Ruby 3 に向けた 新しい並行実行モデルの提案

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Today’s talk

- One goal of Ruby 3: better concurrency support
- Guild: Isolate objects between guilds
    - Objects belong to one guild
    - Threads belong to different guilds can ***run parallel***
    - Communication using ***“transfer membership”***
- No implementation (just idea)

Background
Ruby 3

- 3 goals
  - Performance (JIT compiler)
  - Static type checking
  - **Concurrency**
    - Enable parallel programming in Ruby
    - Better programming experience than ***threads***

Background
Parallel and concurrent thread programming

- Some Ruby interpreters support parallel threads
  - JRuby
  - Rubinius

Multi-thread quiz

- What happen on this program?

```
ary = [1, 2, 3]
t1 = Thread.new{
  ary.concat [4, 5, 6]
}
t2 = Thread.new{
  p ary # what's happen?
}.join
```

(1) **[1, 2, 3]**
(2) **[1, 2, 3, 4, 5, 6]**
(3) **(1) or (2)**

Multi-thread quiz

- Answer: (4) depends on an interpreter

```
ary = [1, 2, 3]
t1 = Thread.new{
  ary.concat [4, 5, 6]
}
t2 = Thread.new{
  p ary # what’s happen?
}.join
```

On MRI, (3) is correct

It will shows
[1, 2, 3] or
[1, 2, 3, 4, 5, 6]
(depends on thread switching timing)

Multi-thread quiz

- Answer: (4) depends on an interpreter

```
ary = [1, 2, 3]
t1 = Thread.new{
  ary.concat [4, 5, 6]
}
t2 = Thread.new{
  p ary # what's happen?
}.join
```

On JRuby:

It can cause Java exception because "Array#concat" is not thread safe

On JRuby …

```
# similar program
h = Hash.new(0)
NA = 1_000
10_000.times{
  ary = []
  (1..10).each{
    Thread.new{
      NA.times{|i|
        ary.concat [i]
      }
    }
  }
  t2 = Thread.new{
    s = ary.dup
  }.join
}
```

```
Unhandled Java exception: java.lang.NullPointerException

java.lang.NullPointerException: null
          rbInspect at org/jruby/RubyBasicObject.java:1105
            inspect at org/jruby/RubyObject.java:516
         inspectAry at org/jruby/RubyArray.java:1469
            inspect at org/jruby/RubyArray.java:1497
       cacheAndCall at org/jruby/runtime/callsite/CachingCallSite.java:293
               call at org/jruby/runtime/callsite/CachingCallSite.java:131
      block in t.rb at t.rb:17
        yieldDirect at org/jruby/runtime/CompiledIRBlockBody.java:156
      yieldSpecific at org/jruby/runtime/IRBlockBody.java:73
      yieldSpecific at org/jruby/runtime/Block.java:136
              times at org/jruby/RubyFixnum.java:291
       cacheAndCall at org/jruby/runtime/callsite/CachingCallSite.java:303
          callBlock at org/jruby/runtime/callsite/CachingCallSite.java:141
               call at org/jruby/runtime/callsite/CachingCallSite.java:145
              <top> at t.rb:3
invokeWithArguments at java/lang/invoke/MethodHandle.java:599
               load at org/jruby/ir/Compiler.java:111
          runScript at org/jruby/Ruby.java:833
          runScript at org/jruby/Ruby.java:825
        runNormally at org/jruby/Ruby.java:760
        runFromMain at org/jruby/Ruby.java:579
      doRunFromMain at org/jruby/Main.java:425
        internalRun at org/jruby/Main.java:313
                run at org/jruby/Main.java:242
               main at org/jruby/Main.java:204
```

jruby 9.1.2.0 (2.3.0) 2016-05-26 7357c8f OpenJDK 64-Bit Server VM 24.95-b01 on 1.7.0_101-b00 +jit [linux-x86_64]
On 8 hardware threads machine

Background
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

Background
Difficulty of multi-threads programs

- We need to synchronize all sharing mutable objects correctly
  - We need to know **which methods are thread-safe**.
  - Easy to track all on small program
  - Difficult to track on **big programs**, especially on **programs using gems**
- We need to check **all of source codes**, or believe **library documents** (but documents should be correct)
- Multi-threads prog. requires **"completeness"**

Background
Difficulty of multi-threads programs (cont.)

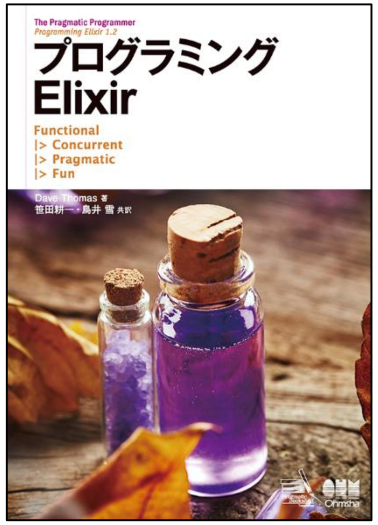
- For debugging, it is difficult to find out the bugs
  - **<u>Backtrace may not work</u>** well because the problem may be placed on another line.
  - Bugs don’t appear frequently with **<u>small data</u>**
  - Difficult to reproduce issues because of **<u>nondeterministic behavior</u>**

Background
FYI: synchronization mechanism

- Many synchronization mechanisms…
    - Mutual exclusion (Mutex), monitor, critical section
    - Transactional memory (optimistic lock)
    - Atomic instructions
    - Synchronized Queue
    - …
    - Research on many lightweight lock algorithms
- They assume we can use them correctly

Study from other languages

- Shell script with pipes, Racket (Place)
  - Copy mutable data between processes w/ pipes
- Erlang/Elixir
  - Do not allow mutable data
- Clojure
  - Basically do not allow mutable data
  - Special data structure to share mutable objects
  - Note that it can share mutable objects on Java layer



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

Summary of approaches

- Communication with copied data (shell scripts)
  - Good: we don’t need locks
  - Bad: copy everything is <u>**slow**</u>
- Prohibit mutable objects
  - Good: we don’t need locks
  - Bad: Ruby utilizes <u>**many “write” operations**</u>. Unacceptable.
- Provide special data structure to share mutable objects
  - Good: we don’t need locks (who don’t use such special data structures)
  - Bad: Difficult to use special data structures.

Previous work for “parallel” Ruby

- Parallel multi-thread (2007 Sasada)
- Better multi-process interface (2012 Nakagawa)
  - Easy and fast shared memory
- Multi-VM (MVM) (2012 Sasada)
  - Make several VMs in one process
  - Similar to ***Place*** in Racket programming langauge

Previous work for “parallel” Ruby

- Parallel multi-thread (2007 Sasada)
  - ☹ Thread isn’t promising (at least Ruby area)
- Better multi-process interface (2012 Nakagawa)
  - ☹ Multi-process consume more memory
- Multi-VM (MVM) (2012 Sasada)
  - ☹ Difficult to share same resources

