Progress report of "Ruby 3 Concurrency"

Cookpad Inc.

Koichi Sasada

<ko1@cookpad.com>

cookpad

Ruby X Elixir Conf Taiwan 2018 (2018/04/28)

Today’s topic

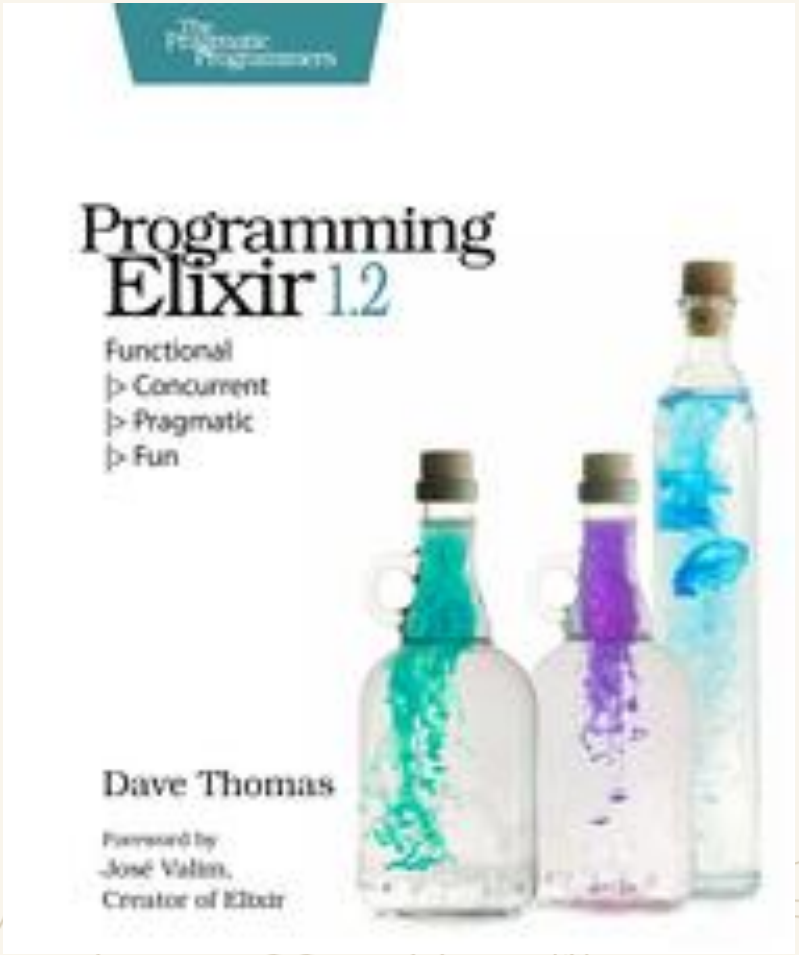
- Difficulty of **Thread programming**
- New concurrent abstraction for Ruby 3 named **Guild**
  - To overcome threading difficulties
- Introduce current Guild development progress
  - Current “Semantics”
  - Current API design and sample code we can run
  - Preliminary performance evaluation

Koichi Sasada

http://atdot.net/~ko1/

- Programmer
  - 2006-2012 Faculty at Univ.
  - 2012-2017 Heroku, Inc.
  - 2017- Cookpad Inc.
- Job: MRI development
  - MRI: Matz Ruby Interpreter
  - Taking a charge of core parts
    - VM, Threads, GC, etc

One of Japanese translators of “Programming Elixir”



Written by Dave Thomas
Translated by
  Koichi Sasada
  Yuki Torii
2016 Ohmsha

Recent achievements for Ruby 2.6

- **Speedup `Proc#call`** because we don't need to care about `$SAFE` any more. [Feature #14318]. With `lc_fizzbuzz` benchmark which uses so many `Proc#call` we can measure **x1.4** improvements [Bug #10212].

- **Speedup `block.call` where `block` is passed** block parameter. [Feature #14330] Ruby 2.5 improves block passing performance. [Feature #14045] Additionally, Ruby 2.6 improves the performance of passed block calling.

RubyKaigi 2016

A proposal of new concurrency model for Ruby 3

Motivation

Productivity (most important for Ruby)

- Thread programming is **too difficult**
- Making **correct/safe** concurrent programs easily

Performance by Parallel execution

- Making parallel programs
- Threads can make concurrent programs, but can’t run them in parallel on MRI (CRuby)
- People want to utilize Multi/many CPU cores

RubyKaigi2016 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

DIFFICULTY OF MULTI-THREADS PROGRAMMING AND HOW TO SOLVE IT?

Muilti-threads programming is difficult

- **Introduce data race, race condition**
- Introduce deadlock, livelock
- Difficulty on debugging because of nondeterministic behavior
  - difficult to reproduce same problem

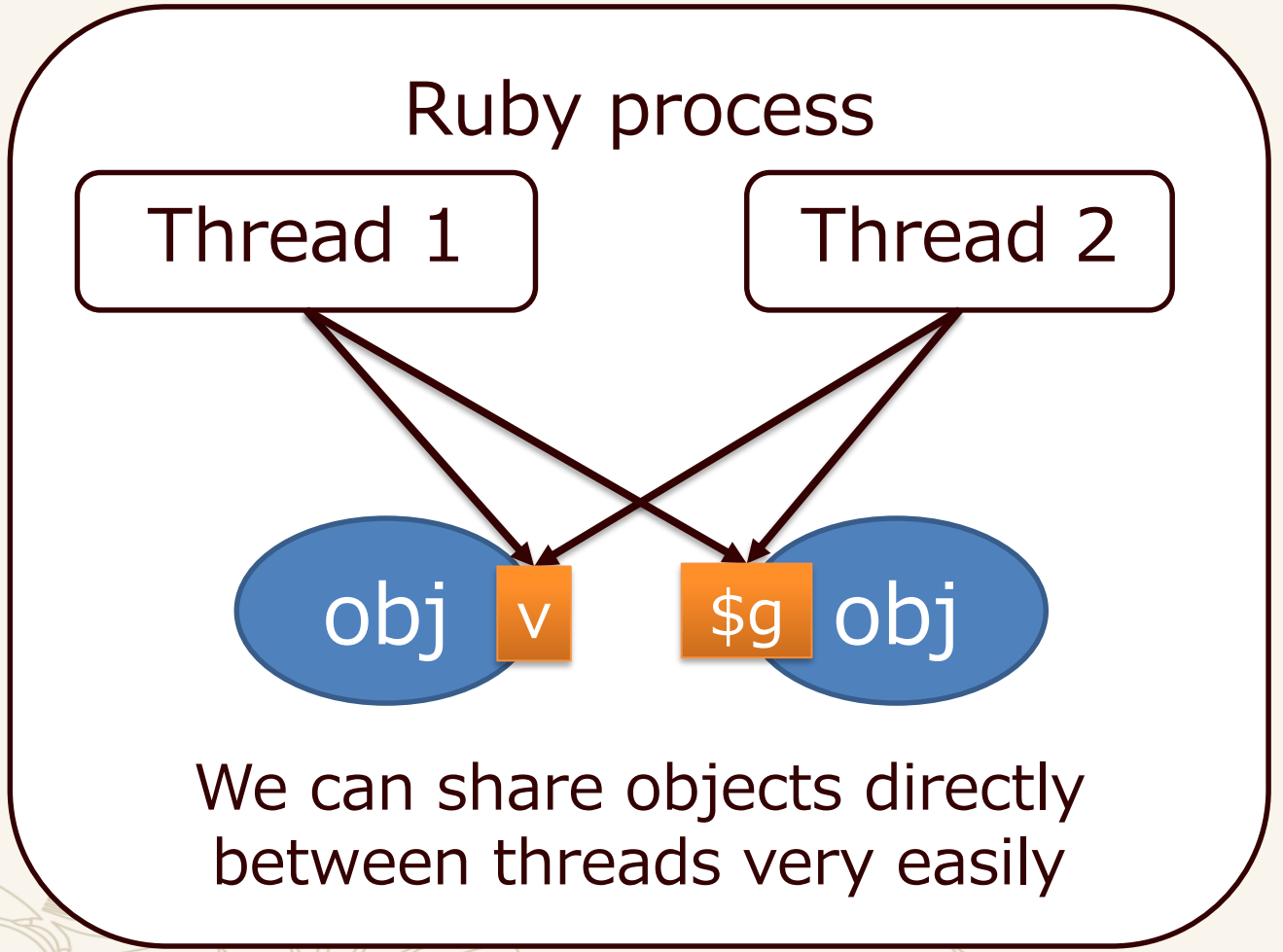
Difficult to make correct (bug-free) programs

- Difficult to tune performance

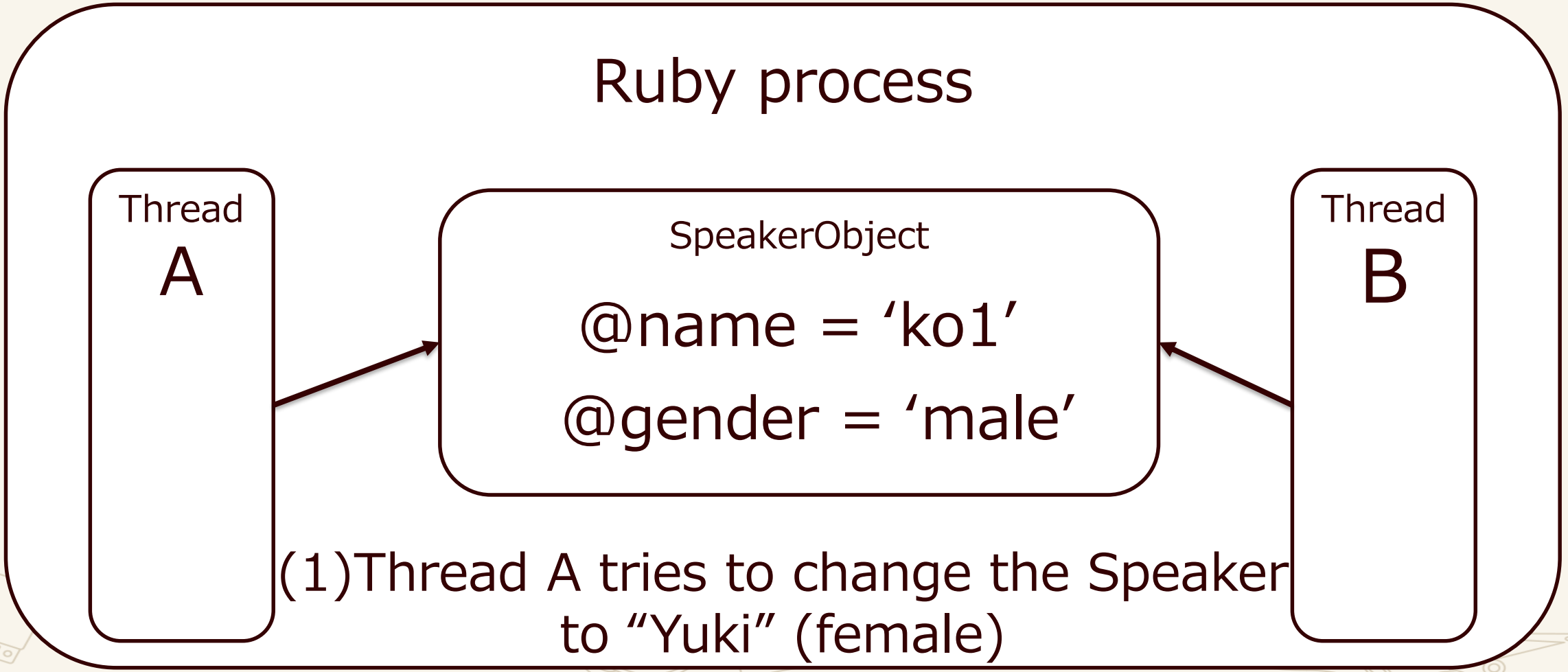
Difficult to make fast programs

Inter-thread communication

```
v = Object.new
$g = Object.new
Thread.new do
  p [v, $g]
end
p [v, $g]
```

