Parallel programming in Ruby3 with Guild

Koichi Sasada

Cookpad Inc.
<ko1@cookpad.com>

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Today's talk

- Ruby 2.6 updates of mine
- Introduction of Guild
  - Design
  - Discussion
  - Implementation
  - Preliminary demonstration

Koichi Sasada

http://atdot.net/~ko1/

- is a programmer
  - 2006-2012 Faculty
  - 2012-2017 Heroku, Inc.
  - 2017- Cookpad Inc.
- Job: MRI development
  - Core parts
    - VM, Threads, GC, etc

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Koichi Sasda

is a father of the youngest attendee of Rails Girls Tokyo 10th

@Cookpad Tokyo office

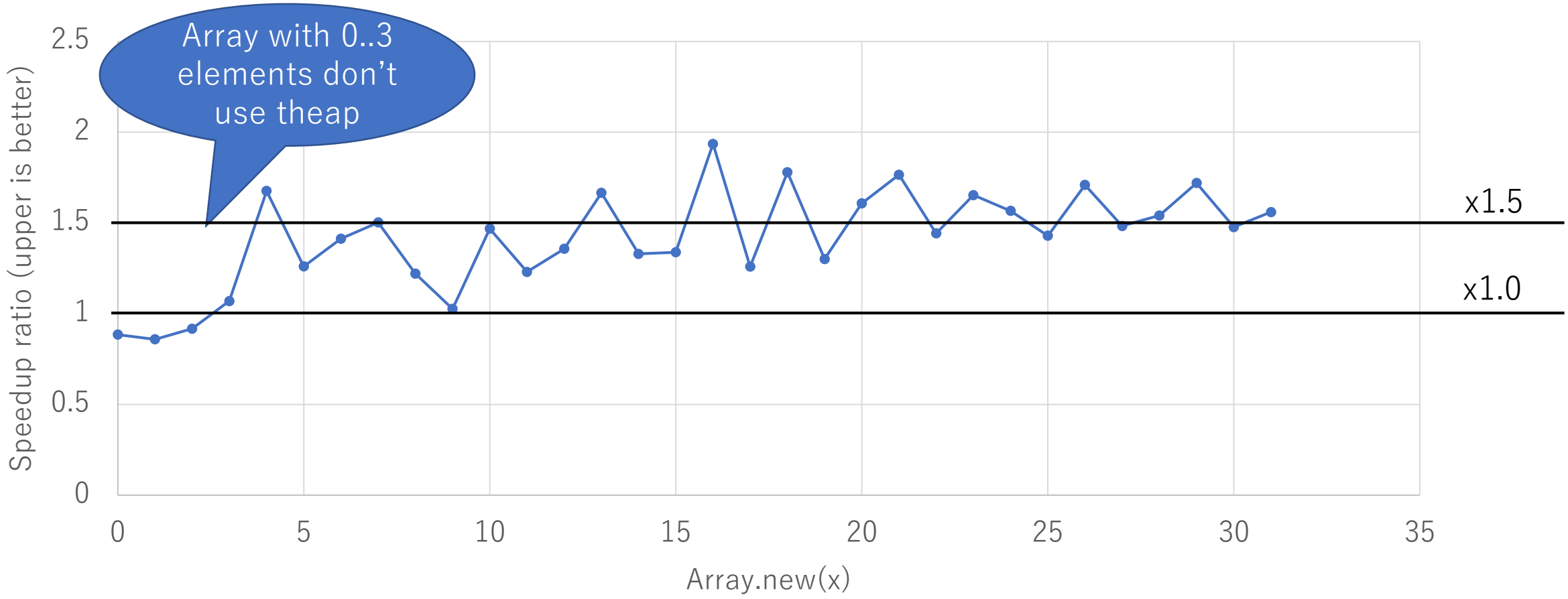
My achievements for Ruby 2.6

- **Speedup `Proc#call` … x1.4** improvements [Bug #10212].
- **Speedup `block.call` where `block` is passed** block parameter. [Feature #14330] (**x2.62**).
- Introduce **Transient heap** [Bug #14858]

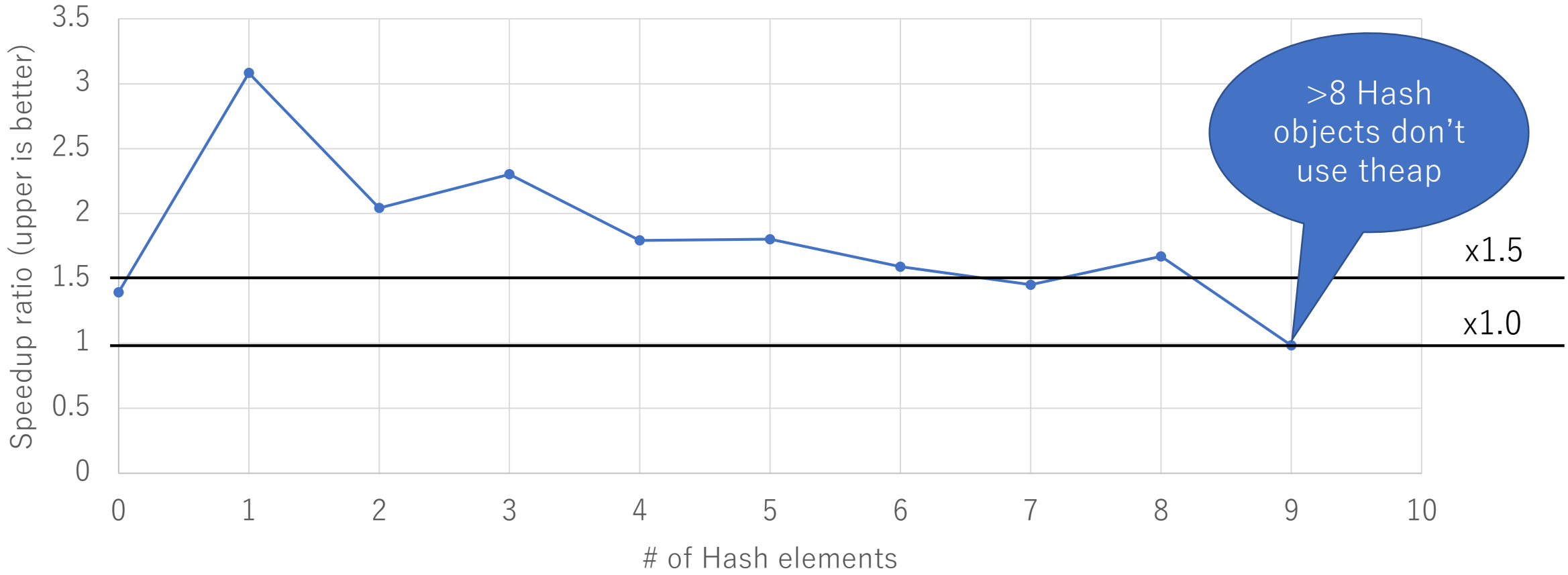
Transient heap

- Manage heap for young memories
  - vs. malloc heap
  - malloc()/free() is heavy operation and introduce memory fragmentation issue and theap solves it.
  - Using Generational copy GC algorithm w/ MRI specific hack
- Array, Object (user defined class), Struct and small Hash objects use theap now
  - Support String is desired, but too difficult

Transient heap
Array creation (loop{Array.new(n))



Transient heap
Small hash creation (loop{h = {…}})



Ruby 2.6: Transient heap Summary

- Transient heap is new memory hack
  - Generational Copy GC technique
  - MRI specific hack to keep compatibility
- Your application **can** improve performance on Ruby 2.6
  - Microbenchmarks show good improvements.
    - x1.5 - x2.0 faster for creation & collection
  - Unfortunately, discourse rails benchmark doesn't show clear perf. improvements

Parallel programming in Ruby3 with Guild

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TL;DR

- Guild is new concurrent abstraction to **force no-sharing** mutable objs for Ruby 3
- Guild specification is **not fixed yet**
- Guild implementation **is not mature** (PoC)
- Your comments are highly welcome!!

Background of Guild

Motivation

Productivity (most important for Ruby)

- Thread programming is **too difficult** because **sharing mutable objects**
- **Correct/safe** concurrent programs easily is important

Performance by Parallel execution

- Utilizing Multi/many CPU cores is important for performance

RubyKaigi2016 (and RubyConf 2016) Proposal

Guild: new concurrency abstraction for Ruby 3

- Idea: **DO NOT SHARE** mutable objects between Guilds
  → No data races, no race conditions

