

RubyConf 2016

# Ruby 3

# Concurrency

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RubyKaigi 2016

# **A proposal of new concurrency model for Ruby 3**

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# Motivation

## **Productivity**

- Thread programming is very difficult
- Making correct concurrent programs easily

## **Performance by Parallel execution**

- Making parallel programs
- Threads can make concurrent programs, but can't run them in parallel
- 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*

# RubyKaigi2016 Proposal

## Guild: new concurrency abstraction for Ruby 3

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

***Kill Threads***

Today's talk

Why is thread programming difficult?

Why does Guild solve this difficulty?

I'll try to shrink this talk (but has 70 pages).  
Long version talk at RubyKaigi2016 is available:

<http://rubykaigi.org/2016/presentations/ko1.html>

## NOTE

“Guild” is proposal for Ruby 3.  
Specifications  
and name of “Guild”  
can be changed.

# Koichi Sasada

- A programmer living in Tokyo, Japan
- Ruby core committer since 2007
  - YARV, Fiber, ... (Ruby 1.9)
  - RGenGC, RincGC (Ruby 2...)



PROGRAMMING  
Language



Koichi is an Employee



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Koichi is an Employee



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# Difficulty of Multi-threads programming

# Multi-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**

# Data race and race condition

- Traditional “Bank amount transfer” example
  - Quoted from Race Condition vs. Data Race  
<http://blog.regehr.org/archives/490>

```
def transfer1 (amount, account_from, account_to)
  if (account_from.balance < amount) return NOPE
  account_to.balance += amount
  account_from.balance -= amount
  return YEP
end
```

# Data race and race condition

```
def transfer1 (amount, account_from, account_to)
  if (account_from.balance < amount) return NOPE
  account_to.balance += amount
  account_from.balance -= amount
  return YEP
end
```

**Can you find all bugs?**

# Data race and race condition

```
def transfer1 (amount, account_from, account_to)
  if (account_from.balance < amount) return NOPE
  account_to.balance += amount
  account_from.balance -= amount
  return YEP
end
```

**Data Race**

# Data race and race condition

```
def transfer1 (amount, account_from, account_to)
  if (account_from.balance < amount) return NOPE
  account_to.balance += amount
  account_from.balance -= amount
  return YEP
end
```

**Race Condition**



# Data race and race condition

- Solution: Lock (synchronize) all over the method

```
def transfer1 (amount, account_from, account_to)
  Thread.exclusive{
    if (account_from.balance < amount) return NOPE
    account_to.balance += amount
    account_from.balance -= amount
    return YEP
  }
end
```

# Difficulty of multi-threads programs

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

Overcome thread difficulty

Key idea

**Problem of multi-thread programming:**

Easy to share mutable objects

**Idea:**

**Do not allow to share mutable objects  
without any restriction**

# Study from other languages

- Do not share mutable objects
  - Copy to send message (shell, druby, ...)
    - ☹️ Copy everything is slow
  - Prohibit mutable objects (functional lang, Erlang, Elxir)
    - ☹️ We can't accept such big incompatibility
  - Share only immutable objects (Place (Racket))
    - ☹️ We want to share other kind of objects
- Allow sharing with restriction
  - Allow mutation only with special protocol (Clojure)
    - ☹️ we can't accept special protocol

**NOTE: we do not list approaches using “type system” like Rust**

# Our goal for Ruby 3

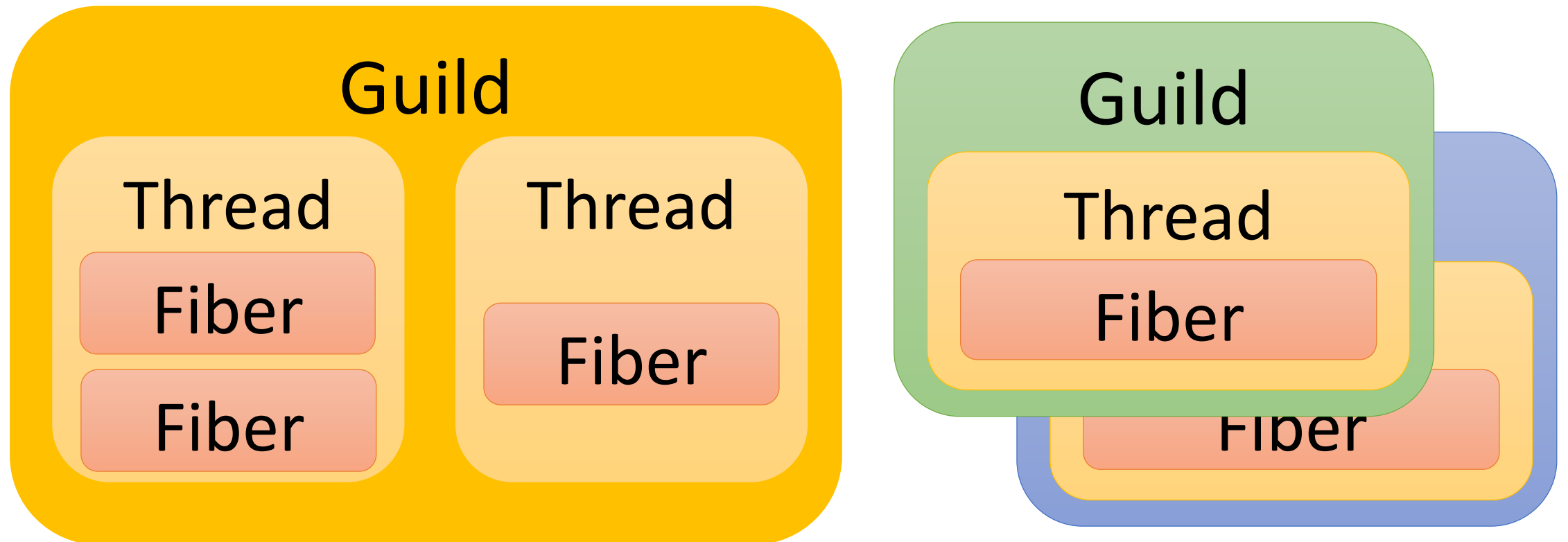
- We need to **keep compatibility** with Ruby 2.
- We can make **parallel program**.
- We **shouldn't consider** about locks any more.
- We **can share** objects with **copy**, but **copy operation should be fast**.
- We **should share immutable objects** if we can.
- We can **provide special objects** to share mutable objects like Clojure if we really need speed.

# “Guild”

New concurrency model for Ruby 3

# Guild: New concurrency abstraction

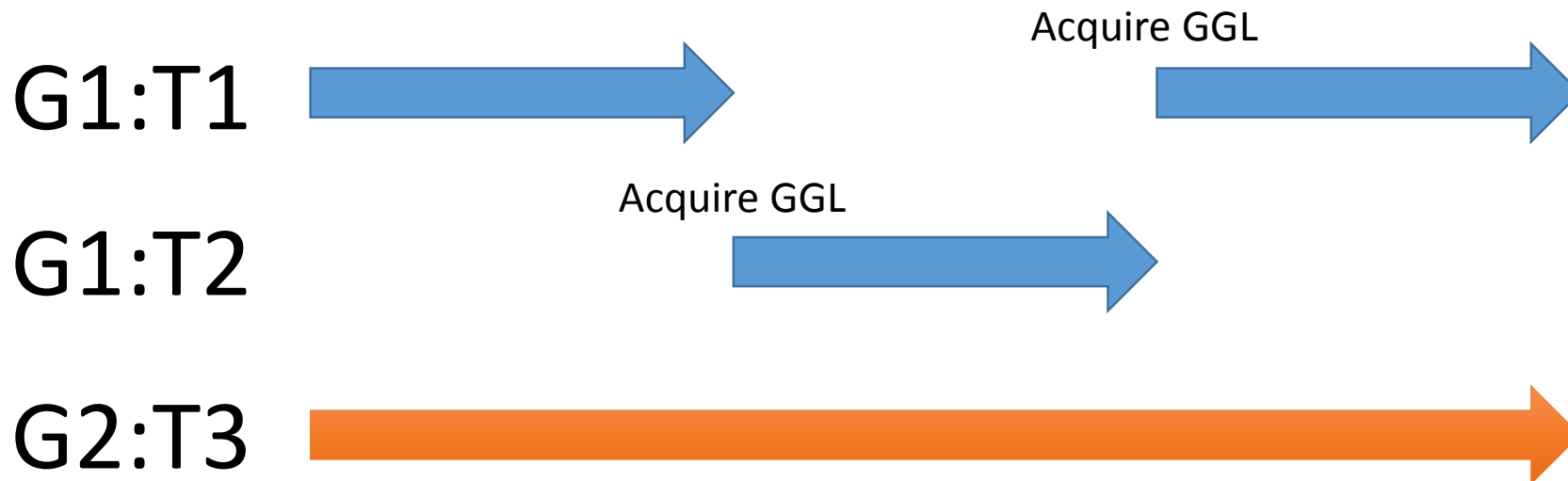
- Guild has at least one thread (and a thread has at least one fiber)





# Threads in different guilds can run in Parallel

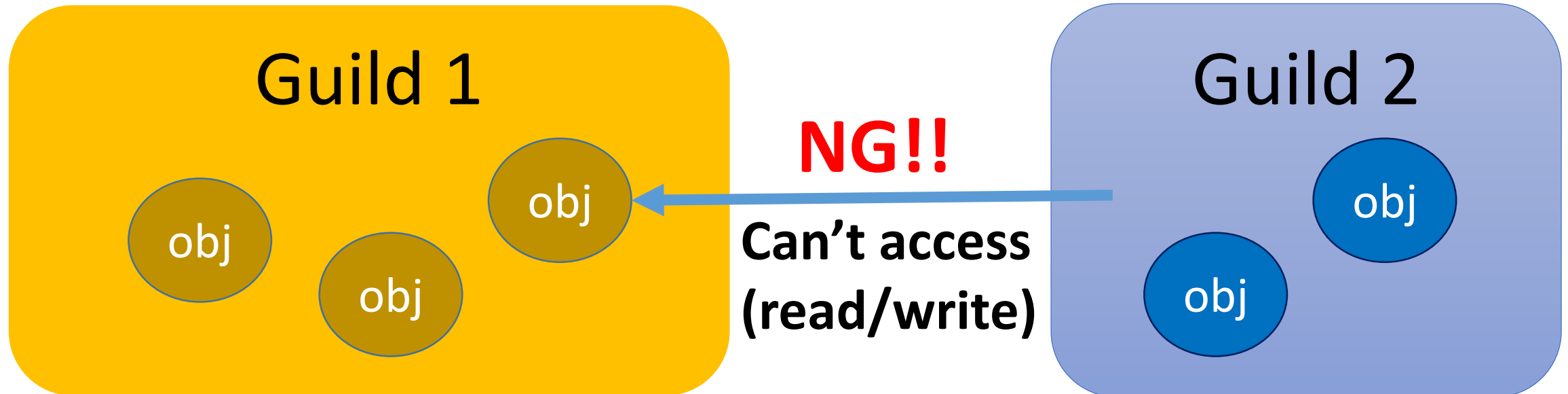
- Threads in different guilds **can run in parallel**
- Threads in a same guild **can not run in parallel** because of GVL (or GGL: Giant Guild Lock)



