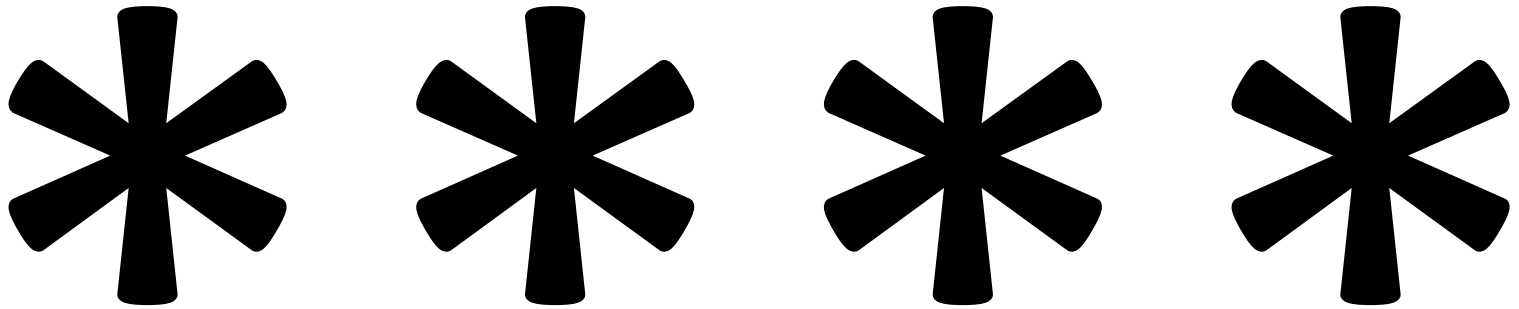
- Knowledge of computer science
  - Computer system, Programming techniques, and many others
  - From:
    - Textbook
    - Academic papers
    - Other implementation
- Feedback from users

Basic technique to improve performance

- Change the algorithm to reduce computation complexity
  - e.g.: Selection sort (O(n^2)) v.s. Quick sort (O(n log(n))
- Chang the data structure to improve data locality
  - e.g.: “list” and “array”
- Remove redundant process
  - e.g.: Using cache (utilize time locality)
- Considering trade-off
  - Speed-up major cases and slow-down minor cases
  - e.g.: speed-up non-exception flow (and slow-down exception cases)
- Machine dependent technique
  - e.g.: Using assembler / CPU register directly
- …

