Lightweight Method Dispatch on MRI

Koichi Sasada
<ko1@heroku.com>

EURUKO2015

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

“Why I wouldn’t use rails for a new company” by Jared Friedman

“The ruby interpreter is just a volunteer effort. Between 2007-2012, there were a number of efforts to fix the interpreter and make it fast (Rubinius, Jruby, YARV, etc) ***But lacking backers with staying power, the volunteers got bored and some of the efforts withered.*** *JRuby is still active and recent versions are showing more promise with performance, but it’s been a long road.”*

Quoted from http://blog.jaredfriedman.com/2015/09/15/why-i-wouldnt-use-rails-for-a-new-company/ (September 15, 2015)

Koichi is an Employee

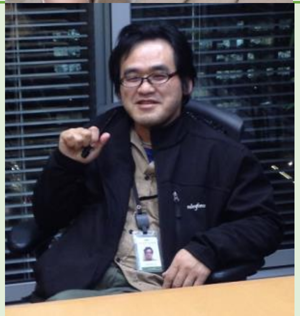
Koichi is a member of Heroku Matz team

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
  - Japanese teacher
  - 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

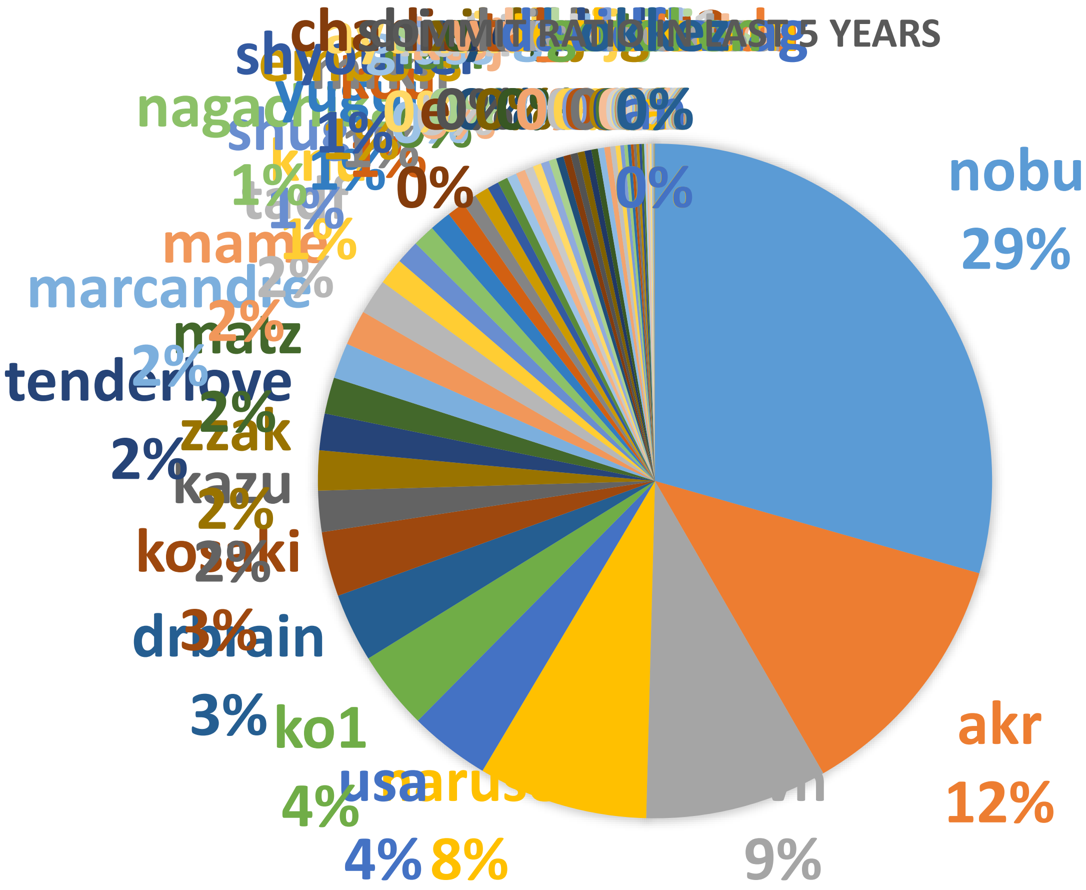
Ruby’s bug

|> Fix Ruby

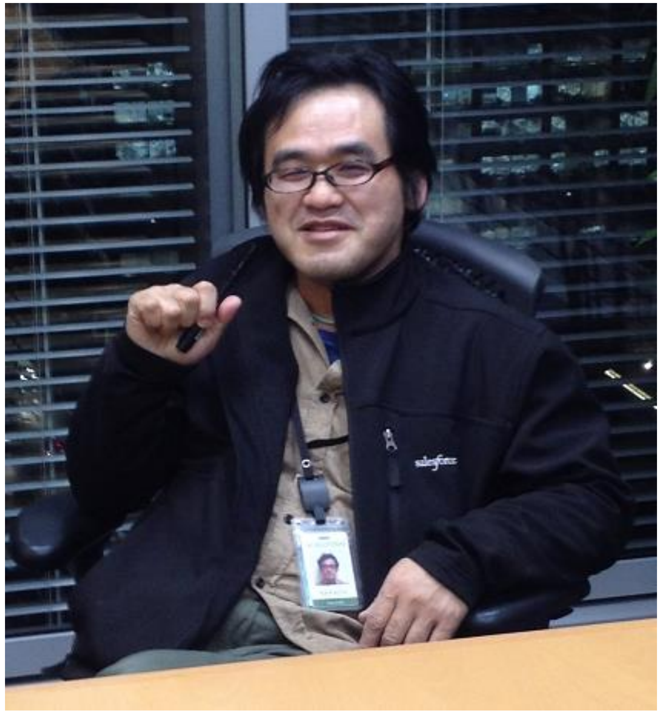
|> Break Ruby

|> And Fix Ruby

Nobu
Patch monster

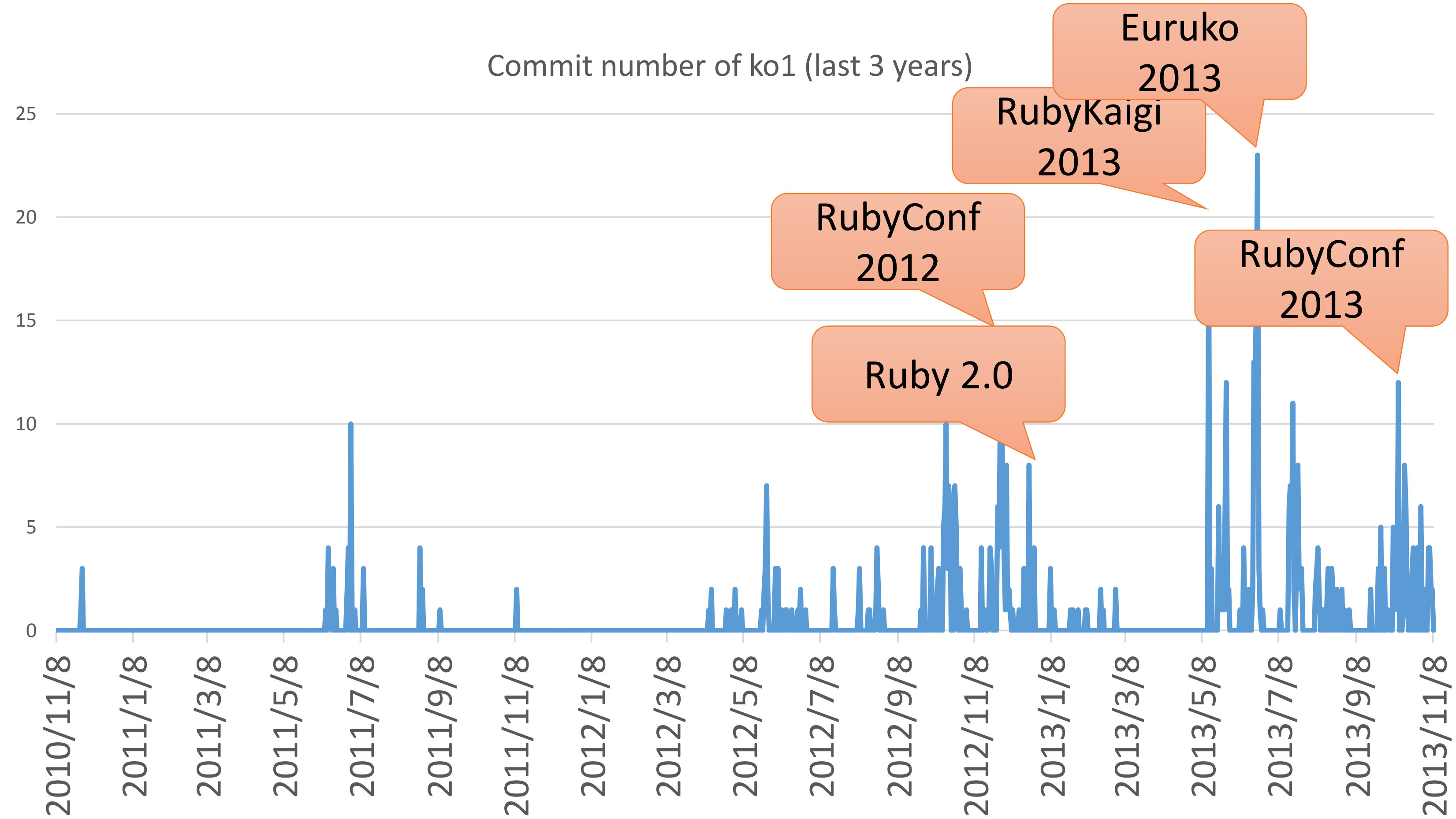


Commit count of MRI



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

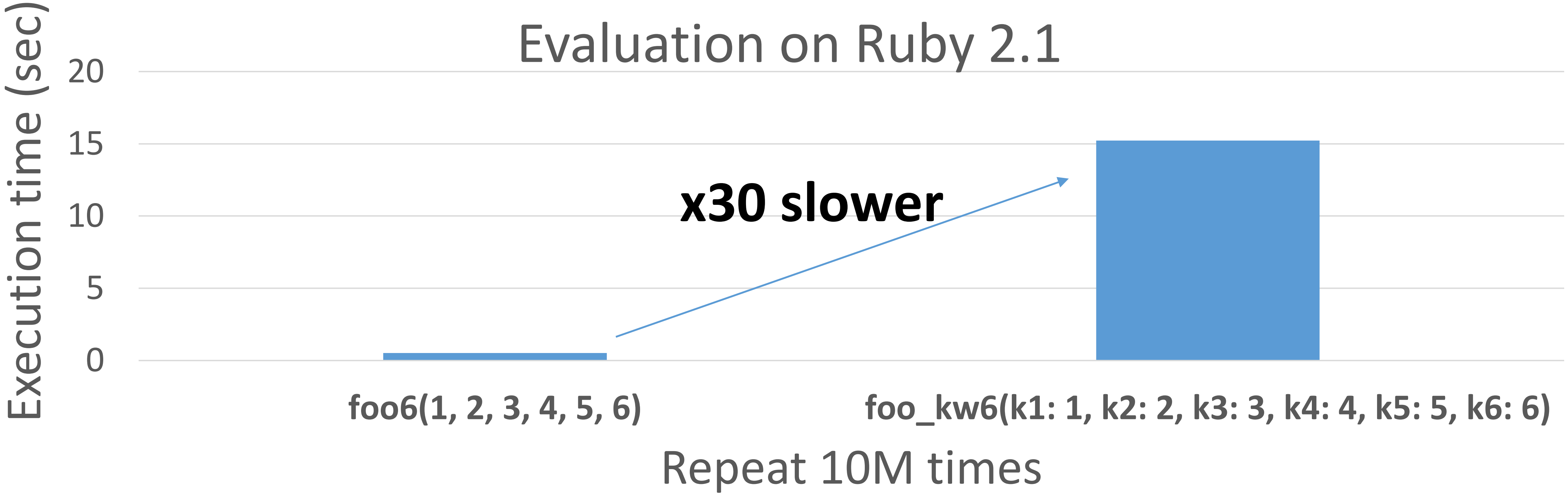
```
before = Symbol.all_symbols.size
1_000_000.times{|i| i.to_s.to_sym} # Make 1M symbols
after = Symbol.all_symbols.size; p [before, after]

# 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

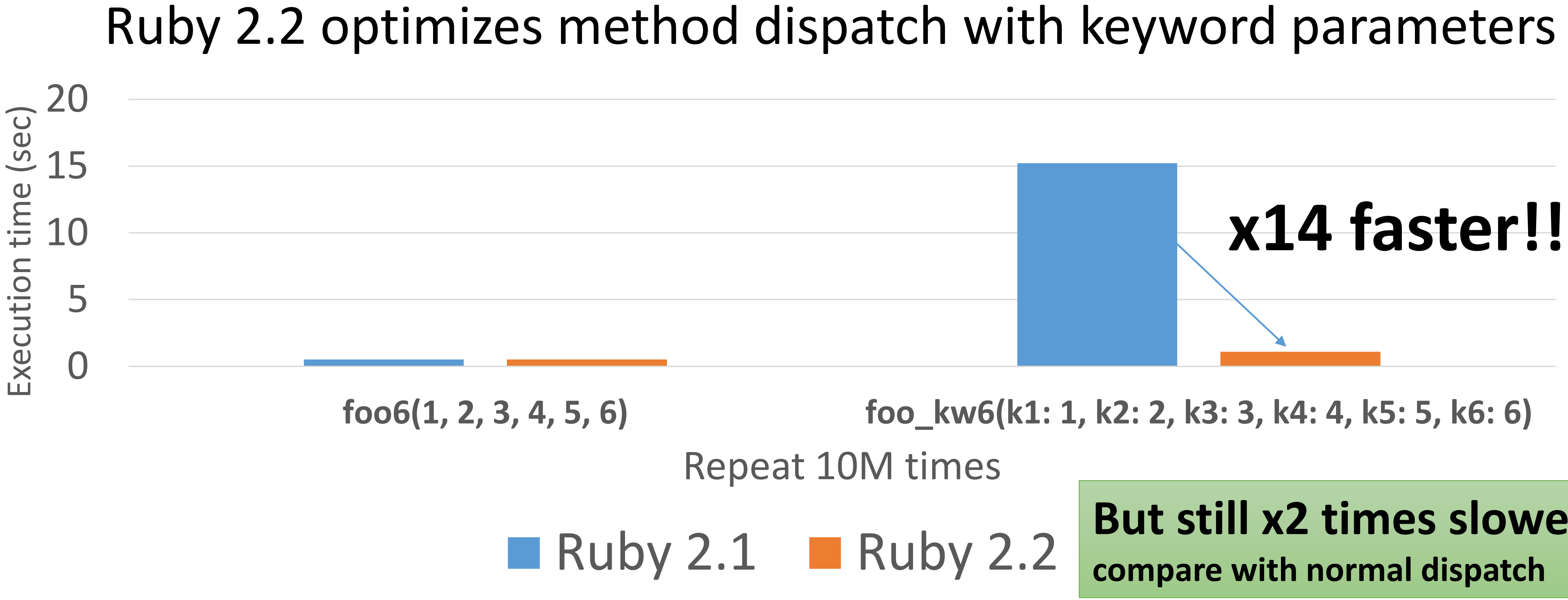
- **Ruby 2.2.0** has memory (object) leak problem
  - Symbols has corresponding String objects
  - Symbols are collected, but Strings are not collected! (leak)
- **Ruby 2.2.1** solved this problem!!