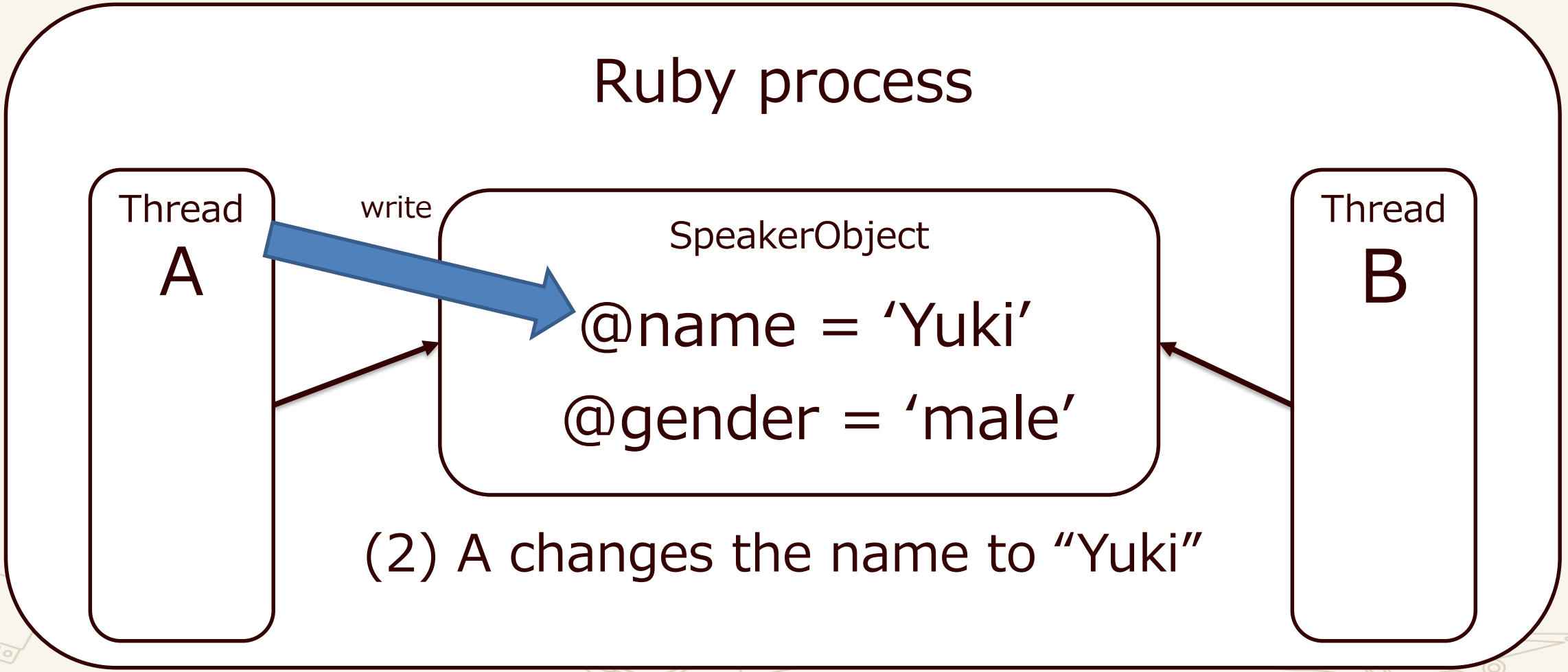


Mutate shared objects
Lucky case



Note: Yuki is my wife.

Mutate shared objects
Lucky case



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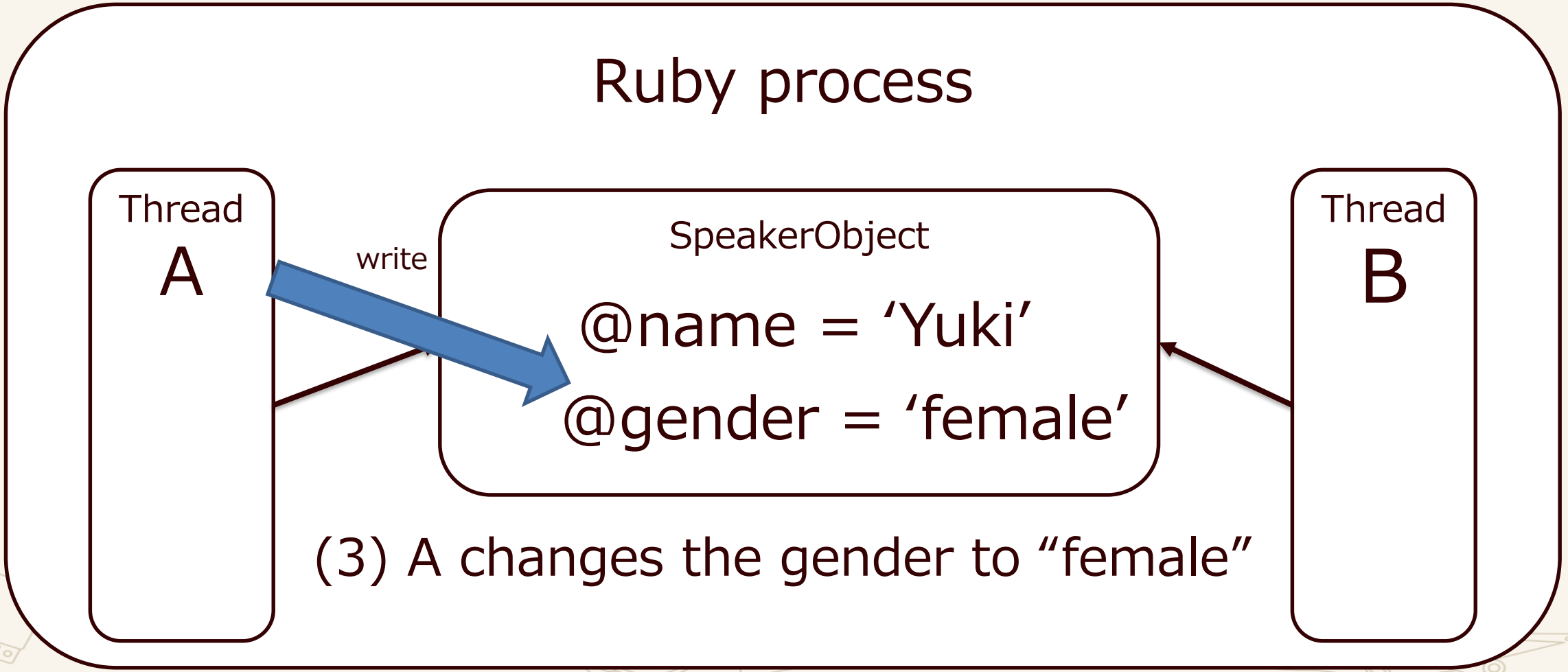