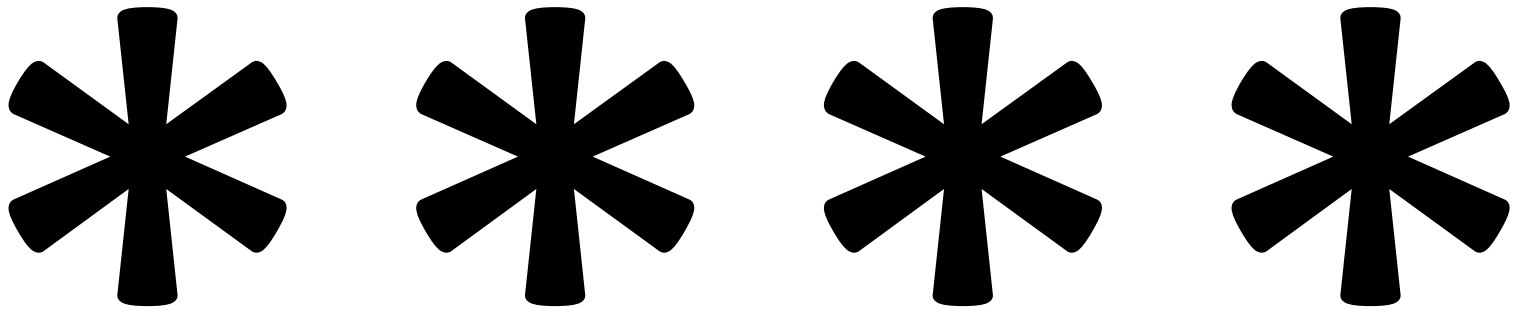
Case studies

Ruby has many

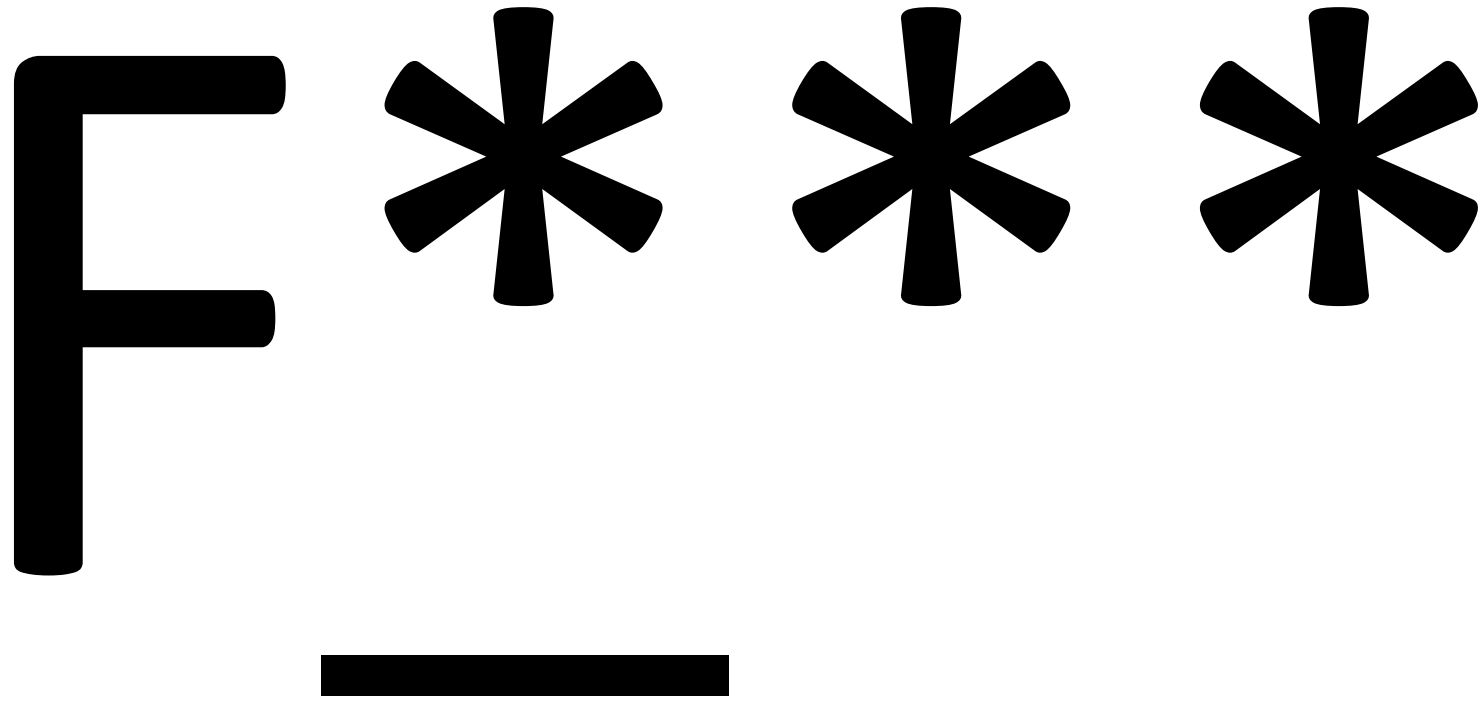


Let’s play hangman game

Ruby has many



Ruby has many



Ruby has many

FU**

Ruby has many

FU**__

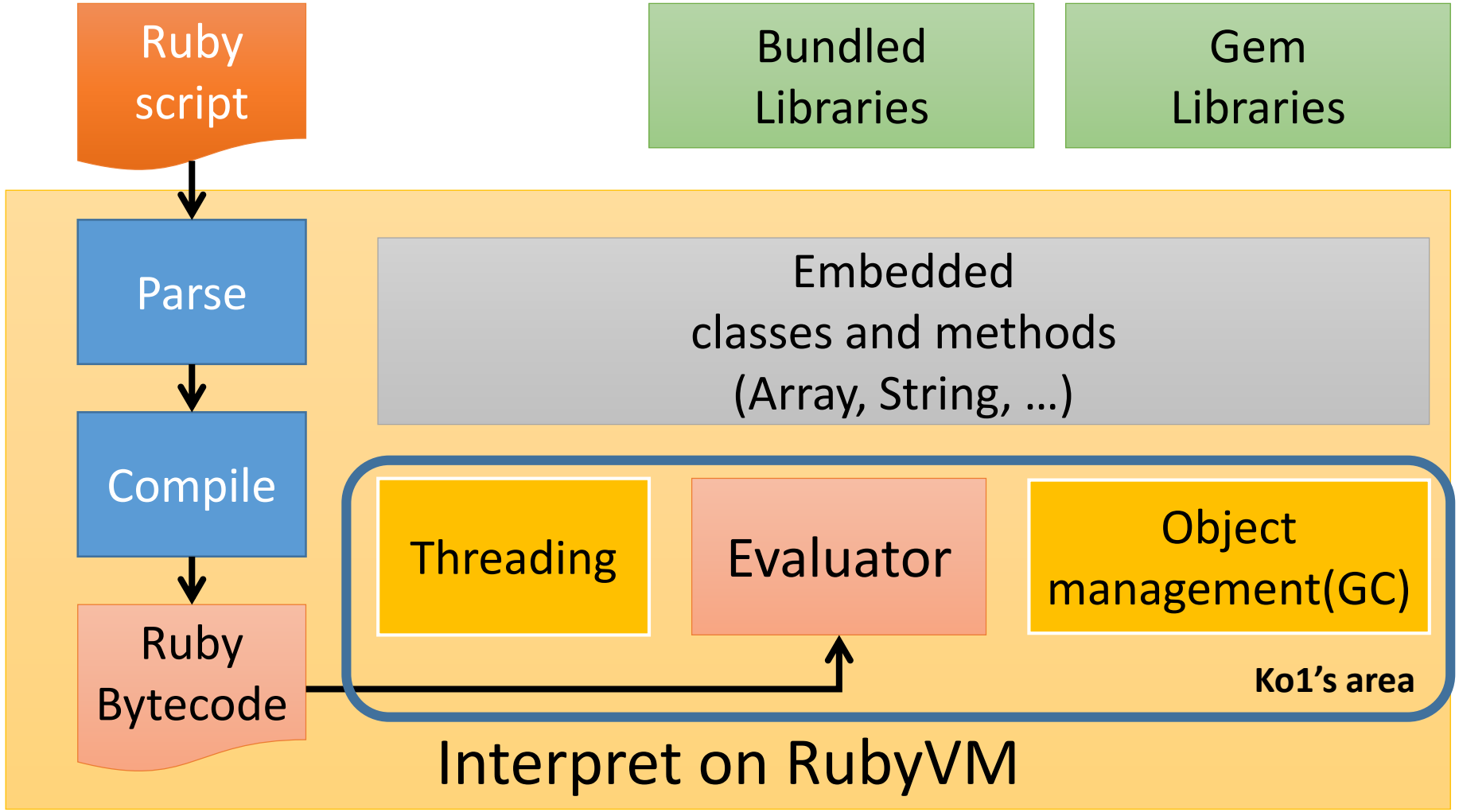
Ruby has many

FUNC

Or Methods

Case study:
Optimize method dispatch

Ruby's components from core developer's perspective



Method dispatch

```
# Example
recv.selector(arg1, arg2)
```

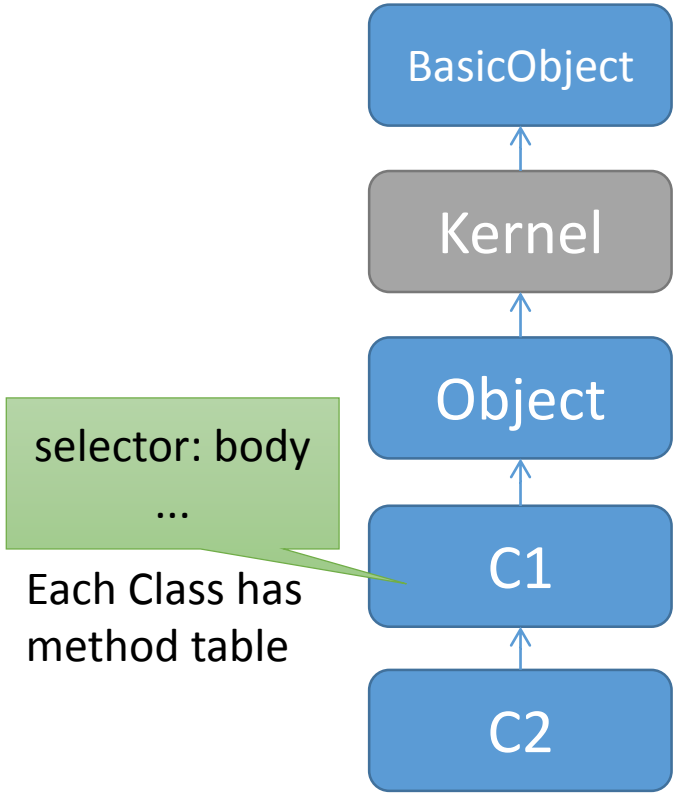
- recv: receiver
- selector: method id
- arg1, arg2: arguments

Method dispatch Overview

1. Get class of `recv' (`klass')
2. Search method `body' named `selector' from `klass'
   - Method is not fixed at compile time
   - **"Dynamic"** method dispatch
3. Dispatch method with `body'
   1. Check visibility
   2. Check arity (expected args # and given args #)
   3. Store `PC' and `SP' to continue after method returning
   4. Build `local environment'
   5. Set program counter
4. And continue VM execution

Overview
Method search

- Search method from `klass’
  1. Search method table of `klass’
     1. if method `body’ is found, return `body’
     2. `klass’ = super class of `klass’ and repeat it
  2. If no method is given, exceptional flow
     - In Ruby language, `method_missing’ will be called



Overview
Checking arity and visibility

- Checking arity
  - Compare with given argument number and expected argument number
- Checking visibility
  - In Ruby language, there are three visibilities
  - can you explain each of them ?:-p
    - public
    - private
    - protected

Overview
Building `local environment’

- How to maintain local variables?

→ Prepare `local variables space’ in stack

→ `local environment’ (short `env’)

- Parameters are also in `env’

Method dispatch Overview (again)

1. Get class of `recv' (`klass')
2. Search method `body' `selector' from `klass'
   - Method is not fixed at compile time
   - "Dynamic" method dispatch
3. Dispatch method with `body'
   1. Check visibility
   2. Check arity (expected args # and given args #)
   3. Store `PC' and `SP' to continue after method returning
   4. Build `local environment'
   5. Set program counter
4. And continue VM execution

It seems very **easy and simple!** and slow...

Method dispatch

- Quiz: How many steps in Ruby's method dispatch?
  - Hint: More complex than I explained overview

① 8 steps
② 12 steps
③ 16 steps
④ 20 steps

Answer is
About ④ 20 steps

Method dispatch
Ruby's case

1. Check caller's arguments
    1. Check splat (*args)
    2. Check block (given by compile time or block parameter (&block))
2. Get class of `recv' (`klass')
3. **Search method `body' `selector' from `klass'**
    - Method is not fixed at compile time
    - **"Dynamic"** method dispatch
4. **Dispatch method with `body'**
    1. Check visibility
    2. Check arity (expected args # and given args #) and process
        1. Post arguments
        2. Optional arguments
        3. Rest argument
        4. Keyword arguments
        5. Block argument
    3. Push new control frame
        1. Store `PC' and `SP' to continue after method returning
        2. Store `block information'
        3. Store `defined class'
        4. Store bytecode info (iseq)
        5. Store recv as self
    4. Build `local environment'
    5. Initialize local variables by `nil'
    6. Set program counter
5. And continue VM execution

... simple?

(*) Underlined items are additonal process

Ruby's case
Complex parameter checking

- "def foo(m1, m2, o1=..., o2=...,
  p1, p2, *rest, &block)"
  - m1, m2: mandatory parameter
  - o1, o2: optional parameter
  - p1, p2: post parameter
  - rest: rest parameter
  - block: block parameter
- From Ruby 2.0, keyword parameter is supported

Method dispatch

1. CHeck caller's arguments
    1. Check splat (*args)
    2. Check block (given by compile time or block parameter (&block))
2. Get class of `recv' (`klass')
3. **Search method `body' `selector' from `klass'**
    - Method is not fixed at compile time
    - **"Dynamic"** method dispatch
4. **Dispatch method with `body'**
    1. Check visibility
    2. Check arity (expected args # and given args #) and process
        1. Post arguments
        2. Optional arguments
        3. Rest argument
        4. Keyword arguments
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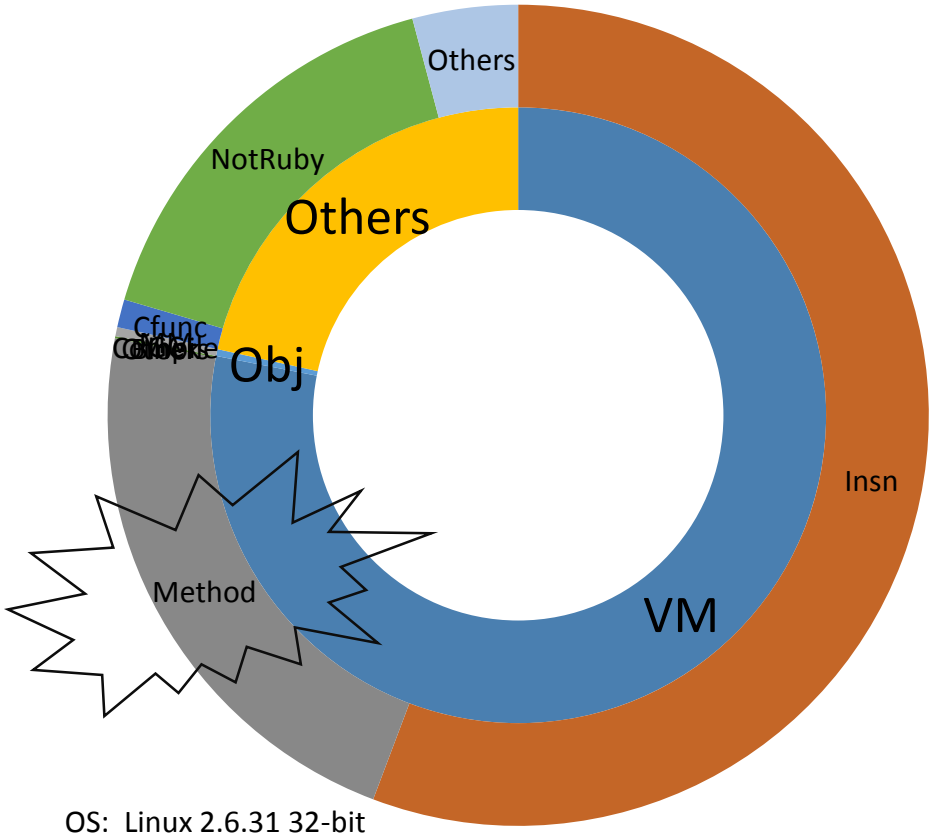
    4. Build `local environment'
    5. Initialize local variables by `nil'
    6. Set program counter
5. And continue VM execution

Complex and Slow!!!