  - However, 2.2.1 also has problem (rarely you encounter BUG at **the end of process [Bug #10933]** ← 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



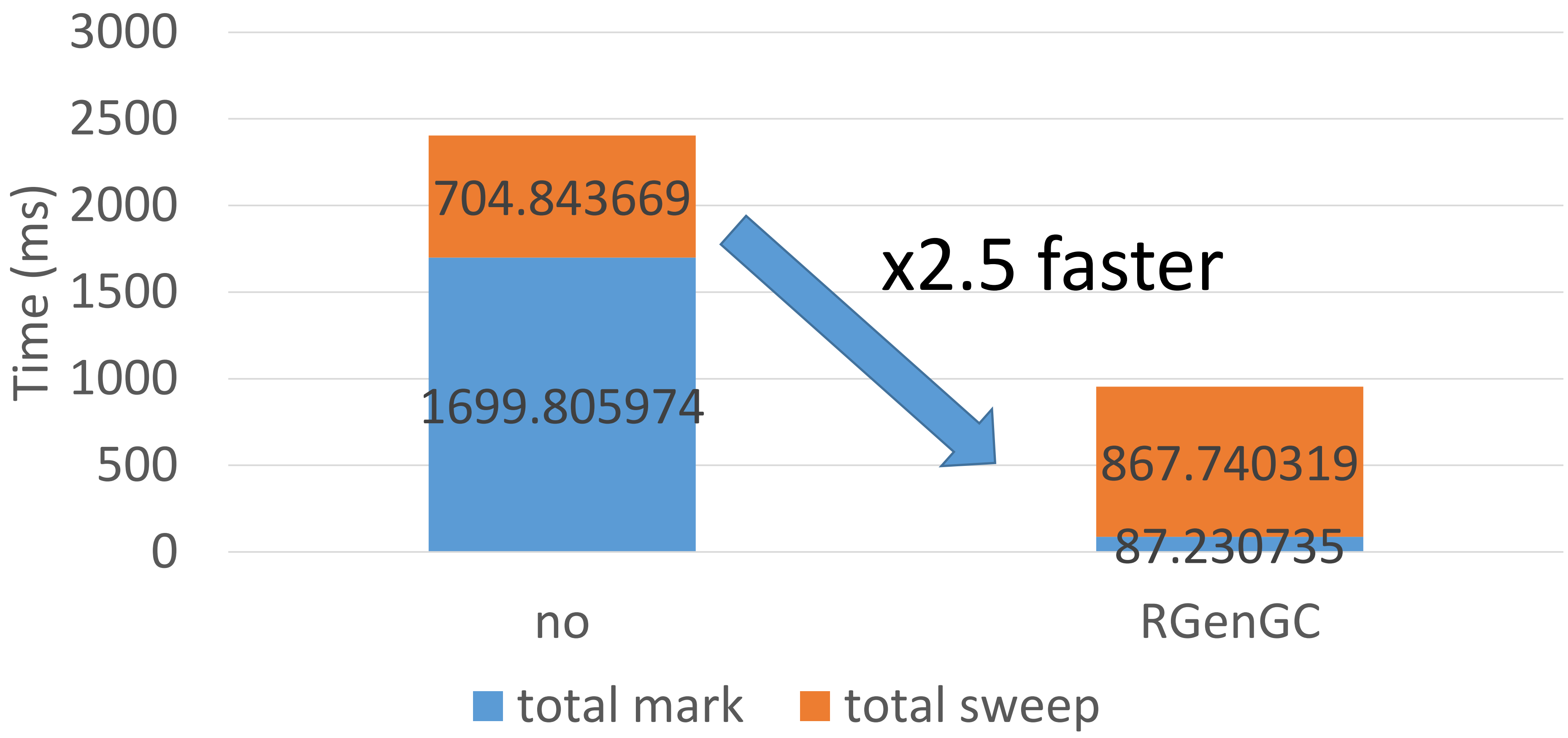
But still x2 times slower
compare with normal dispatch

Ruby 2.2
Incremental GC

Goal

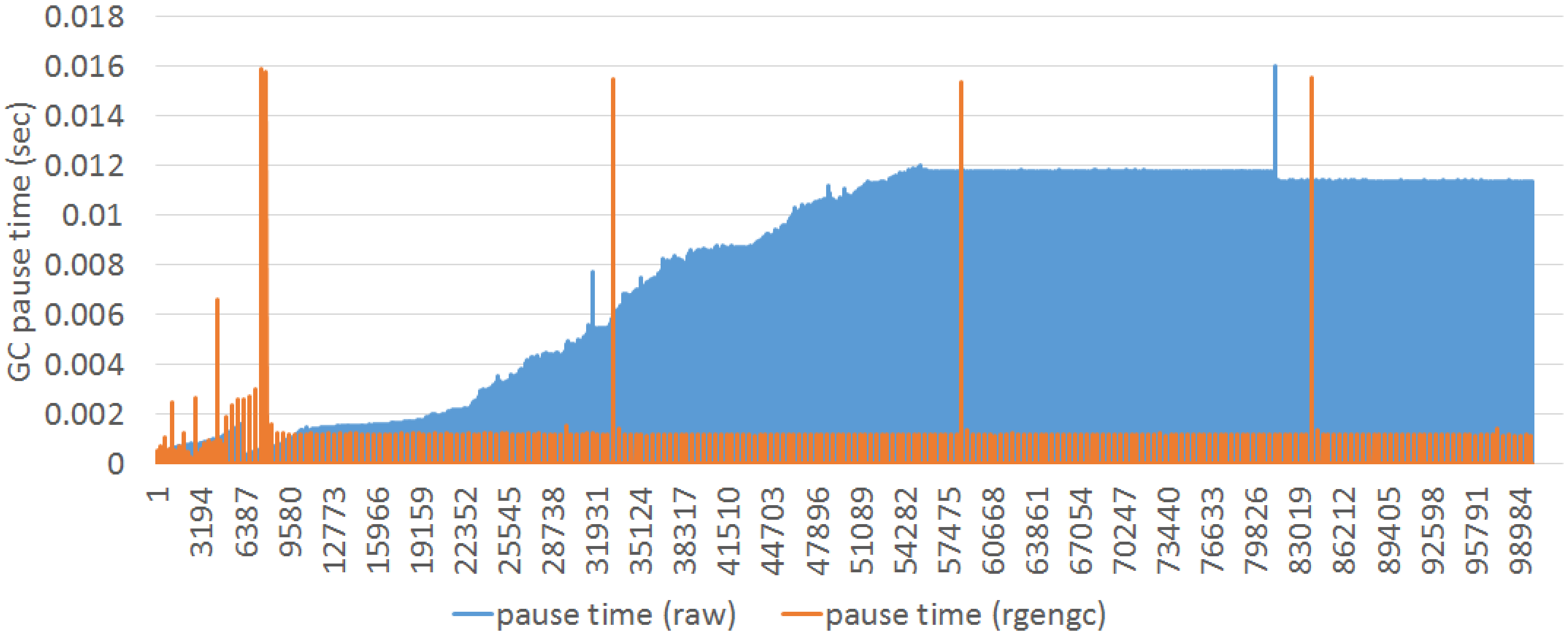
	Before Ruby 2.1	Ruby 2.1 RGenGC	Incremental GC	Ruby 2.2 Gen+IncGC
Throughput	Low	High	Low	High
Pause time	Long	Long	Short	Short

RGenGC from Ruby 2.1: Micro-benchmark



RGenGC from Ruby 2.1: Pause time

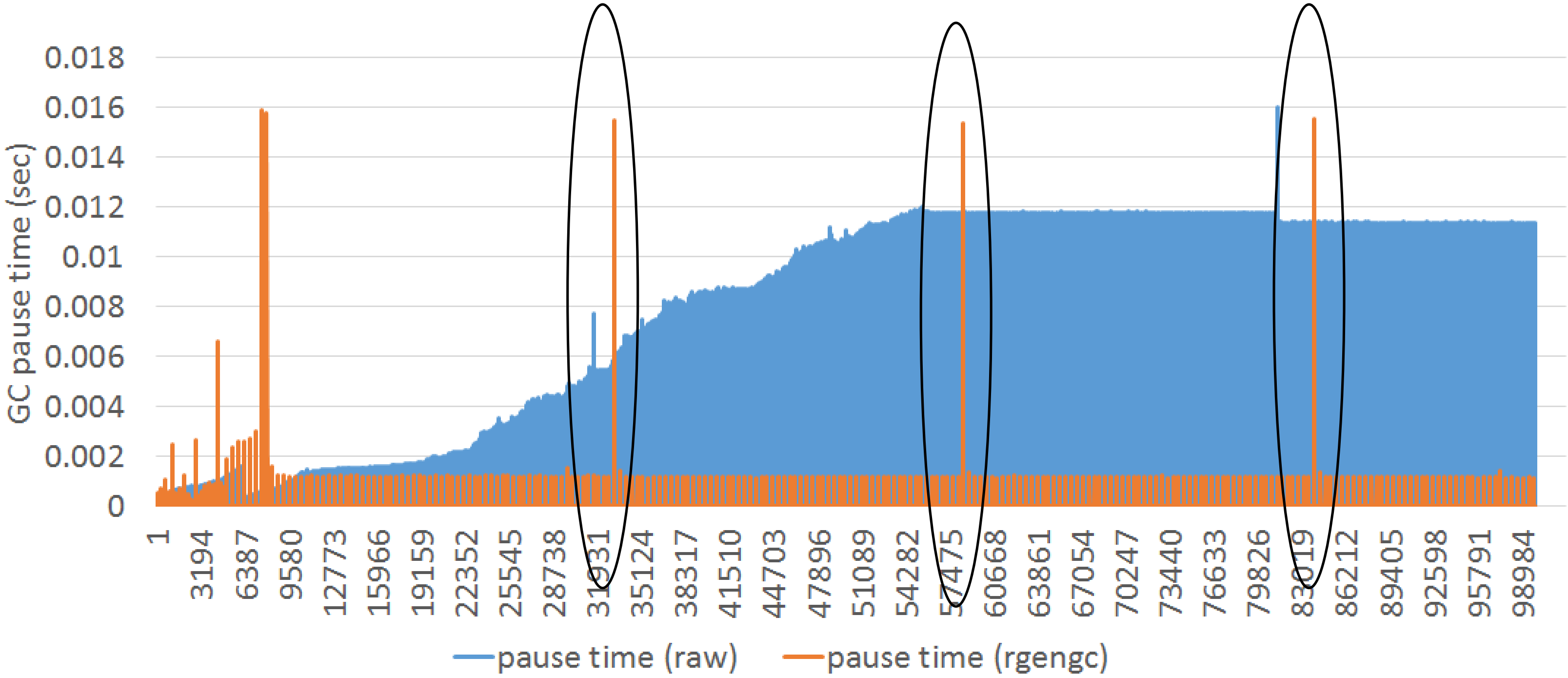
Most of cases, FASTER ☺



(w/o rgengc)

RGenGC from Ruby 2.1: Pause time

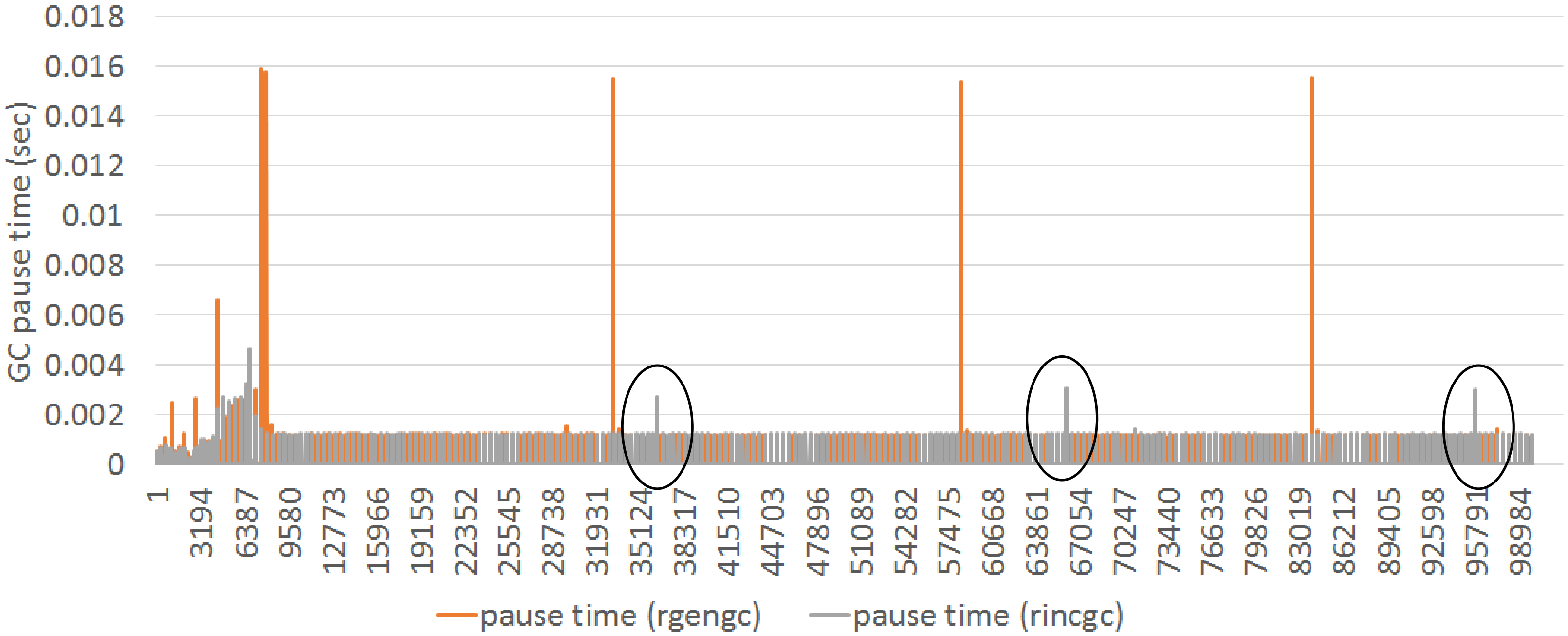
Several peaks ☹



(w/o rgengc)

Ruby 2.2 Incremental GC

Short pause time ☺



Heroku Matz team and Ruby core team
Next target is

Ruby 2.3

New magic comment:
Frozen string literal