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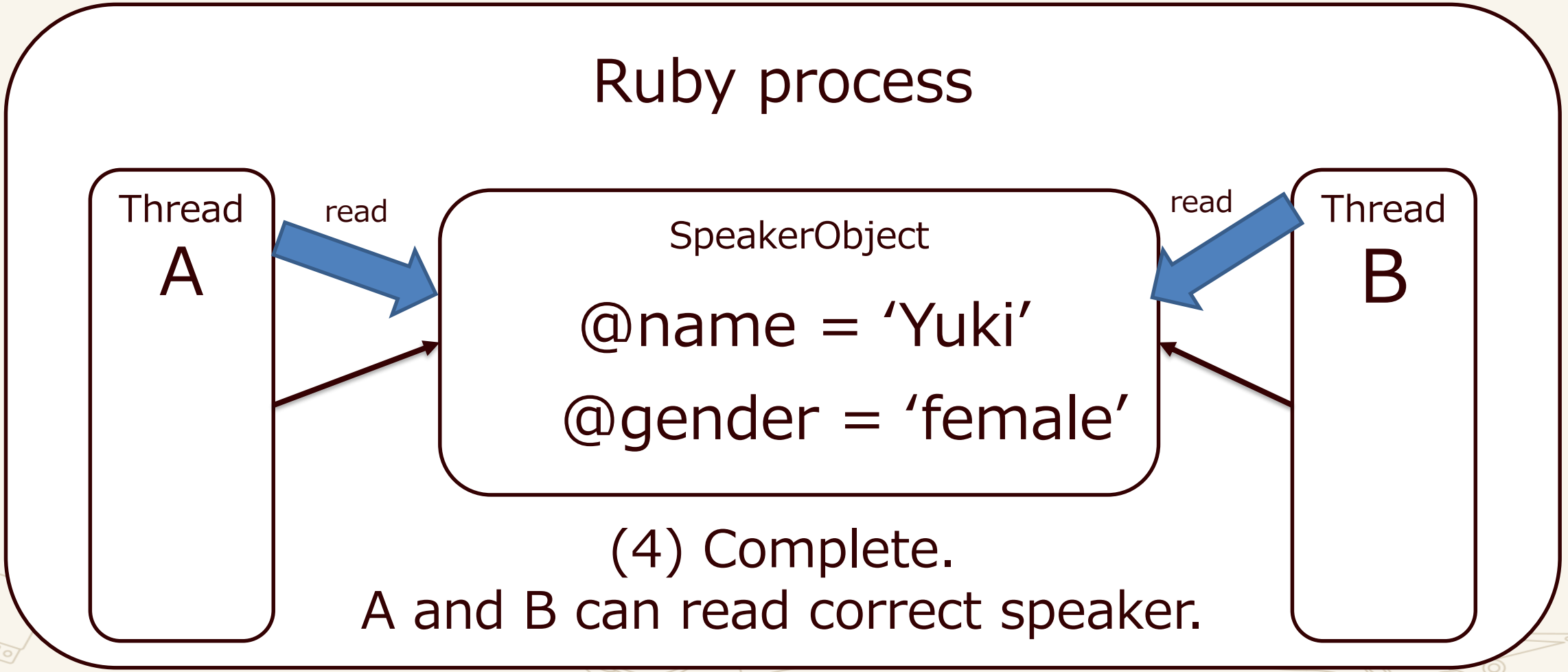
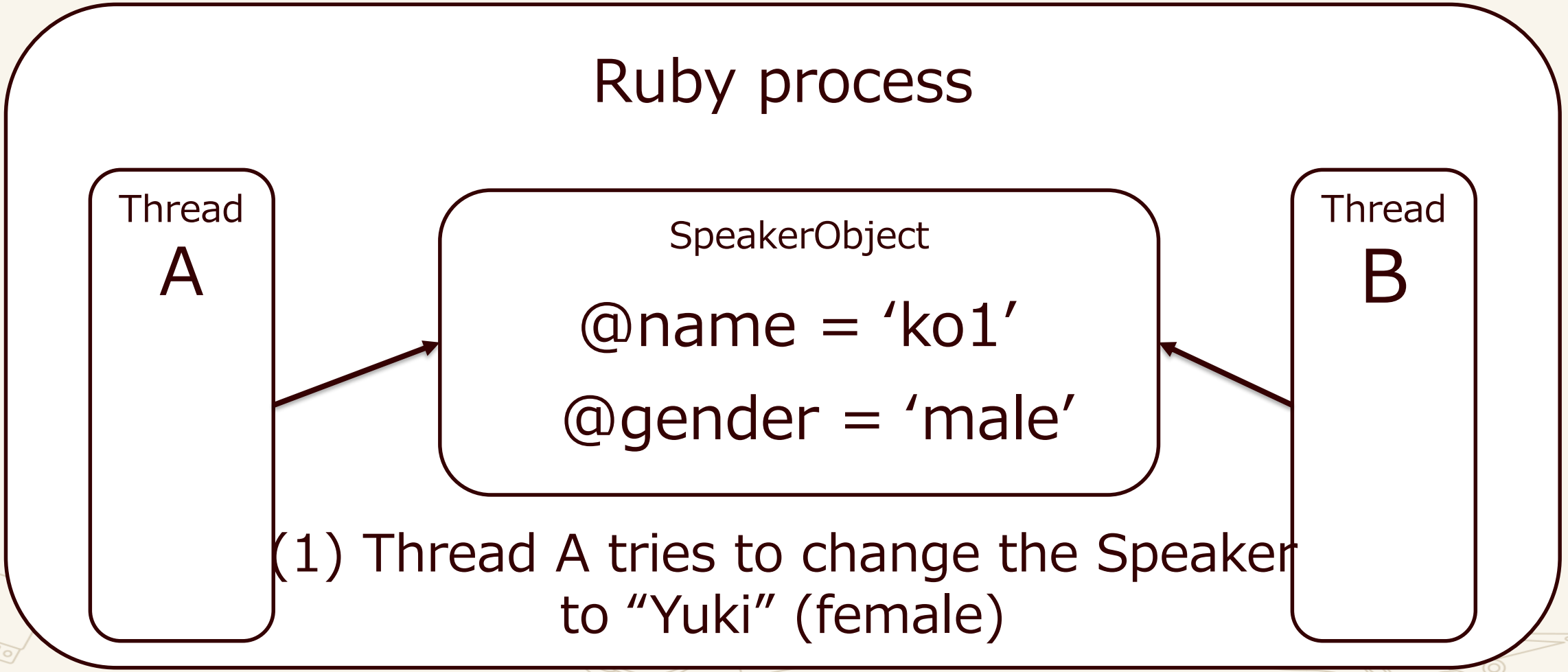
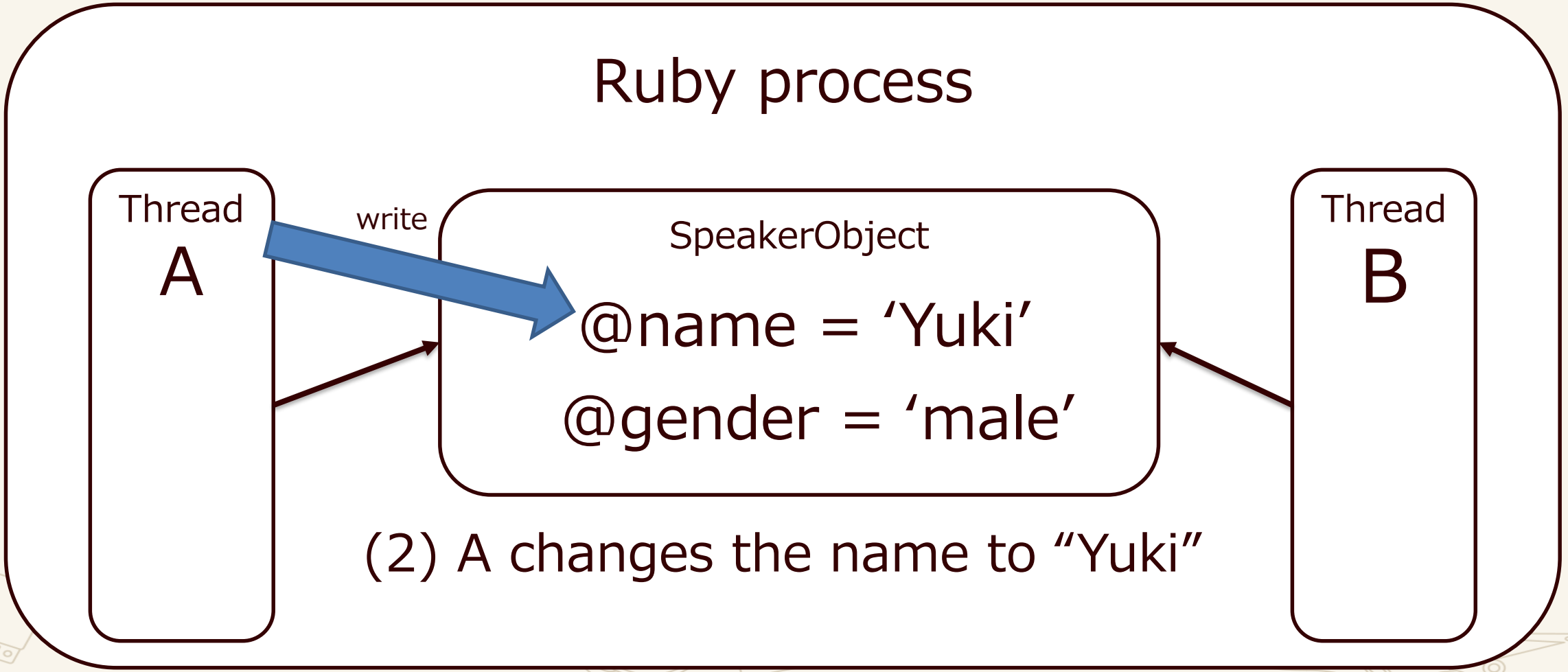


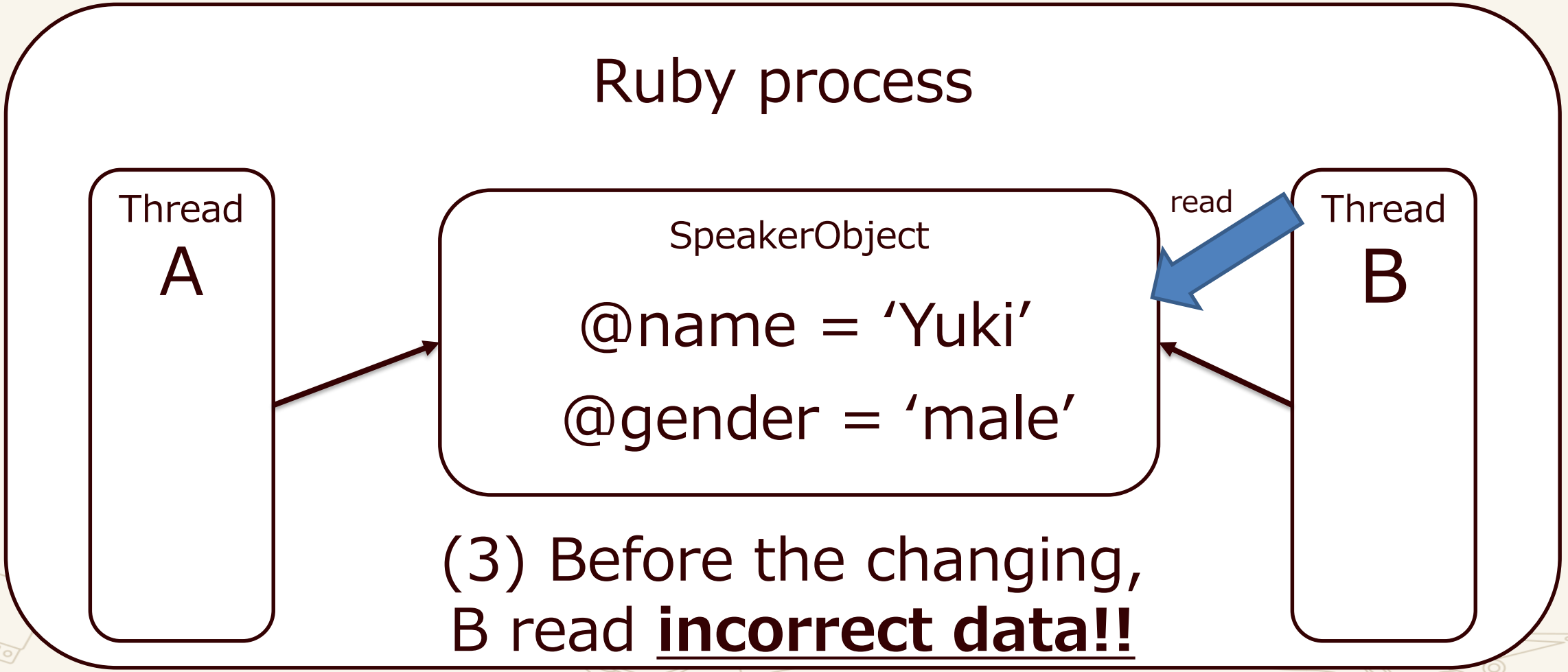
Mutate shared objects
Problematic case



Mutate shared objects
Problematic case



Mutate shared objects
Problematic case



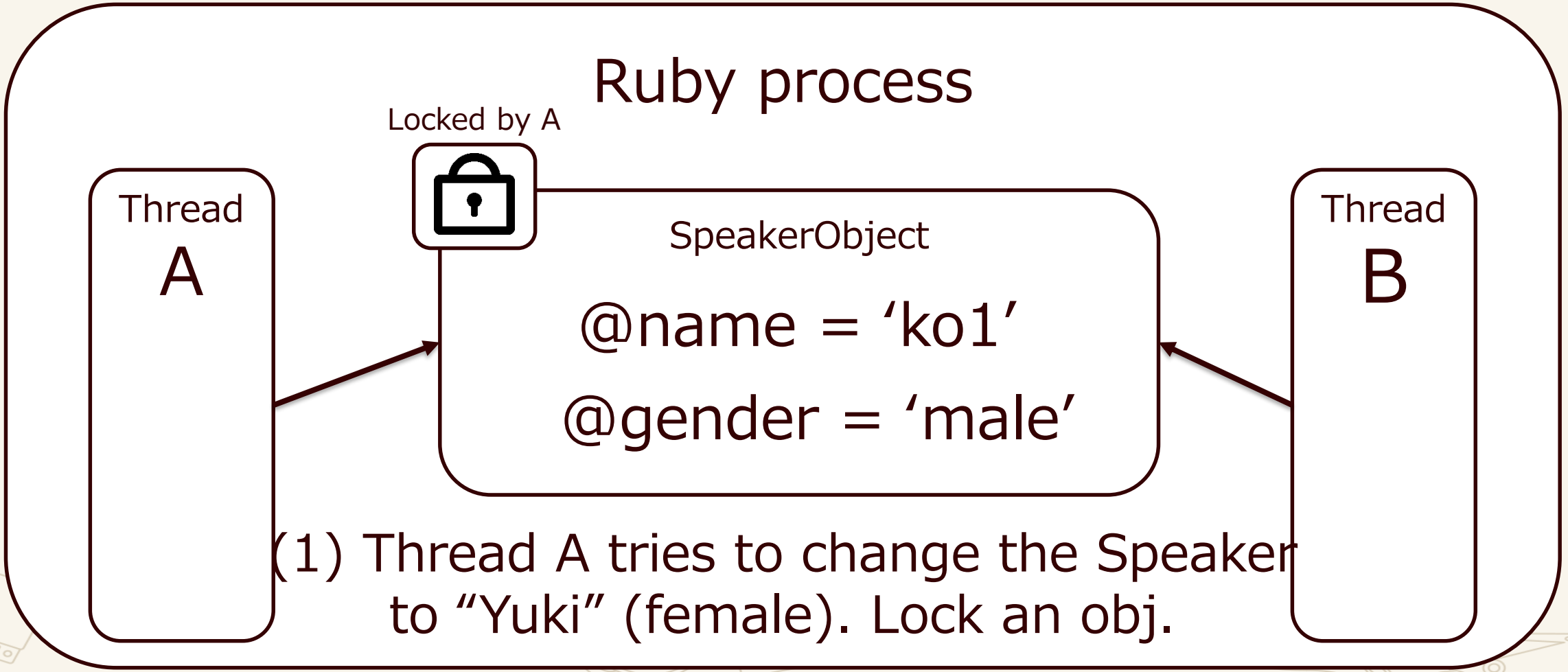
(3) Before the changing,
B read **incorrect data!!**

Note: Yuki should be female.