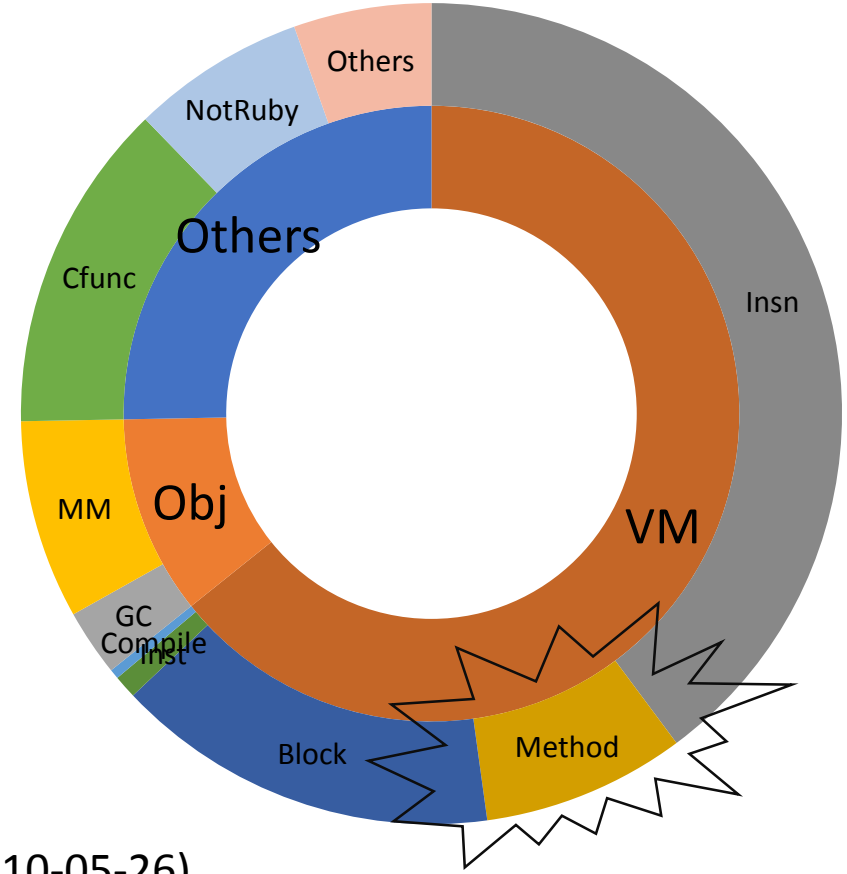
Method dispatch Overhead

Method dispatch overhead is big especially on micro-benchmarks ☺

Fib



Pentomino



OS: Linux 2.6.31 32-bit
CPU: IntelCore2Quad 2.66GHz
Mem: 4GB
C Compiler: GCC 4.4.1, -O3
Profiled by Oprofile

ruby 1.9.3dev (2010-05-26)
Profiled by Mr. Shiba

Speedup techniques for method dispatch

1. Specialized instructions
2. Method caching
3. Caching checking results
4. Special path for `send' and `method_missing'

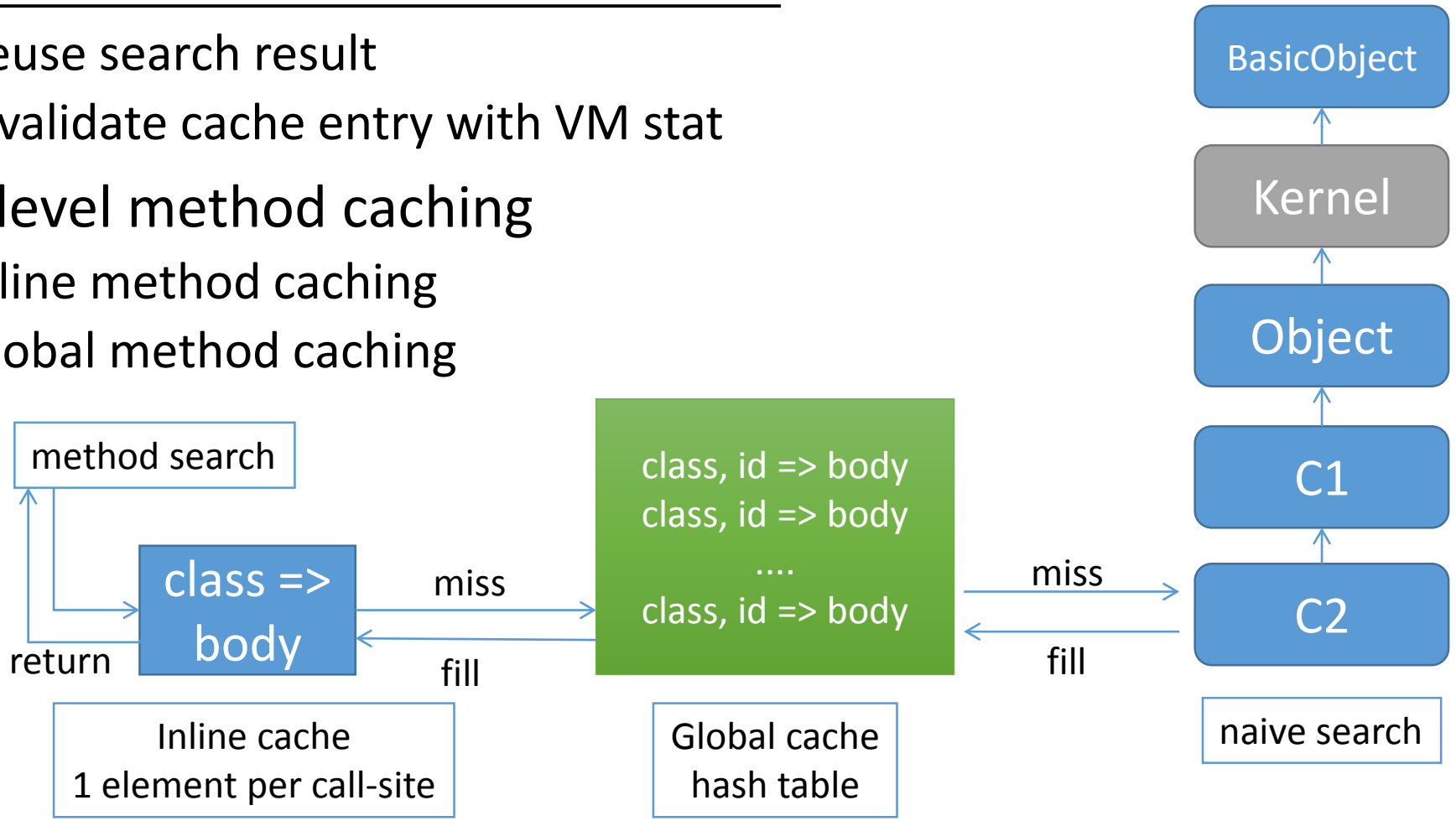
Optimization
Specialized instruction (from Ruby 1.9.0)

- Make special VM instruction for several methods
  - +, -, *, /, …

```
def opt_plus(recv, obj)
  if recv.is_a(Fixnum) and obj.is_a(Fixnum) and
      Fixnum#+ is not redefined
      return Fixnum.plus(recv, obj)
  else
    return recv.send(:+, obj) # not prepared
  end
end
```

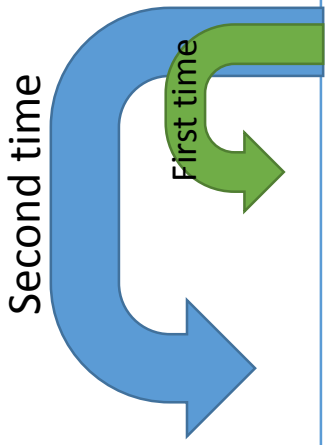
Optimization
Method caching (from Ruby 1.9.0)