Our goal for Ruby 3

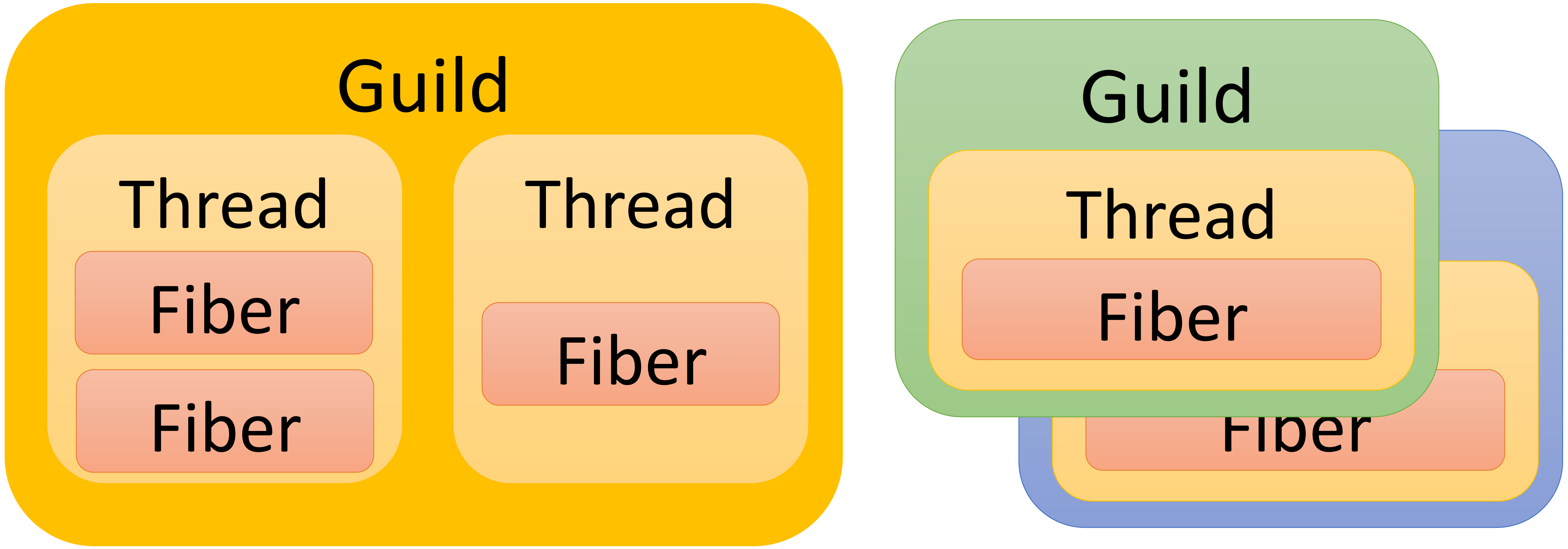
- **We need to keep compatibility** with Ruby 2.
- We can make **parallel program**.
- We **shouldn't consider** about locks any more.
- We **can share** objects with copy, but **copy operation should be fast.**
- We **should share objects** if we can.
- We can **provide special objects** to share mutable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

“Guild”

New concurrency model for Ruby 3

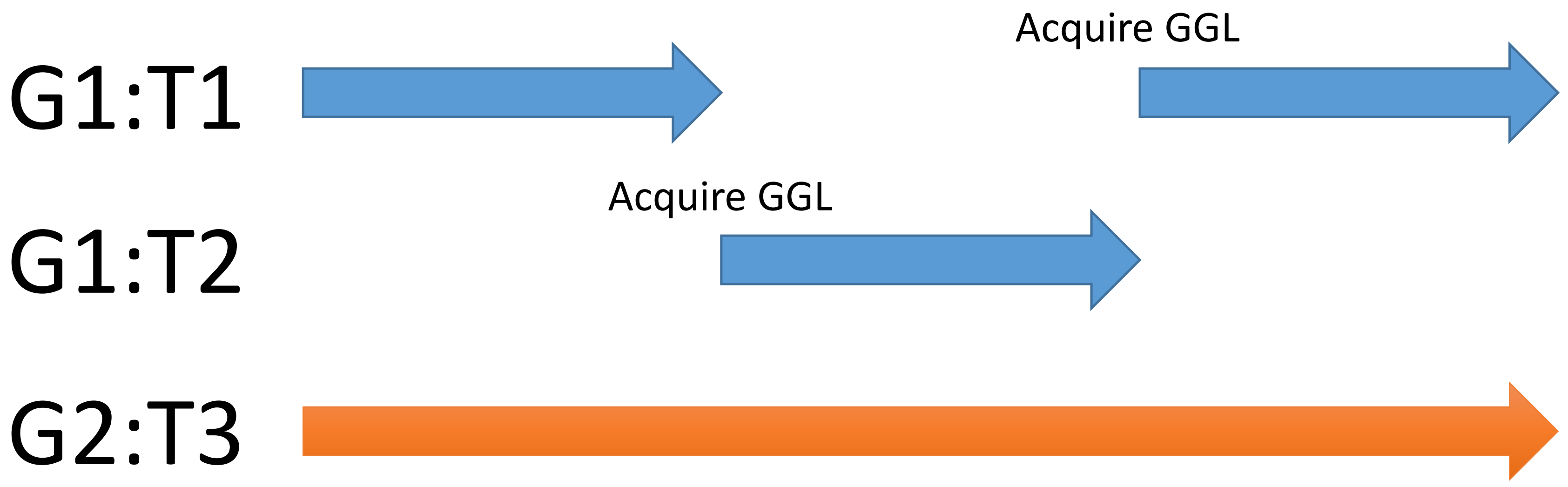
Guild: New concurrency abstraction

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



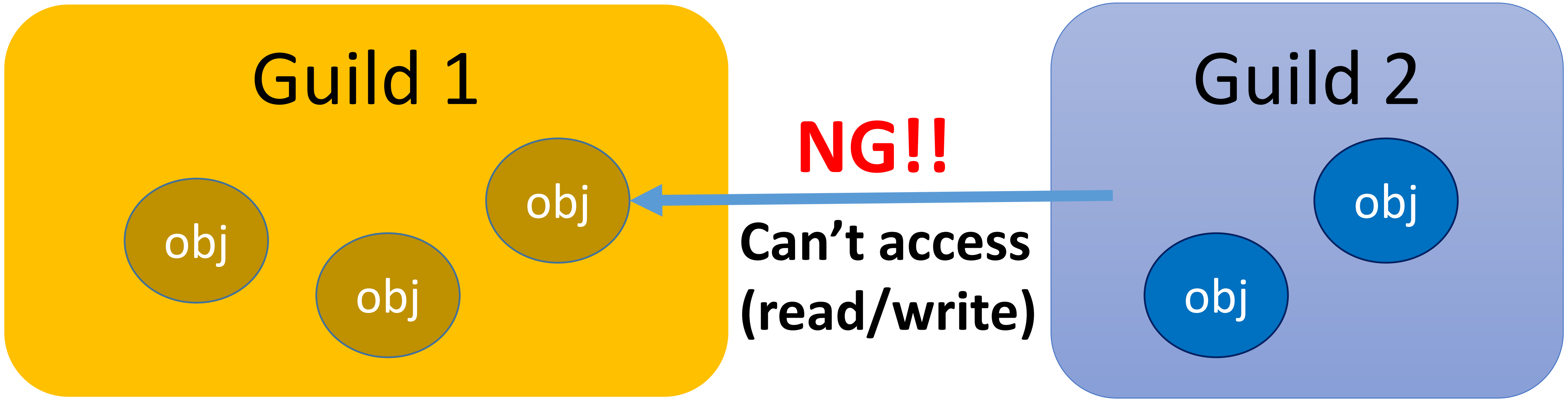
Threads in different guilds can run in Parallel

- 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)



Guild and objects: All objects have their own membership

- All of mutable objects should belong to only one Guild (all mutable objects are member of one guild)
- Other guilds can not access objects



Object membership
Object type

- 3 types of objects
  - Unshared objects
    - Mutable objects (normal case)
    - Belong to one Guild
  - Shared objects
    - Immutable objects
    - Special shared objects
      - Class, module, Communication objects (Guild, channel)

Object membership

Only one guild can access mutable object

→ **We don’t need to consider about locks**

Because:

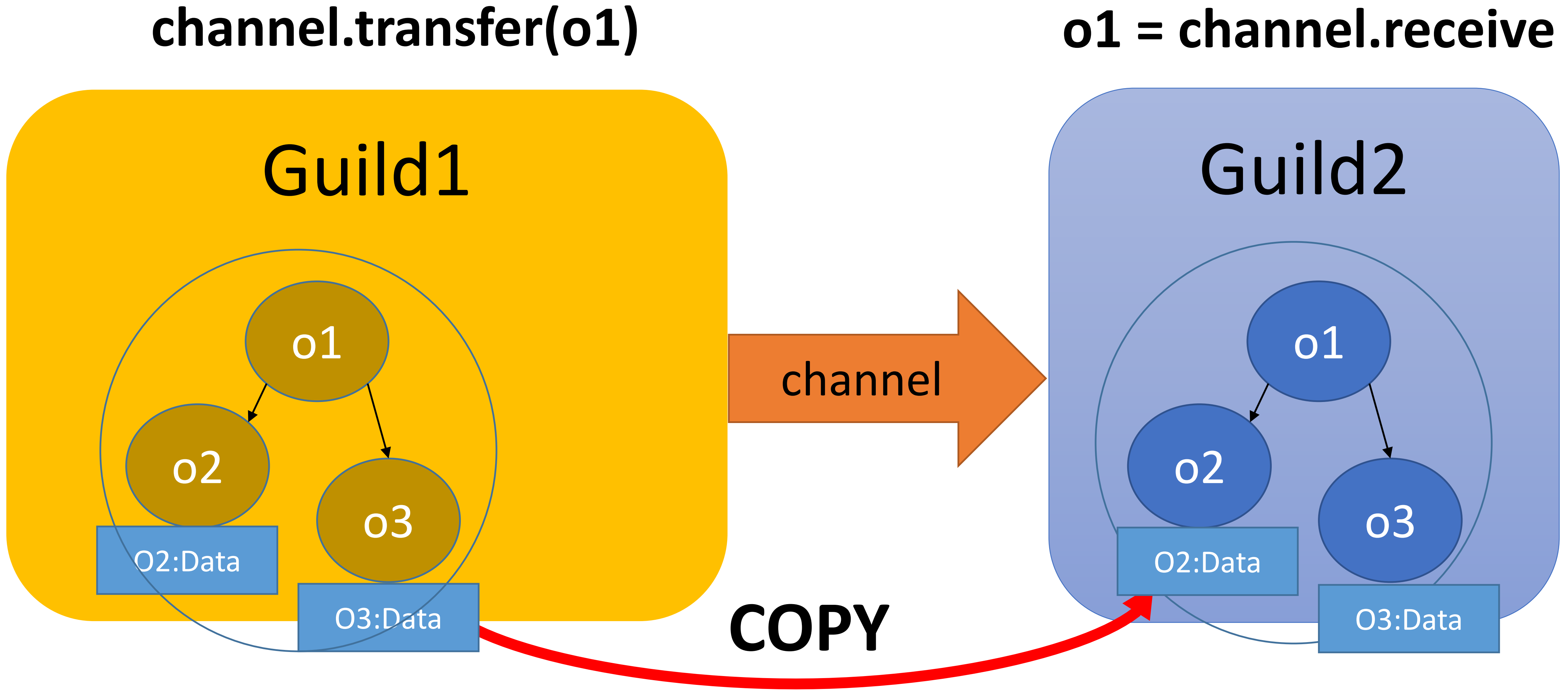
NO data races and NO race conditions

(if all guilds use only one thread)

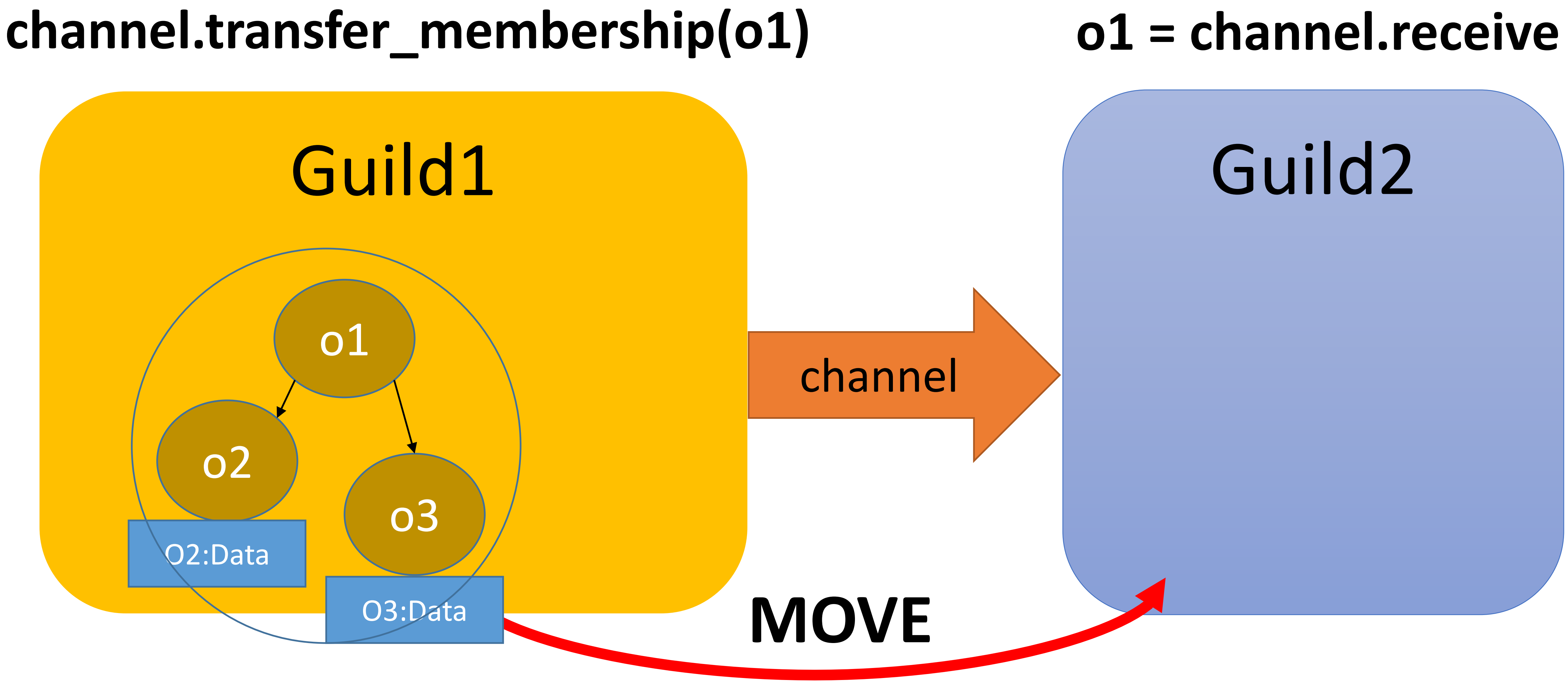
Inter guilds communication

- **“Guild::Channel”** to communicate each guilds
- Two communication methods
  1. **Copy**
  2. **Transfer membership** or **Move** in short
     - Note that we don’t guarantee identity transfer

Copy using Channel



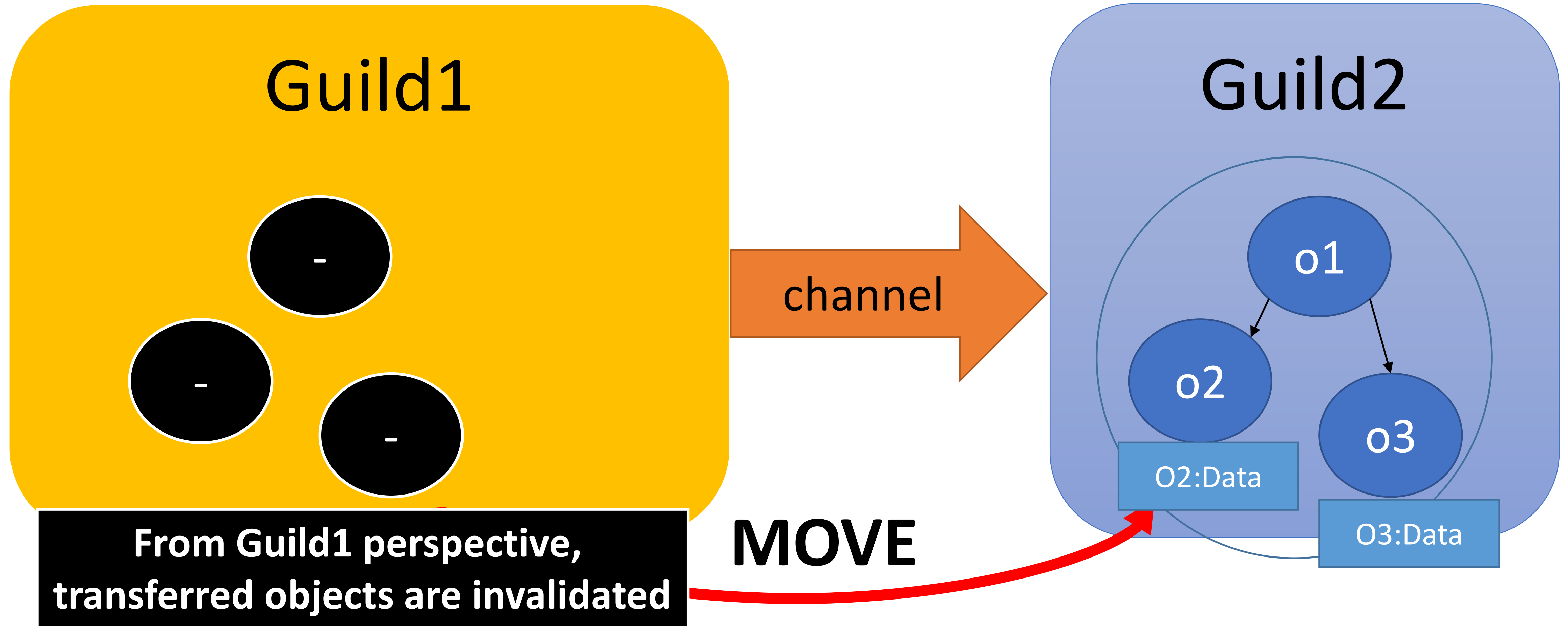
Move using Channel



Move using Channel

channel.transfer_membership(o1)