Important rule:

Mutable Objects have a membership

- All of mutable objects should belong to **only one Guild** exclusively
- Because Guild is not “**Community**”



# Object membership

Only one guild can access mutable object

→ **We don't need to consider about locks**  
(if Guild has only one thread)

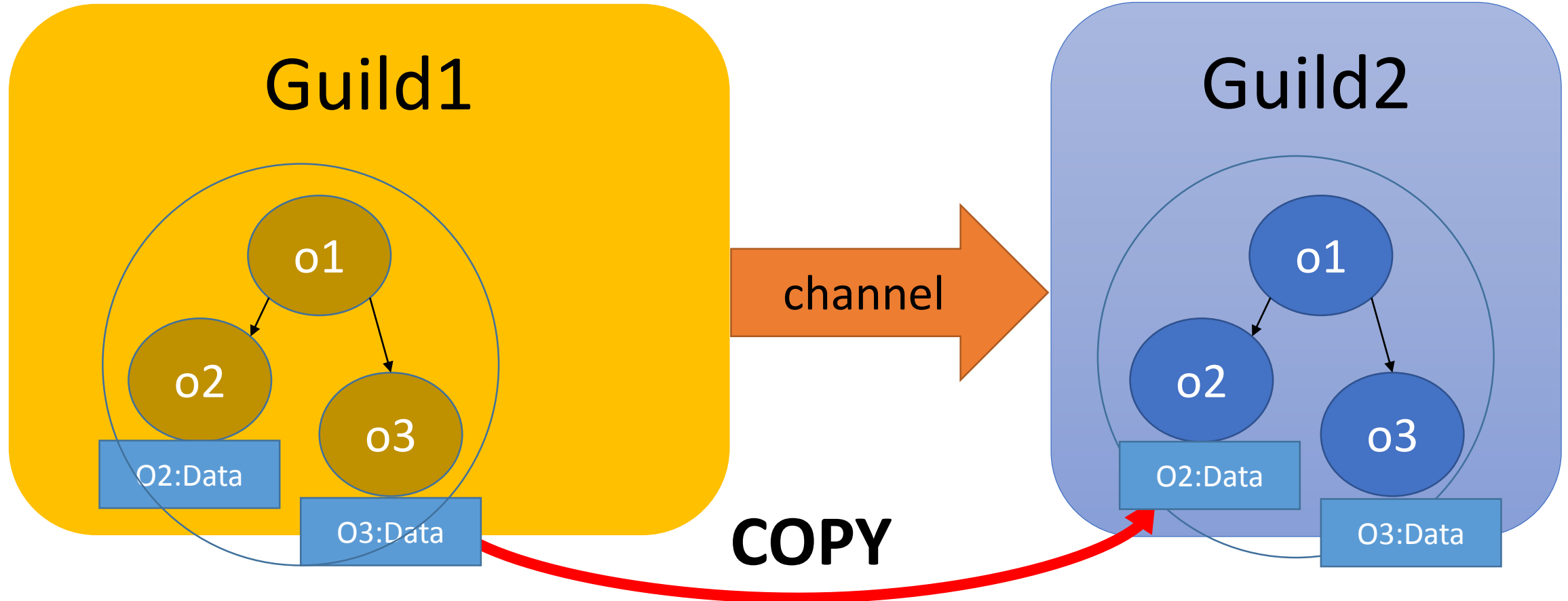
# Inter-guild communication

- **“Guild::Channel”** to communicate each guilds
- Two communication methods
  1. **Copy**
  2. **Move (transfer\_membership)**

# Copy using Channel

`channel.transfer(o1)`

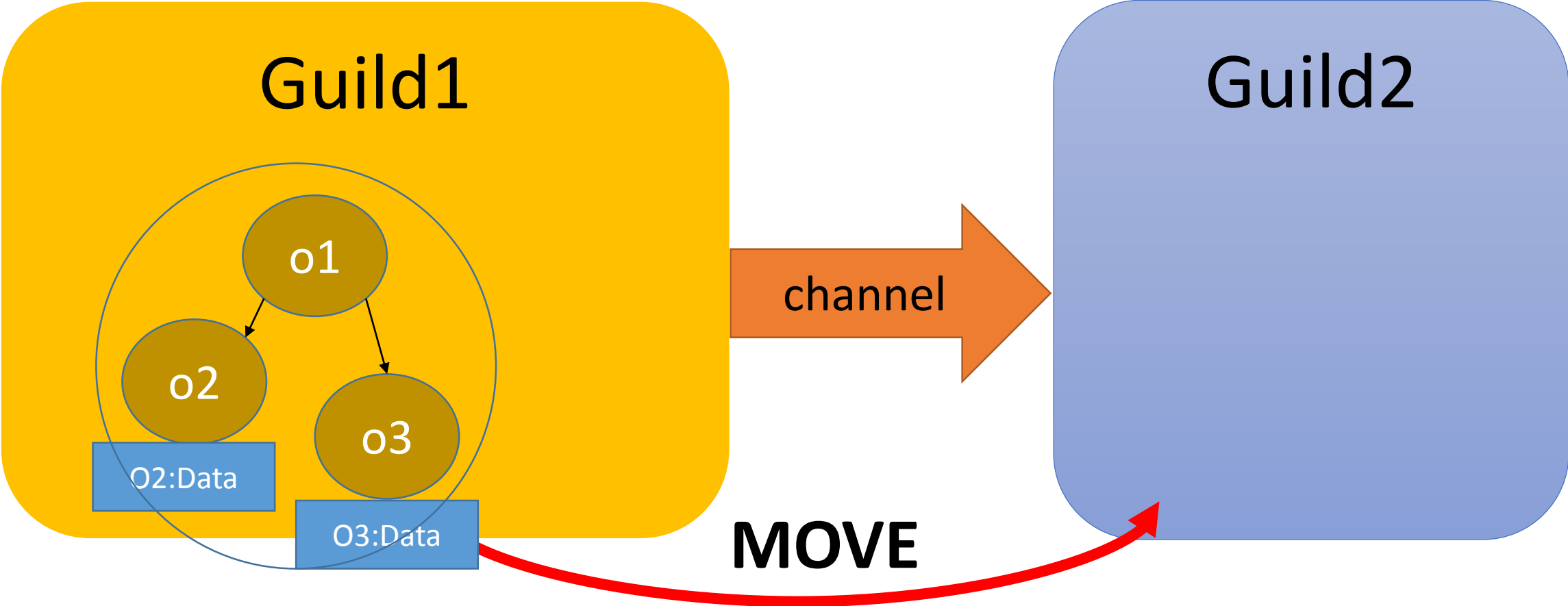
`o1 = channel.receive`



# Move using Channel

```
channel.transfer_membership(o1)
```

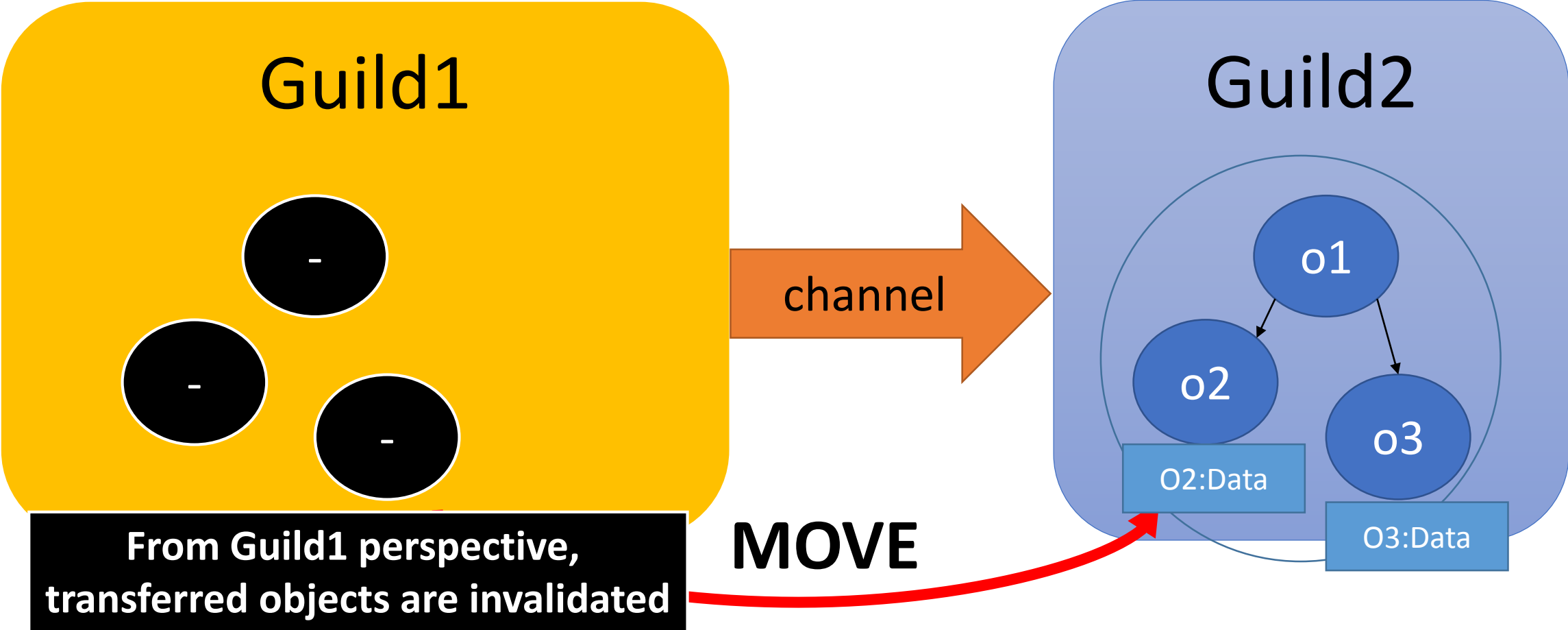
```
o1 = channel.receive
```



# Move using Channel

```
channel.transfer_membership(o1)
```

```
o1 = channel.receive
```



# Move using Channel

- Prohibit accessing to left objects
  - Cause exceptions and so on
  - ex) `obj = "foo"`  
`ch.move (obj)`  
`obj.upcase`      **#=> Error!!**  
`p(obj)`            **#=> Error!!**