- **<u>Eliminate method search overhead</u>**
  - Reuse search result
  - Invalidate cache entry with VM stat
- Two level method caching
  - Inline method caching
  - Global method caching



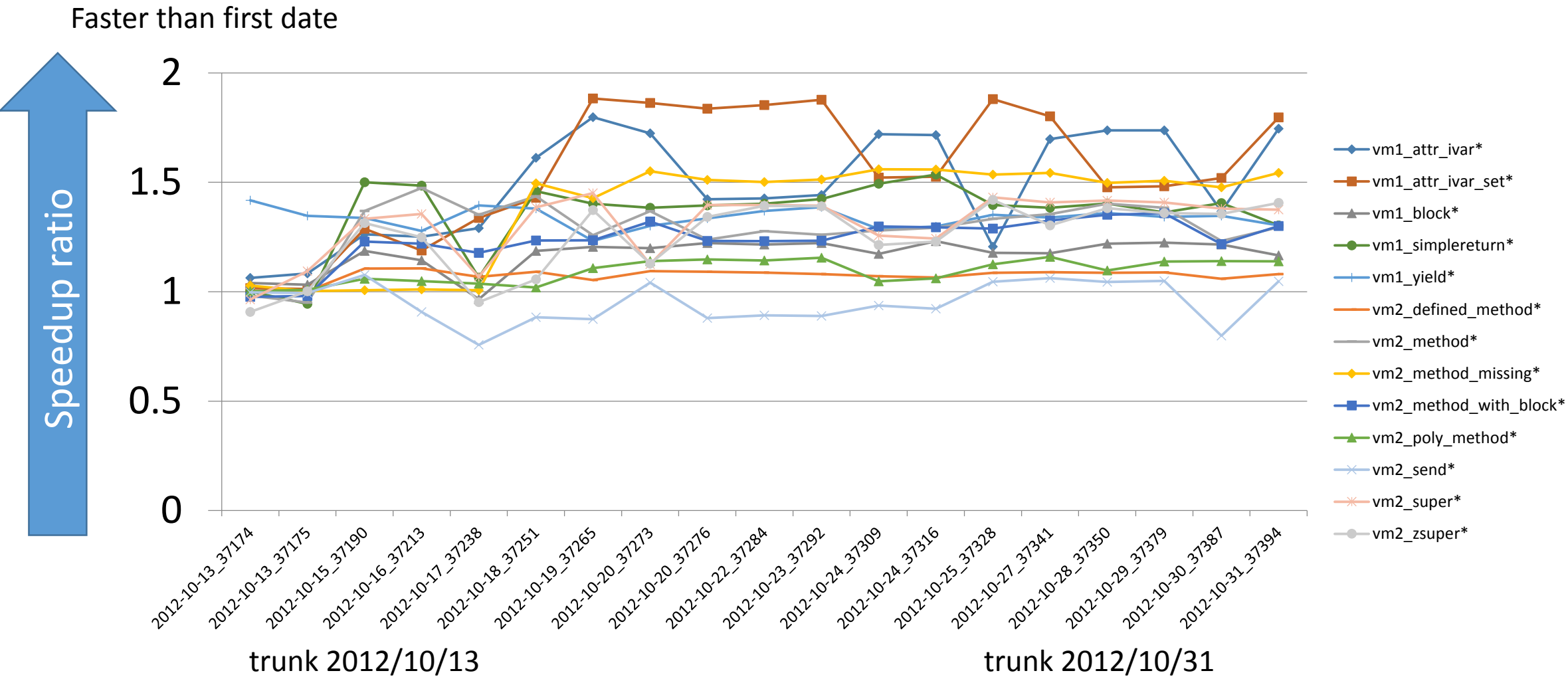
Optimization
Caching checking results (from 2.0.0)

- Idea: Visibility and arity check can be skipped after first checking
  - Store result in inline method cache



1. Check caller's arguments
2. Search method `body' `selector' from `klass'
3. Dispatch method with `body'
   1. **Check visibility and arity**
      1. **Cache result into inline method cache**
   2. Push new control frame
   3. Build `local environment'
   4. Initialize local variables by `nil'

Evaluation result
Micro benchmarks

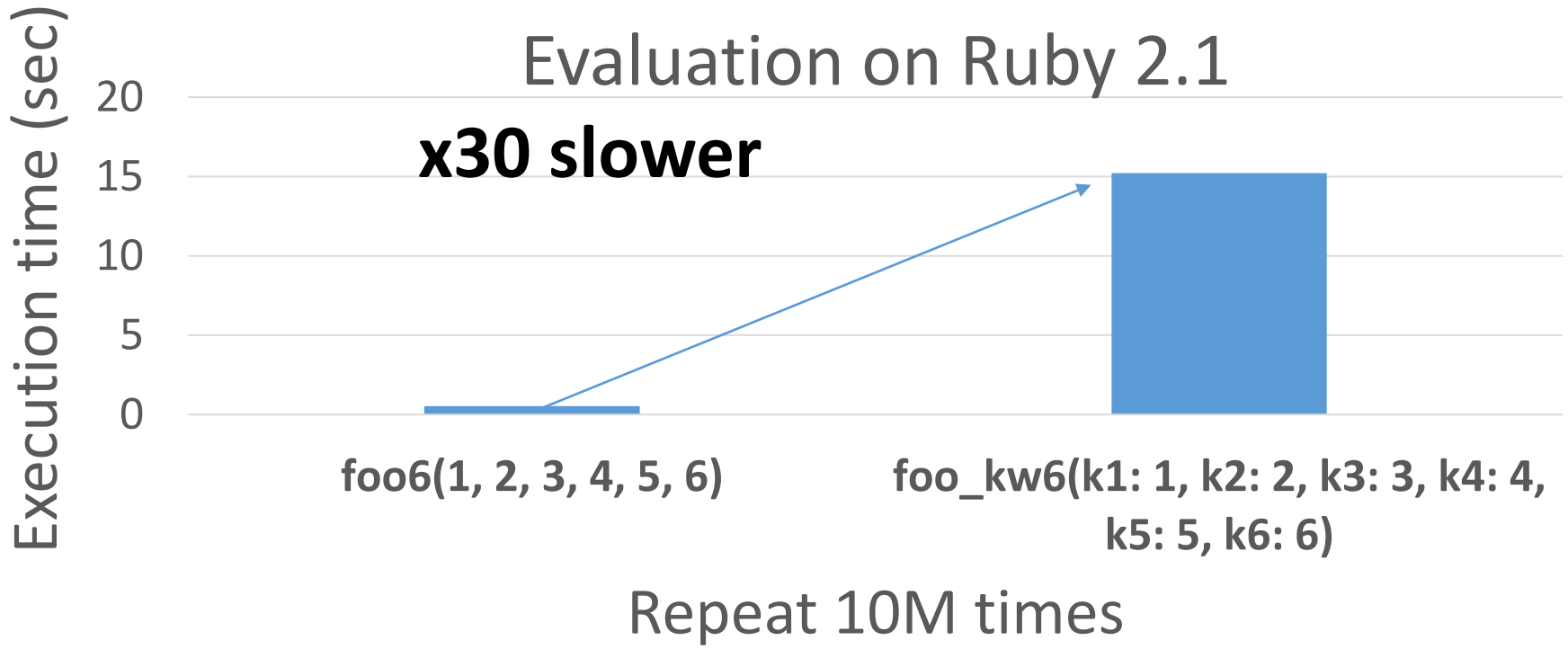


Case study
Faster keyword parameters

Keyword parameters from Ruby 2.0

```
# def with keywords
def foo(a, b, key1: 1, key2: 2)
  …
end
# call with keywords
foo(1, 2, key1: 123, key2: 456)
```

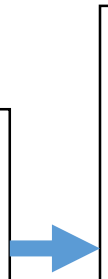
Slow keyword parameters



Why slow, compare with normal parameters?

1. **Hash creation**
2. **Hash access**

```
def foo(k1: v1, k2: v2)
  …
end
foo(k1: 1, k2: 2)
```



```
def foo(h = {})
  k1 = h.fetch(:k1, v1)
  k2 = h.fetch(:k2, v2)
  …
end
foo( {k1: 1, k2: 2} )
```