o1 = channel.receive

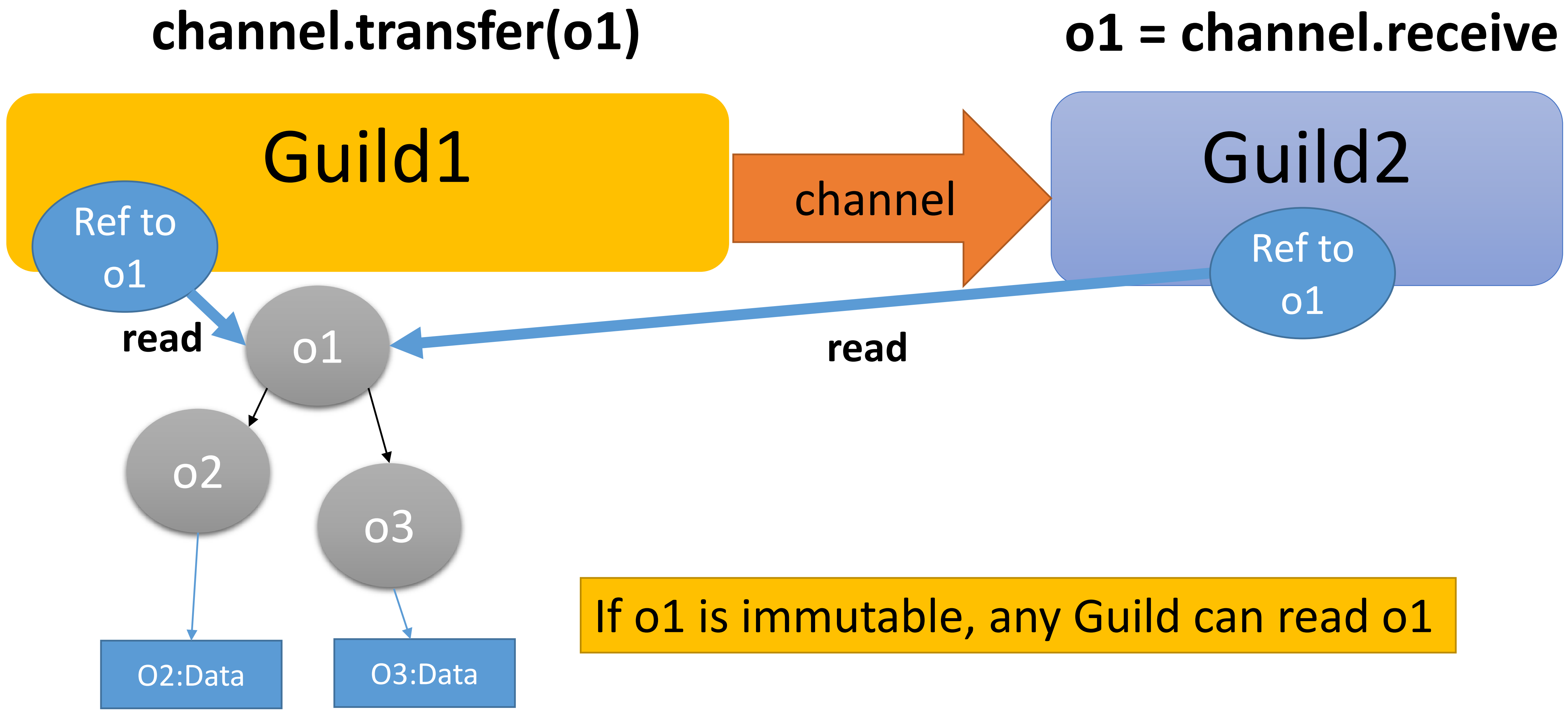


From Guild1 perspective, transferred objects are invalidated

Sharing immutable objects

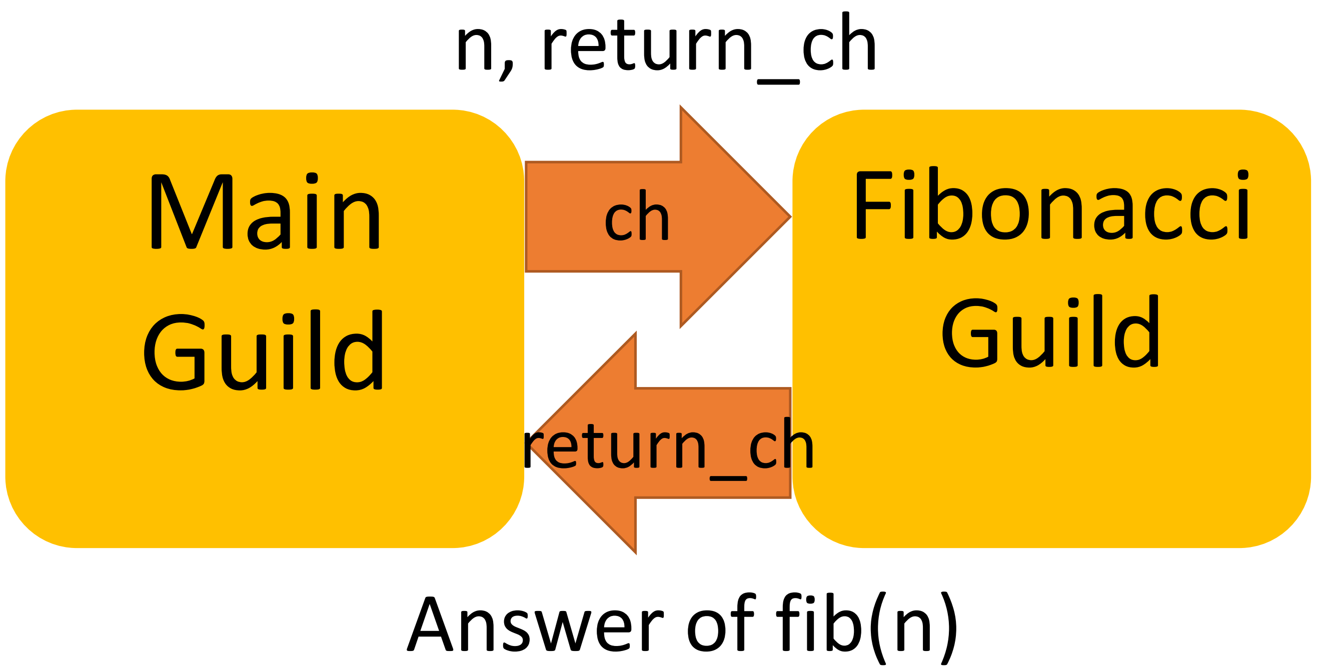
- **Immutable objects** can be shared with any guilds
    - a1 = [1, 2, 3].freeze: a1 is **Immutable object**
    - a2 = [1, Object.new, 3].freeze: a2 is **not immutable**
- We only need to send references
    - very lightweight, like thread-programming
- **Numeric objects, symbols, true, false, nil**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