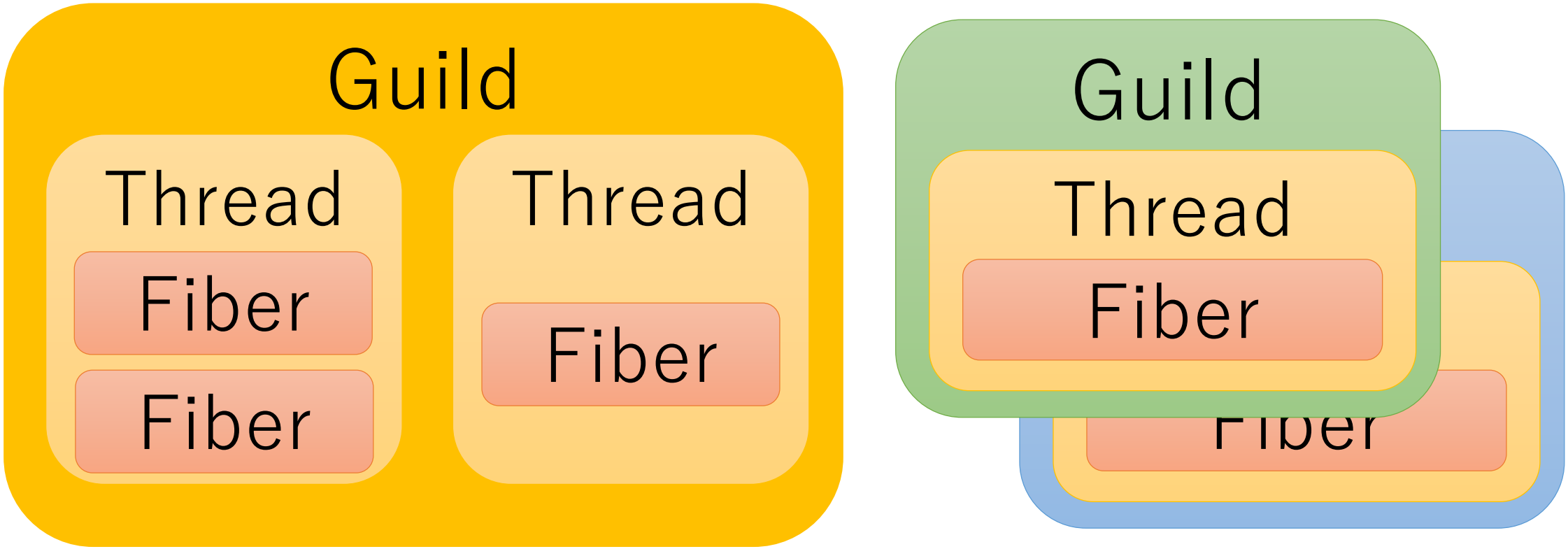
Replace Threads to Guilds

Design of Guild

Not fixed yet.

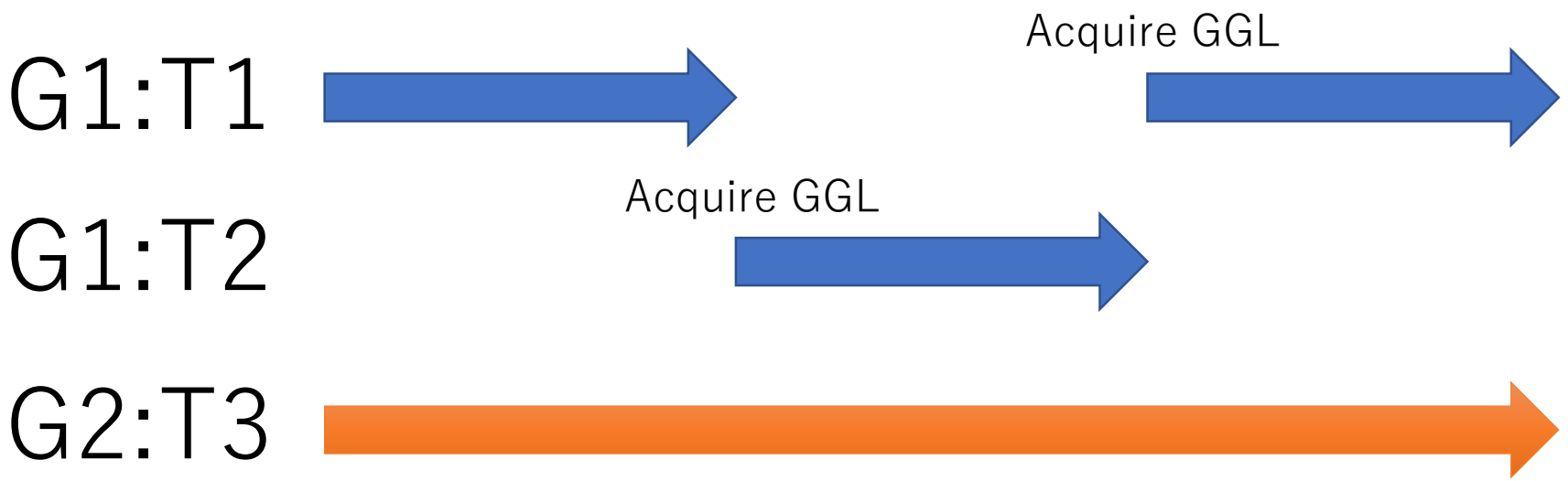
Guilds, Threads and Fibers

- Guild has at least one thread (and a thread has at least one fiber)



Threads in different guilds can run in PARALLEL

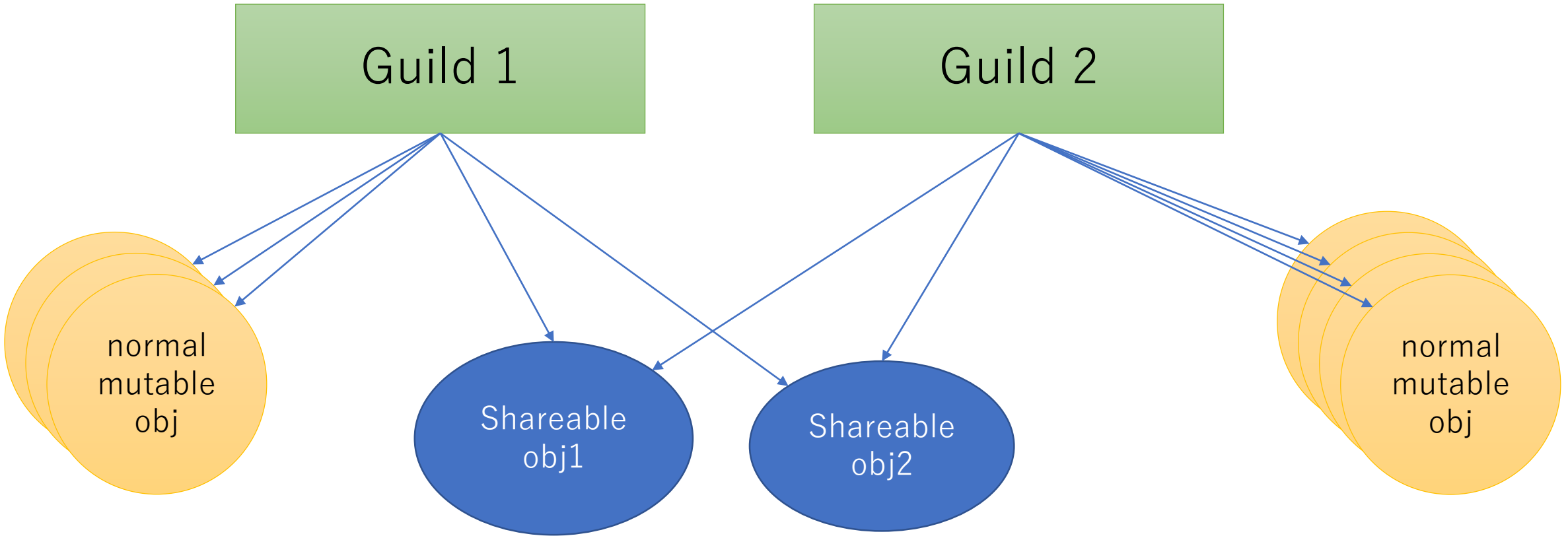
- Threads in different guilds can run in parallel
- Threads in a same guild can not run in parallel because of GVL (or GGL: Giant Guild Lock)



Making Guilds

```
g1 = Guild.new do
  expr1
end
g2 = Guild.new do
  expr2
end
# Two new Guilds and Threads are created
# expr1 and expr2 can run in parallel
```

Inter-Guild communication
Share only “shareable” objects

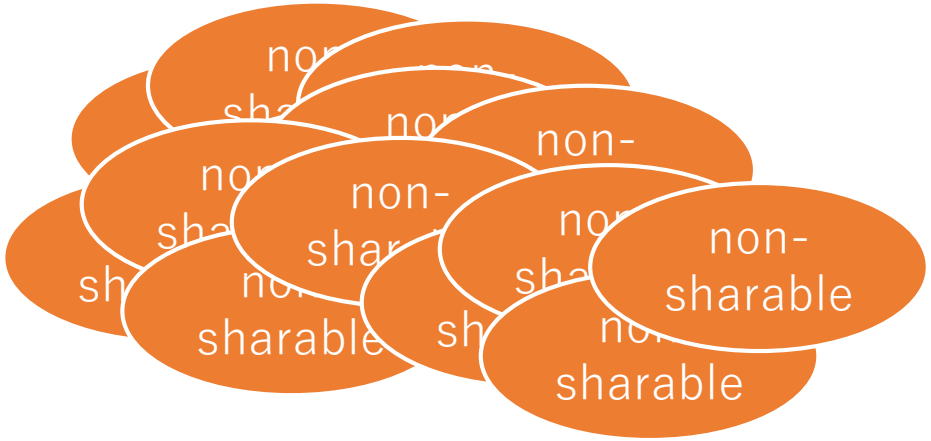


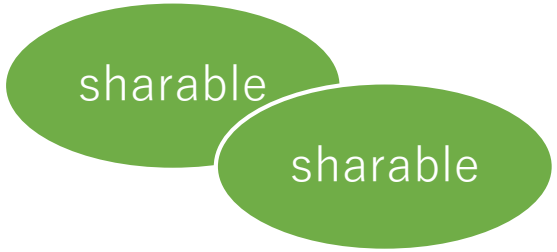
Design “shareable” and “non-sharable”

- You can enjoy usual mutating programming **without any thread-safe concerns** because we can’t share mutable objects between Guilds. They are “non-sharable”.
- In other words, **you can’t make thread-unsafe** (data-racy) programs on Guilds.