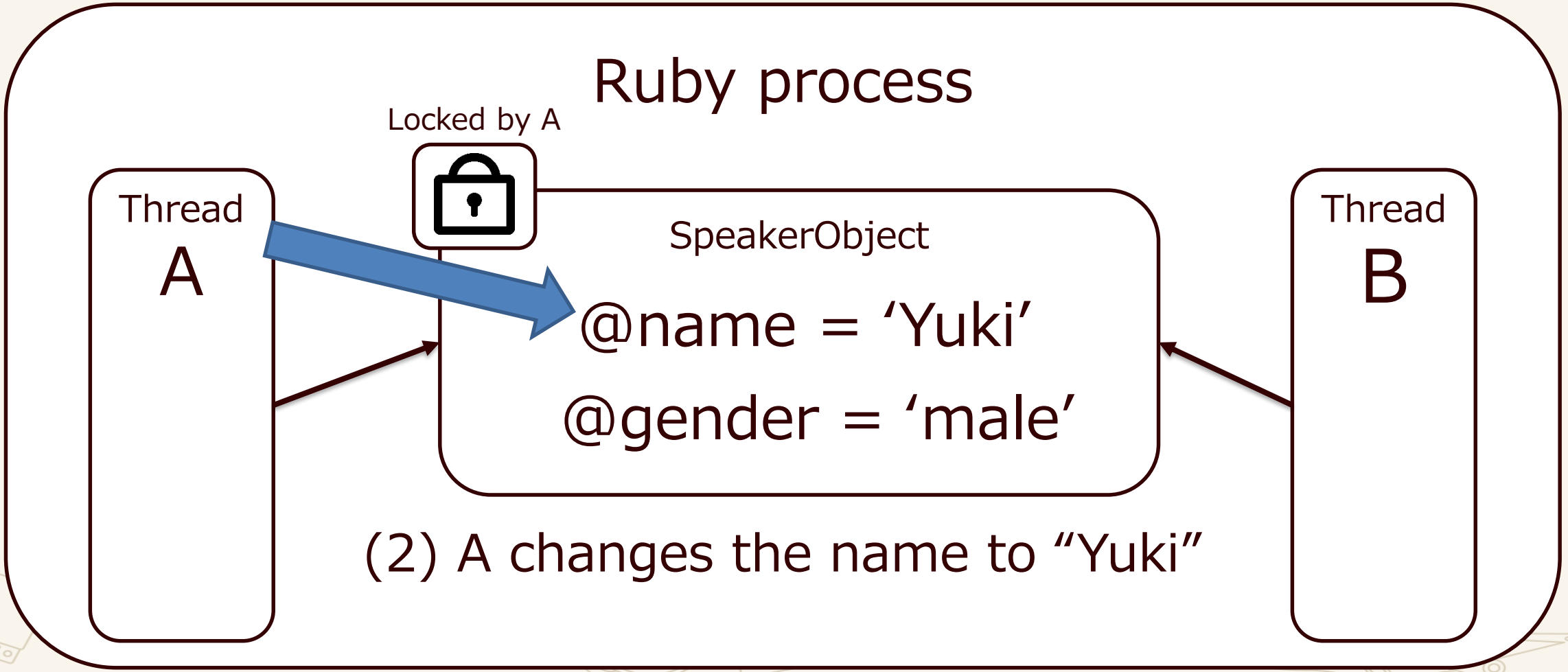
Inter-thread communication Synchronization

- Require synchronization for shared data
  - `Mutex`, `Queue` and so on
    - Usually `Queue` is enough
  - To prohibit simultaneous mutation
  - We need to keep consistency for each objects

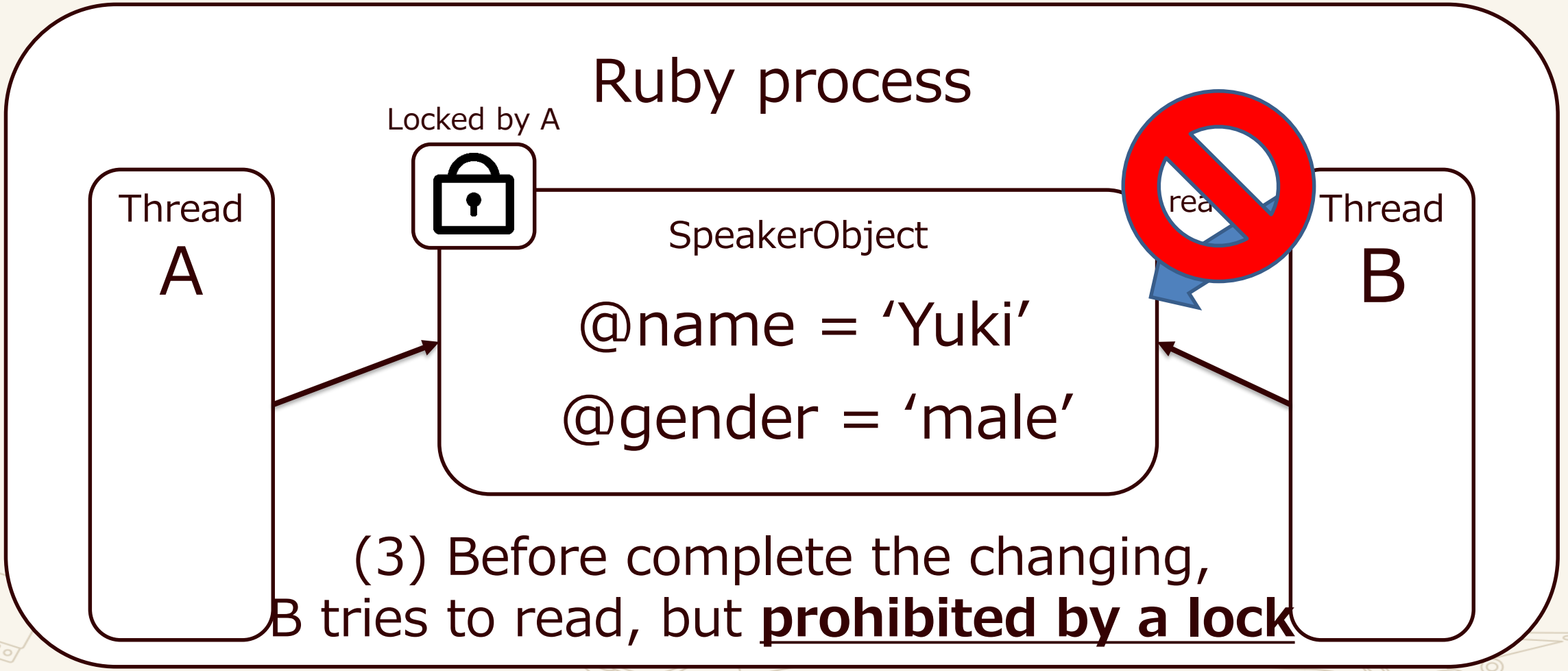
Mutate shared objects
With lock



Mutate shared objects
With lock



Mutate shared objects
With lock



Difficulty of multi-threads programs **Easy to share objects between Threads**

- We need to synchronize all sharing **mutable objects** correctly
  - Easy to share objects, but difficult to recognize
    - We can track on a small program, but…
    - Difficult to track them on **big programs**, especially on **programs using many gems**
- We need to check **whole source codes includes libraries**, or believe **library documents** (but documents should be correct)

Goal of Ruby 3 concurrency

- Easy to make **“Correct” concurrent program**
  - Restrict sharing mutable objects between threads
  - Introducing Objects **ISOLATION** mechanism
- Support parallel programming
  - Running programs simultaneously on multi-cores
  - Introducing **MINIMUM** synchronizations to MRI
- Keep compatibility with Ruby 2

Key idea

Problem of multi-thread programming:

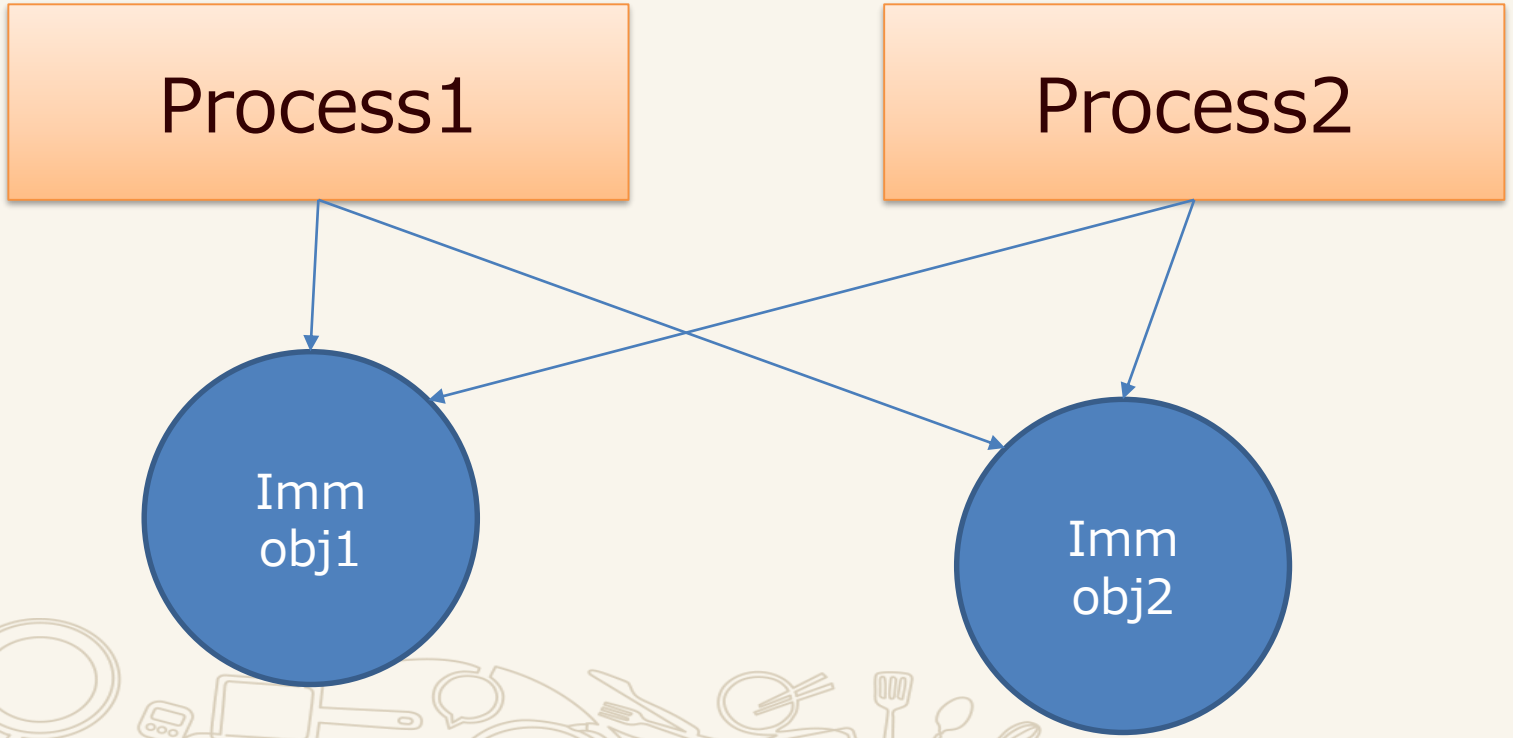
Easy to share mutable objects

Idea:

Do not allow to share mutable objects without any restriction

Options (1)
Make all objects immutable

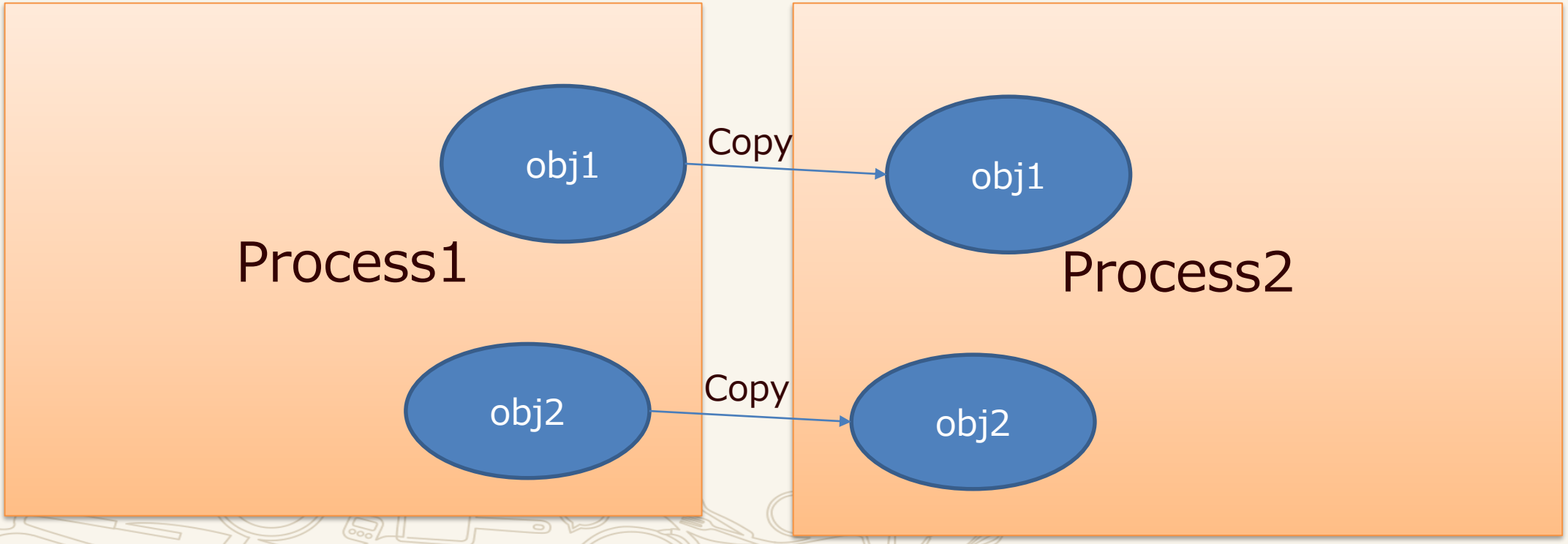
Like Elixir!!



But it break Ruby's compatibility!!

Option (2)
Copy everything

Like shell script (pipe), dRuby, …

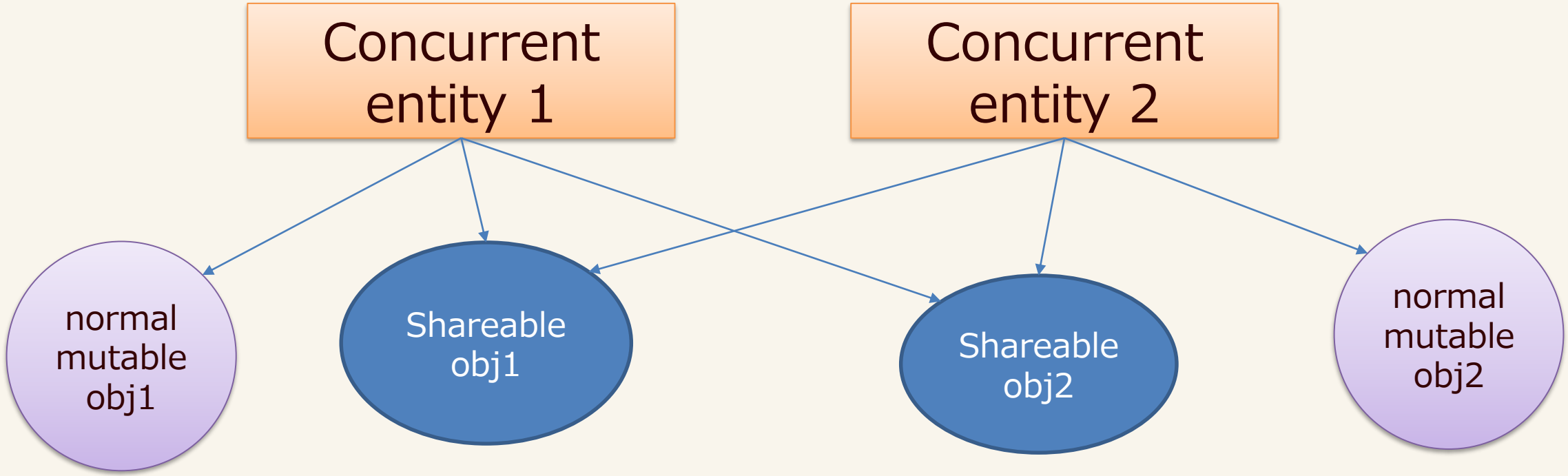


But it is difficult (sometimes) and copying causes overhead.

Options

- (1) Make all objects immutable
  - Good: No mutable sharing
  - Bad: Huge incompatibility issue
- (2) Copy everything
  - Good: No mutable sharing, no compatible problem
  - Bad:
    - No sharing objects is difficult to make programs
    - Copy overhead
- **(3) Share only “shareable” objects**

Options (3)
Share only “shareable” objects



Good: (Normal) mutable objects can’t share between concurrent entities
Good: Easy to share “shareable” objects
Good: No compatible issue (at least on only 1 concurrent entity)

GUILD

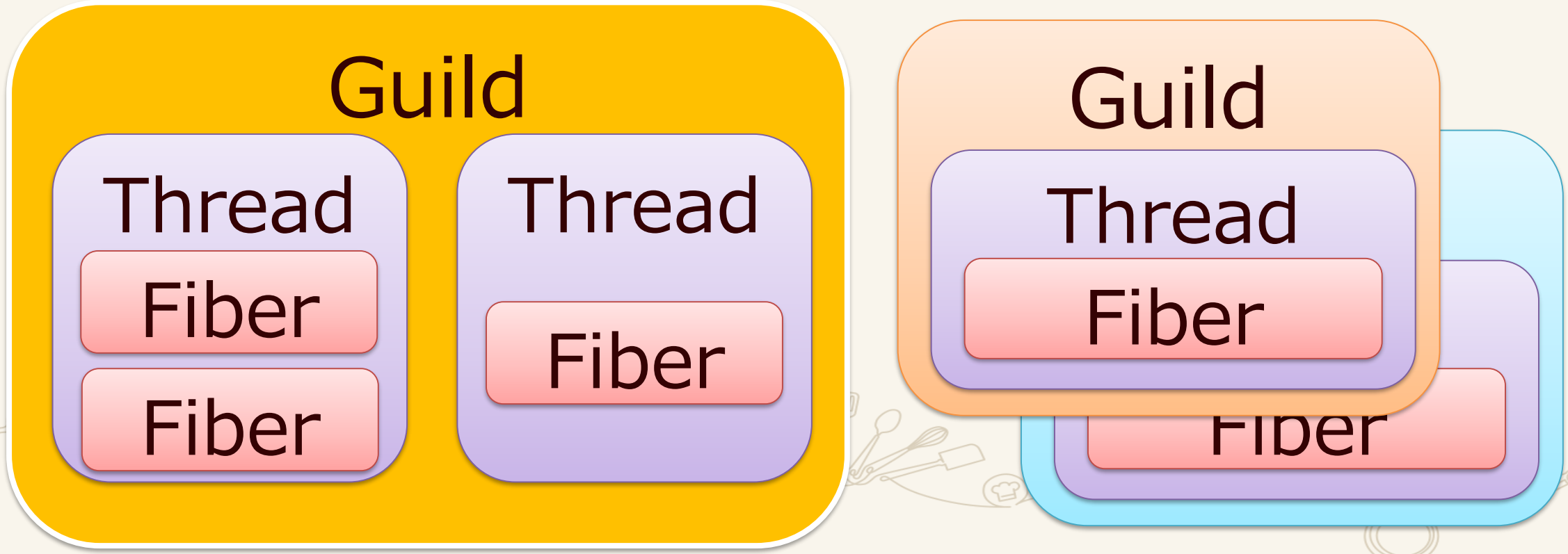
NEW CONCURRENT ABSTRACTION FOR RUBY3

Guild Guide

- Guilds, Threads and Fibers
  - Relations between Guilds, Threads and Fibers
  - How to create Guilds in Ruby code?
- Inter-Guild communication
  - Isolation design: Shareable and non-shareable objects
  - Send by copy and move
- Example patterns

Guilds, Threads and Fibers

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



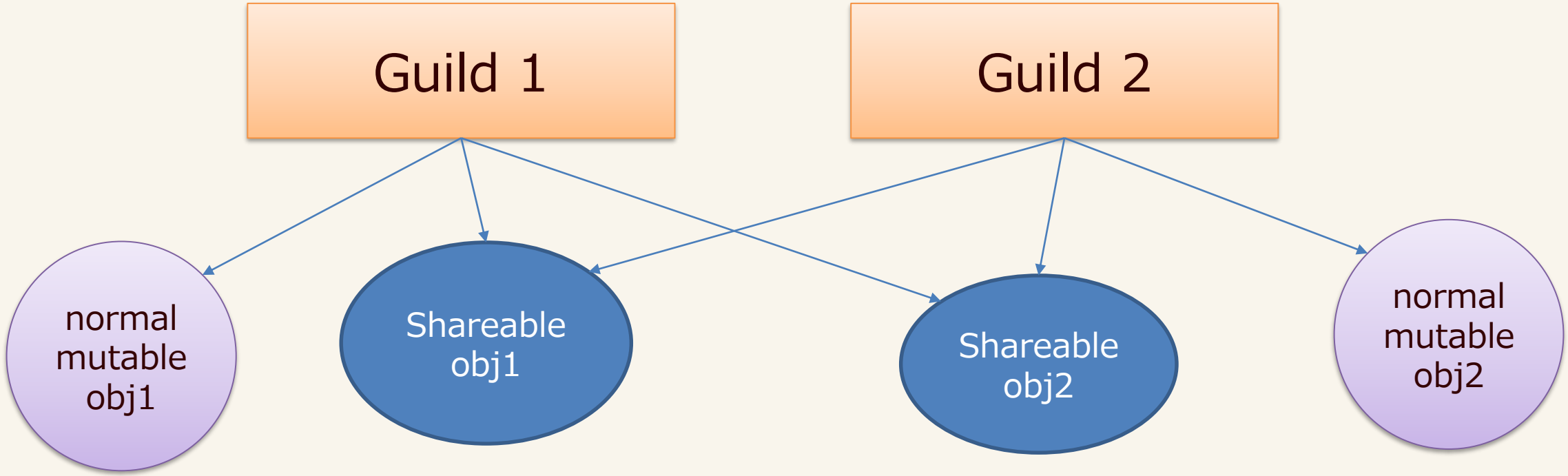
Threads in different guilds can run in **PARALLEL**