# Use cases for copy and move

- You can copy small objects (dRuby does)
  - Parameter array (**[:do\_foo, 1, 2, 3]**, like Erlang)
- You can move small amount number of objects
  - Move a long string and modify them in parallel

# Sharing immutable objects

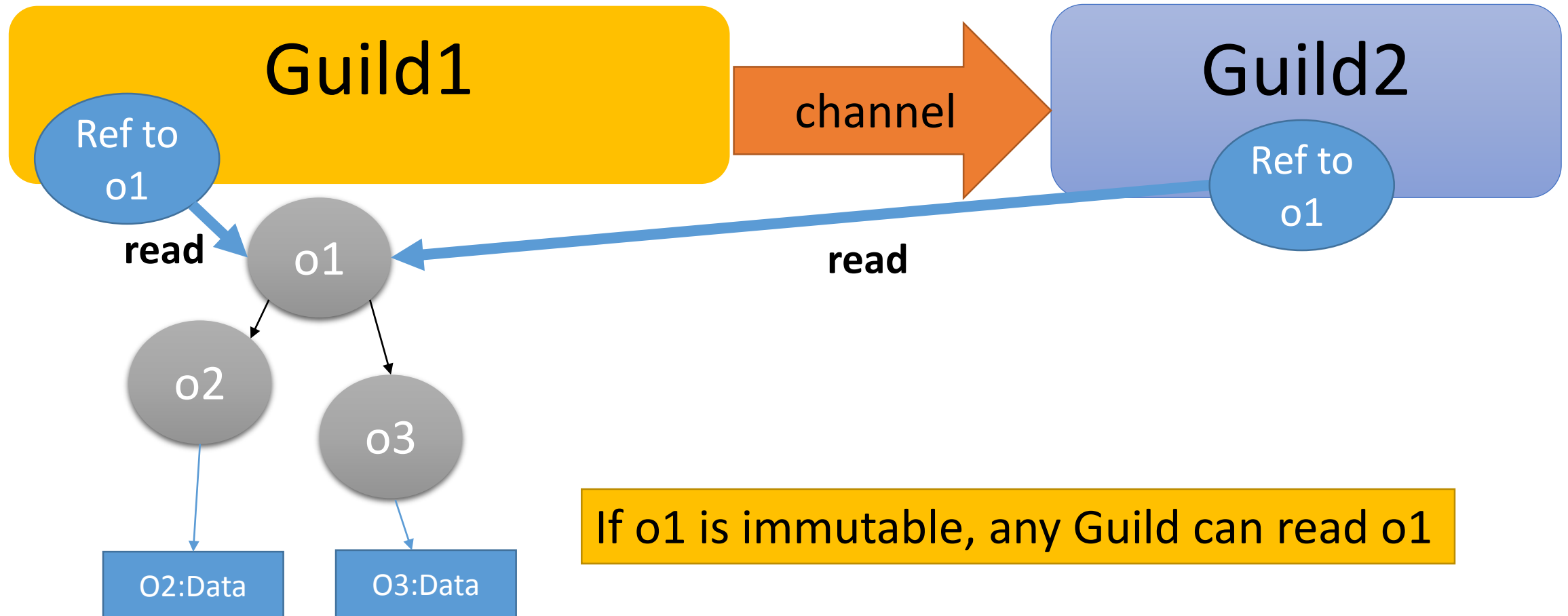
- **Immutable objects** can be shared with any guilds
  - `a1 = [1, 2, 3].freeze`: a1 is **Immutable object**
  - `a2 = [1, Object.new, 3].freeze`: a2 is **not immutable**
- We only need to send references
  - Very lightweight, like thread-programming
- **Numeric objects, symbols, true, false, nil** are immutable (from Ruby 2.0, 2.1, 2.2)

# Sharing immutable objects

We can share reference to immutable objects

`channel.transfer(o1)`

`o1 = channel.receive`

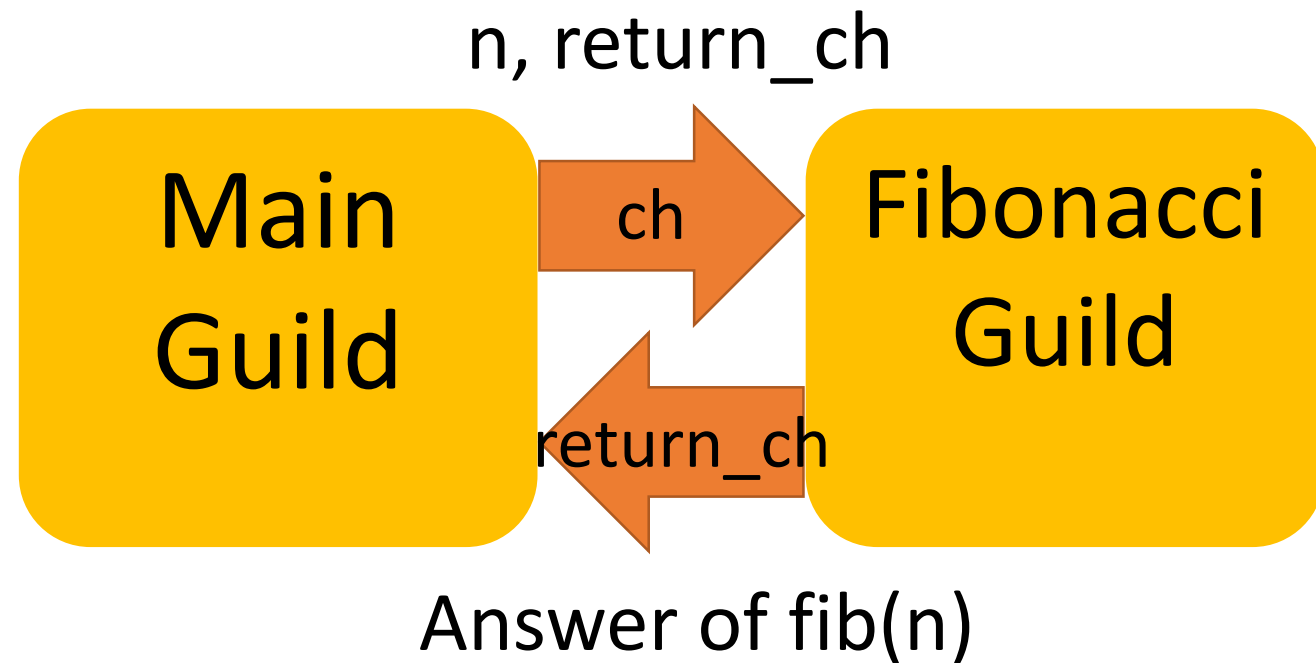


If o1 is immutable, any Guild can read o1

# Use-case 1: master – worker type

```
def fib(n) ... end
g_fib = Guild.new(script: %q{
  ch = Guild.default_channel
  while n, return_ch = ch.receive
    return_ch.transfer fib(n)
  end
})
```

```
ch = Guild::Channel.new
g_fib.transfer([3, ch])
p ch.receive
```



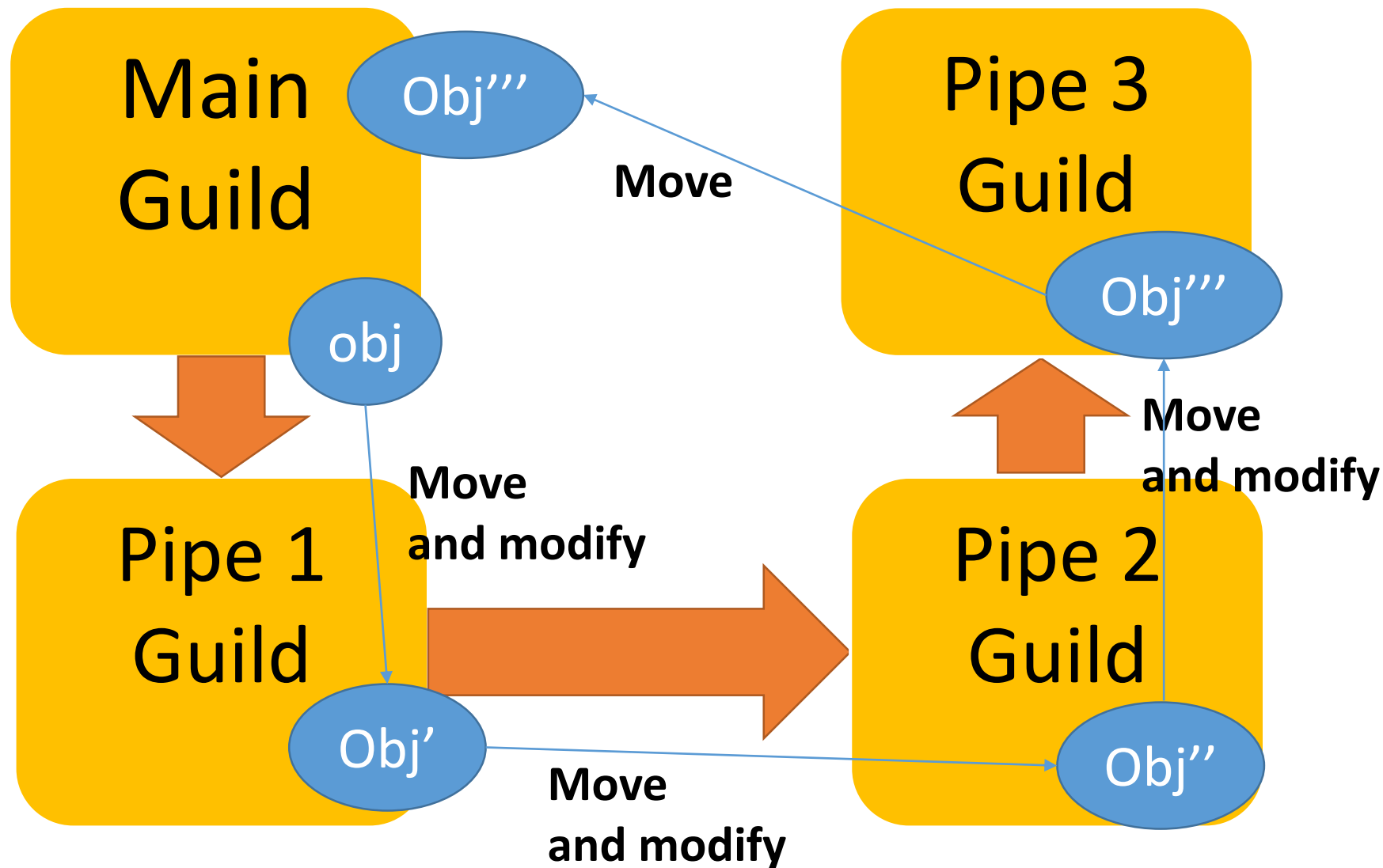
**NOTE: Making other Fibonacci guilds, you can compute fib(n) in parallel**