Design “shareable” and “non-sharable”

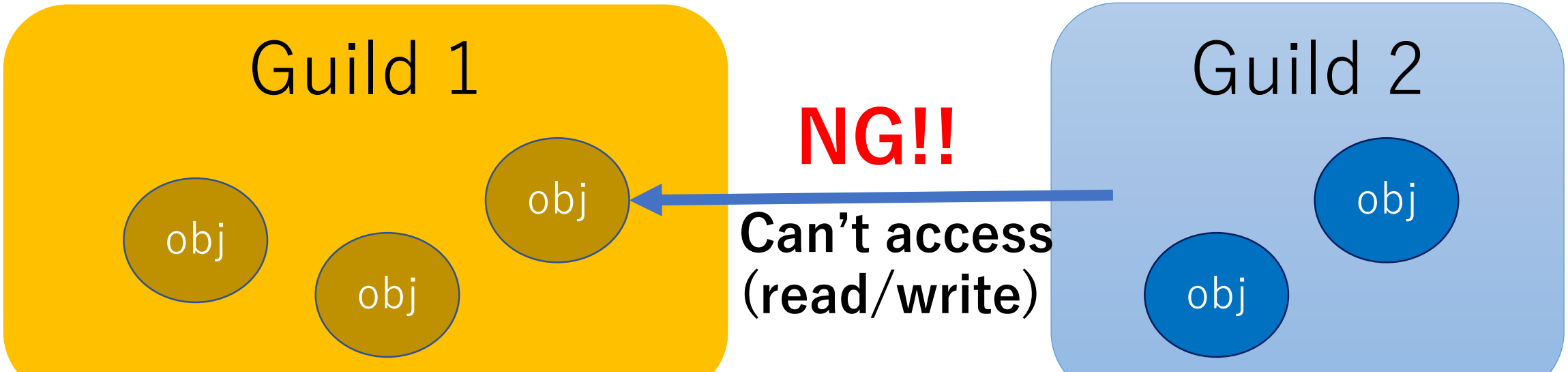
- On concurrent programs, most of objects are not shared (thread-local)
  - **Tons** of local objects and **a few** sharing objects
  - You only need to care about a few sharable objects





Design “shareable” and “non-sharable”

- **Non-shareable** objects == most of objects
  - Most of mutable objects (String, Array, …)
  - They are **member of only one Guild**
  - If you use only 1 Guild, it compatible with Ruby 2



Design “Shareable” and “non-sharable”

- **Shareable** objects
  - (1) Immutable objects (Numeric, Symbol, …)
  - (2) Class/Module objects
  - (3) Special mutable objects
  - (4) Isolated Proc
- Important invariant
  - Sharable objects only refer to sharable objects

Shareable objects
(1) Immutable objects

- **Immutable objects** can be shared with any guilds
  - Because no mutable operations for them
- **“Immutable” != “Frozen”**
  - `a1 = [1, 2, 3].freeze`: a1 is **Immutable**
  - `a2 = [1, Object.new, 3].freeze`: a2 is not Immutable
  - Maybe we will introduce deep freeze feature
- Example of immutable objects
  - Numeric objects, symbols, true, false, nil are immutable
  - Frozen string objects are immutable (if they don’t have instance variables)

Shareable objects
(2) Class/Module objects

- All objects (including any sharable objects) point to own classes
  - Good:
    - Easy Implementation and good communication performance
    - Sharing class/module objects makes program easier
  - Bad:
    - They can point to other mutable objects with Constants, @@class_variable and @instance_variables

```
class C
  Const = [1, 2, 3] # Const points a mutable
array
end
# We will introduce special protocol for them
```

Shareable objects
(3) Special mutable objects

- Introduce shared/concurrent data structure
  - Shared hash, array, …
  - Software transactional memory (from Clojure, …), …
  - Guild objects and so on
- They require **special protocol** to force synchronization explicitly
  - They can’t mutate without synchronizations.
  - Easy to make correct concurrent programs
- Compared with normal Array, Hash, … they should require special synchronization protocol to access

Shareable objects
(4) Isolated Proc

- Normal Proc can point to mutable objects with outer local variable (free-variables)

```
a = []; Proc.new{p a}.call
```

- Introduce Isolated Proc (made by Proc#isolate) which is prohibited to access outer variables

```
a = []; Proc.new{p a}.isolate.call
  #=> RuntimeError (can't access a)
```

Shareable objects
(4) Isolated Proc

```
# Initial block for Guild is isolated proc
g1 = Guild.new do
  expr1   # Make isolated block and invoke
end
g2 = Guild.new do
  p g1 #=> RuntimeError (can't access "g1")
       #   because block is isolated
end
```

FYI: Other languages using similar ideas

- Similar to Guild
  - Racket: Place (imm. or special mut. values)
  - Kotlin/Native: Worker (check ownership)
- Almost isolated
  - Shell script: Process (copy byte stream)
  - JavaScript: Worker
- Everything immutable
  - Erlang, Elxir: Process

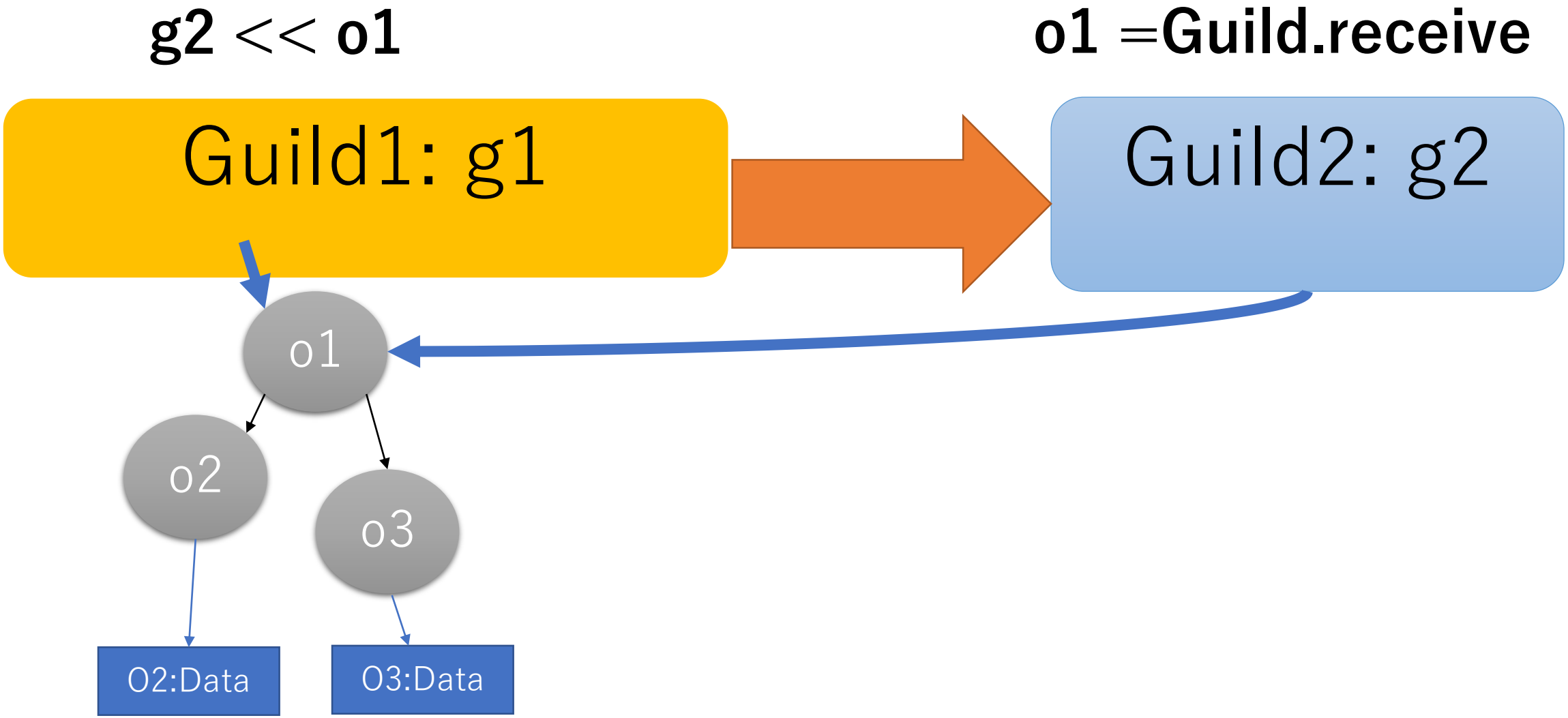
Inter-Guild communication API

- **Actor model**, send/receive semantics
  - **Not fixed yet** (discuss later)
- Destination addresses are represented by Guild itself like Erlang/Elixir processes
- Sending shareable objects means sending only references to the objects (lightweight)
- Two methods to send non-shareable objects
  - (1) **COPY**
  - (2) **MOVE**

Sending objects between Guilds

```
g1 = Guild.new do # create Isolated Proc
  n = Guild.receive
  r = fib(n)
  Guild.parent << r
end
g1 << 30 # or g1.send(30)
p Guild.receive #=> 1346269
```