```
# -*- frozen-string-literal: true -*-
p 'foo'.frozen? #=> true

# There are many discussion.
# Please join us.
```

http://www.flickr.com/photos/donkeyhotey/8422065722

Break

Ruby has so many

****

Let’s play hangman game

Ruby has so many

****

___

Ruby has so many

F***

_

Ruby has so many

FU**

Ruby has so many

FU**___

Ruby has so many

FUNCtions

Or Methods

How many function/method call?

Importance of optimization
for “function/method dispatch”

Easy way to measure method dispatch count

```
# at the beginning of your application
$c = 0; TracePoint.trace(:call, :a_call){$c+=1}
END{puts “call: #{$c}”}

# and your app…
```

Measuring method dispatch counts

- RDoc application
    - Make RDoc documents from Ruby’s source
    - **120M≒100M** dispatches in **60 sec**
- Tak(20, 10, 0) benchmark using recursive calls
    - Famous benchmark

      ```
      def tak x, y, z
        y < x ? tak(tak(x-1, y, z), tak(y-1, z, x), tak(z-1, x, y)) : z
      end
      ```

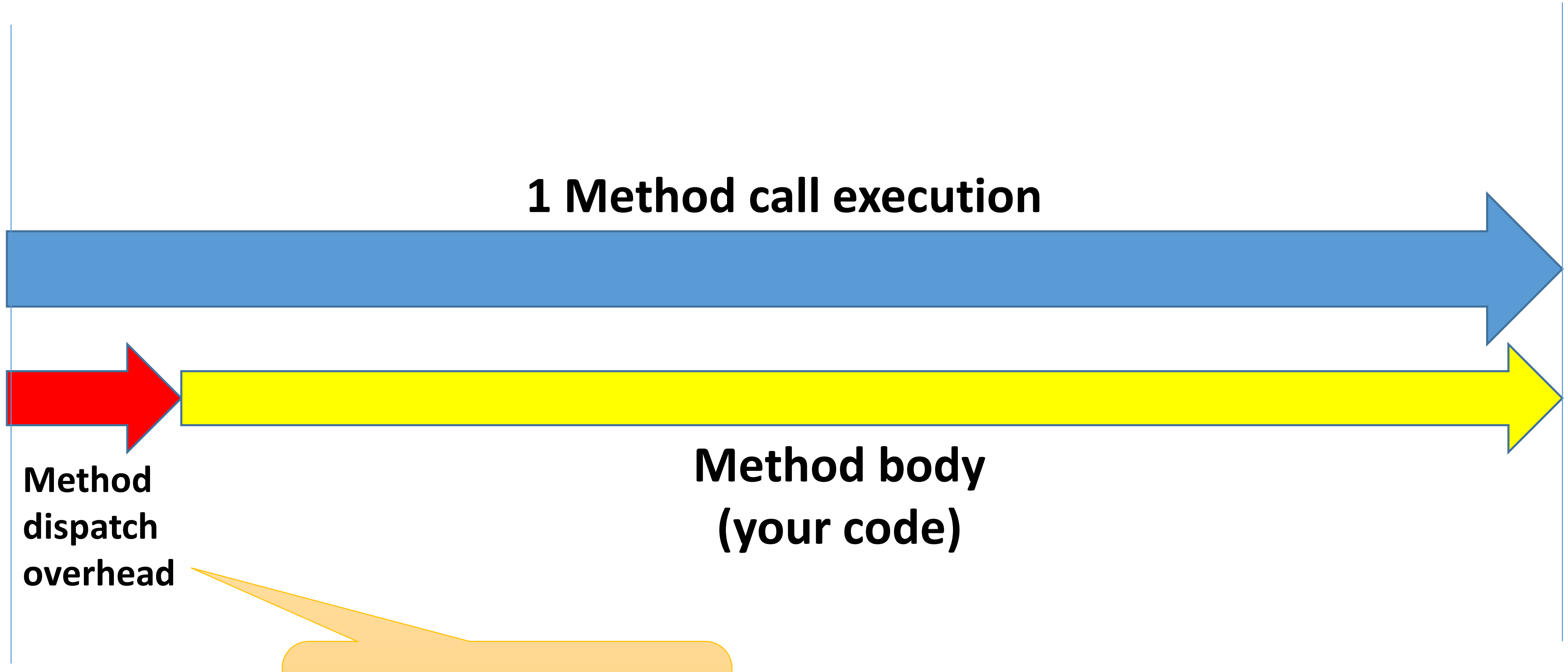
    - **100M** dispatches in **4.5 sec**

Ruby has so many

FUNCtions

Or Methods

Execution time of method



1 Method call execution

Method dispatch overhead

Method body (your code)

Today's topic

100M method dispatches Estimation

- 1sec/method dispatch #=> 100M sec => about 3 years
- 1msec/method dispatch #=> 100M ms => about 1 days
- 1usec/method dispatch #=> 100M us => 100 sec
  - 1us is 3000 clocks on 3GHz CPU
- 10nsec/method dispatch #=> 1,000M ns => 1sec
  - 10ns is 30 clocks on 3GHz CPU
- 1nsec/method dispatch #=> 100M nsec => 0.1 sec
  - 1ns is 3 clocks on 3GHz CPU

Matter or not matter

- 1 sec method dispatch overhead in 60 sec application (rdoc)

  #=> **doesn’t matter**

- 1 sec method dispatch overhead in 4 sec application (tak)

  #=> **big concern**

- Maybe most of applications are located between these two applications
  - RDoc app has complex methods, so that dispatch cost is not a matter
  - Tak app has a simple method, so that dispatch cost slows app directly

BTW
1sec / method dispatch

```
# CAUTION:
# Do not insert this line in your friends’ application

TracePoint.trace(:call){sleep 1}
```

Requirements
Revisit Ruby’s method dispatch