- 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 are run in parallel
```

Inter-Guild communication
Share only “shareable” objects

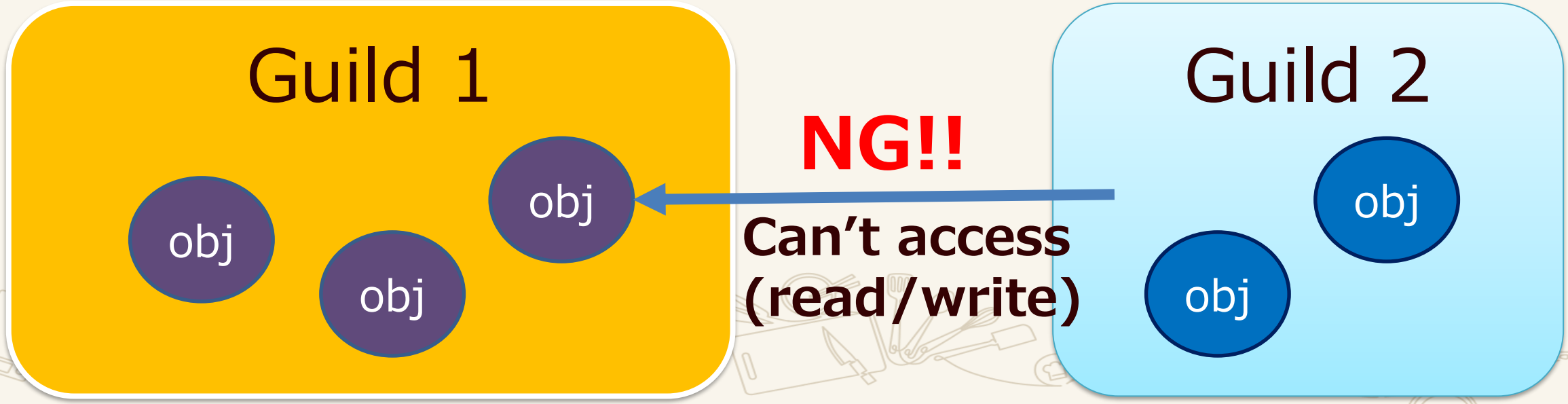


Design “Shareable” and “non-sharable”

- On concurrent programs, most of objects are not shared (thread-local)
  - **Tons** of local objects and **a few** sharing objects
  - We can introduce sharing objects which requires synchronization to make correct concurrent programs but they cause additional overhead

Design “Shareable” and “non-sharable”

- **Non-shareable** objects
  - (normal) Mutable objects (String, Array, …)
  - They are **member of only one Guild**
  - Using 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

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
- **Numeric objects, symbols, true, false, nil** are immutable (from Ruby 2.0, 2.1, 2.2)
- **Frozen string objects** are immutable (if they don’t have instance variables)

Shareable objects
(2) Class/Module objects

- All objects (includes any sharable objects) point to own classes
  - Good: Sharing class/module objects makes program easier
  - Bad: They can points 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 process to force synchronization explicitly

  → Correct concurrent programs
- Compared with normal Array, Hash, … they require special synchronization protocol to access

Shareable objects
(4) Isolated Proc

- normal Proc can points 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)
```

(there are more details but skip)

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
```

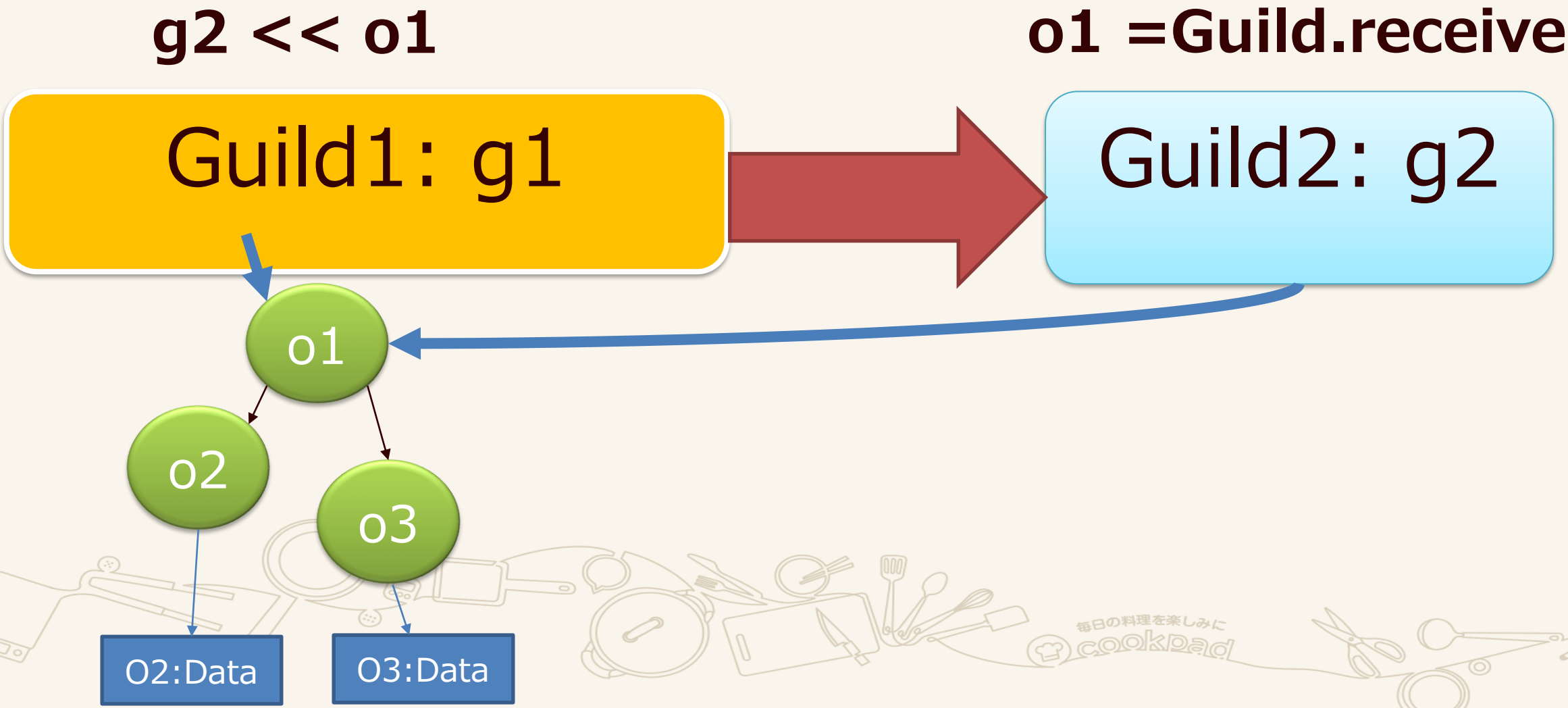
Inter-Guild communication API

- send/receive semantics
- Address is represented by Guild itself like Erlang/Elixir processes
- Sending shareable objects means sending only references to the objects (lightweight)
- Two method 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.send(r)
end
g1 << 30
p Guild.receive #=> 1346269
```

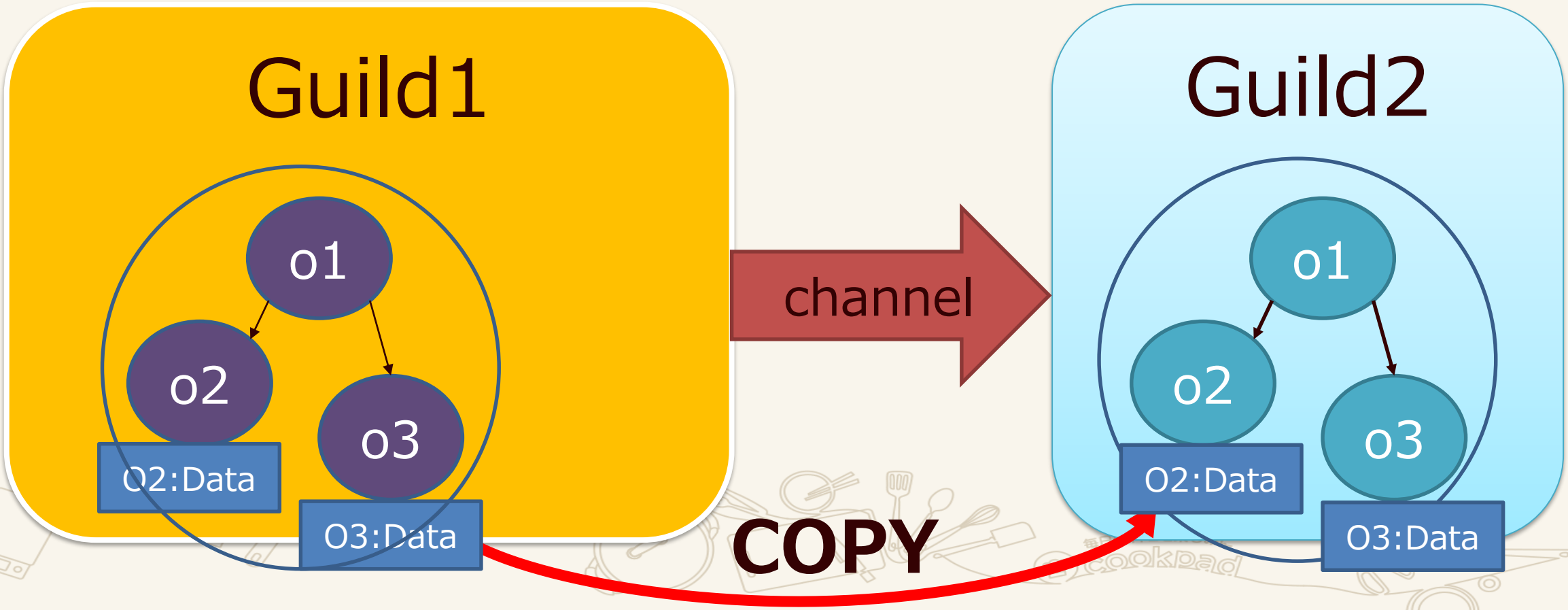
Sending shareable objects



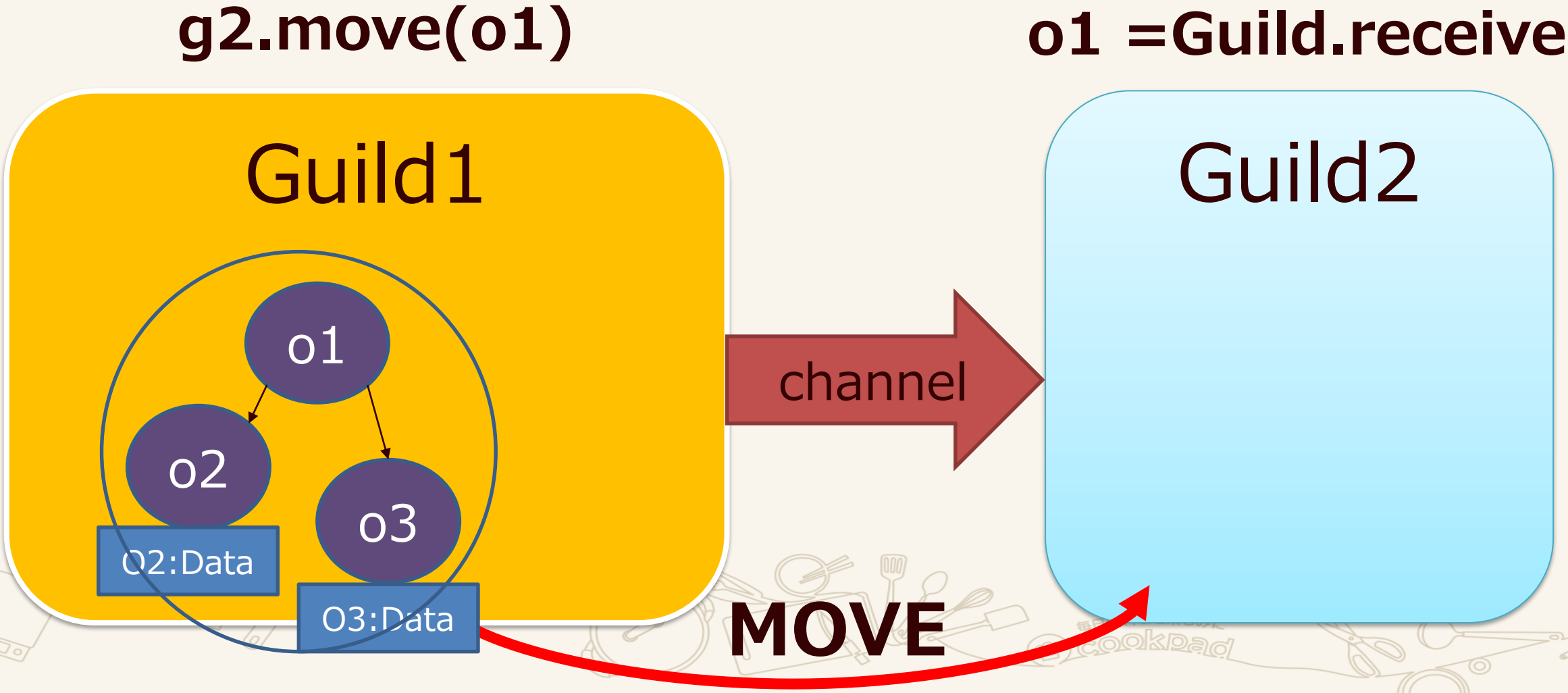
Sending non-shareable objects
(1) Send by **Copy**