Sharing immutable objects
We can share reference to immutable objects



Use-case 1: master – worker type

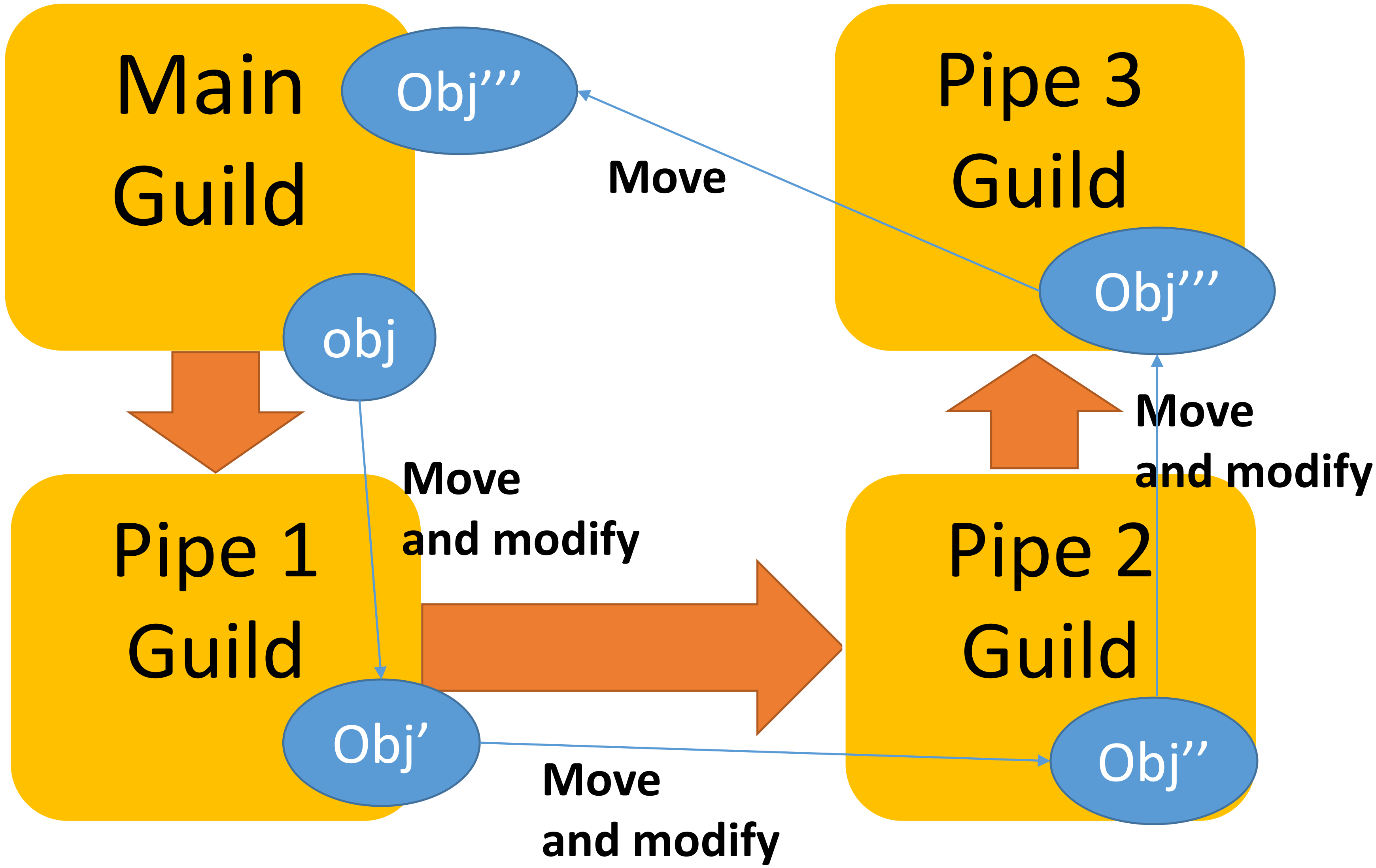
```
def fib(n) ... end
g_fib = Guild.new(script: %q{
  ch = Guild.default_channel
  while n, return_ch = ch.receive
    return_ch.transfer fib(n)
  end
})

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

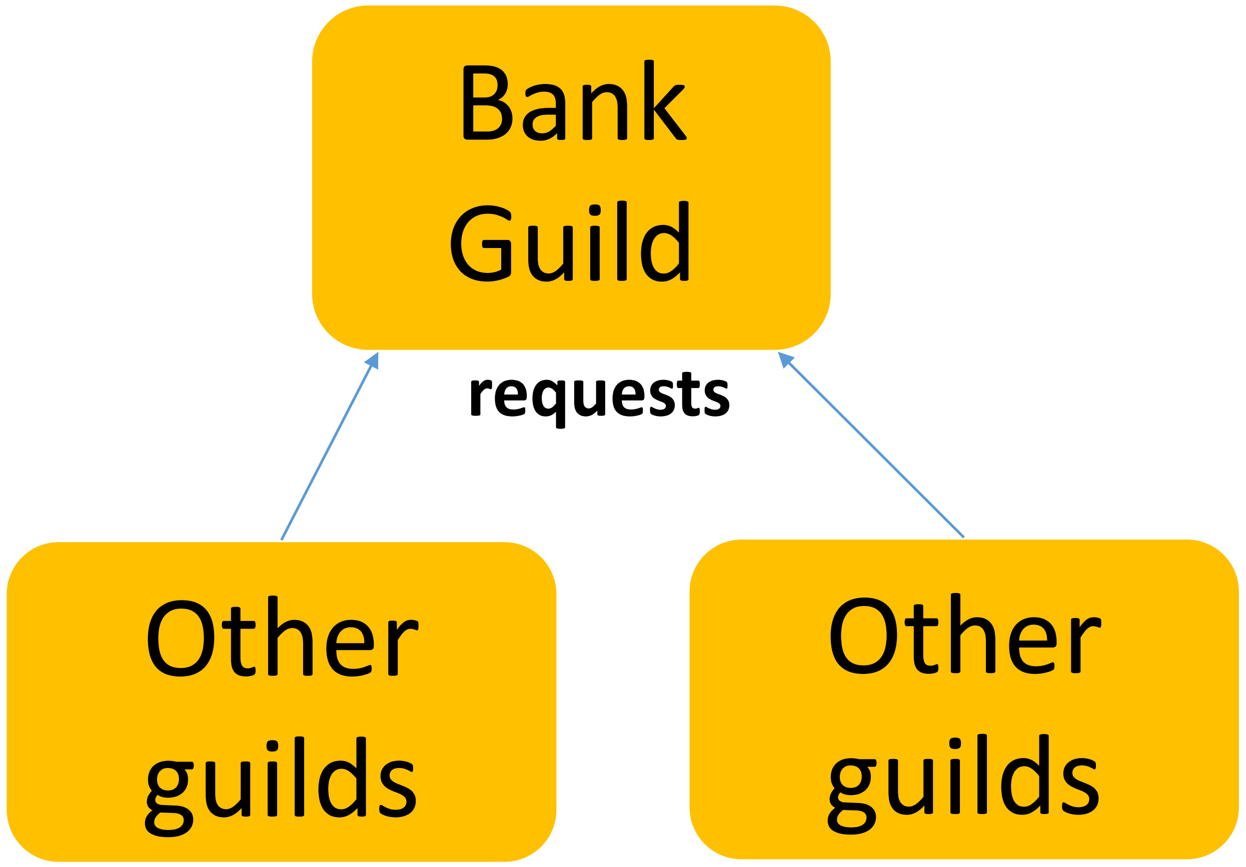
```
result_ch = Guild::Channel.new
g_pipe3 = Guild.new(script: %q{
  while obj = Guild.default_channel.receive
    obj = modify_obj3(obj)
    Guild.argv[0].transfer_membership(obj)
  end
}, argv: [result_ch])
g_pipe2 = Guild.new(script: %q{
  while obj = Guild.default_channel.receive
    obj = modify_obj2(obj)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