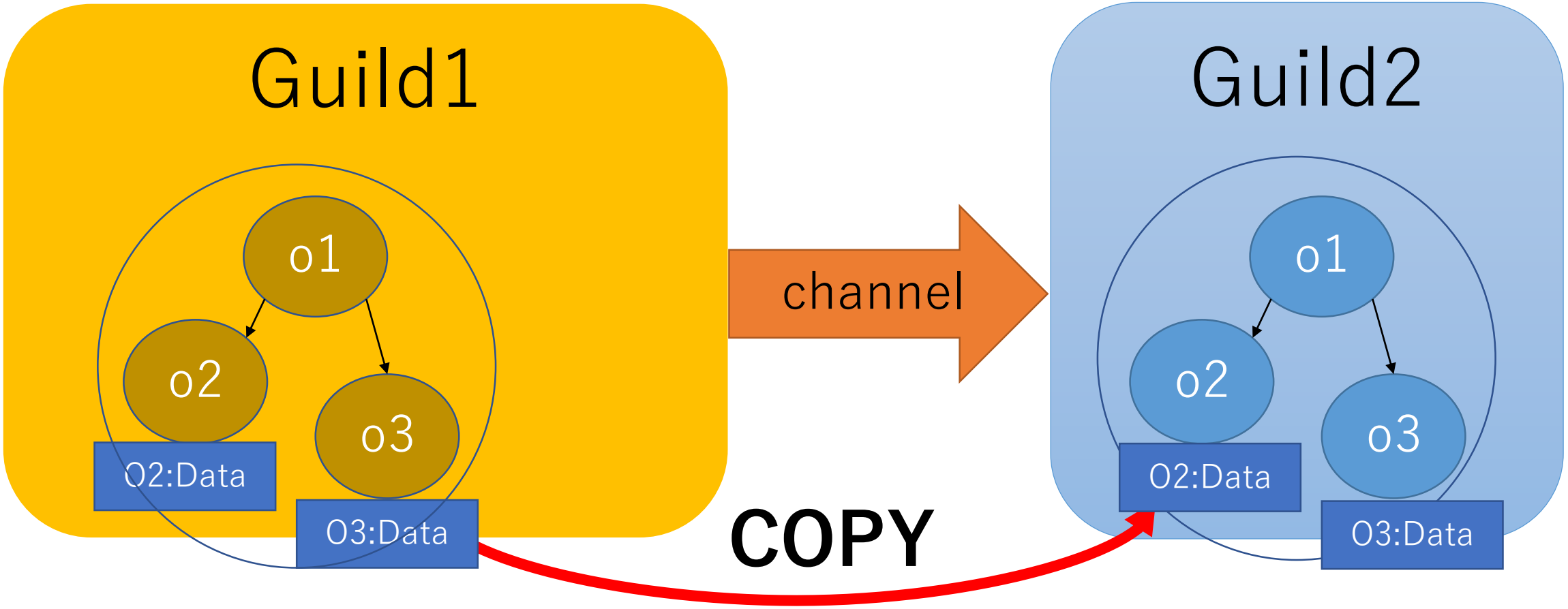
Sending shareable objects



Sending non-shareable objects (1) Send by **Copy**

g2 << o1

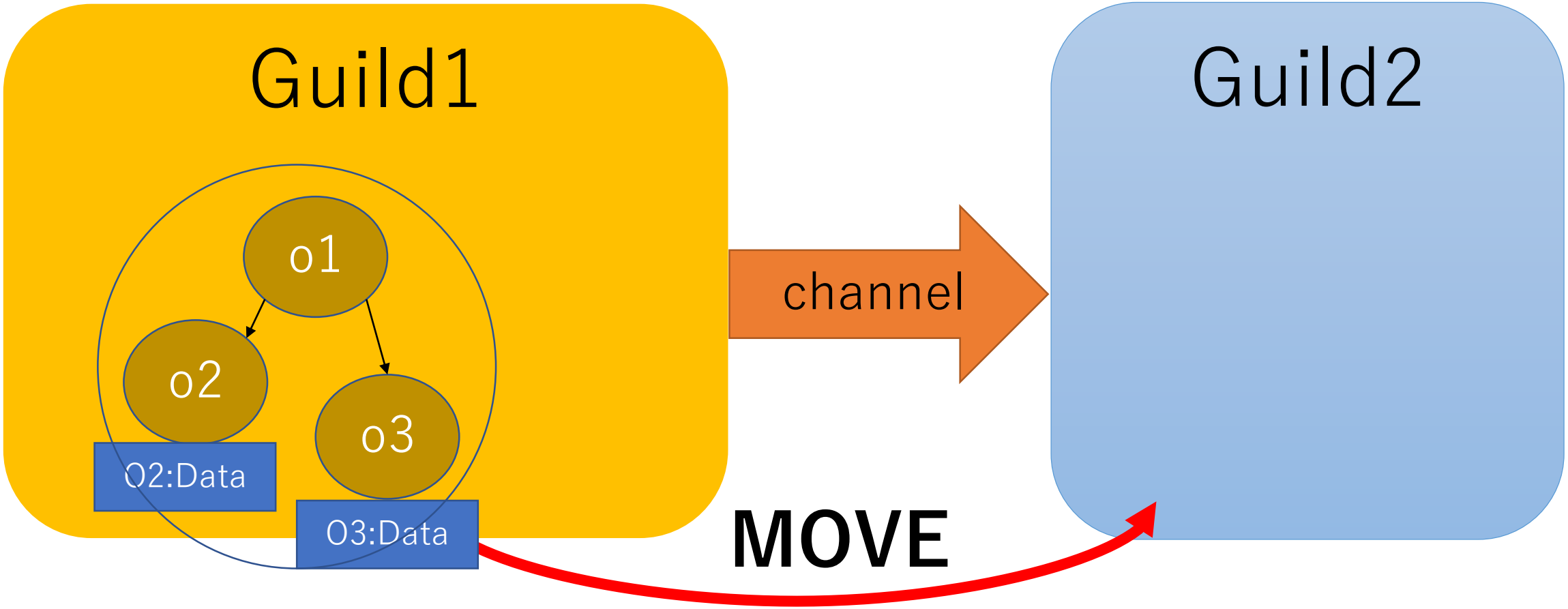
o1 = Guild.receive



Sending non-shareable objects (2) Send by **Move**

g2.move(o1)

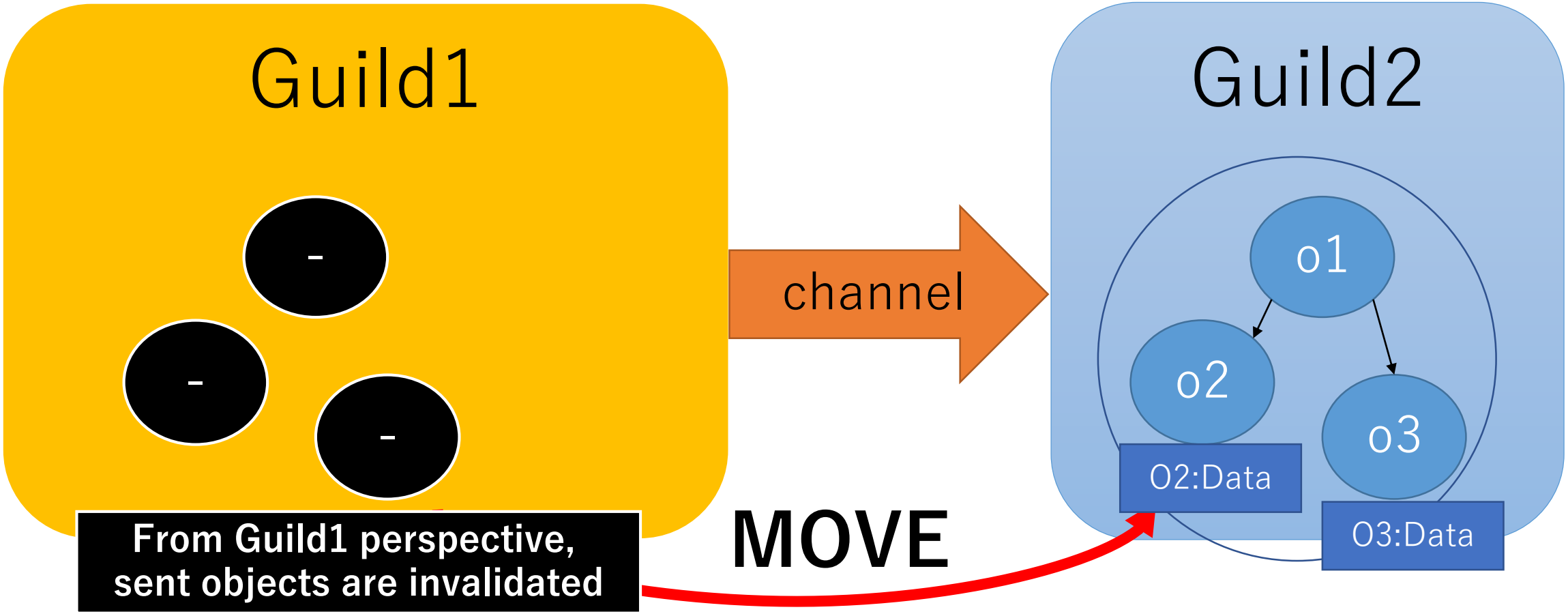
o1 =Guild.receive



Sending non-shareable objects (2) Send by **Move**

g2.move(o1)

o1 = Guild.receive



Sending non-shareable objects (2) Send by **Move**

- If we don't access sent objects after sending them (and there are many such cases), we can send them faster
- Examples
  - Huge string data
  - I/O objects (send request I/O to workers)

Summary of sharable/non-sharable objects with copy/move operations

- Non-sharable objects
  - Normal mutable objects (like String, Array, …)
  - Only one Guild can access such objects == membership
  - We can send them by COPY or MOVE
- Shareable objects
  - Several types of shareable objects
  - They requires special synchronization protocol to mutate them
  - We can share them between Guilds by sending references

Mutable objs are NOT shared accidentally as Thread
→ Safe concurrent programming

Discussion: How to represent communication channel?