# Use-case 2: pipeline

```
result_ch = Guild::Channel.new
g_pipe3 = Guild.new(script: %q{
  while obj = Guild.default_channel.receive
    obj = modify_obj3(obj)
    Guild.argv[0].transfer_membership(obj)
  end
}, argv: [result_ch])
g_pipe2 = Guild.new(script: %q{
  while obj = Guild.default_channel.receive
    obj = modify_obj2(obj)
    Guild.argv[0].transfer_membership(obj)
  end
}, argv: [g_pipe3])
g_pipe1 = Guild.new(script: %q{
  while obj = Guild.default_channel.receive
    obj = modify_obj1(obj)
    Guild.argv[0].transfer_membership(obj)
  end
}, argv: [g_pipe2])

obj = SomeClass.new

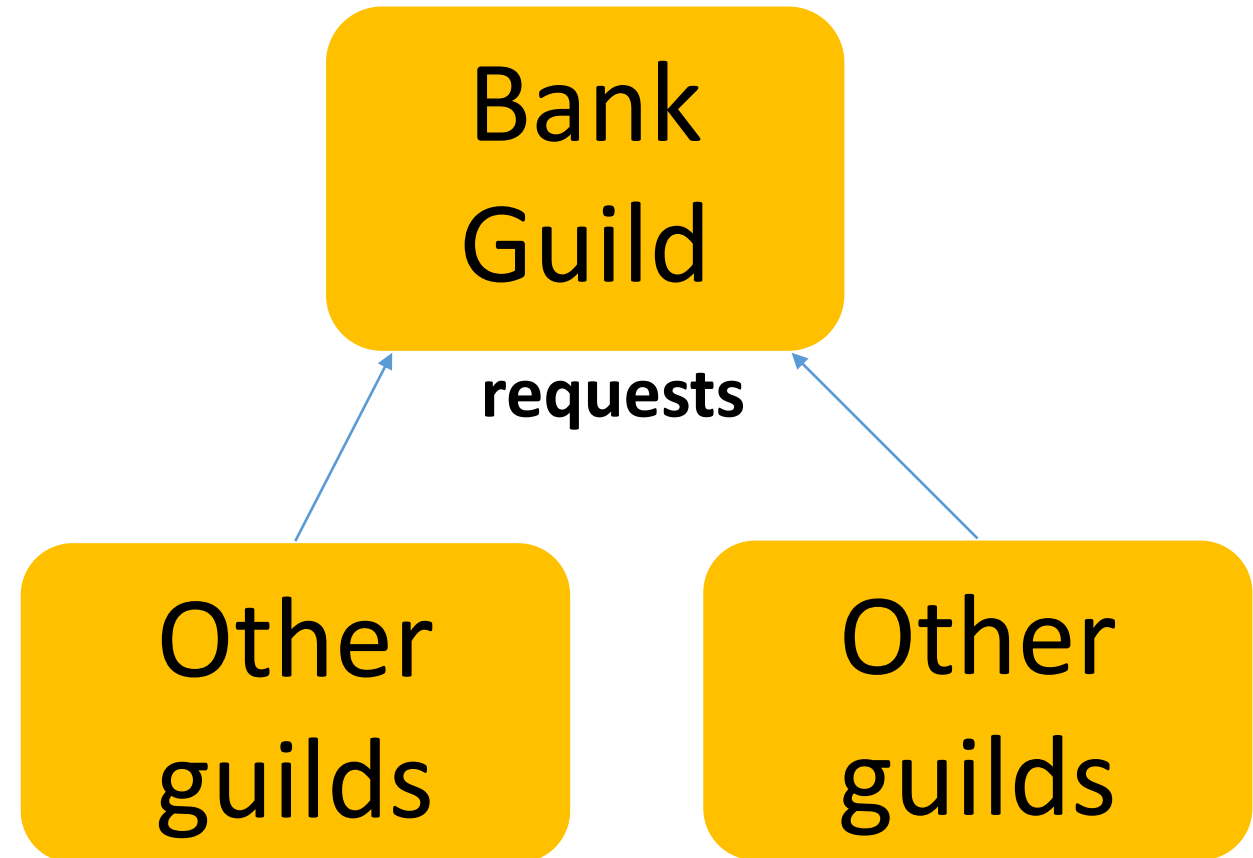
g_pipe1.transfer_membership(obj)
obj = result_ch.receive
```



# Use-case: Bank example

```
g_bank = Guild.new(script: %q{
  while account_from, account_to, amount,
    ch = Guild.default_channel.receive
    if (Bank[account_from].balance < amount)
      ch.transfer :NOPE
    else
      Bank[account_to].balance += amount
      Bank[account_from].balance -= amount
      ch.transfer :YEP
    end
  end
end
})
...
```

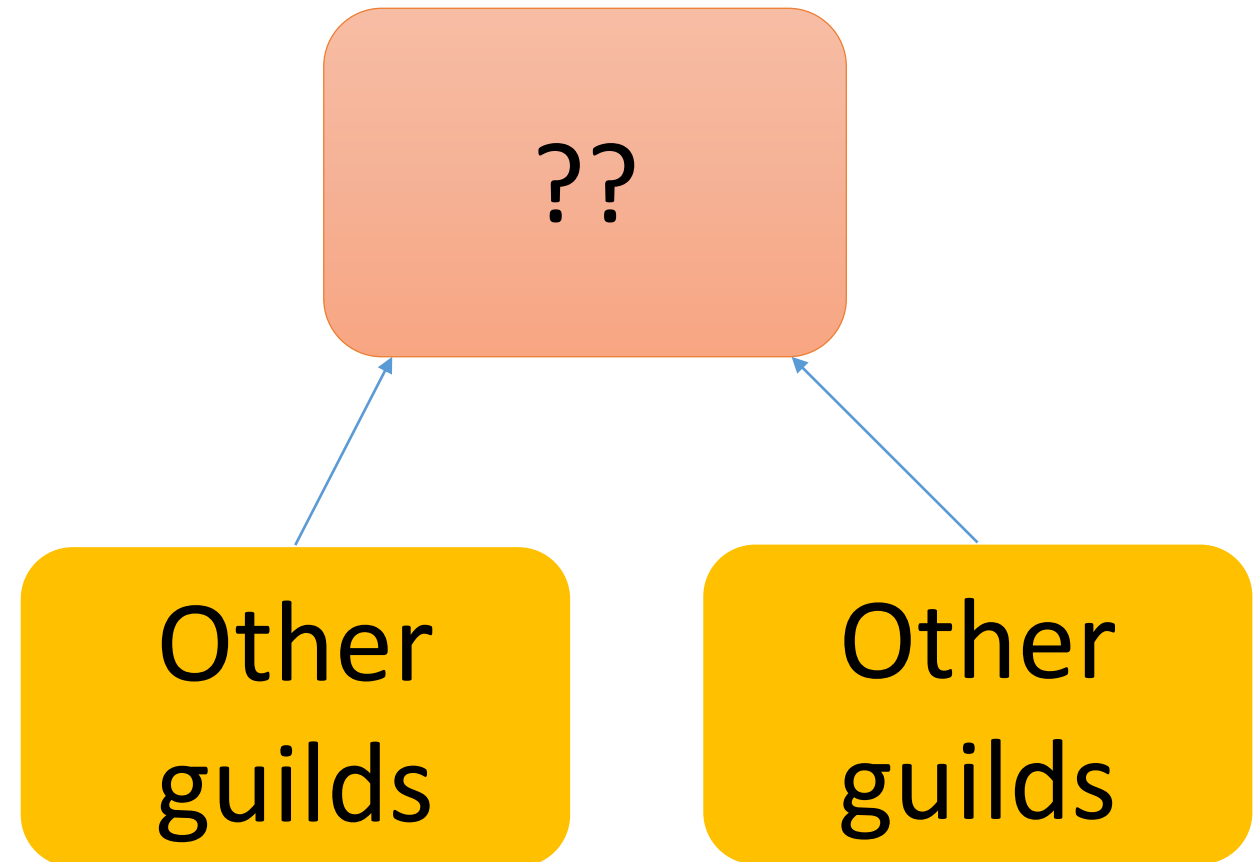
**Only bank guild maintains bank data**



# Use-case:

## Introduce special data structure

- Ideas of special data structure to share mutable objects
  - Use external RDB
  - In process/external Key/value store
  - Software transactional memory
  - ...



# Compare between threads and guilds

- Threads:

- 😊 Inter threads communication is very fast
- 😊 We already know thread-programming
- 😞 Difficult to make correct thread-safe programs

- Guilds:

- 😞 Inter guilds communication introduces overhead
  - 😊 “Move” technique can reduce this kind of overheads
- 😞 We need to learn this model
- 😞 We need to make parallel programs from scratch
- 😊 We don't need to care about synchronizations any more

Trade-off: Performance v.s. Safety/Easily

Which do you want to choose?