```
# Simple method call

def simple_foo(x)
  …
end
…
foo(123)
```

# Complex method call

```
protected # visibility
def complex_foo(m1, m2, o1=1, o2=2, *r, p1, p2, k1: 1, k2: 2, kr:, **kw, &b)
  … # body
end
…
complex_foo(v1, v2, *a1, v3, v4, *a2, k1: 1, k2: 2, kr: 3, **kw, &block)
```

# RubyQuiz: can you explain everything?

Complex method dispatch
Caller side

- Normal arguments: m(v1, v2)
- Splatting arguments: m(*a1, *a2)
- Block argument: m(&block)
- Keyword arguments: m(k1: v1, k2: v2)
- Combination: m(v1, v2, *a1, v3, *a2, k1: 1, &b)
  - Ex) v1=v2=v3=a1=a2=b=v1=nil

    p(v1, v2, *a1, v3, *a2, k1: v1, &b) #=> ...?

Complex method dispatch
Callee side (defined methods)

- Parameters
  - Mandatory parameters
  - Optional parameters
  - Rest parameter
  - Post parameters
  - Keyword parameters
    - Optional keyword parameters
    - Required keyword parameters
    - Rest keyword parameters
  - Block parameter or block passing directly

Complex method dispatch
Callee side (defined methods)

- Visibility
  - Public
  - Private
  - Protected

# RubyQuiz: can you explain everything?

Complex method dispatch
Dynamic features

- Classes can extend methods
    - Open class
    - “include”/”prepend”
    - “extend” by instance objects
- Method missing
- Refinements (using)
- …

Complex method dispatch
Calling interface

- Call by Ruby’s scripts
- Call by “send”
- Call by interpreters
  - E.g: Implicit conversions using to_int, to_a, …
- Call by C extensions

Design
What should we do?

Basic logic of method dispatch

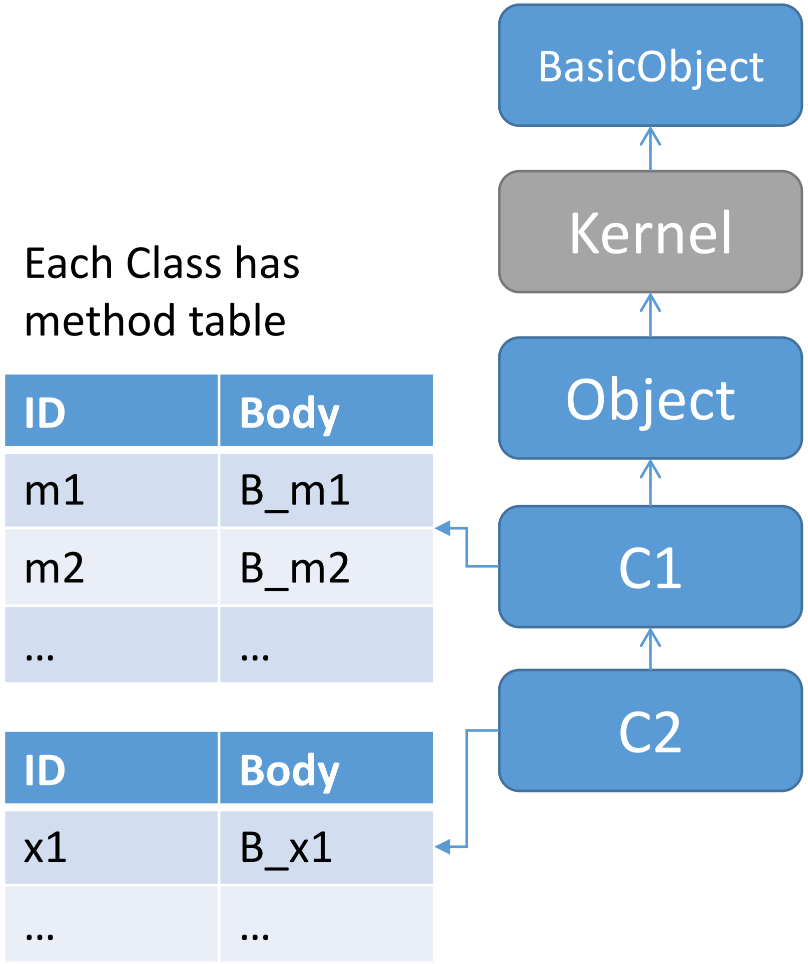
1. Get class of receiver (`klass’)
2. Search a method `body’ from `klass’
3. Check availability, visibility and an arity of passed arguments
4. Construct a method frame with `body’
5. And continue VM execution

Basic logic of method dispatch

1. Get class of receiver (`klass’)
2. **Search a method `body’ from `klass’**
3. Check availability, visibility and an arity of passed arguments
4. Construct a method frame with `body’
5. And continue VM execution

Search a method body

- 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



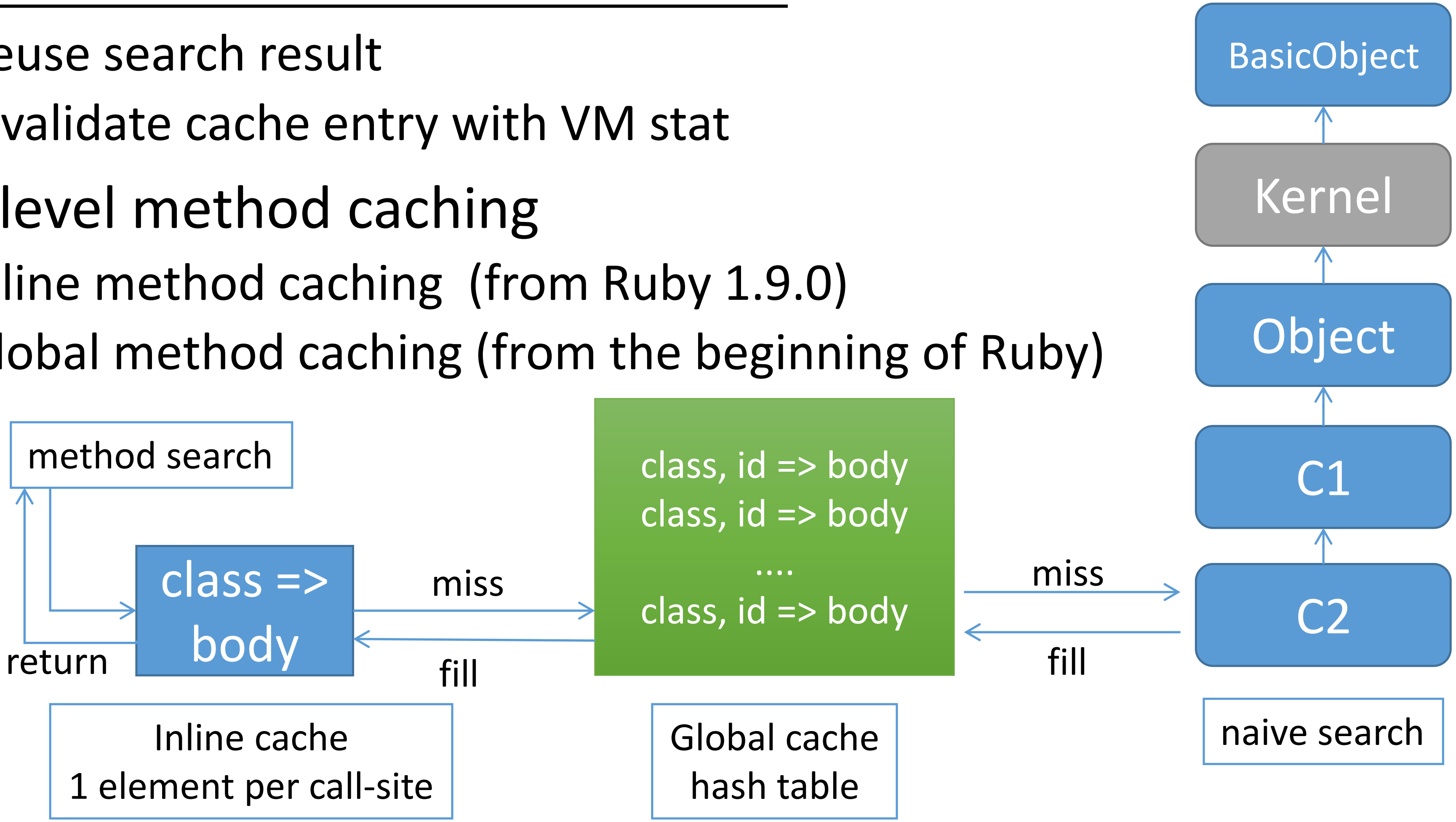
Each Class has method table

ID	Body
m1	B_m1
m2	B_m2
…	…

ID	Body
x1	B_x1
…	…

Optimization
Method caching

- **Eliminate method search overhead**
  - Reuse search result
  - Invalidate cache entry with VM stat
- Two level method caching
  - Inline method caching (from Ruby 1.9.0)
  - Global method caching (from the beginning of Ruby)



Optimization
Method table (from Ruby 2.3)

- Make special Hash table for method table
  - To make search faster
  - To make more compact (lower memory usage, about 1/2)
  - https://bugs.ruby-lang.org/issues/11420
- Introduce method ID → method body related table
  - Ruby 2.2 and before use common table data structure shared with Hash objects. It is general and many features (ex: ordering), but over spec only for this purpose.

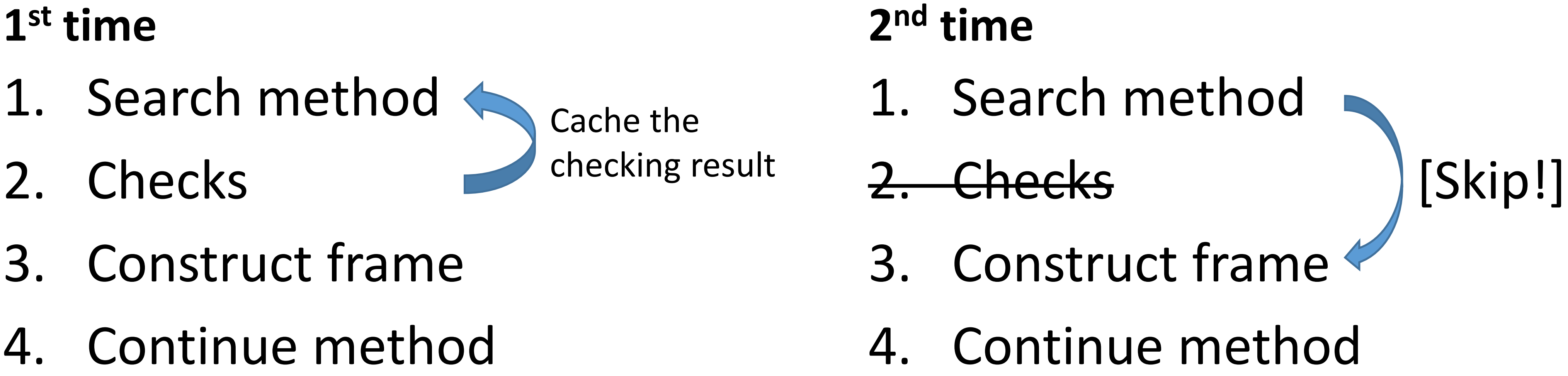
Basic logic of method dispatch

1. Get class of receiver (`klass’)
2. Search a method `body’ from `klass’
3. **Check availability, visibility and an arity of passed arguments**
4. Construct a method frame with `body’
5. And continue VM execution

Check the availability, visibility and an arity

- Method body checking
  - Not found → call method_missing
- Visibility checking
  - Not found → call method_missing
- Arity checking
  - Not matched → raise ArgumentError

Optimization (from Ruby 2.0)
Caching checking results into inline method cache



1st time

1. Search method
2. Checks
3. Construct frame
4. Continue method

Cache the checking result

2nd time

1. Search method
2. ~~Checks~~
3. Construct frame
4. Continue method

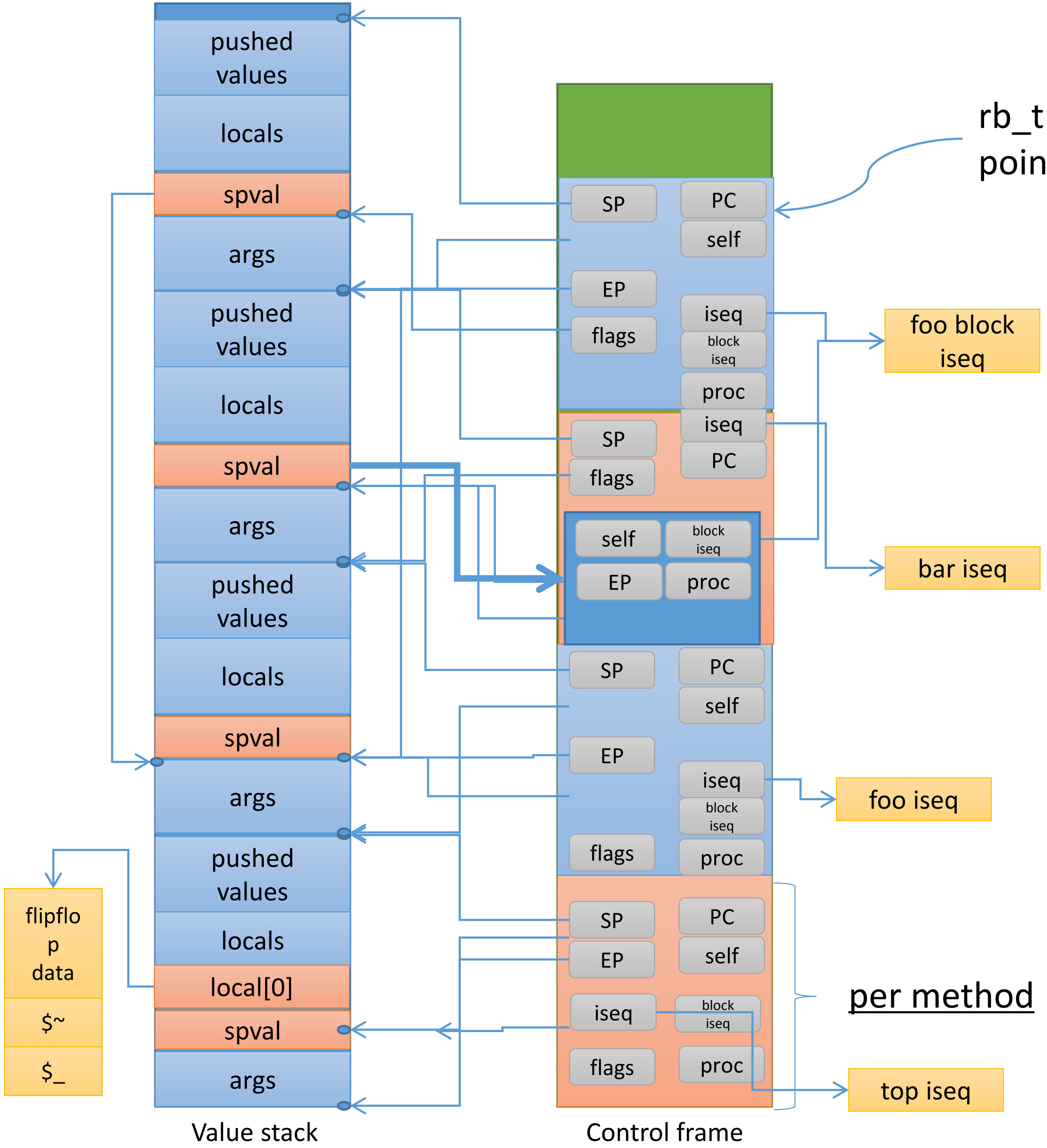
[Skip!]

Basic logic of method dispatch

1. Get class of receiver (`klass’)
2. Search a method `body’ from `klass’
3. Check availability, visibility and an arity of passed arguments
4. **Construct a method frame with `body’**
5. And continue VM execution

Construct a method frame

- Each method needs **a method frame** to maintain:
  - Local variables (includes method parameters)
  - Passed block information
  - Current method information (used by backtrace and so on)
  - …



rb_thread_t::cfp
points current control frame