- Actor model
  - Destination is specified by a Guild
  - `guild << obj`
  - Erlang/Elixir, …
- CSP model
  - Destination is specified by a channel
  - `ch << obj`
  - Go, JavaScript, Kotolin/native, Racket, …
- They have advantages and disadvantages…

Retrieve multiple channels

- Sometimes we need to manipulate with multiple channel
  - Data channel and control channel
  - Monitoring channel for child Guilds
- How to provide APIs to support it?

Go language goroutine and channels

https://tour.golang.org/concurrency/5

```
        select {
        case c <- x:
            x, y = y, x+y
        case <-quit:
            fmt.Println("quit")
            return
        }
```

Erlang/Elixir Process

```
# https://elixir-lang.org/getting-started/processes.html
iex> receive do
...>   {:hello, msg} -> msg
...>   {:world, msg} -> "won't match"
...> end
```

JavaScript Worker and MessageChannel

```
// https://developer.mozilla.org/en-US/docs/Web/API/MessageChannel
var channel = new MessageChannel();
var output = document.querySelector('.output');
var iframe = document.querySelector('iframe');

// Wait for the iframe to load
iframe.addEventListener("load", onLoad);

function onLoad() {
  // Listen for messages on port1
  channel.port1.onmessage = onMessage;

  // Transfer port2 to the iframe
  iframe.contentWindow.postMessage('Hello from the main page!', '*', [channel.port2]);
}
// Handle messages received on port1
function onMessage(e) {
  output.innerHTML = e.data;
}
```

Racket place

```
; https://docs.racket-lang.org/reference/sync.html#%28def._%28%28quote._~23~25kernel%29._handle-evt%29%29
> (define msg-ch (make-channel))
> (define exit-ch (make-channel))
> (thread
   (λ ()
     (let loop ([val 0])
       (printf "val = ~a~n" val)
       (sync (handle-evt
              msg-ch
              (λ (val) (loop val)))
             (handle-evt
              exit-ch
              (λ (val) (displayln val)))))))
```

Multiple channels for Actor model

- Support “Tag” (shows channel)
  - `guild.send_to(:data, obj)`
  - `guild.send(obj)` send to the default tag
- Receive with multiple tag
  - `Guild.receive(tag1, tag2, …){|tag, obj| …}`

```
g2 = Guild.new{
  cont = true
  while cont
    Guild.receive(:data, :ctrl){|tag, obj|
      case tag
      when :data
        calc(obj)
      when :ctrl
        case obj
        when :exit
          cont = false
        else
          raise "unknown"
        end
      end
    }
  end
}
```

Multiple channels for CSP model

- Making channels explicitly
- Send to a channel
  - `ch << obj`
- Receive with multiple channels
  - `Guild::Channel.receive(ch1, ch2, …){|ch, obj| …}`

```
g2 = Guild.new(data_ch, cntl_c){|d_ch, c_ch|
  cont = true
  while cont
    # wait for multiple channel
    Guild::Channel.receive(d_ch, c_ch){|ch, obj|
      case ch
      when d_ch
        calc(obj)
      when c_ch
        case obj
        when :exit
          cont = false
        else
          raise "unknown ctrl: #{obj}"
        end
      end
    }
  end
}
```

Guild Implementation

Preliminary implementation includes many bugs, performance issues.

https://github.com/ko1/ruby/tree/guild

Guild context

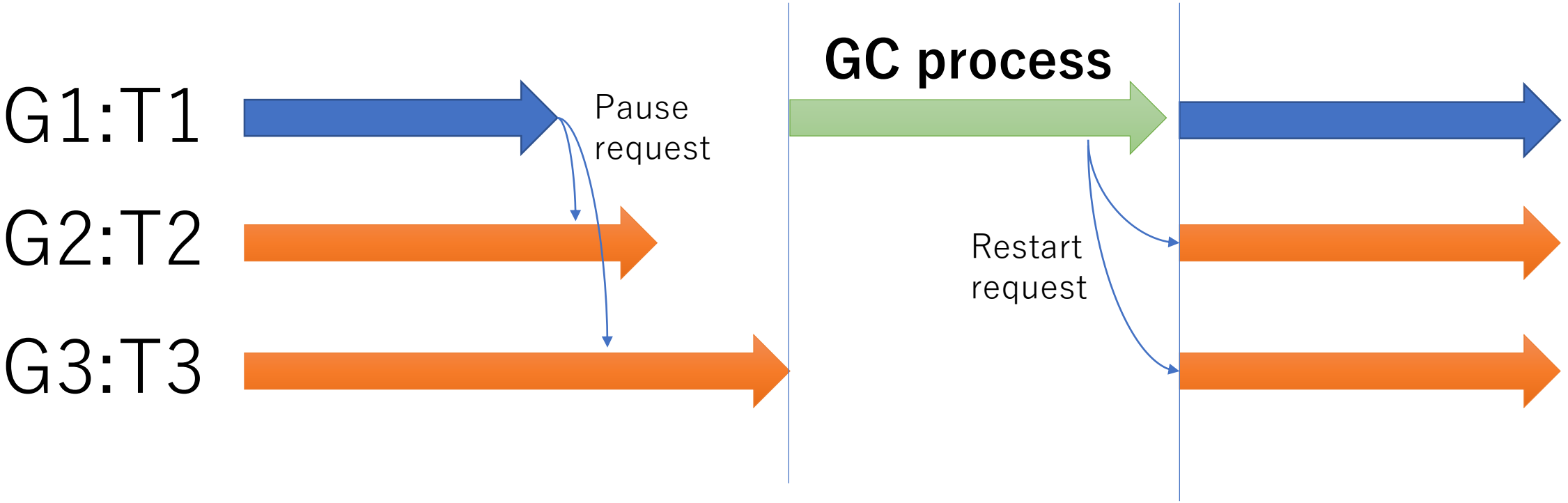
- Before Guild
  - VM -> *Threads -> *Fibers
- After Guild
  - VM -> *Guilds -> *Threads -> *Fibers
  - Introduce `rb_guild_t`.

Introduce synchronizations

- Before Guild
  - Multiple threads cannot run simultaneously
- After Guild
  - Run (native) threads in parallel
- Need to introduce many **synchronizations**
  - Introduce VM-wide locks for VM-wide resources
  - It is the multi-thread programming!!

Garbage collection

- Stop all Guilds (threads) at GC process

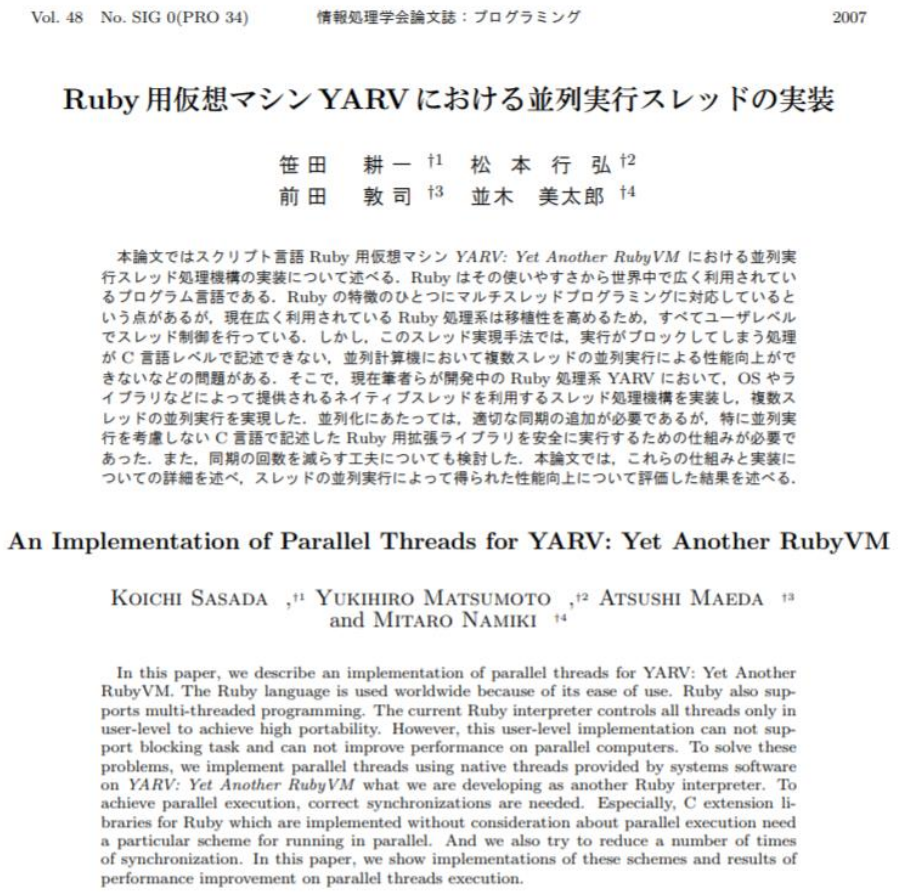


Implementation is not completed

- Features
  - Fix GC bug
  - **Prohibit** sharing non-sharable objects
  - **Introduce synchronizations** to protect VM-wide resources (process-global)
  - **Introduce “sharable” object** protocols
- Performance
  - **Reduce synchronizations**
  - **Per Guild** Garbage collection
  - **Introduce new “C API” to reduce TLS access**