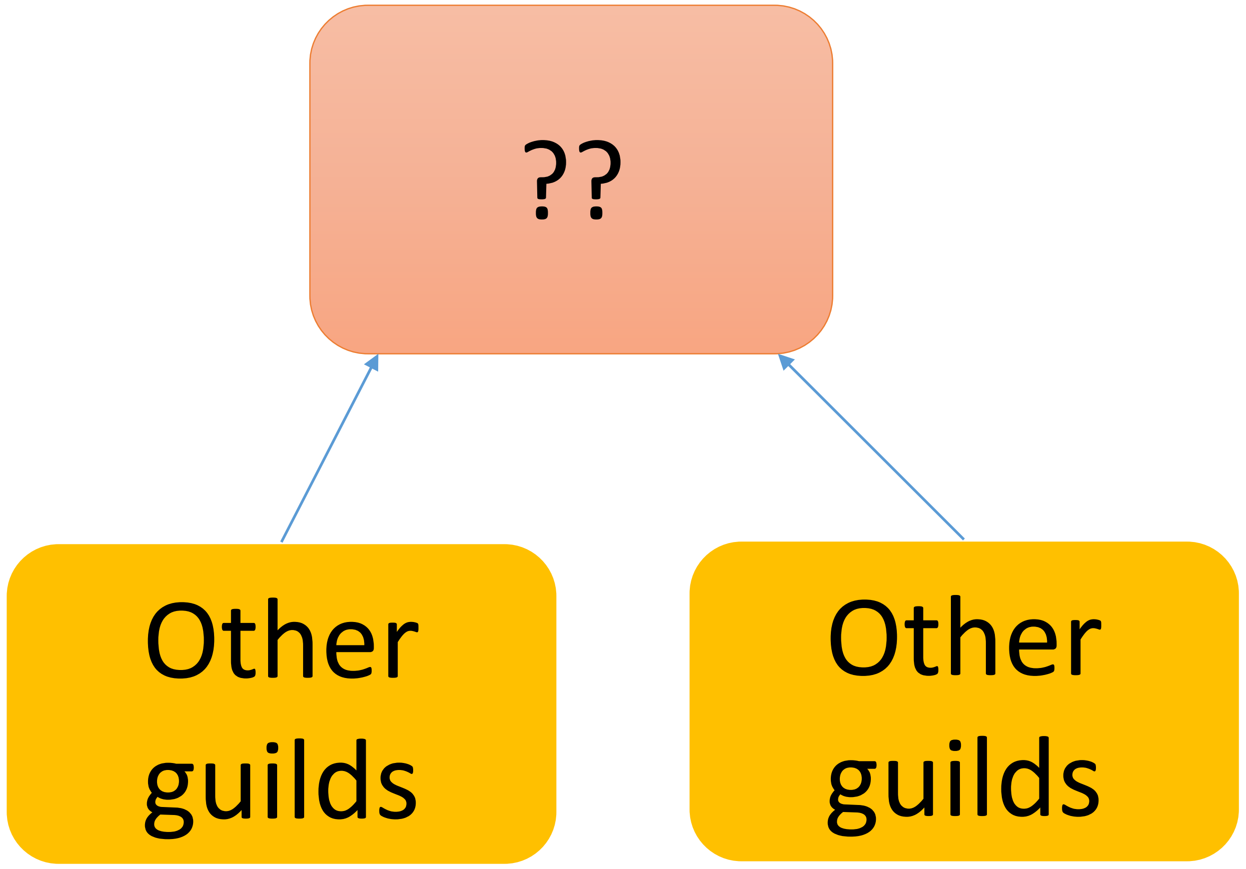
```
g_bank = Guild.new(script: %q{
 while account_from, account_to, amount,
         ch = Guild.default_channel.receive
  if (Bank[account_from].balance < amount)
   ch.transfer :NOPE
  else
   Bank[account_to].balance += amount
   Bank[account_from].balance -= amount
   ch.transfer :YEP
  end
 end
})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

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
  - …



Summary of use cases

- Making multiple workers and compute in parallel
  - Requests and responses are communicate via channels
  - You can send it with copy or move
  - Maybe web application can employ this model
- Making Pipeline structures and compute in parallel
  - Each task has own Guild
  - Receive target object, modify it and send it next pipeline
  - You will send it with move (transfer membership)
  - It will help applications like applying several filters for input data
- Own responsibility by one Guild
  - All accesses are managed by one responsible Guild