# Discussion: The name of “Guild”

- “Guild” is good metaphor for “object’s membership”
- Check duplication
  - Nobody using as programming terminology (maybe)
  - There are no duplicating top-level classes and modules in all of rubygems
  - First letter is not same as other similar abstractions
    - For variable names
    - P is for Processes, T is for Threads, F is for Fibers

# Implementation of “Guild”

- How to achieve **“object membership”**
- How to implement **“Inter Guilds communication”**
- How to design **“shared mutable data”**
- How to isolate **“process global data”**

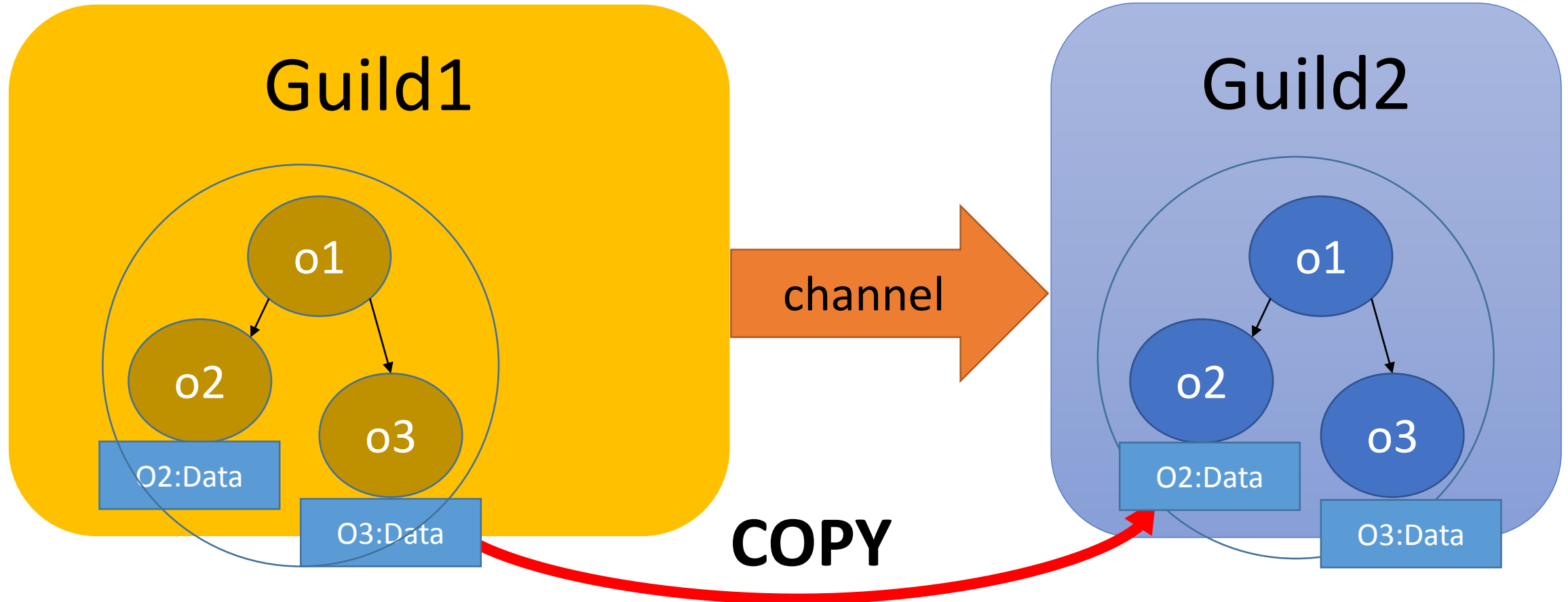
# How to implement inter Guilds communication

- Copy
- Move (transfer membership)