Future optimizations

- Koichi Sasada, et.al. : An Implementation of Parallel Threads for YARV: Yet Another RubyVM (2007)
  - They introduced several optimization techniques to reduce synchronizations



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Ruby用仮想マシンYARVにおける並列実行スレッドの実装

笹田 耕一 †1 松本 行弘 †2
前田 敦司 †3 並木 美太郎 †4

本論文ではスクリプト言語 Ruby 用仮想マシン *YARV: Yet Another RubyVM* における並列実行スレッド処理機構の実装について述べる．Ruby はその使いやすさから世界中で広く利用されているプログラム言語である．Ruby の特徴のひとつにマルチスレッドプログラミングに対応しているという点があるが，現在広く利用されている Ruby 処理系は移植性を高めるため，すべてユーザレベルでスレッド制御を行っている．しかし，このスレッド実現手法では，実行がブロックしてしまう処理が C 言語レベルで記述できない，並列計算機において複数スレッドの並列実行による性能向上ができないなどの問題がある．そこで，現在筆者らが開発中の Ruby 処理系 YARV において，OS やライブラリなどによって提供されるネイティブスレッドを利用するスレッド処理機構を実装し，複数スレッドの並列実行を実現した．並列化にあたっては，適切な同期の追加が必要であるが，特に並列実行を考慮しない C 言語で記述した Ruby 用拡張ライブラリを安全に実行するための仕組みが必要であった．また，同期の回数を減らす工夫についても検討した．本論文では，これらの仕組みと実装についての詳細を述べ，スレッドの並列実行によって得られた性能向上について評価した結果を述べる．

An Implementation of Parallel Threads for YARV: Yet Another RubyVM

Koichi Sasada ,†1 Yukihiro Matsumoto ,†2 Atsushi Maeda †3
and Mitaro Namiki †4

In this paper, we describe an implementation of parallel threads for YARV: Yet Another RubyVM. The Ruby language is used worldwide because of its ease of use. Ruby also supports multi-threaded programming. The current Ruby interpreter controls all threads only in user-level to achieve high portability. However, this user-level implementation can not support blocking task and can not improve performance on parallel computers. To solve these problems, we implement parallel threads using native threads provided by systems software on *YARV: Yet Another RubyVM* what we are developing as another Ruby interpreter. To achieve parallel execution, correct synchronizations are needed. Especially, C extension libraries for Ruby which are implemented without consideration about parallel execution need a particular scheme for running in parallel. And we also try to reduce a number of times of synchronization. In this paper, we show implementations of these schemes and results of performance improvement on parallel threads execution.

Naming of “Guild”

Why “Guild”?

- Prefix should be different from “P” (Process), “T” (Therad) and “F” (Fiber).
- Ownership can be explained with the word “Membership”.
  - All (normal) objects belong to one Guild.
  - Easy to explain “Move” semantics

Any problem?

- “Move” operation is not so popular operation (most of case “copy” is enough)
- No other languages use this terminology

- Naming is important

- Just now “Guild” is a code name of this project

Demonstrations

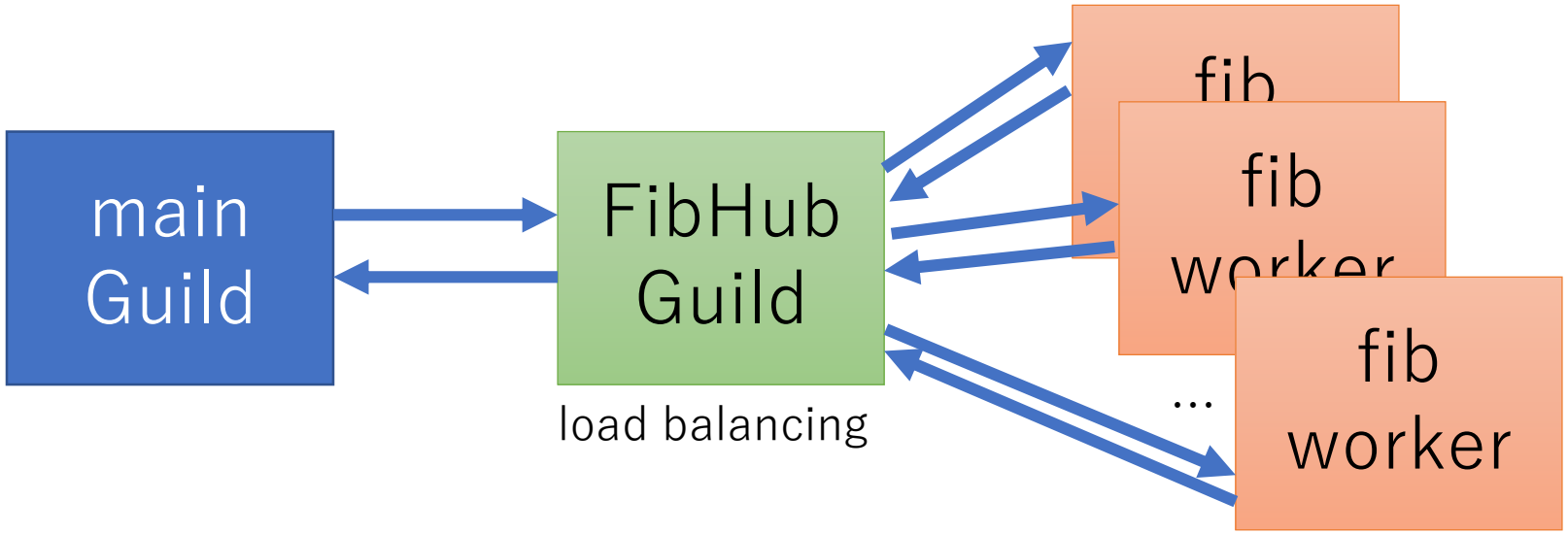
on the current PoW implementation.

Demonstration (on 40 vCPUs)

- CPU 40 virtual CPUs (2 x 10 x 2)
  - Intel(R) Xeon(R) CPU E5-2630 v4 @ 2.20GHz
    - x10 cores
    - x2 hyper threading
  - x2 CPUs
- Ubuntu 16.10
  - Already EOL ☹

Demonstration (on 40 vCPUs)

- Workload
  - Calculate **fib(23)** x 100_000 times
    - Serial version: `100_000.times{ fib(23) }`
    - Guild version:



We can change # of workers

https://gist.github.com/ko1/e5327126a77e078a0ffdf005013592ea

```
FIBHUB = make_worker_hub do |n|
  [n, fib(n)]
end
# library
def make_worker_hub n_workers = WN, &worker_proc
  pp WN: n_workers if $VERBOSE

  Guild.new(n_workers, worker_proc) do |nw, wp|
    guilds = nw.times.map do
      Guild.new do
        while data = Guild.receive
          result = wp.call(data)
          Guild.parent << [:ans, Guild.current, result]
        end
      end
    end
    requests = []
```

Make worker guilds

```
    while true
      cmd, sender_guild, data = *Guild.receive
      case cmd
      when :req
        if g = guilds.pop
          g << data
        else
          requests << data
        end
      when :ans
        Guild.parent << data
        if req = requests.pop
          sender_guild << req
        else
          guilds << sender_guild
        end
      end
    end
  end
end
```