```
def foo
  bar{
    ..
  }
end
def bar
  yield
end
foo
```

Ruby 1.9 VM stacks structure

Local variables with complex passed arguments and method parameters

```
# complex method parameters
def complex_foo(m1, m2, o1=1, o2=2, *r, p1, p2, k1: 1, k2: 2, kr:, **kw, &b)
  … # body
end
…
# complex method dispatch
complex_foo(v1, v2, *a1, v3, v4, *a2, k1: 1, k2: 2, kr: 3, **kw, &block)
```

Basic logic of method dispatch

1. Get class of receiver (`klass’)
2. Search a method `body’ from `klass’
3. Check availability, visibility and an arity of passed arguments
4. **Construct a method frame with `body’**
5. And continue VM execution

Detailed logic of method dispatch

1. Get class of receiver (`klass’)
2. Search a method `body’ from `klass’
3. Check availability, visibility and an arity of passed arguments
    1. Check arity (expected args # and given args #) and process
        1. Post arguments
        2. Optional arguments
        3. Rest argument
        4. Keyword arguments
        5. Block argument
4. **Construct a method frame with `body’**
    1. 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
5. And continue VM execution

Optimization (from Ruby 1.9.0)
Specialized instruction

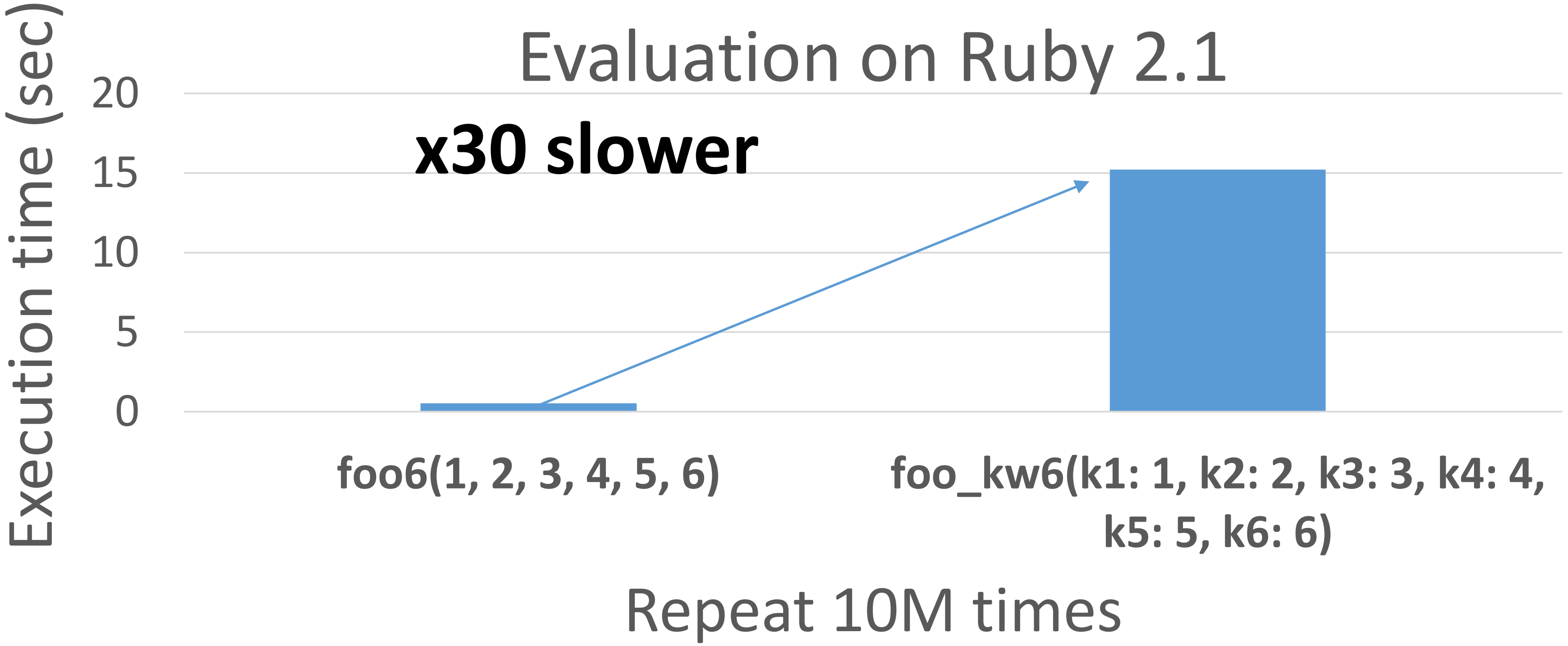
- Make special VM instruction for several methods
  - +, -, *, /, …