# Copy using Channel

`channel.transfer(o1)`

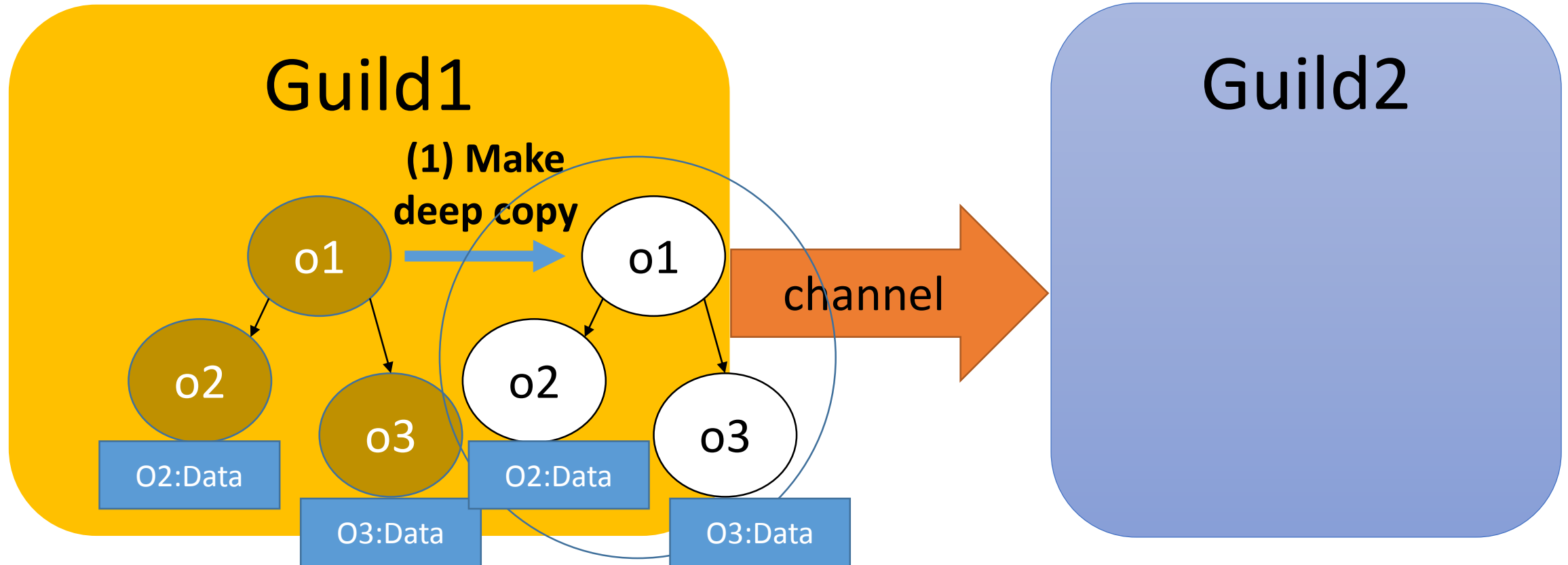
`o1 = channel.receive`



# Copy using Channel Implementation

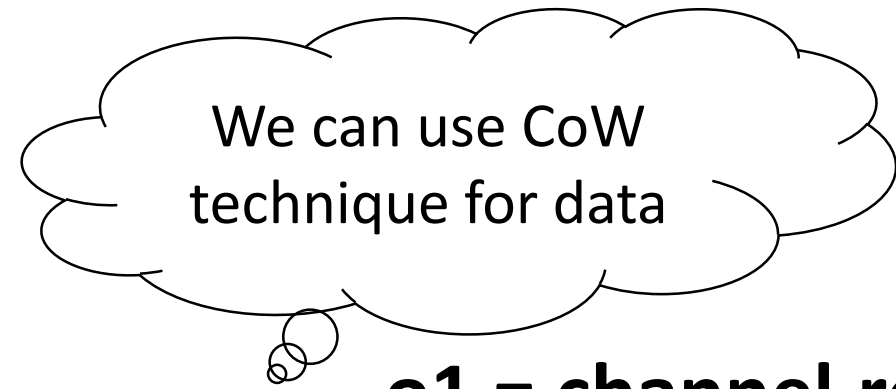
`channel.transfer(o1)`

`o1 = channel.receive`

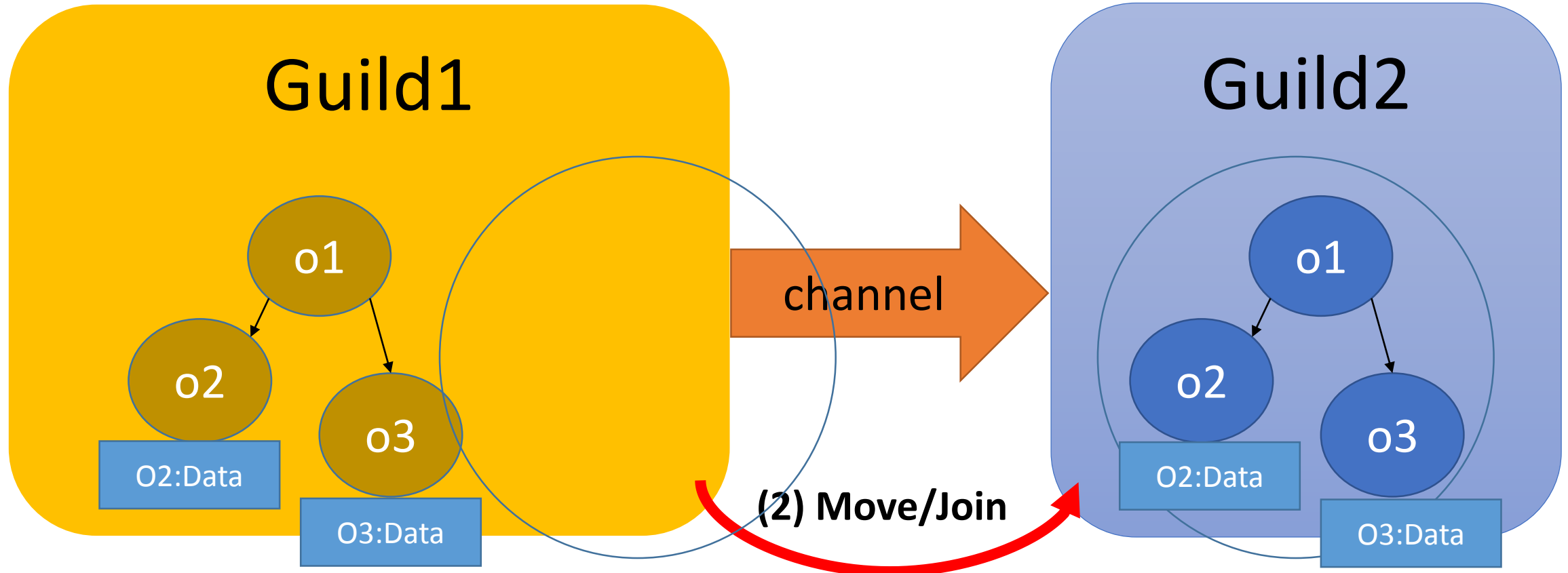


# Copy using Channel Implementation

`channel.transfer(o1)`



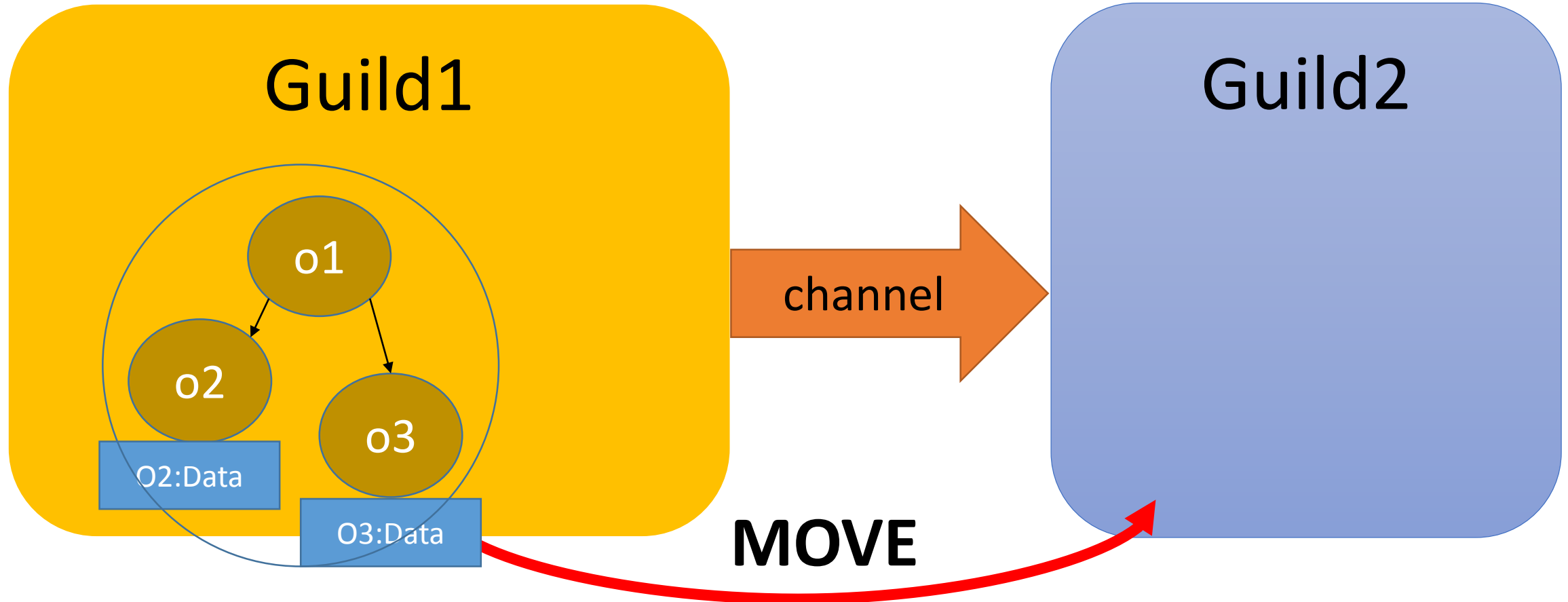
`o1 = channel.receive`



# Move using Channel

`channel.transfer_membership(o1)`

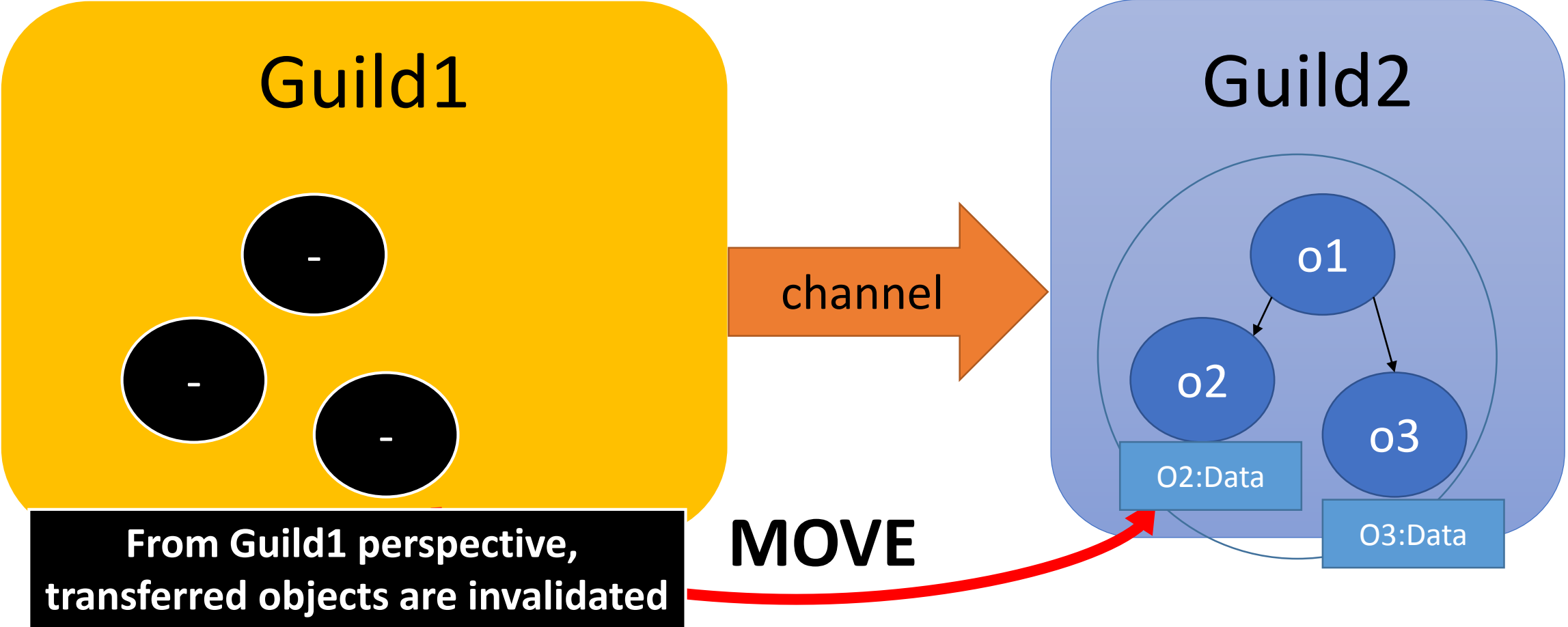
`o1 = channel.receive`



# Move using Channel

```
channel.transfer_membership(o1)
```

```
o1 = channel.receive
```

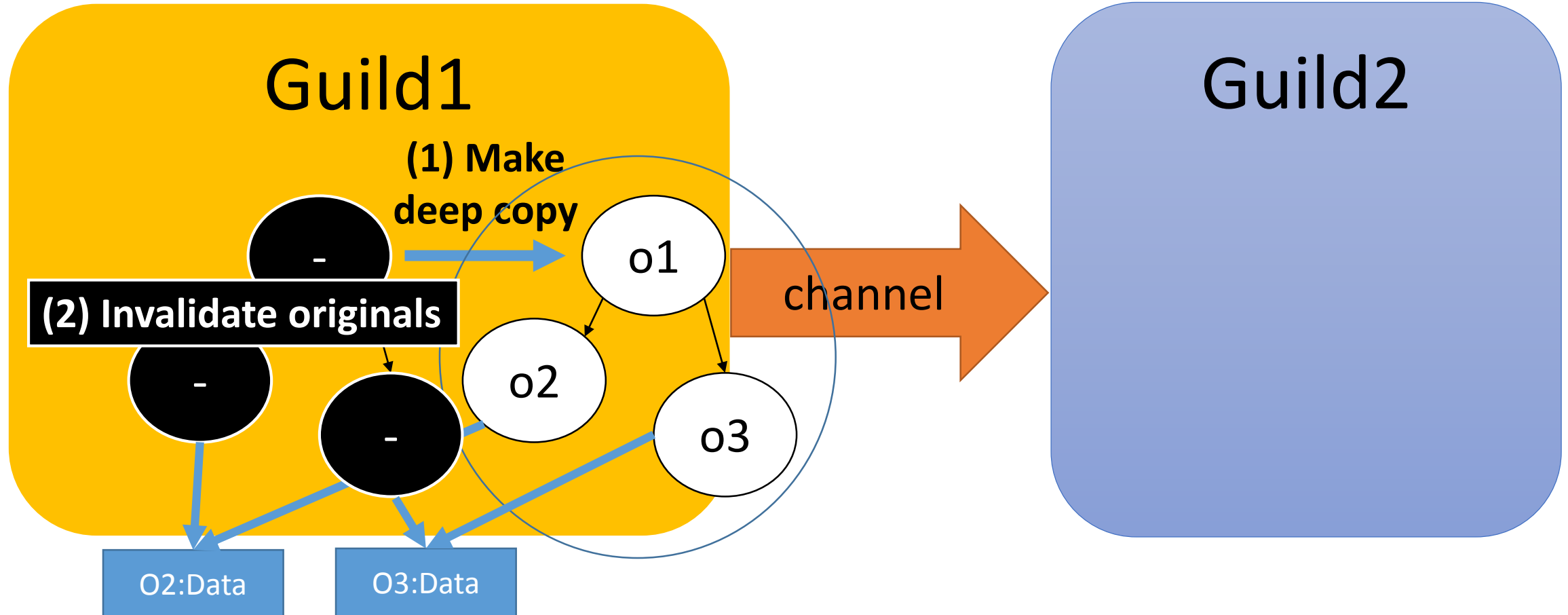




# Move using Channel Implementation

`channel.transfer_membership(o1)`

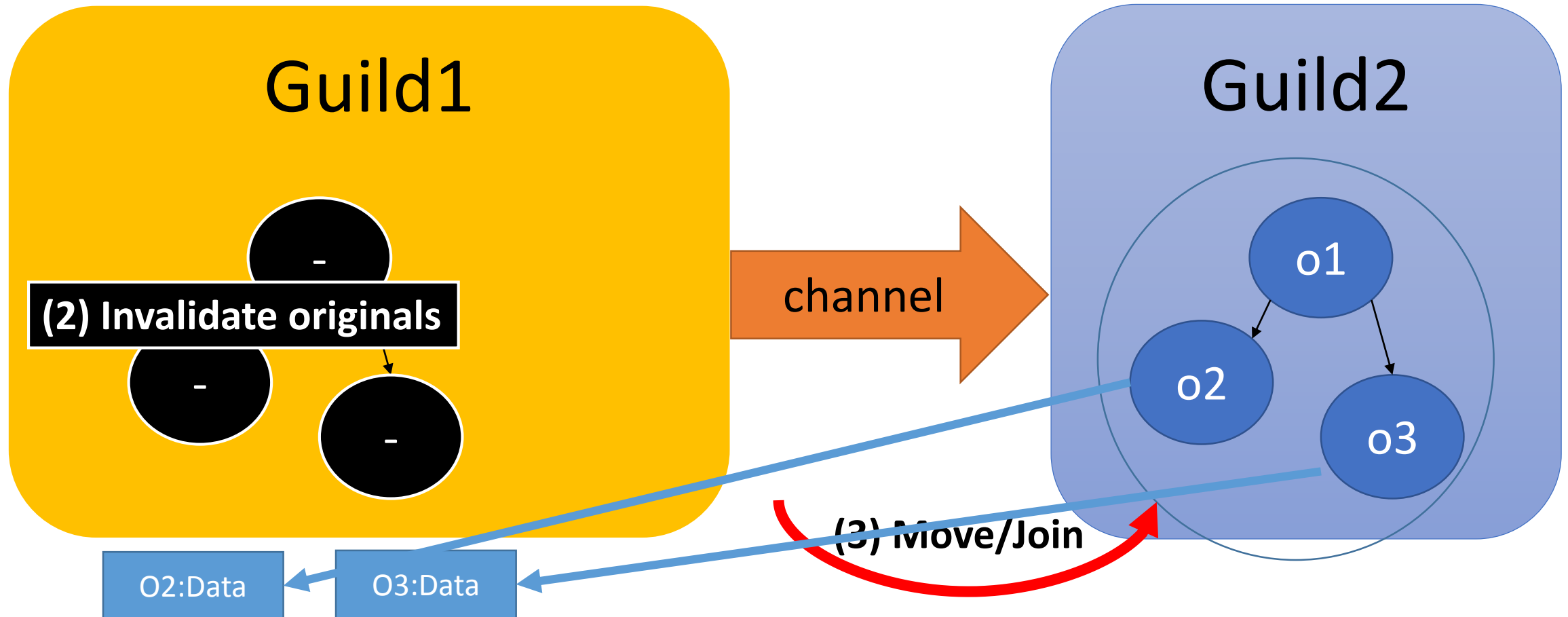
`o1 = channel.receive`



# Move using Channel Implementation

`channel.transfer_membership(o1)`

`o1 = channel.receive`



# Move using Channel Implementation

- “Move” is not a reference passing,  
but a **copy object headers**
  - Objects don't need to know own guild
  - Interpreter doesn't need to check guilds
- Mutable objects live in same guild their entire life

# Ruby global data

- Global variables (\$foo)
  - Change them to Guild local variables
- Class and module objects
  - Share between guilds
- Class variables
  - Change them to guild local. So that it is guild/class local variables
- Constants
  - Share between guilds
  - However if assigned object is not a immutable object, this constant is accessed only by setting guilds. If other guilds try to access it, them cause error.
- Instance variables of class and module objects