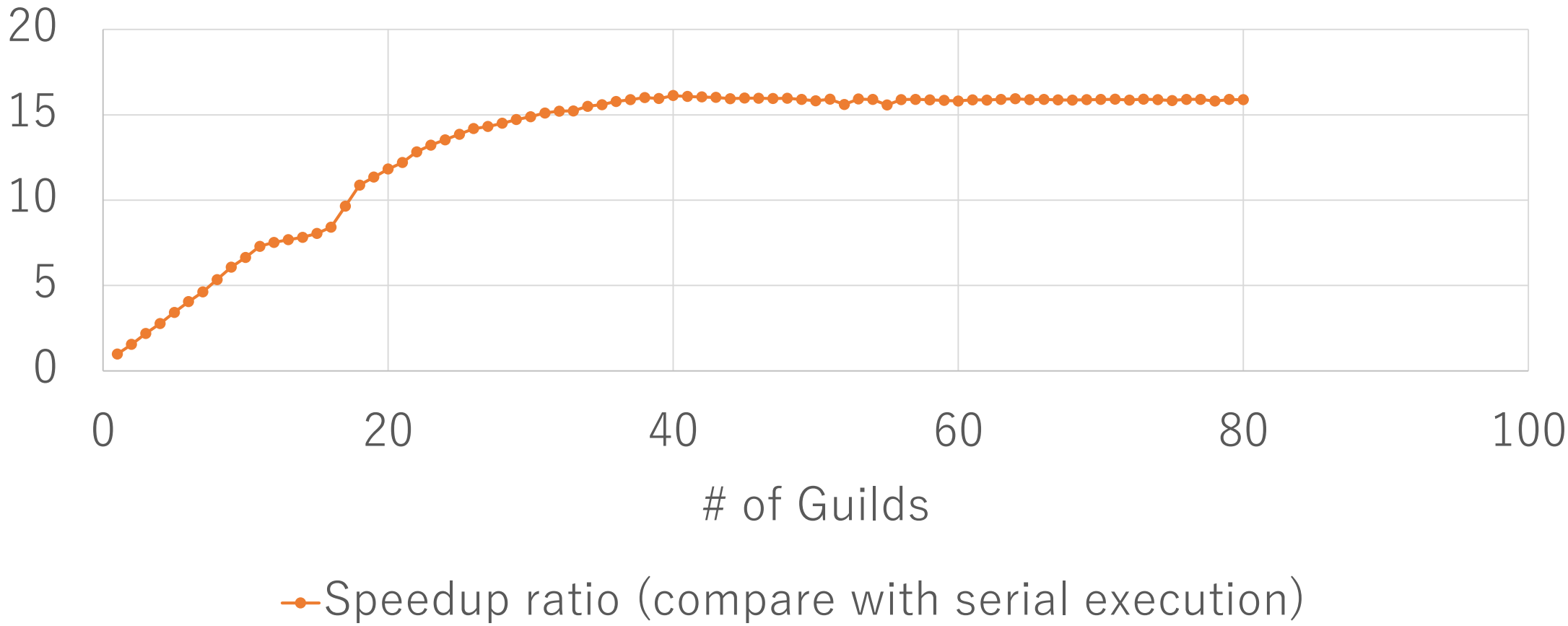
Receive a request from master
Send a task
if an idle worker is available

Receive an answers from workers
Send an answers to master

Send a remaining task
to the worker if exists

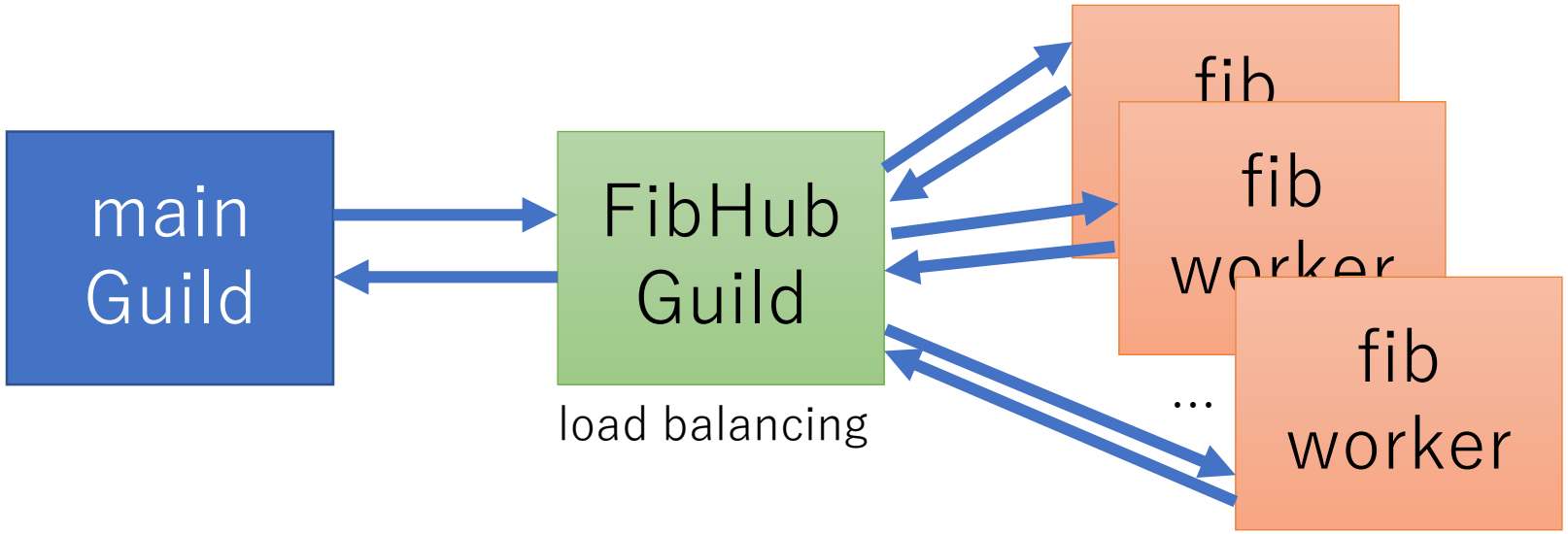
You don’t need to write such common code
but we provide some kind of a framework

fib(23) with # of Guilds on 40 vCPUs

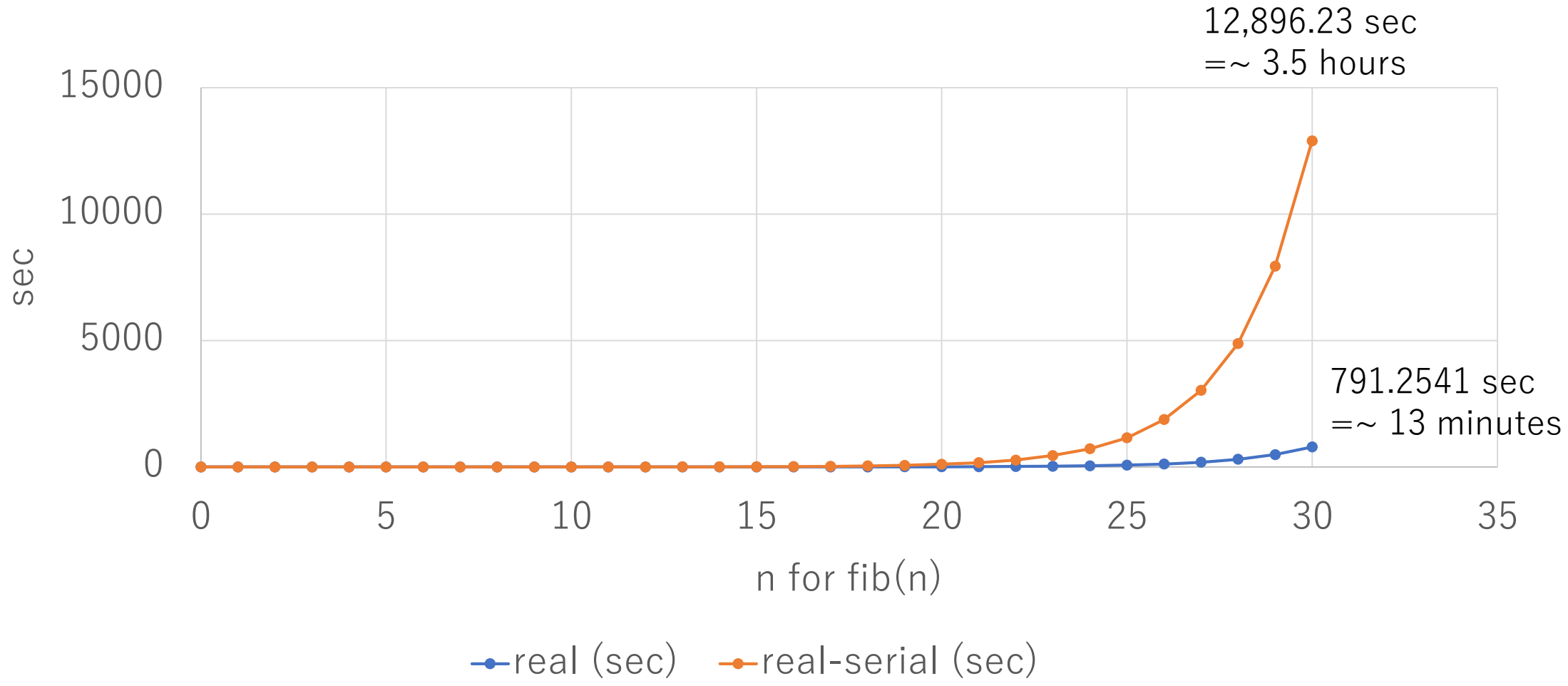


Demonstration (on 40 vCPUs)