  - If you want to share mutable objects, we need special data structures
  - External RDBs or key/value stores are also good idea for this purpose

Compare between Thread model and Guild model

- On threads, it is **difficult to find out** which objects are shared mutable objects
- On Guilds, there are **no shared mutable objects**
  - If there are special data structure to share mutable objects, we only need to check around this code

→ Encourage "Safe" and "Easy" programming

Compare between Thread model and Guild model

- On threads, inter threads communication is very fast.
- On guilds, inter guilds communication introduce overhead
  - “Move” (transfer membership) technique can reduce this kind of overheads

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
  - First letter is not same as other similar abstractions
    - For variable names
    - P is for Processes, T is for Threads, F is for Fibers
  - There are no duplicating top-level classes and modules in all of rubygems

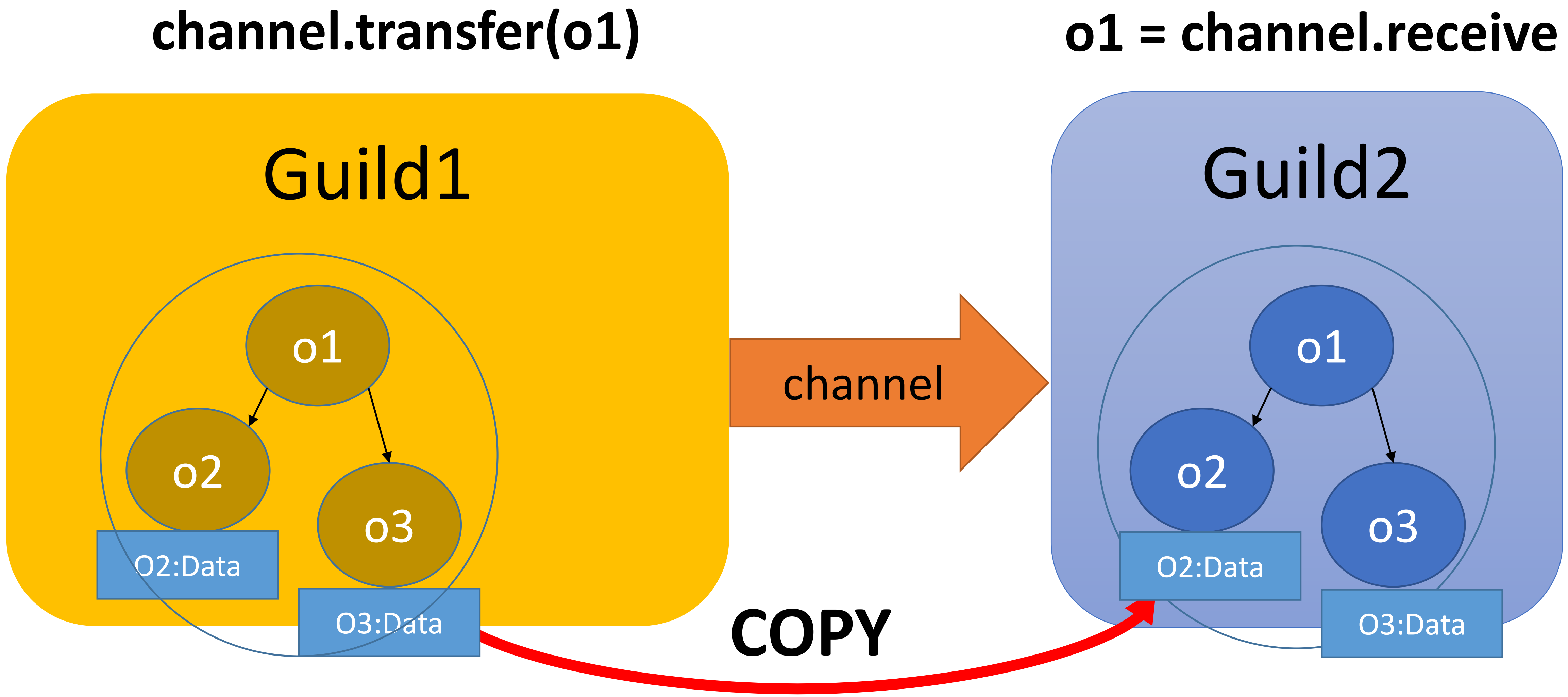