```
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
```

Keyword parameters from Ruby 2.0

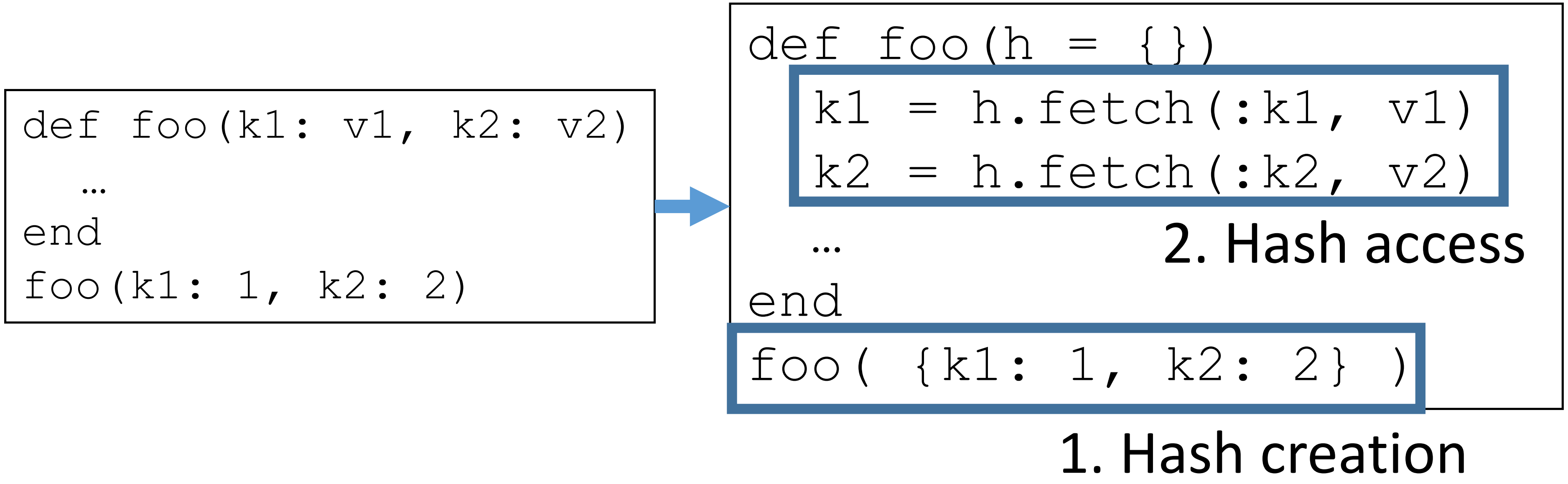
```
# def with keywords
def foo(a, b, key1: 1, key2: 2)
  …
end
# call with keywords
foo(1, 2, key1: 123, key2: 456)
```

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

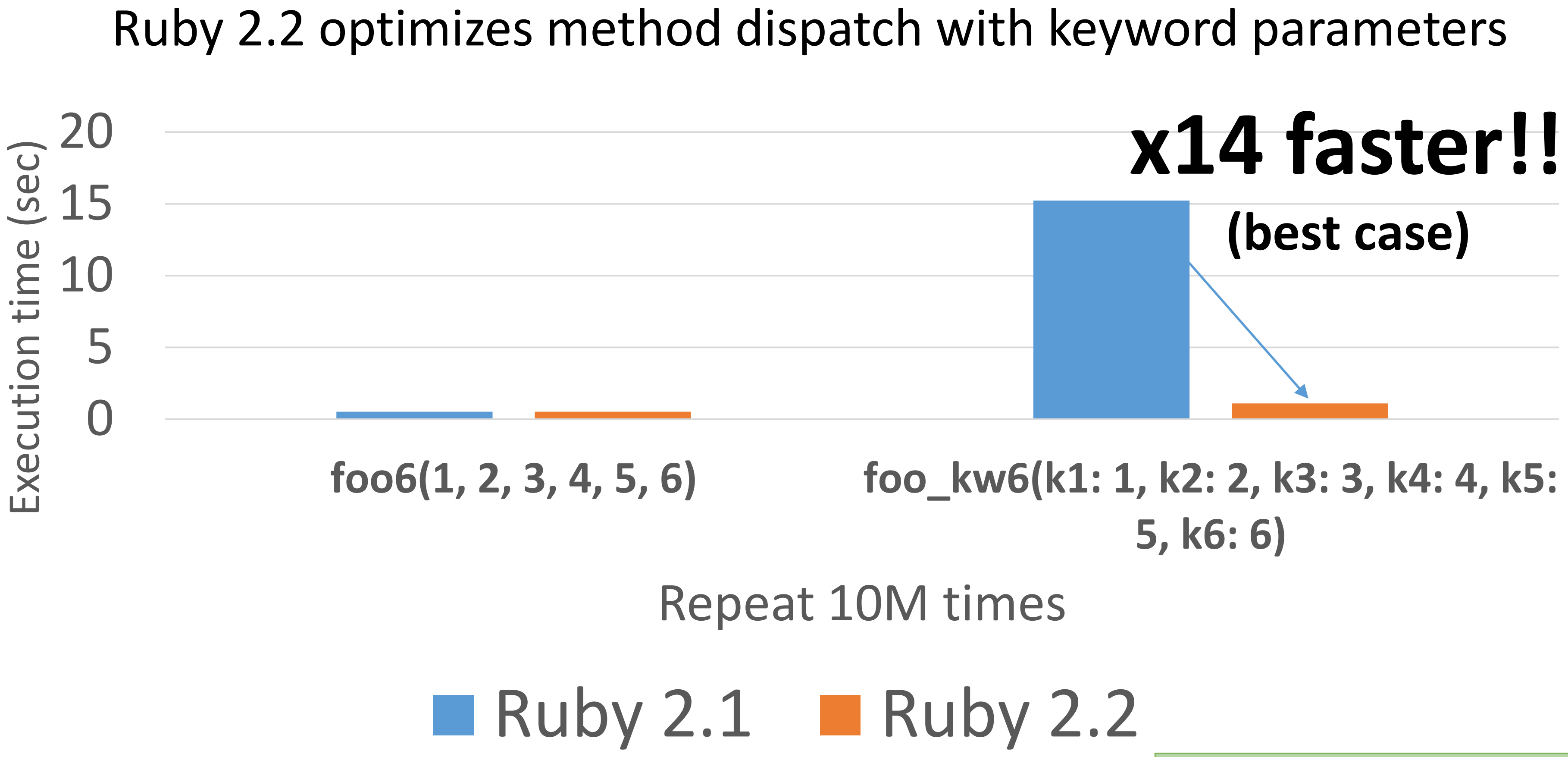
Optimization (from Ruby 2.2) Fast Keyword parameters

- 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)



x14 faster!!

(best case)

But still x2 times slower

compare with normal dispatch

Another Idea:
90% of methods are like simple method calls