  - Difficult. There are several approaches.
- Proc/Binding objects
  - Make it copy-able with env objects or env independent objects
- ObjectSpace.each\_object
  - OMG

***Keep compatibility with Ruby 2***

# Interpreter process global data

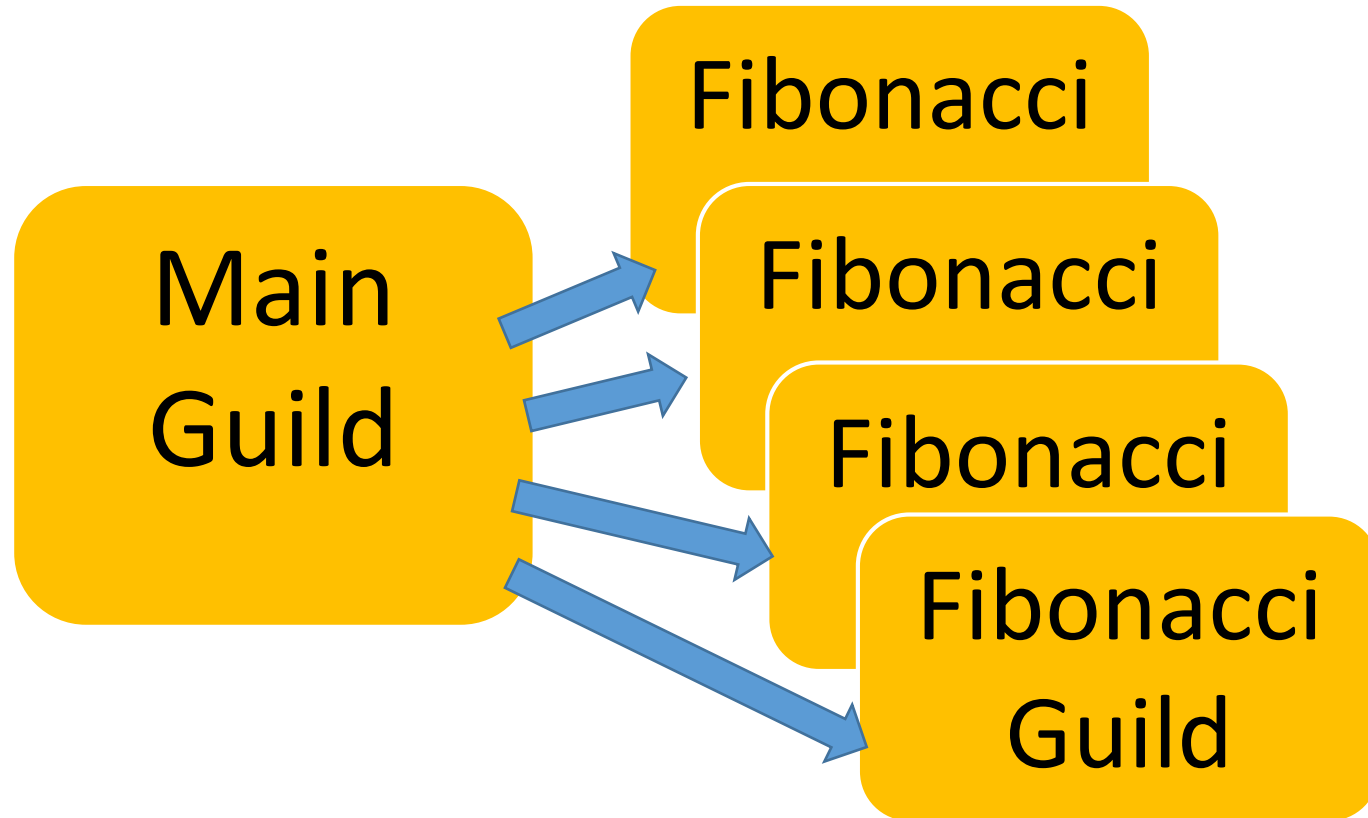
- GC/Heap
  - Share it. Do stop the world parallel marking- and lazy concurrent sweeping.
  - Synchronize only at page acquire timing. No any synchronization at creation time.
- Inline method cache
  - To fill new entry, create an inline cache object and update atomically.
- Tables (such as method tables and constant tables)
  - Introduce mutual exclusions.
- Current working directory (cwd)
  - Each guild should have own cwd (using openat and so on).
- Signal
  - Design new signal delivery protocol and mechanism
- C level global variables
  - Avoid them.
  - Main guild can use C extensions depends on them
- Current thread
  - Use TLS (temporary), but we will change all of C APIs to receive context data as first parameter in the future.

# Performance evaluation

- On 2 core virtual machine
  - Linux on VirtualBox on Windows 7
- Now, we can't run Ruby program on other than main guild, so other guilds are implemented by C code

# Performance evaluation

## Simple numeric task in parallel

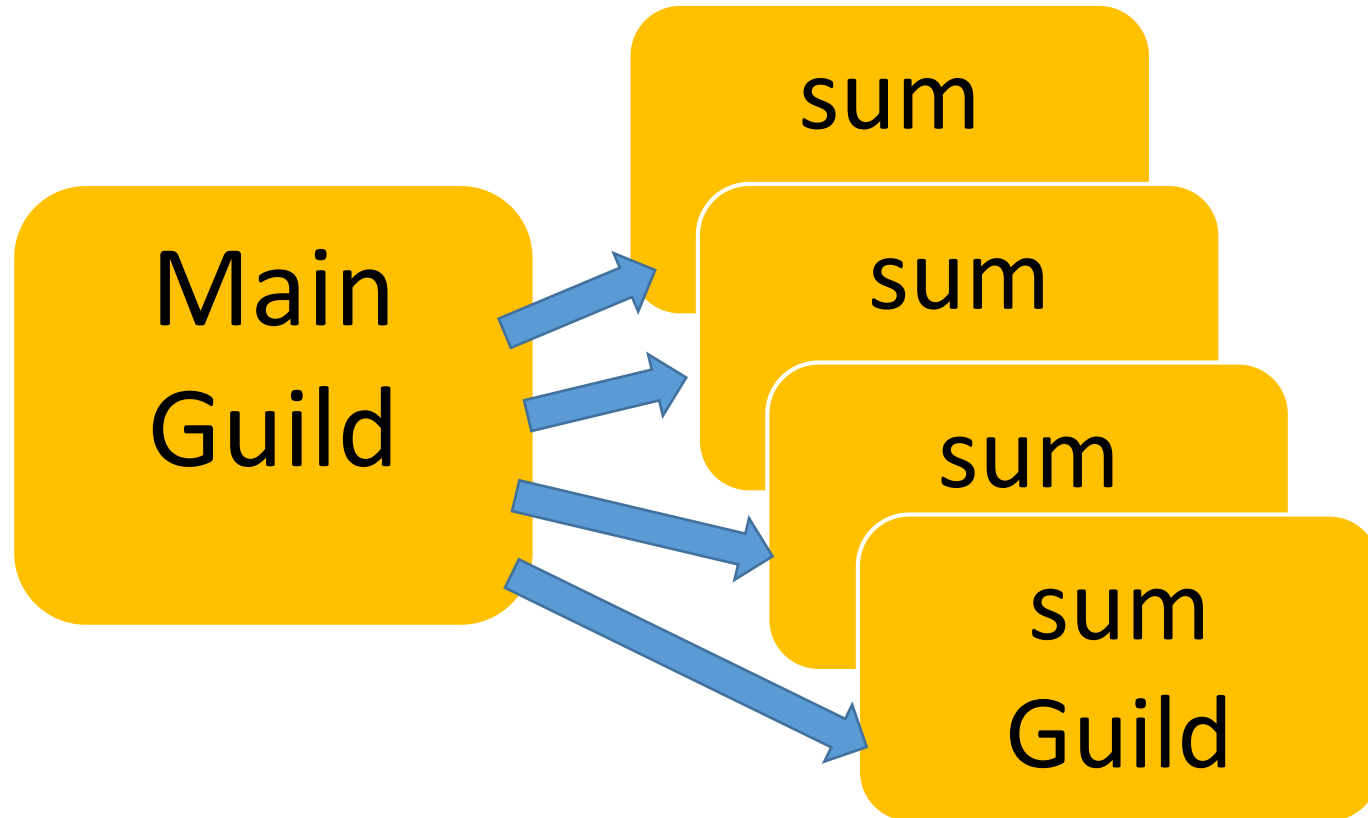


	Execution time (sec)
Single-Guild	19.45
Multi-Guild	10.45

Total 50 requests to compute fib(40)  
Send 40 (integer) in each request

# Performance evaluation

## Copy/Move



Total 100 requests to compute sum of array  
Send `(1..10_000_000).to_a` in each request