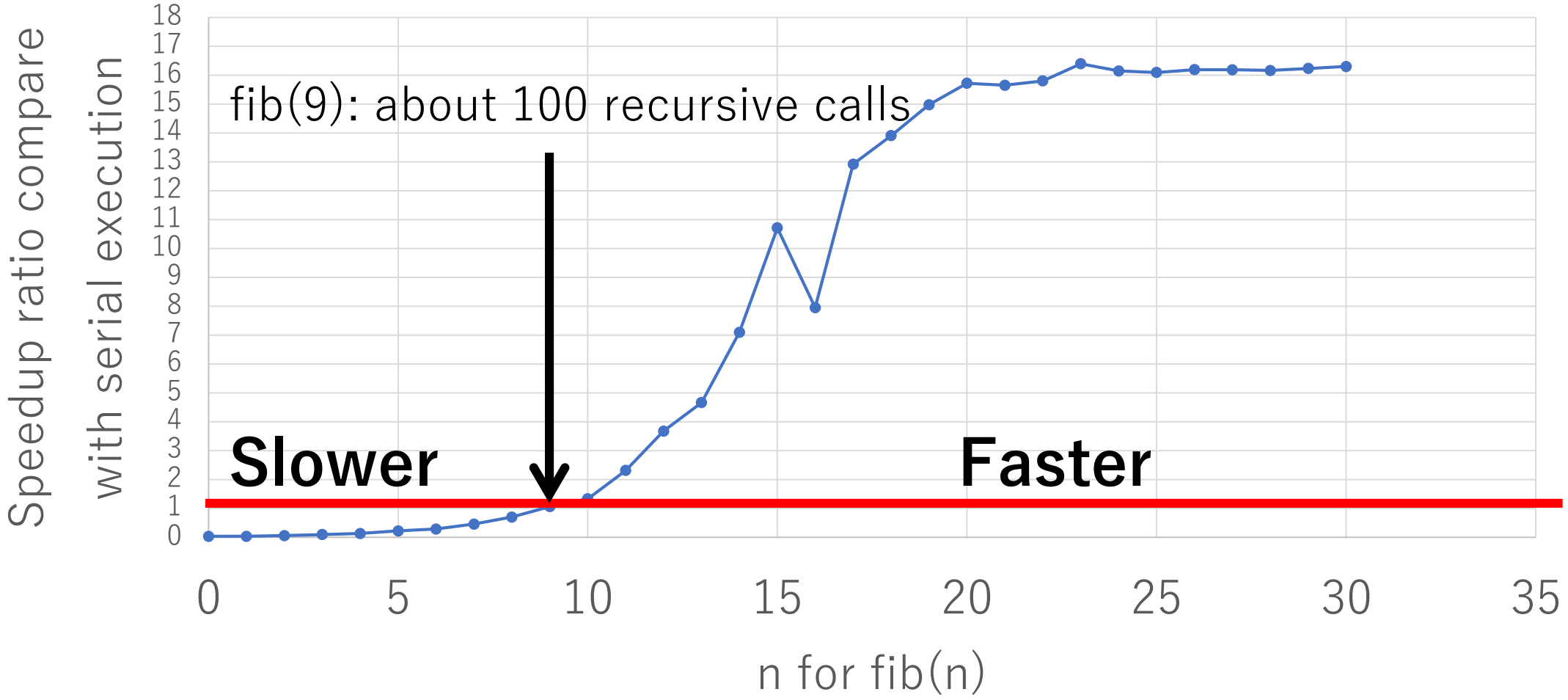
- Workload
  - Calculate **fib(n)** x 100_000 times (0 ≦ n ≦ 30)
    - Serial version: 100_000.times{ fib(23) }
    - Guild version: 40 Guilds



Execution time (sec) of **fib(n) x 100_000** with 40 Guilds on 40 vCPUs



fib(n) with 40 Guilds on 40 vCPUs



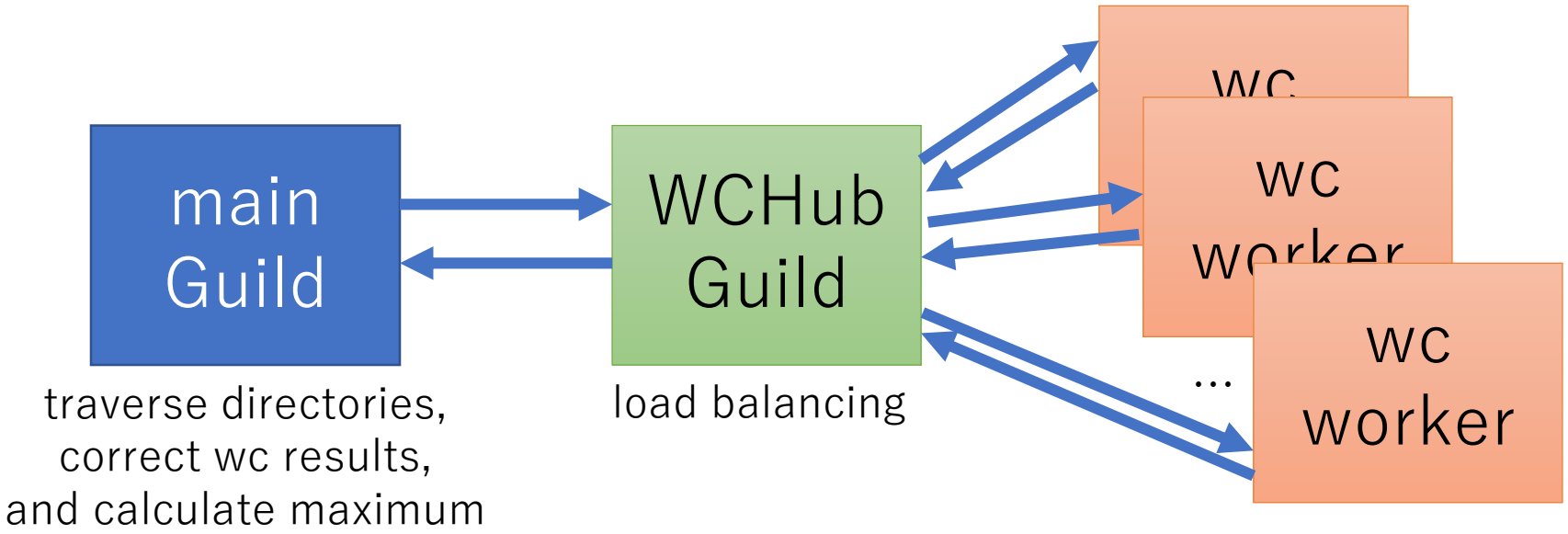
Demonstration (on 40 virtual CPU)

- Workload
  - Calculate wordcount for files and find a file which contains maximum number of words.
    - on “ruby/test/**/*” files (1,108 files)

```
def word_count file
  r = File.read(file).b.upcase.split(/¥W/).uniq.size
end
```

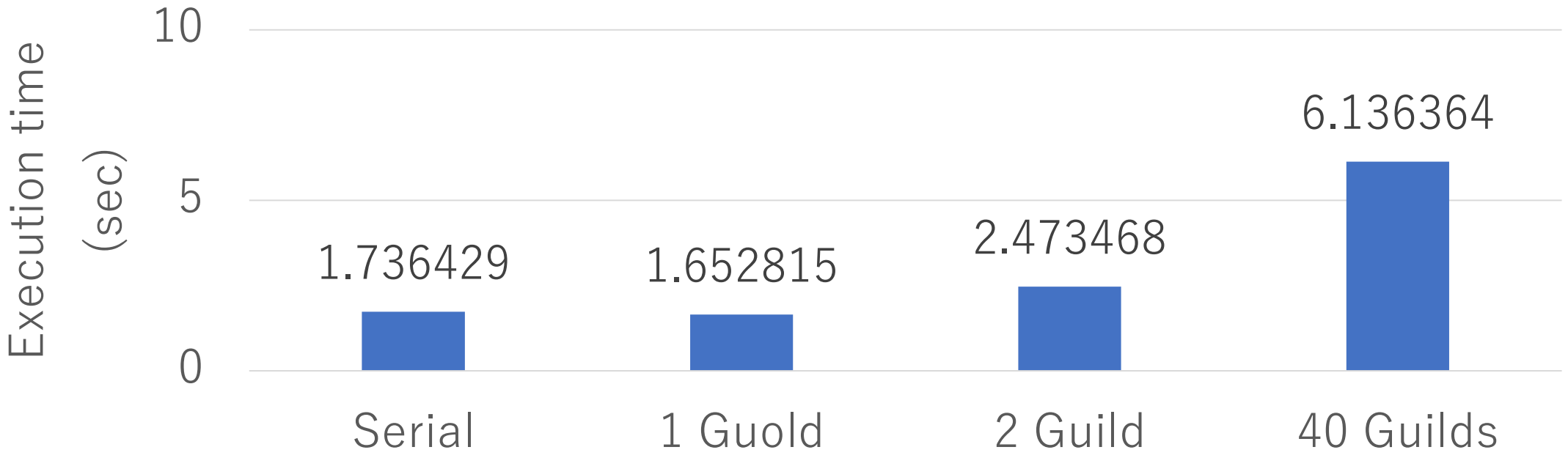
Demonstration (on 40 virtual CPU)

- Workload
  - Calculate wordcount for files and find a file which contains maximum number of words.
    - on “ruby/test/**/*” files (1,108 files)



We can change # of workers

Demonstration (on 40 virtual CPU)



It is **SLOW** with multiple Guilds
because GC/object allocation require naïve global locking
(current implementation limitation) and huge contentions.

Today's talk

- Ruby 2.6 updates of mine
- Introduction of Guild
  - Design
  - Discussion
  - Implementation
  - Preliminary demonstration

Thank you for your attention

Parallel programming in Ruby3 with Guild

Koichi Sasada

Cookpad Inc.
<ko1@cookpad.com>

cookpad

Pros./Cons. Matrix

	Process	Guild	Thread	Auto-Fiber	Fiber
Available	Yes	**No**	Yes	**No**	Yes
Switch on time	Yes	Yes	Yes	**No**	**No**
Switch on I/O	Auto	Auto	Auto	**Auto**	No
Next target	Auto	Auto	Auto	Auto	**Specify**
Parallel run	**Yes**	**Yes**	No (on MRI)	No	No
Shared data	**N/A**	**(mostly) N/A**	Everything	Everything	Everything
Comm.	Hard	**Maybe Easy**	**Easy**	**Easy**	**Easy**
Programming difficulty	Hard	**Easy**	Difficult	**Easy**	**Easy**
Debugging difficulty	Easy?	**Maybe Easy**	Hard	Maybe hard	**Easy**