g2 << o1

o1 = Guild.receive



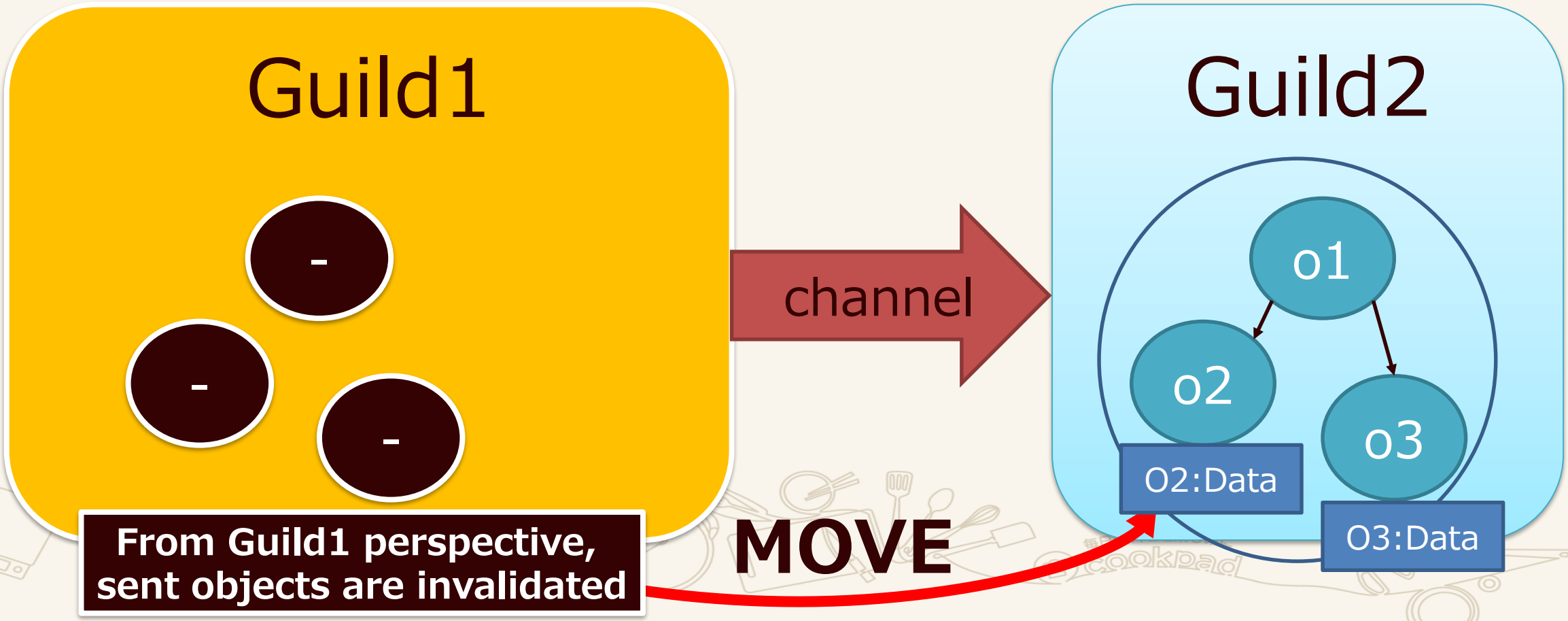
Sending non-shareable objects (2) Send by **Move**



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 operation (send request I/O to workers)

Summary of object sharing/non-sharing

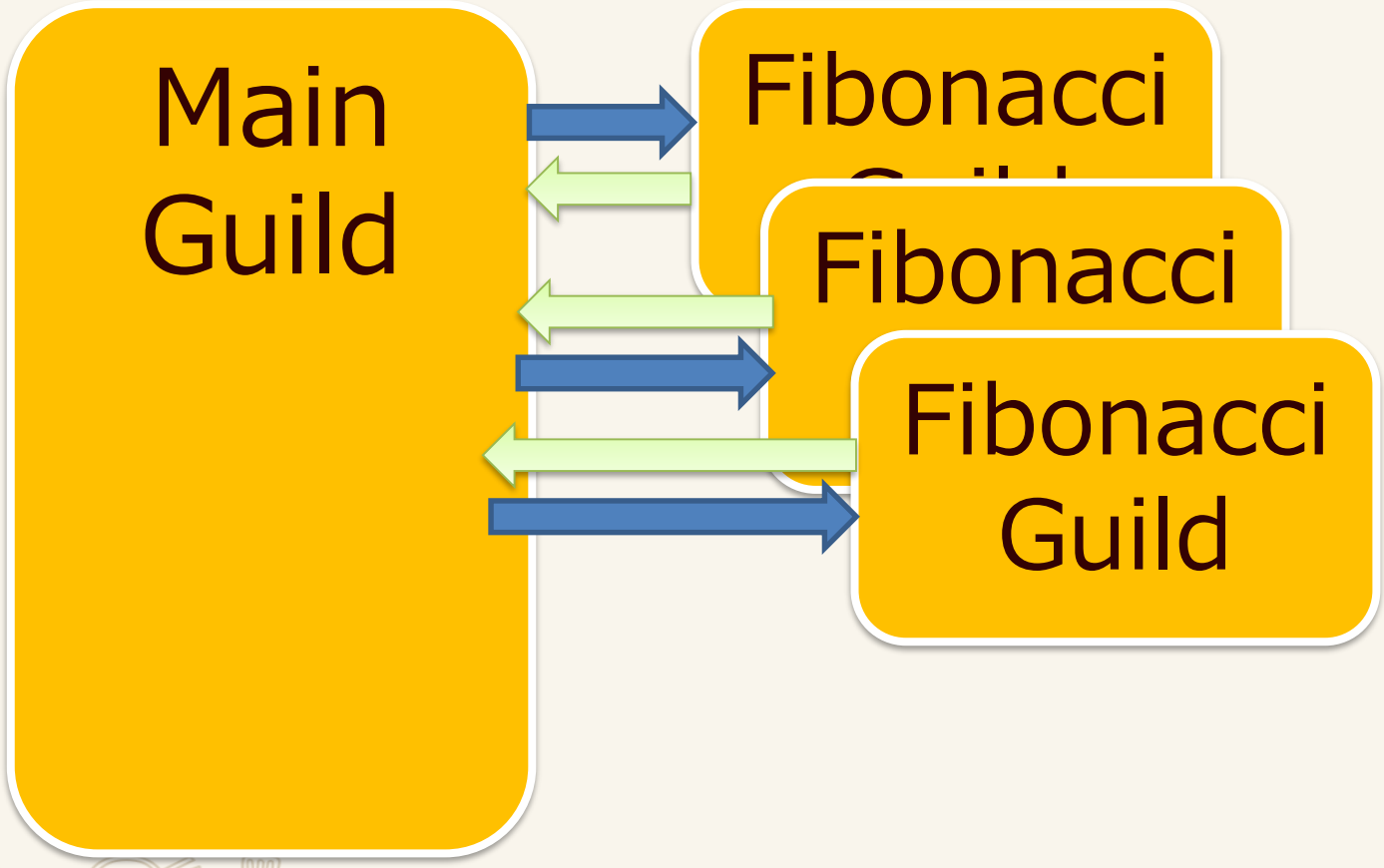
- Shareable objects
  - Several types of shareable objects
  - We can share them between Guilds
- Non-sharable objects
  - Normal mutable objects (like String, Array, …)
  - **Only one Guild** can access such objects == membership
  - We can **send** them by **COPY** or **MOVE**
- Mutable objects are **NOT** shared **accidentally** as Thread programming → **Correct concurrent Prog**.

Patterns

- (1) Master-worker pattern
- (2) Pipeline pattern

(1) Master-worker pattern

```
# make N guilds
gs = N.times.map{
  Guild.new do
    n = Guild.receive
    Guild.parent << fib(n)
  end
}
# send task
gs.each{|g|
  g << P
}
# receive answers
N.times{
  p Guild.receive
}
```



(2) Pipeline pattern

- Run different tasks for one data
- Example

```
str = '  foobarbaz  `
str = str.strip.upcase.gsub('A', `B’) #=> "FOOBBRBBZ"

#=> There are 3 different tasks
str = str.strip
str = str.upcase
str = str.gsub('A', `B’)
```

```
# on Elixir
str |> String.trim
    |> String.upcase
    |> String.replace(…)
```

(2) Pipeline pattern

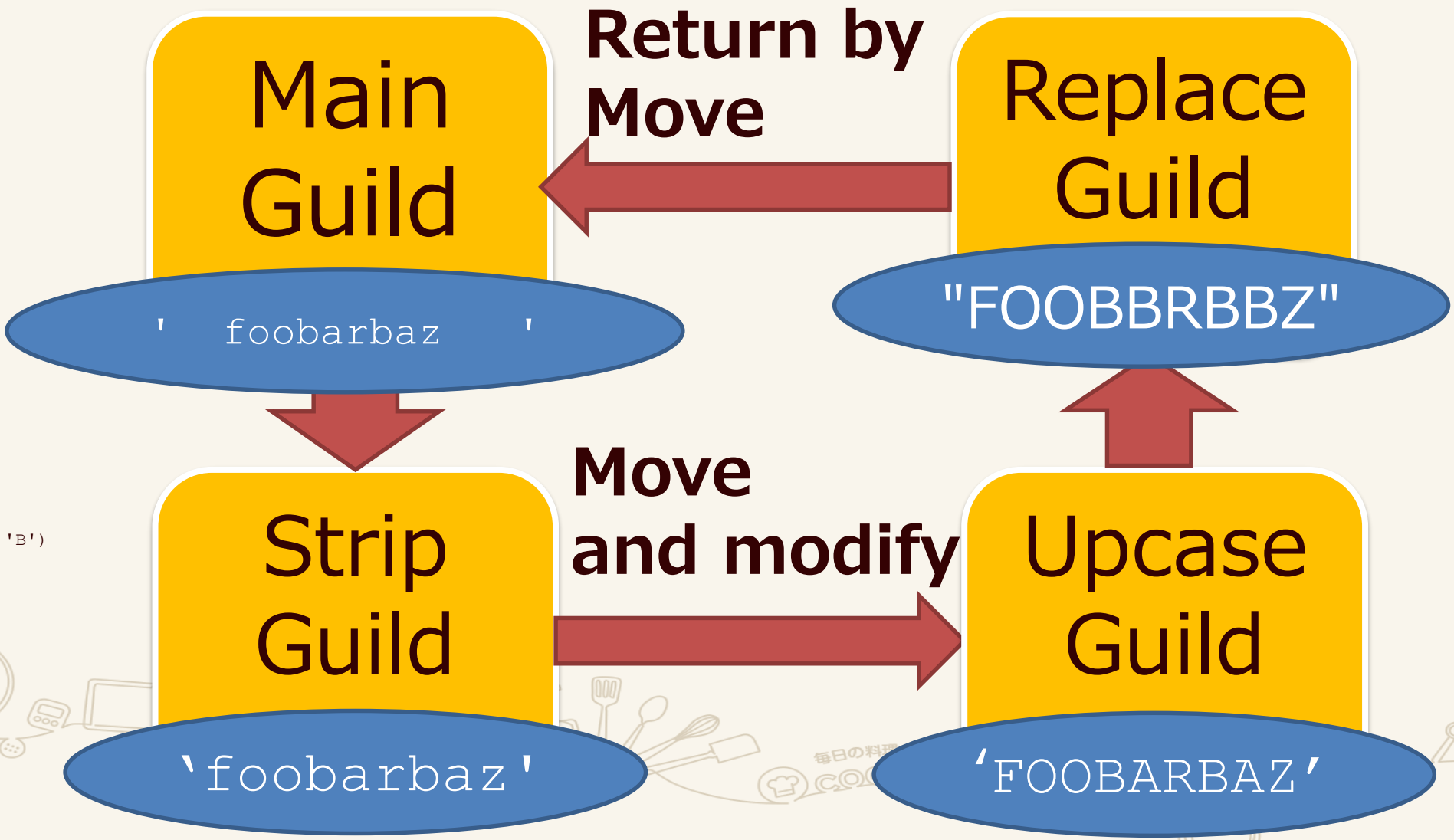
```
g_strip = Guild.new do
  next_guild = Guild.receive
  while str = Guild.receive
    next_guild.move str.strip
  end
  next_guild << nil
end

g_upcase = Guild.new do
  next_guild = Guild.receive
  while str = Guild.receive
    next_guild.move str.upcase
  end
  next_guild << nil
end

g_replace = Guild.new do
  next_guild = Guild.receive
  while str = Guild.receive
    next_guild.move str.gsub('A', 'B')
  end
  next_guild << nil
end

g_strip << g_upcase
g_upcase << g_replace
g_replace << Guild.current

g_strip.move '  foobarbaz   '
p Guild.receive
```