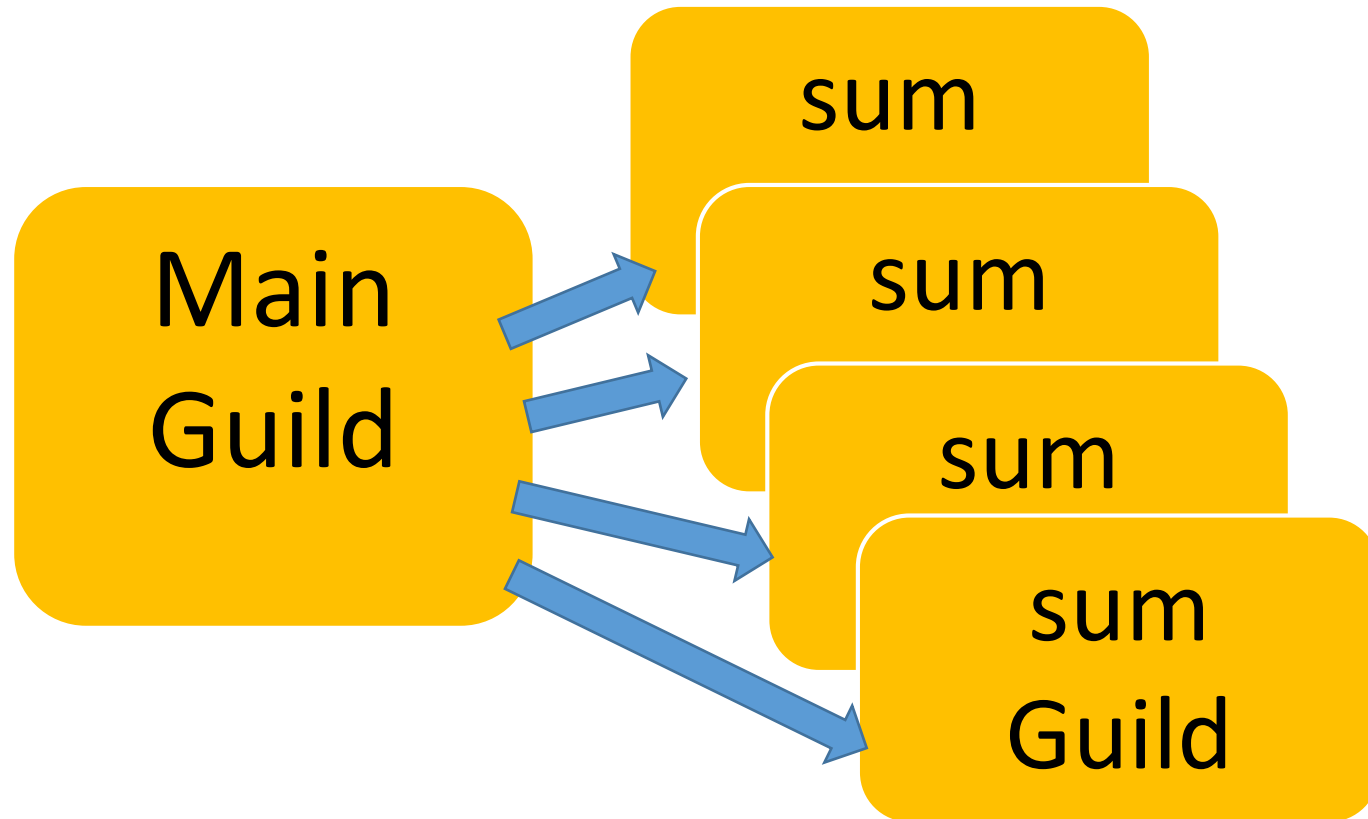
	Execution time (sec)
Single-Guild	1.00
Multi/ref	0.64
Multi/move	4.29
Multi/copy	5.16

**Too slow!!**  
**Because "move" need to check all of elements**



# Performance evaluation

## Copy/Move



	Execution time (sec)
Single-Guild	1.00
Multi/ref	0.64
Multi/move	0.64

**If we know this array only has immutable objects,  
we don't need to check all elements => special data structure**

# Check our goal for Ruby 3

- **We need to keep compatibility** with Ruby 2.
  - **OK:** Only in main guild, it is compatible.
- We can make **parallel program**.
  - **OK:** Guilds can run in parallel.
- We **shouldn't consider** about locks any more.
  - **OK:** Only using copy and move, we don't need to care locks.
- We **can share** objects with copy, but **copy operation should be fast.**
  - **OK:** Move (transfer membership) idea can reduce overhead.
- We **should share objects** if we can.
  - **OK:** We can share immutable objects fast and easily.
- We can **provide special objects** to share mutable objects like Clojure if we really need speed.
  - **OK:** Yes, we can provide.

**Satisfied!**

# FAQ

- Q: Can we try Guild now?
- A: No.
  - Implementation on MRI is big project. Not yet.
    - Supporting this project is welcome.
  - Some guys are trying to implement it on JRuby.

# FAQ

- Q: Should we wait Guild for Ruby 3?
- A: Not sure.
  - 2.6? 2.7? 2.8?
  - I want to implement it next year.

# FAQ

- Q: Can Guild replace ALL of Thread programs?
- A: No.
  - To utilize Guild, you need to rewrite your programs.
  - I assume 90% of programs are easy to replace.
  - For example, “moving” IO object is easy to understand, so that web application server is easy to implement.

# FAQ

- Q: Membership seems “**ownership**”. Right?
- A: Yes.
  - Actually, we call this idea “ownership” before.
  - We named “**membership**” because “Guild” is not owner of members.

# FAQ

- Q: “Moving” cause huge overhead for big object graph (like big Hash object). Right?
- A: Yes.
  - We need to move all of objects (e.g. Hash entries).
  - We need to introduce special data structures for such big object graph (like Clojure).
  - I believe people can change their mind to fit this model.

# FAQ

- Q: Can we share Proc object?
- A: No.
  - Good question. I'm thinking several options:
    - Allow to copy local environment (variables)
    - Allow to move local environment (variables)
    - Introduce isolated Proc

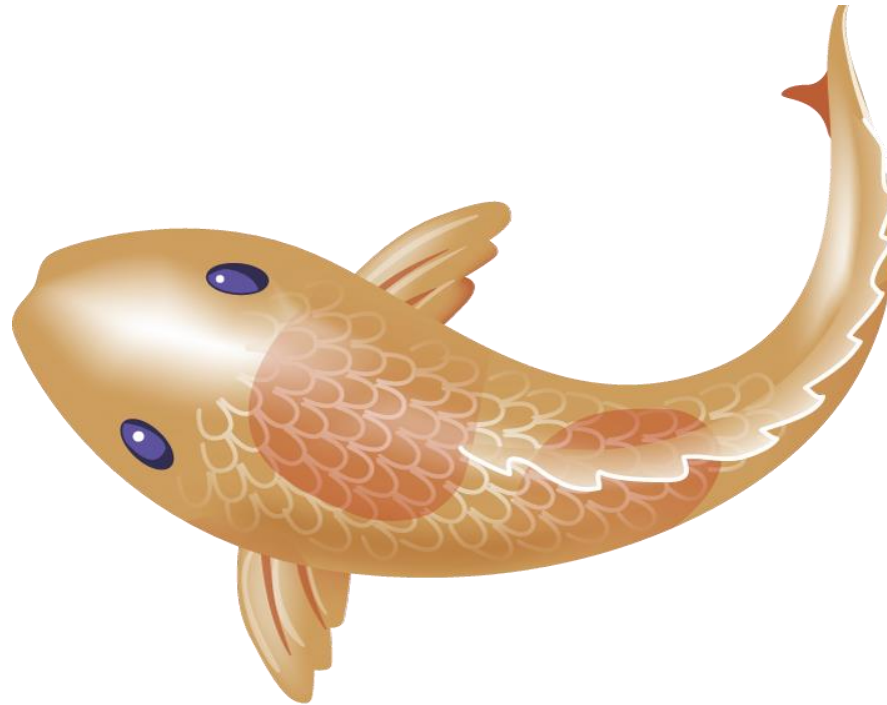


# Summary

- Introduce “why threads are very difficult”
- Propose new concurrency abstraction “Guild” for Ruby 3
  - Not implemented everything yet, but I show key ideas and preliminary evaluation

# Thank you for your attention

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# Approach comparison

	Process/MVM	Place (Racket)	<i>Guild</i> <i>(copy/move)</i>	Thread
Heap (GC)	Separate	Separate	<b>Share</b>	Share
Communication Mutable objects	Copy	Copy	<b>Copy/Move</b>	Share
Communication Immutable object	Copy	Share (maybe)	<b>Share</b>	Share
Lock	Don't need	Don't need	<b>(mostly) Don't need</b>	Required
ISeq (bytecode)	Copy	Share	<b>Share</b>	Share
Class/Module (namespace)	Copy	Copy (fork)	<b>Share</b>	Share

# Related work

- **“Membership transfer”** is proposed by [Nakagawa 2012], but not completed
- Alias analysis with type systems
  - Ruby doesn't support static type checking
- Dynamic alias analysis with runtime checking
  - We need to reduce dynamic check overhead
  - We can't insert dynamic checking completely (this is why I found **“membership transfer”**)