2. Hash access

1. Hash creation

Optimization technique of keyword parameters from Ruby 2.2

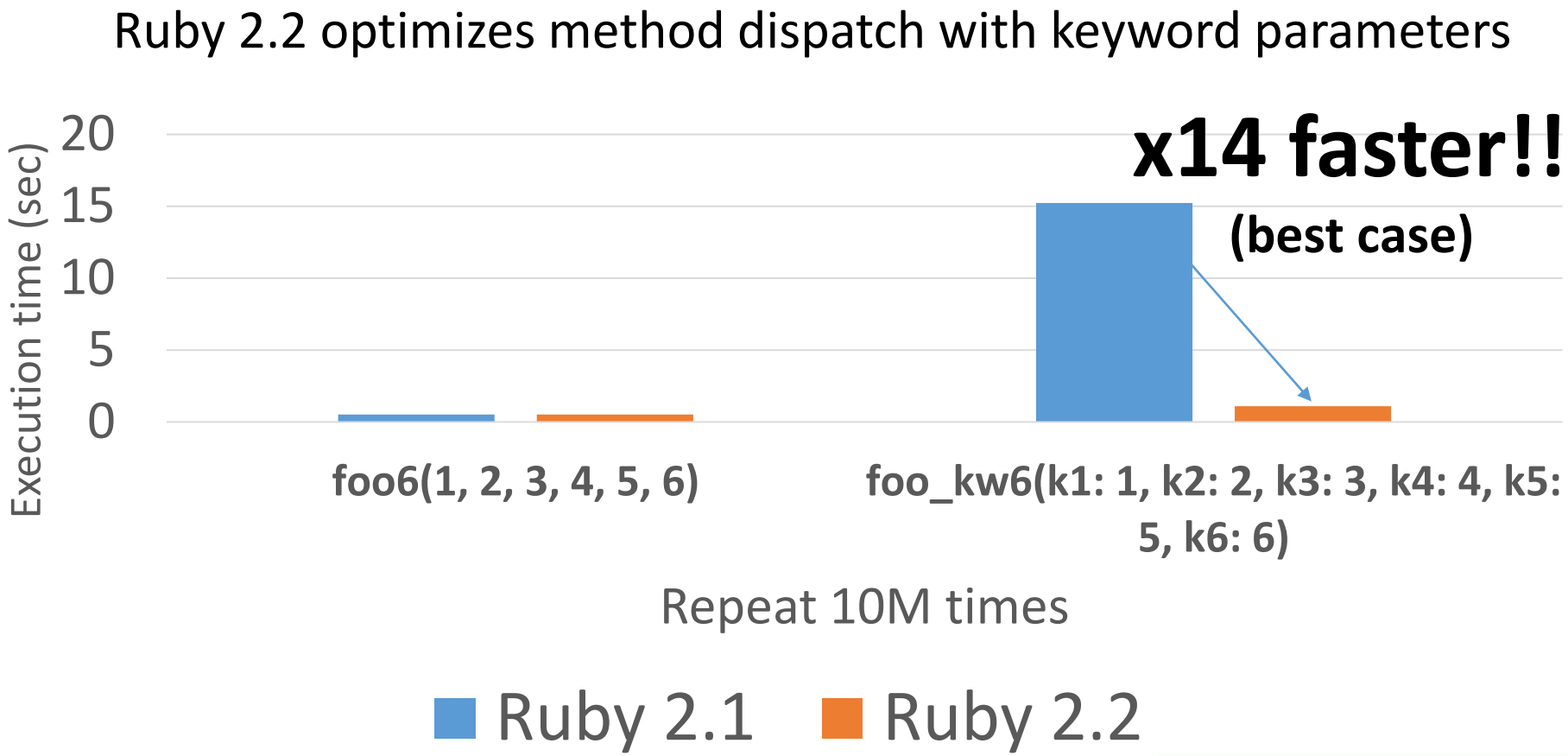
- Key technique

→ Pass “a keyword list”

nstead of a Hash object

Check “Evolution of Keyword parameters” at Rubyconf portugal'15
http://www.atdot.net/~ko1/activities/2015_RubyConfPortgual.pdf

Result: Fast keyword parameters (Ruby 2.2.0)



But still x2 times slower
compare with normal dispatch

Case study
Garbage collection

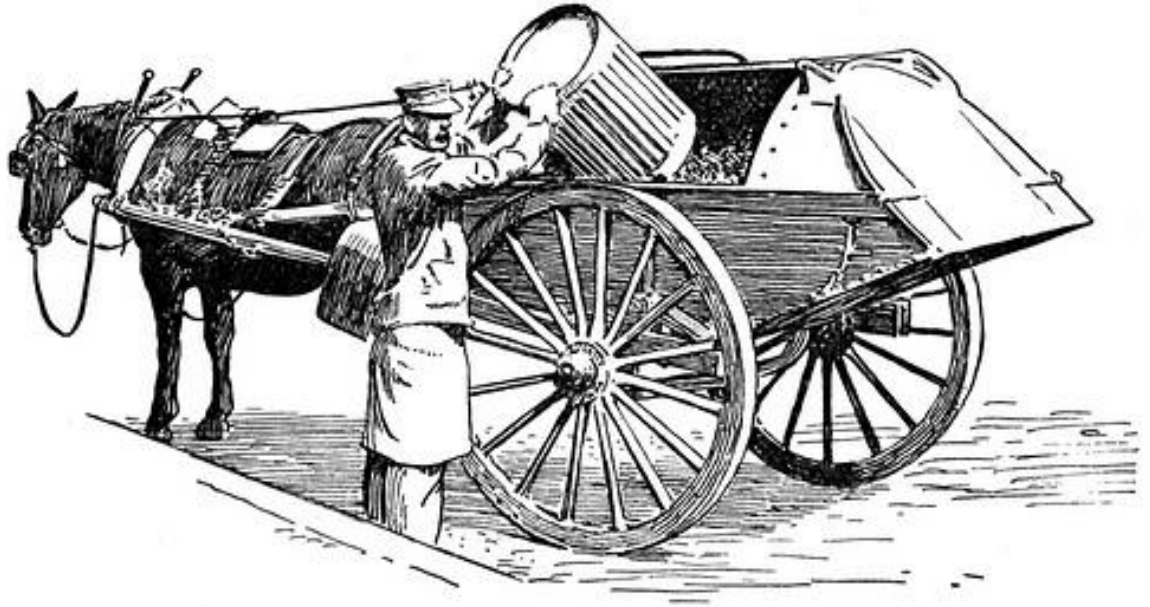
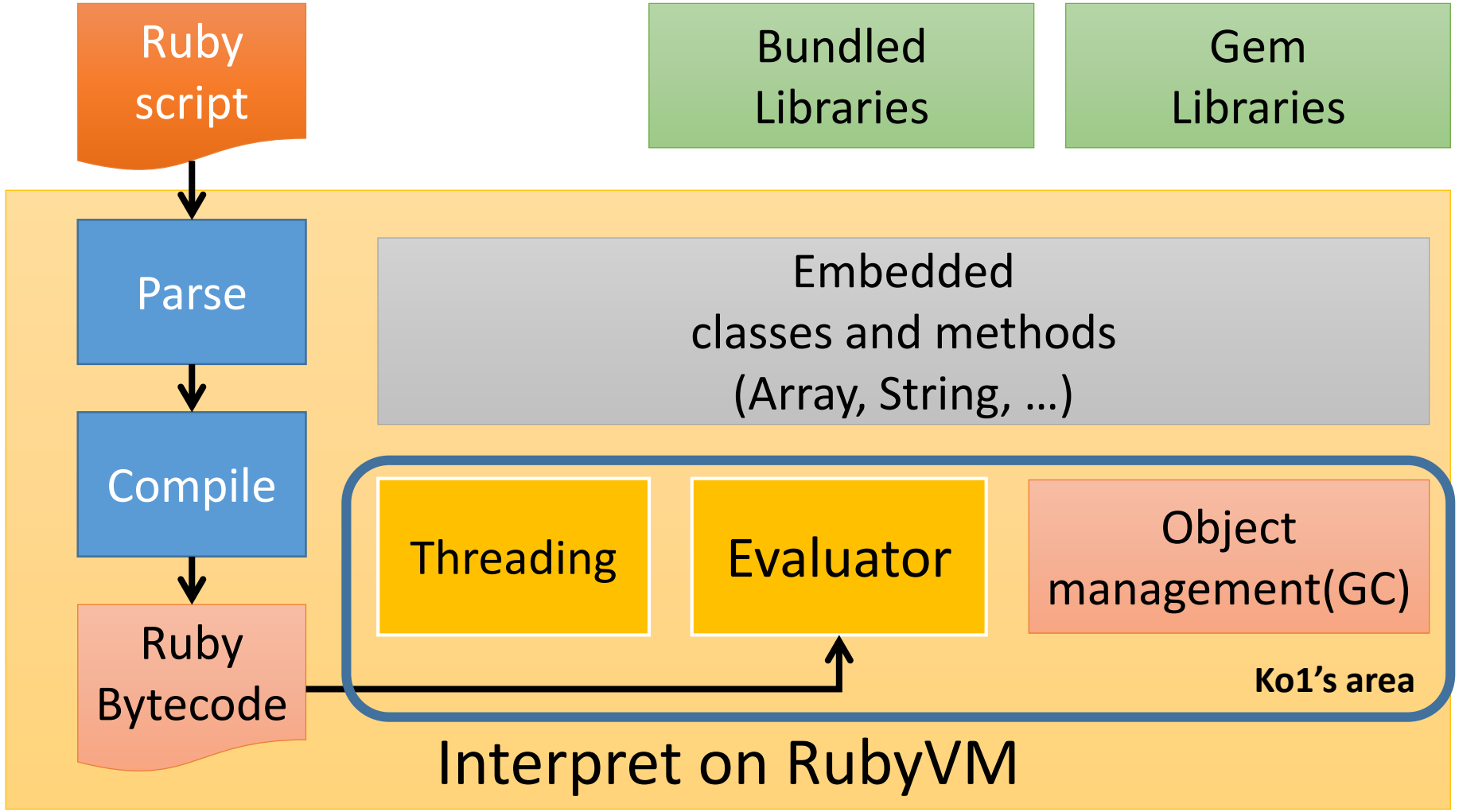


FIG. 109. — A GARBAGE COLLECTOR.