```
# Simple method call
def simple_foo(x)
  …
end
…
foo(123)
```

Optimization (from Ruby 2.3)
Caching checking results into inline method cache

1st time

1. Search method
2. Checks
3. Construct frame
4. Continue method

Cache the checking result

2nd time

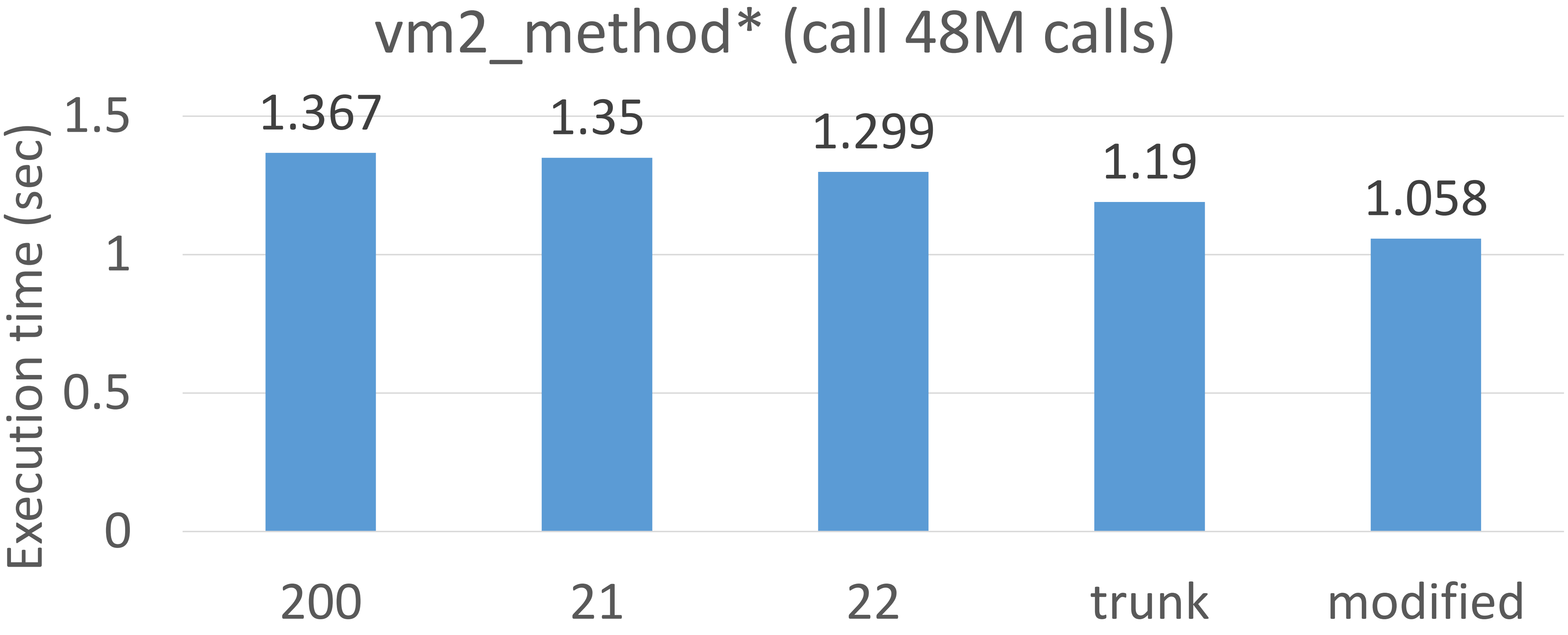
1. Search method
2. ~~Checks~~
3. Construct frame
    1. Simple code setup
        - Call inline code for 0 param, 0 locals
        - Call inline code for 0 param, 1 locals
        - Call inline code for 1 param, 0 locals
        - ….
    2. Complex code setup
4. Continue method

[Skip!]

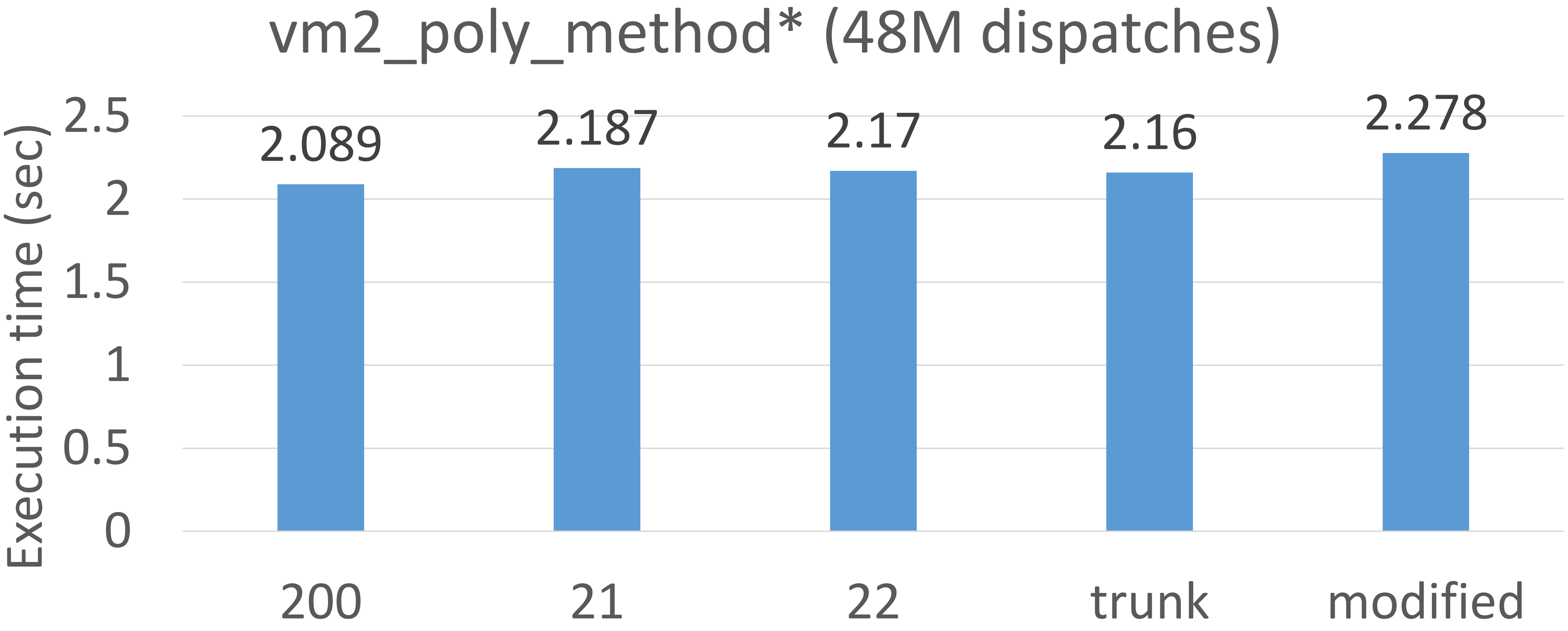
Optimization (from Ruby 2.3)
Caching checking results into inline method cache

- Make dispatch function
  - Base C function: dispatch(…, param, local){ /* setup frame */ }
  - Make several inline codes
    - dispatch_0_0(…){dispatch(.., 0, 0);}
    - dispatch_0_1(…){dispatch(.., 0, 1);}
    - dispatch_1_0(…){dispatch(.., 1, 0);}
    - dispatch_0_1(…){dispatch(.., 0, 1);}
    - …
- And call inline dispatch function (if it is possible)

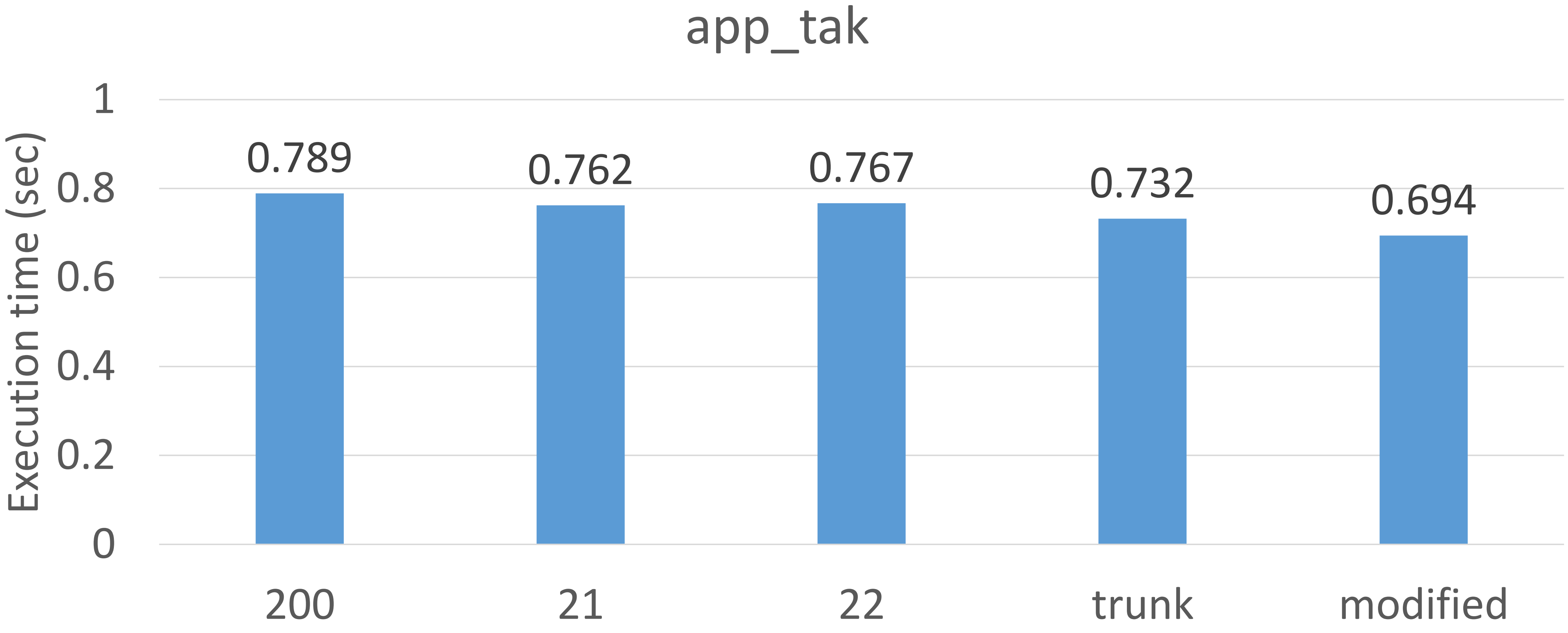
Evaluation
Dispatch same method (hit inline cache)



Evaluation
Dispatch different methods (miss inline cache)



Evaluation
Tak function



Rough estimation

- Hit inline cache: about 1.1 sec on 48M call

  → 23ns / call

  → 78 clocks on 3.4GHz CPU

- Miss inline cache: about 2.3 sec on 48M call

  → 48ns / call

  → 163 clocks on 3.4GHz

Summary

- Method dispatch is key feature for Ruby
- Ruby’s method has rich features
- Many optimization techniques on MRI are invented by many people

Summary

Ruby/MRI is getting better and better.

Thank you for your attention

Koichi Sasada

<ko1@heroku.com>

heroku