(2) Pipeline pattern
Framework for frequent patterns

```
class Guild
  # Make series of Guilds for a pipeline
  def self.pipeline *tasks
    task_guilds = tasks.map{|task|
      Guild.new do
        next_guild = Guild.recv
    next_g = Guild.current
    task_guilds.reverse_each{|g|
      g.send next_g
      next_g = g
    }
    task_guilds.first
  end
end
```

```
g = Guild.pipeline -> str { str.strip },
                   -> str { str.upcase },
                   -> str { str.gsub('A', 'B') }
```

We need to design a library like OTP.

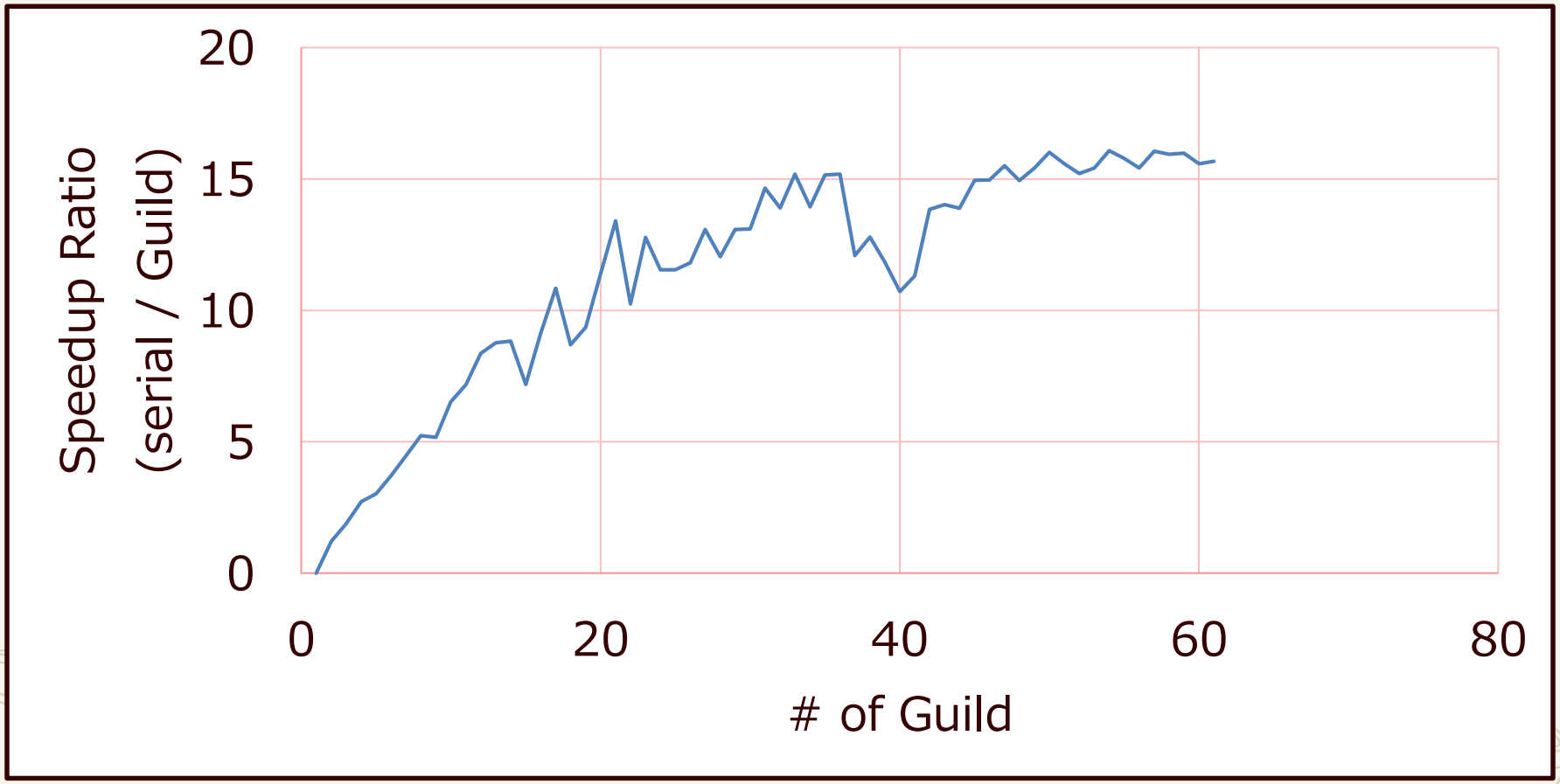
Supposed usecases

- Web application backend
  - Guild pool for request workers
  - Straight forward approach

Experimental results

Run fib(36) on 40 cores machine

(2 HT x 10 cores x 2 processors Xeon E5-2630 v4)



Experimental results

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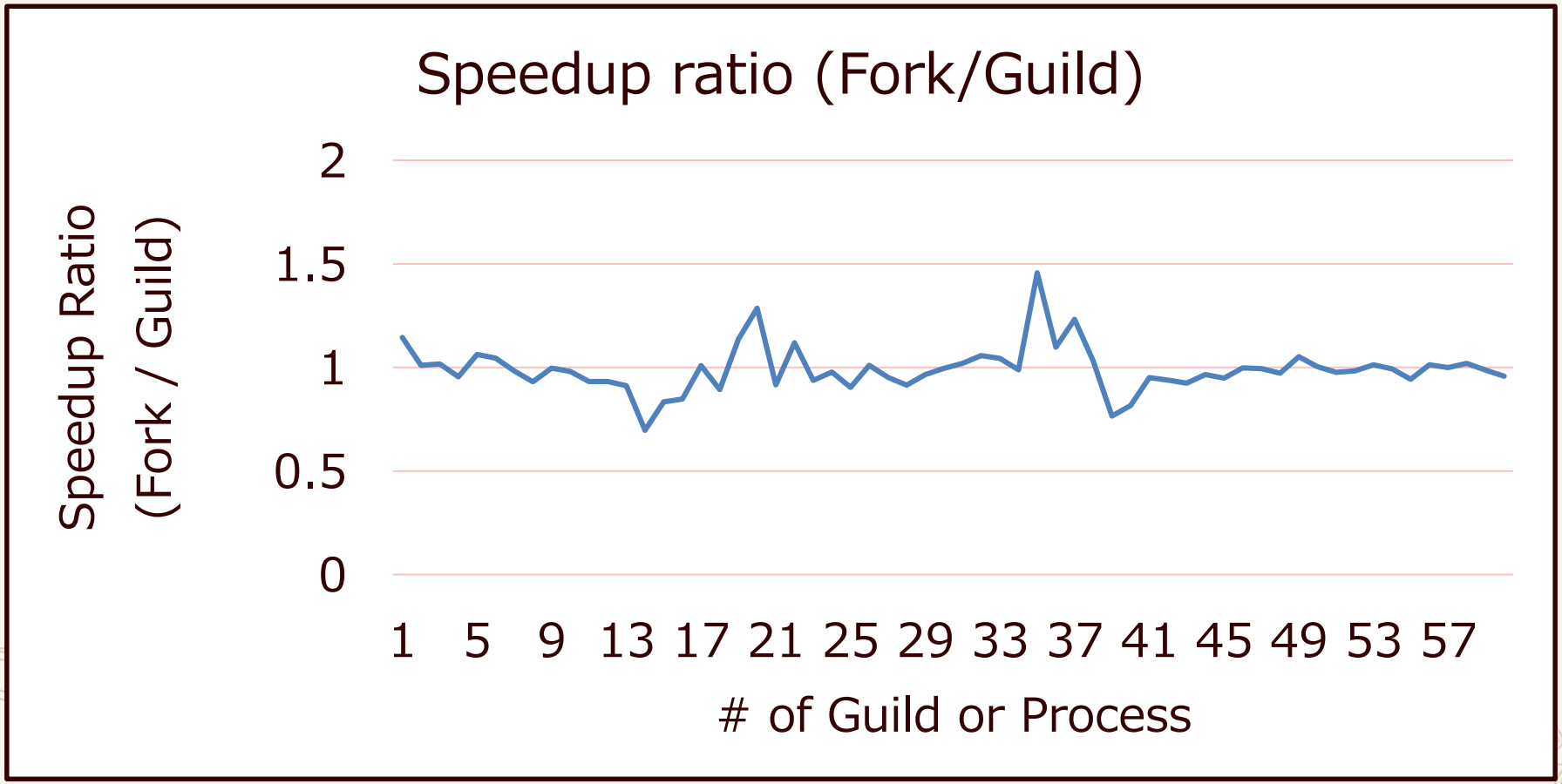

Note
There are more and more details to discuss

- Semantics: so many topics
  - Global variables
  - Instance variables for shareable objects
  - Class/Module specific shared data synchronization
    - Constants, class variables
    - Method table
  - C API compatibility for thread safety
  - Isolated Proc semantics and error detections
  - Supports (syntax, runtime) to make immutable objects
  - I/O? Current working directory?
  - How to define moving protocol?
  - What kind of “Transaction” is supported for shareable data?
  - ObjectSpace.each_object?
  - Signal handlers?
  - …
- Implementation: we need to revisit all of MRI code to change the assumption “GVL/GIL can protect all”
  - How to reduce internal locks for performance?
  - How to make parallel GC?
  - Rewrite MRI implementations to make them thread-safe (e.g.: Regex)
  - Introduce new C APIs to accept “ec” parameters to remove TLS access overhead
  - Really compatible with Ruby 2?
  - …

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**

Today’s topic

- Difficulty of **Thread programming**
- New concurrent abstraction for Ruby 3 named **Guild**
  - To overcome threading difficulties
- Introduce current Guild development progress
  - Current “Semantics”
  - Current API design and sample code we can run
  - Preliminary performance evaluation

Thank you for your attention

Koichi Sasada
<ko1@cookpad.com>

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