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

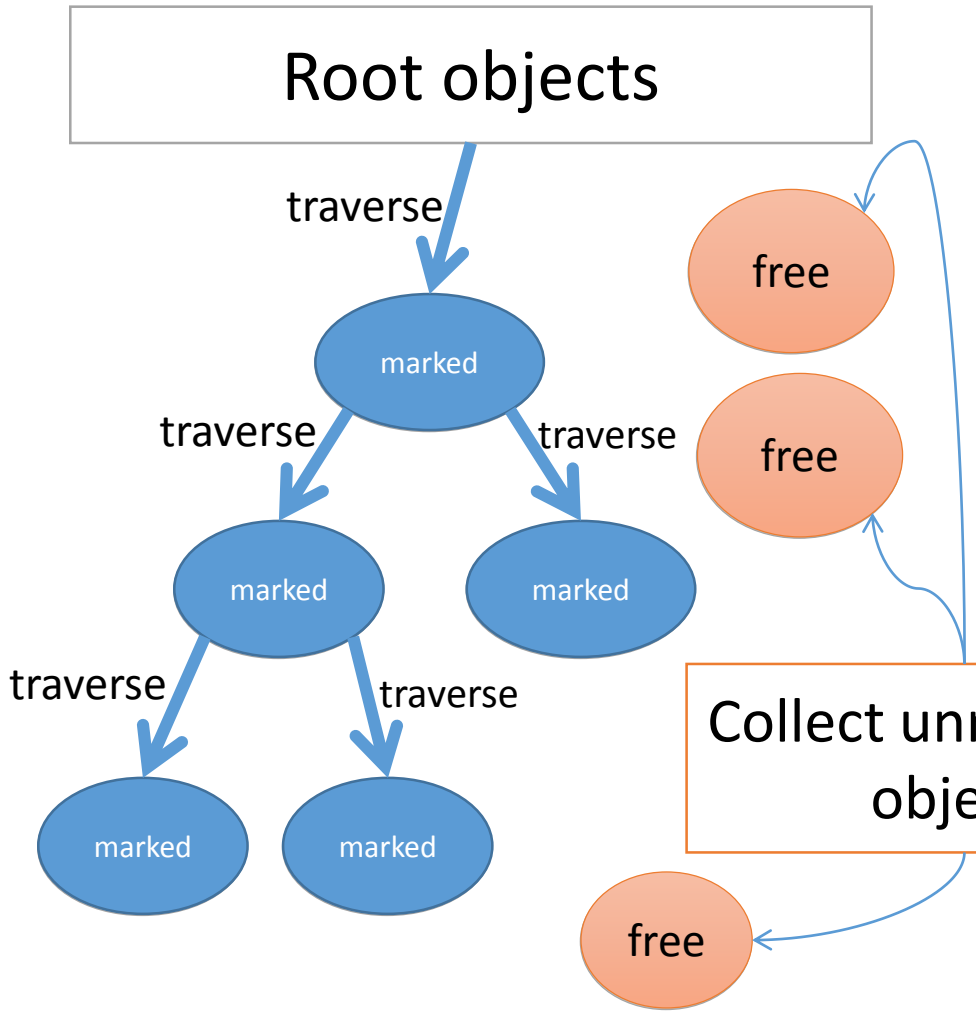
Ruby's components from core developer's perspective



Automatic memory management
Basic concept

- **Garbage collector recycled “unused” objects automatically**

Mark & Sweep algorithm

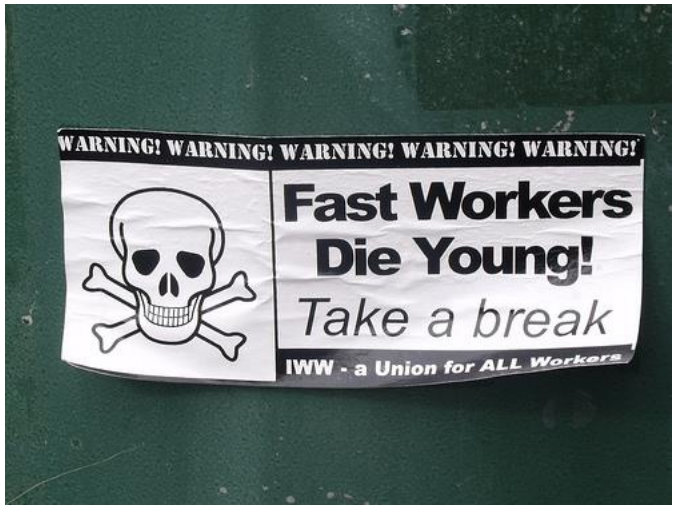


1. Mark reachable objects from root objects
2. Sweep ***unmarked*** objects (collection and de-allocation)

Generational GC (GenGC) from Ruby 2.1.0

- Weak generational hypothesis:

“Most objects die young”



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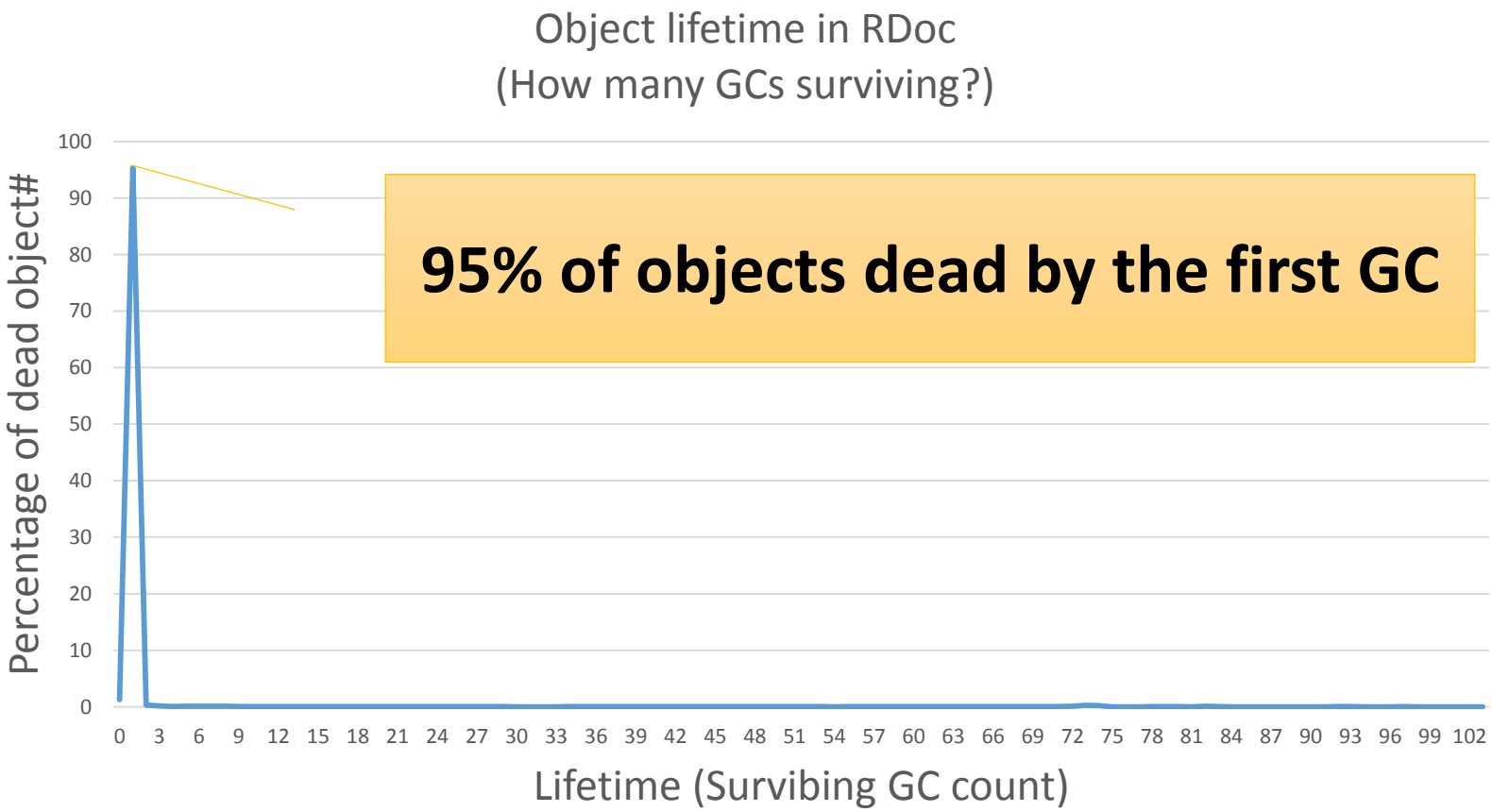
→ Concentrate reclamation effort only on the young objects

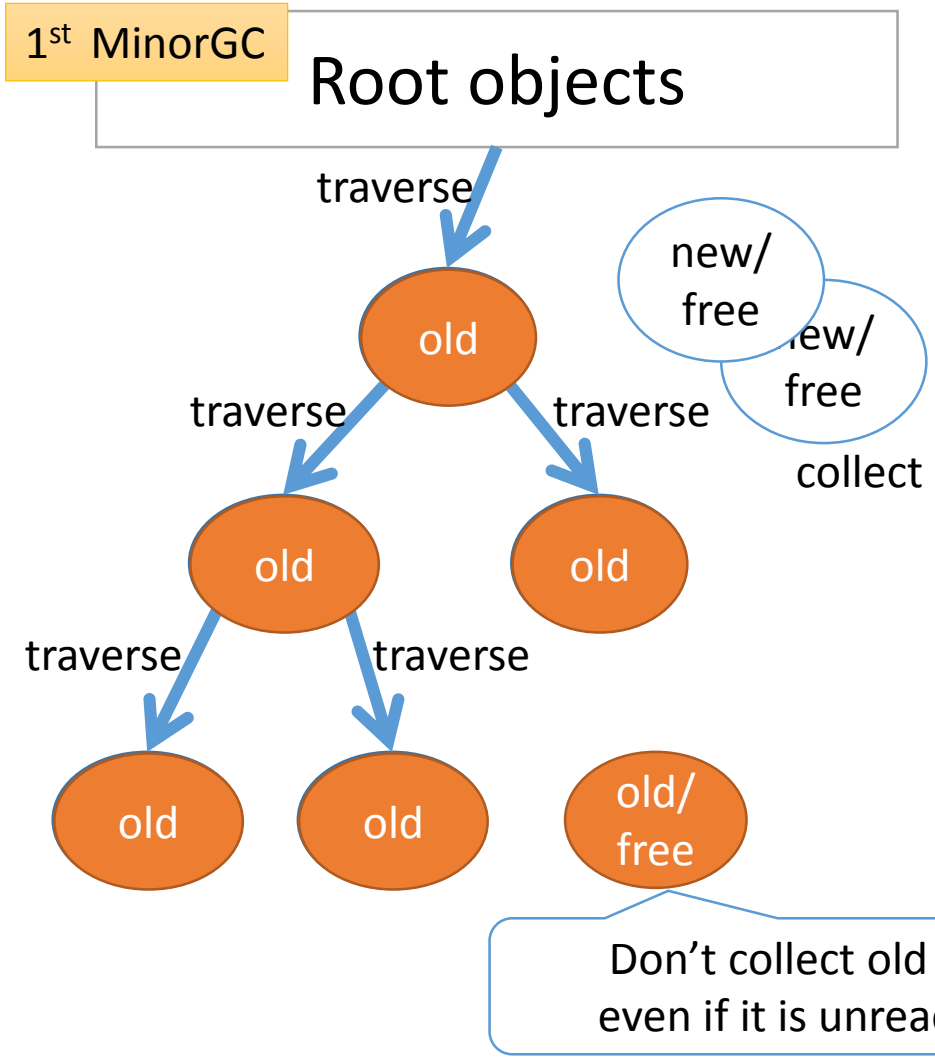
Generational hypothesis



Generational GC (GenGC)

- Separate young generation and old generation
  - Create objects as young generation
  - Promote to old generation after surviving n-th GC
- Usually, GC on young space (minor GC)
- GC on both spaces if no memory (major/full GC)

GenGC [Minor M&S GC] (1/2)

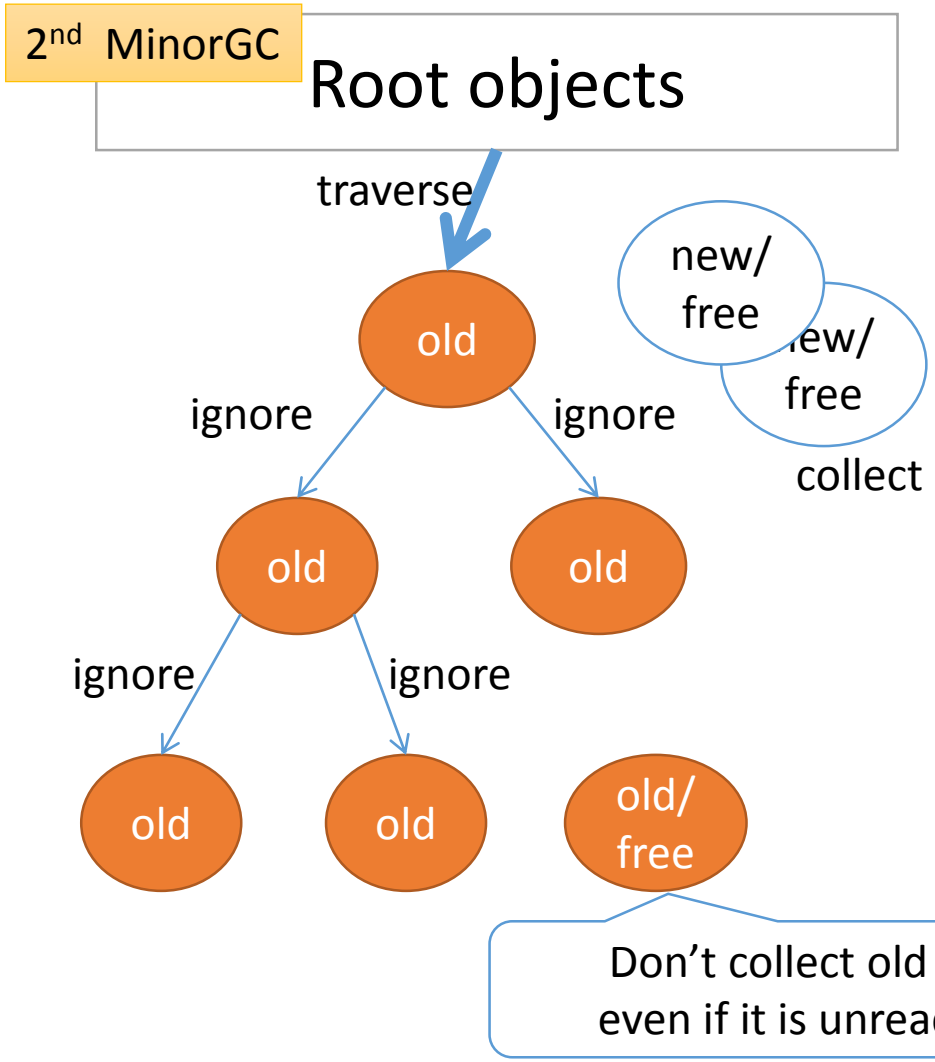


- Mark reachable objects from root objects.
  - Mark and **promote to old generation**
  - Stop traversing after old objects

→ Reduce mark overhead

- Sweep not (marked or old) objects
- Can't collect Some unreachable objects

GenGC [Minor M&S GC] (2/2)



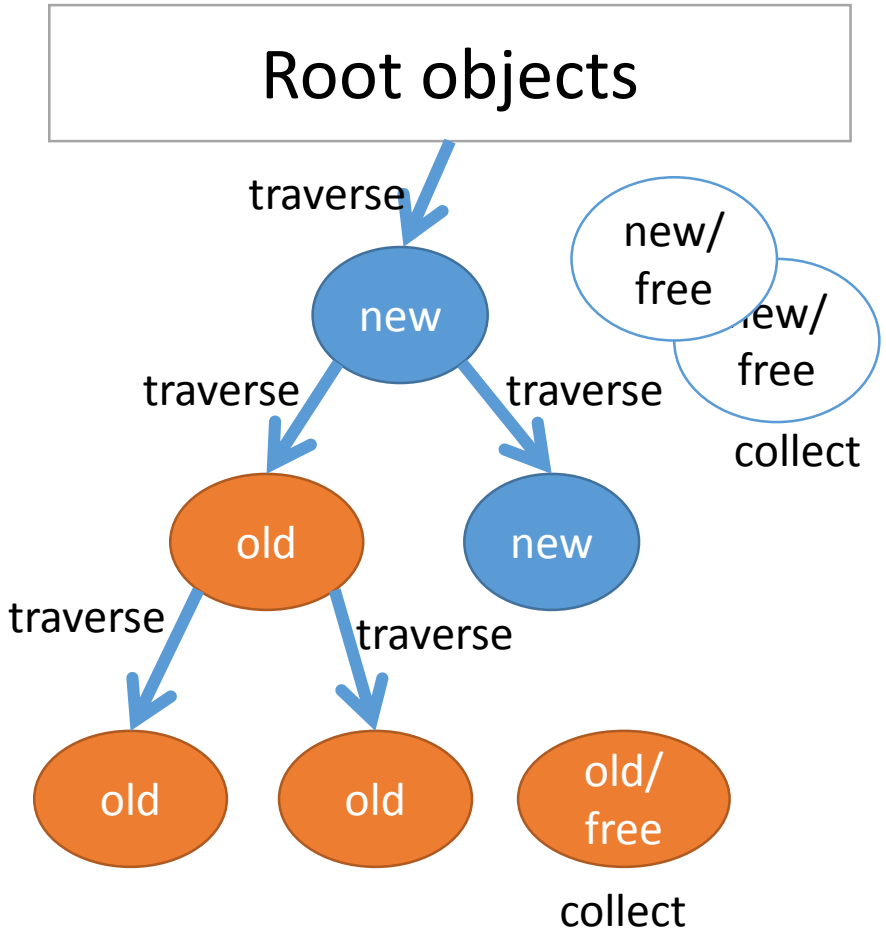
- Mark reachable objects from root objects.
  - Mark and **promote to old generation**
  - Stop traversing after old objects

→ Reduce mark overhead

- Sweep not (marked or old) objects

- Can't collect Some unreachable objects

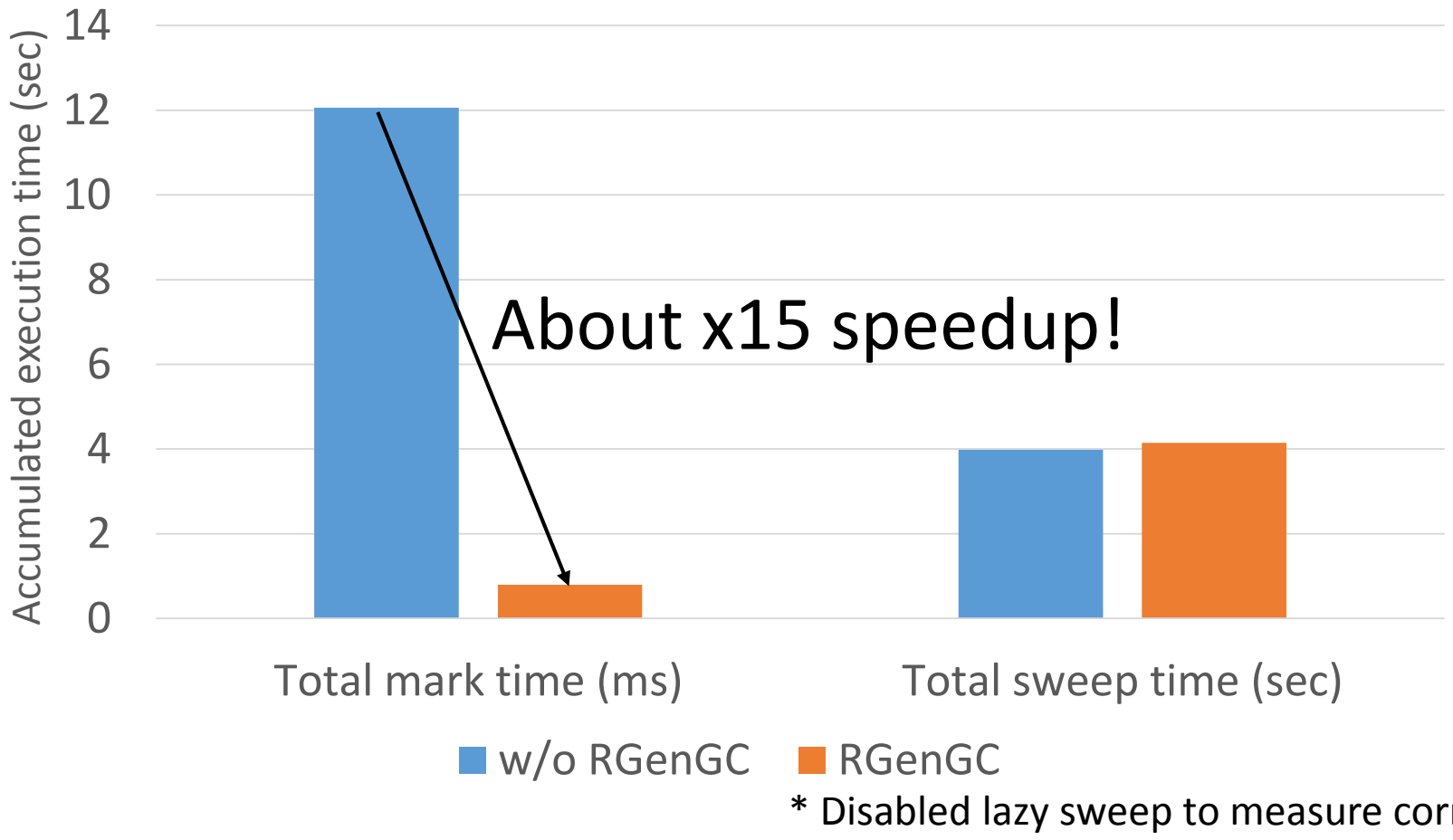
GenGC [Major M&S GC]



- Normal M&S
- Mark reachable objects from root objects
  - Mark and **promote to old gen**
- Sweep unmarked objects

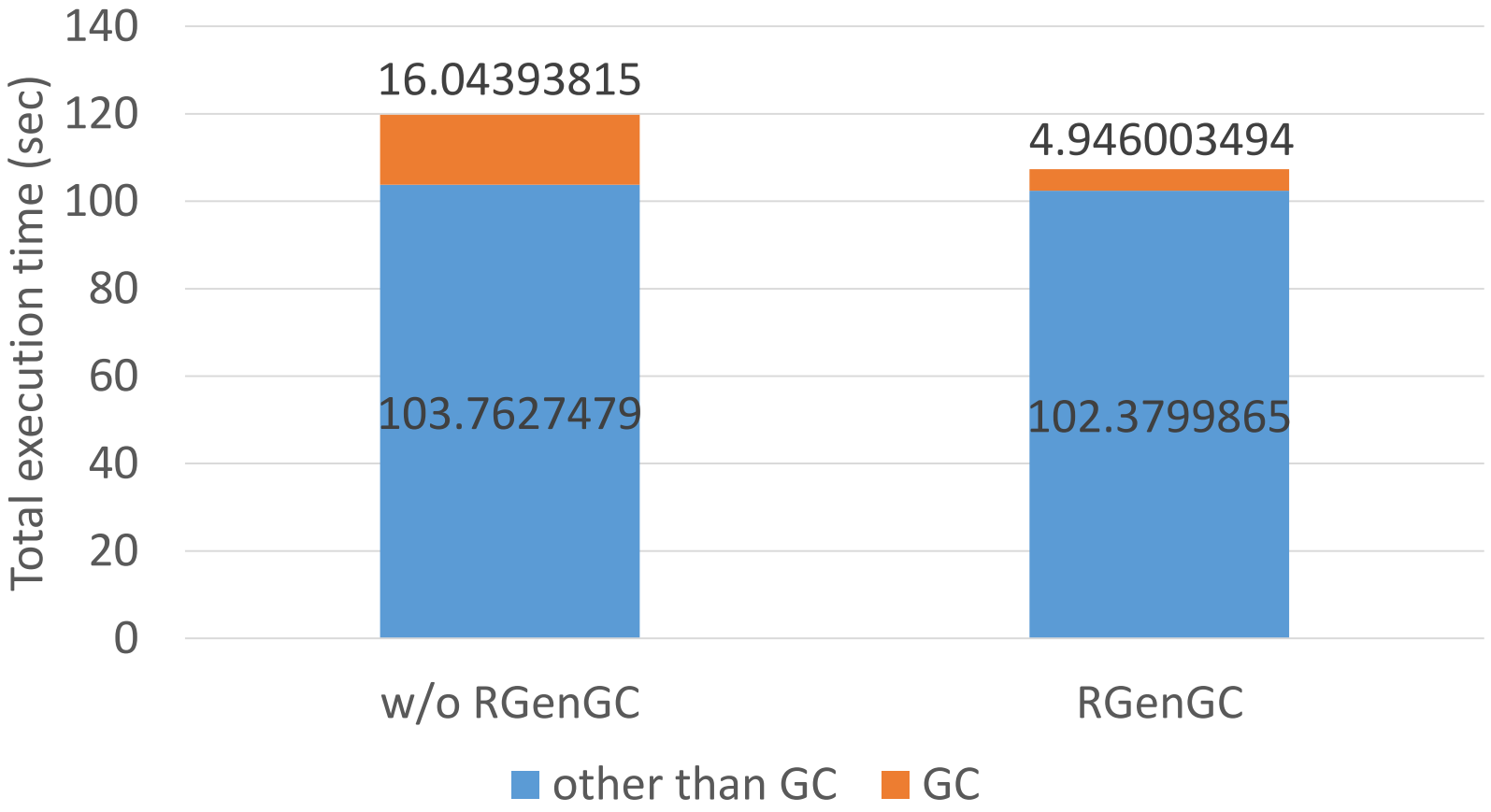
- *Sweep all unreachable (unused) objects*

RGenGC from Ruby 2.1.0
Performance evaluation (RDoc)



* Disabled lazy sweep to measure correctly.

RGenGC from Ruby 2.1.0
Performance evaluation (RDoc)



* 12% improvements compare with w/ and w/o RGenGC
* Disabled lazy sweep to measure correctly.

Summary

Summary
Repeating “Basic flow” is my daily job

1. Observe Ruby interpreter
2. Make assumption the reason of slowness
3. Consider ideas to overcome
4. Implement ideas
5. Measure the result
   - Bad/same performance → Goto 4, 3, 2 or 1
   - Good performance! → Commit it.

Summary

Ruby/MRI is getting better and better.

Thank you for your attention

Koichi Sasada

<ko1@heroku.com>

heroku