Implementation of “Guild”

- How to implement inter Guilds communication
- How to isolate process global data

How to implement inter Guilds communication

- Copy
- Move (transfer membership)

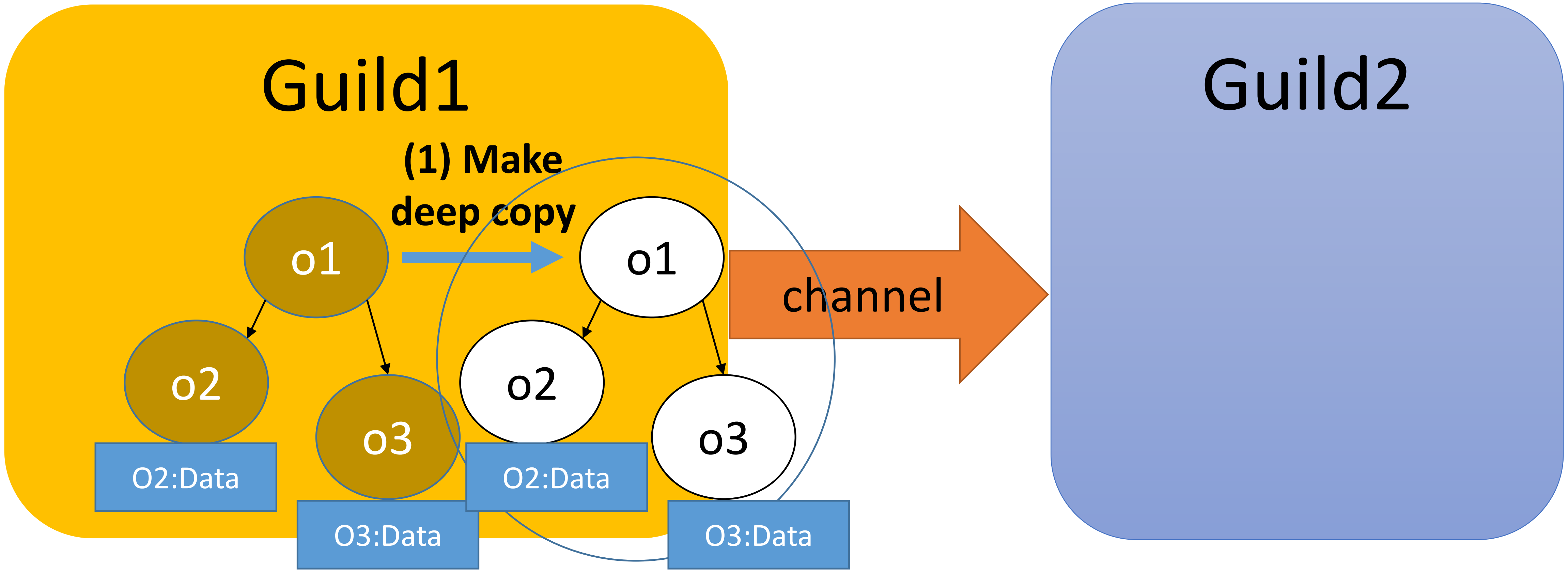
Copy using Channel



Copy using Channel Implementation

channel.transfer(o1)

o1 = channel.receive

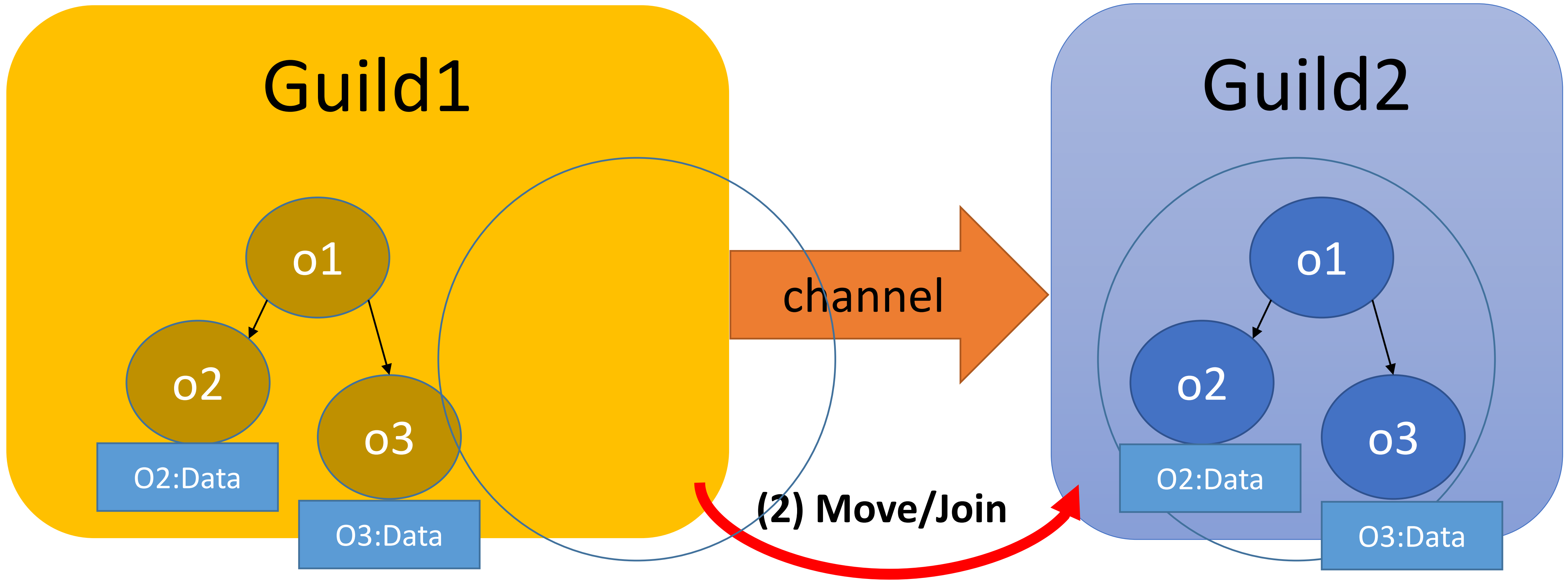


Copy using Channel Implementation

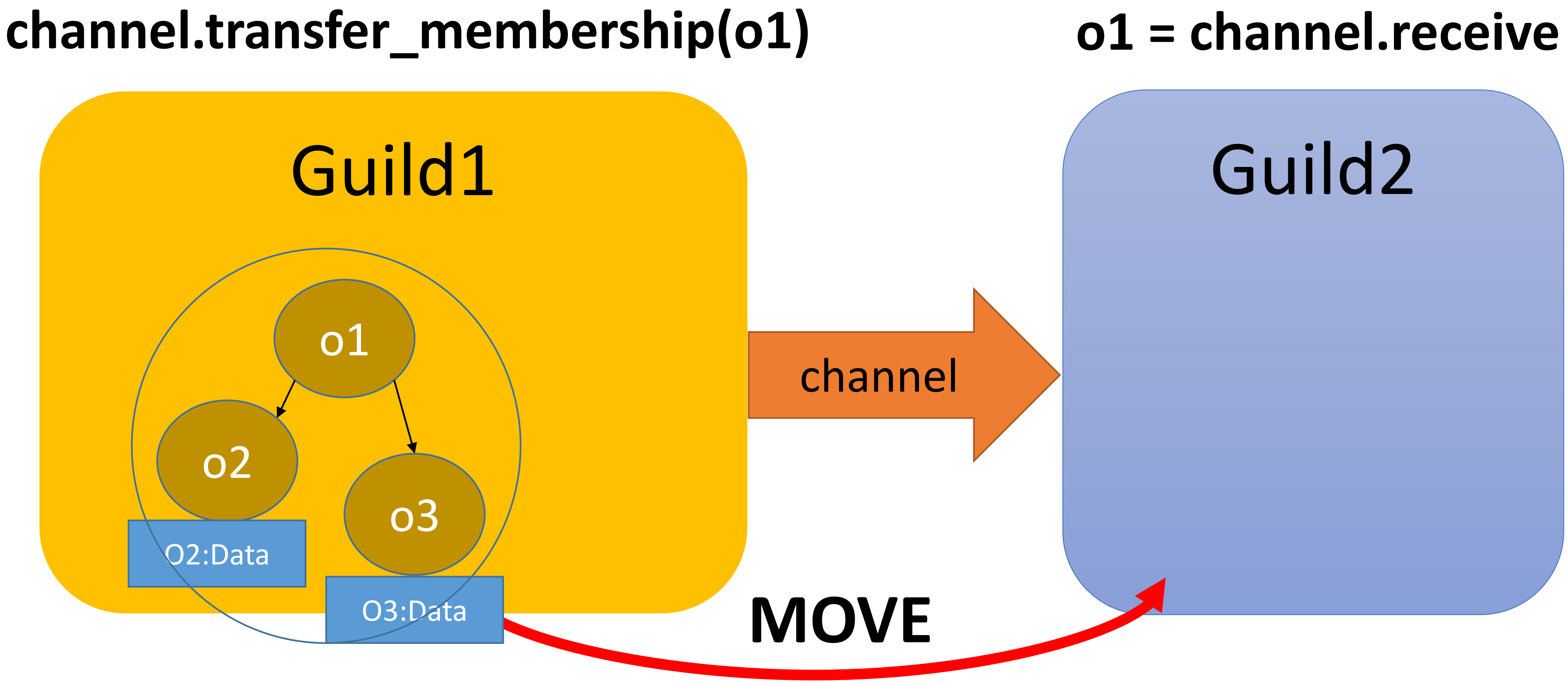
We can use CoW technique for data

channel.transfer(o1)

o1 = channel.receive



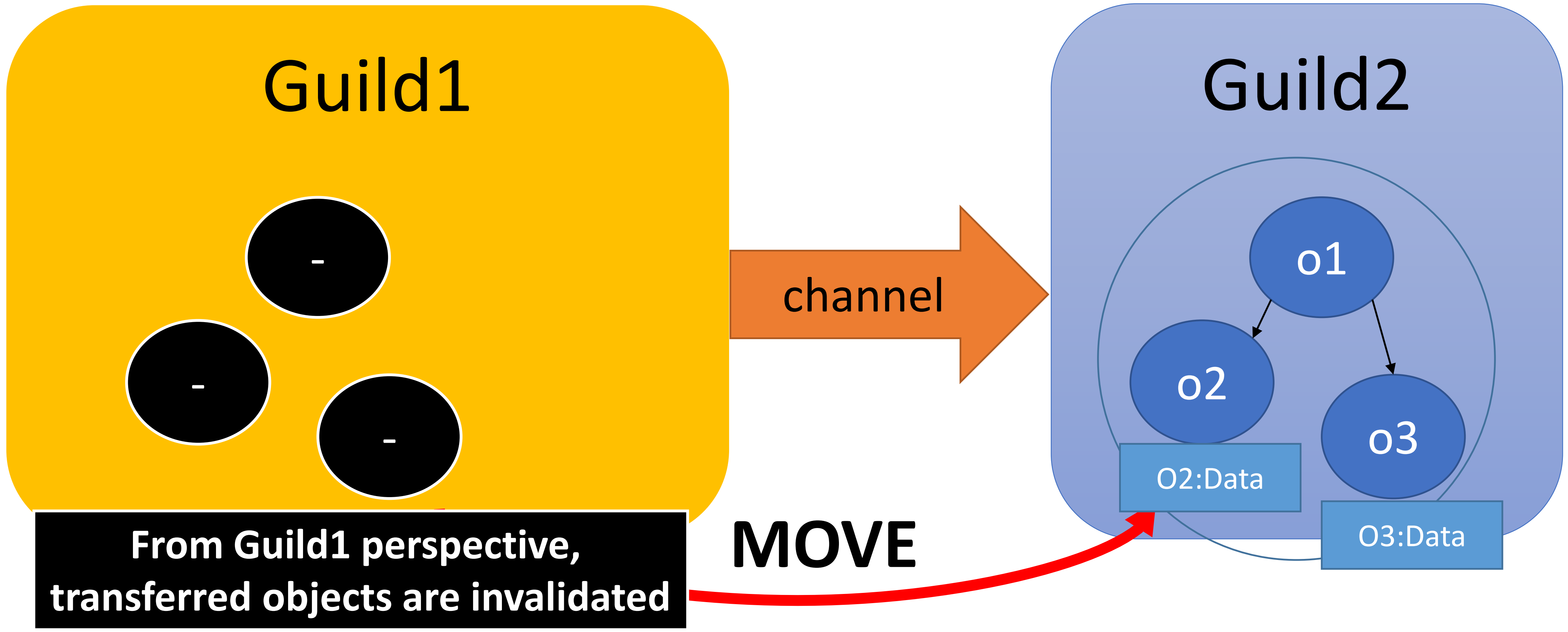
Move using Channel



Move using Channel

channel.transfer_membership(o1)

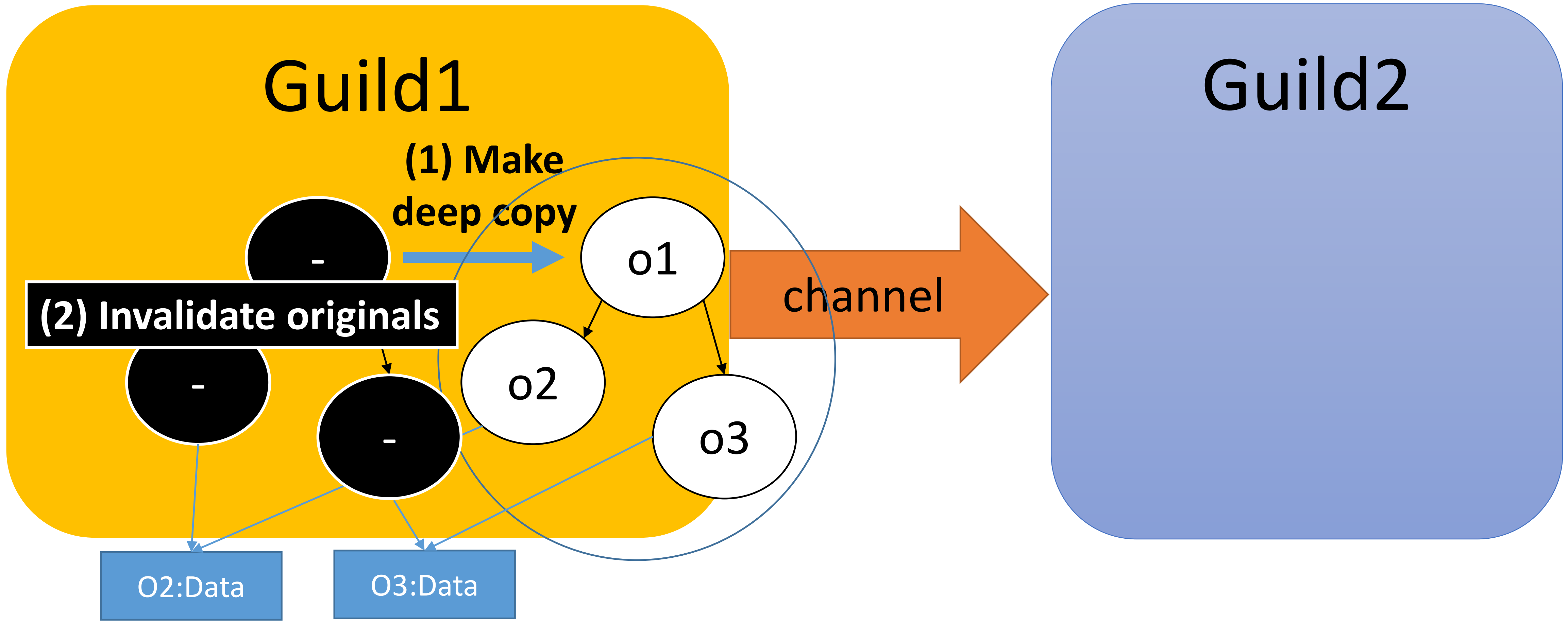
o1 = channel.receive


Guild1
-
-
-
channel
Guild2
o1
o2
o3
O2:Data
O3:Data
MOVE
From Guild1 perspective, transferred objects are invalidated

Move using Channel Implementation

channel.transfer_membership(o1)

o1 = channel.receive



Move using Channel Implementation

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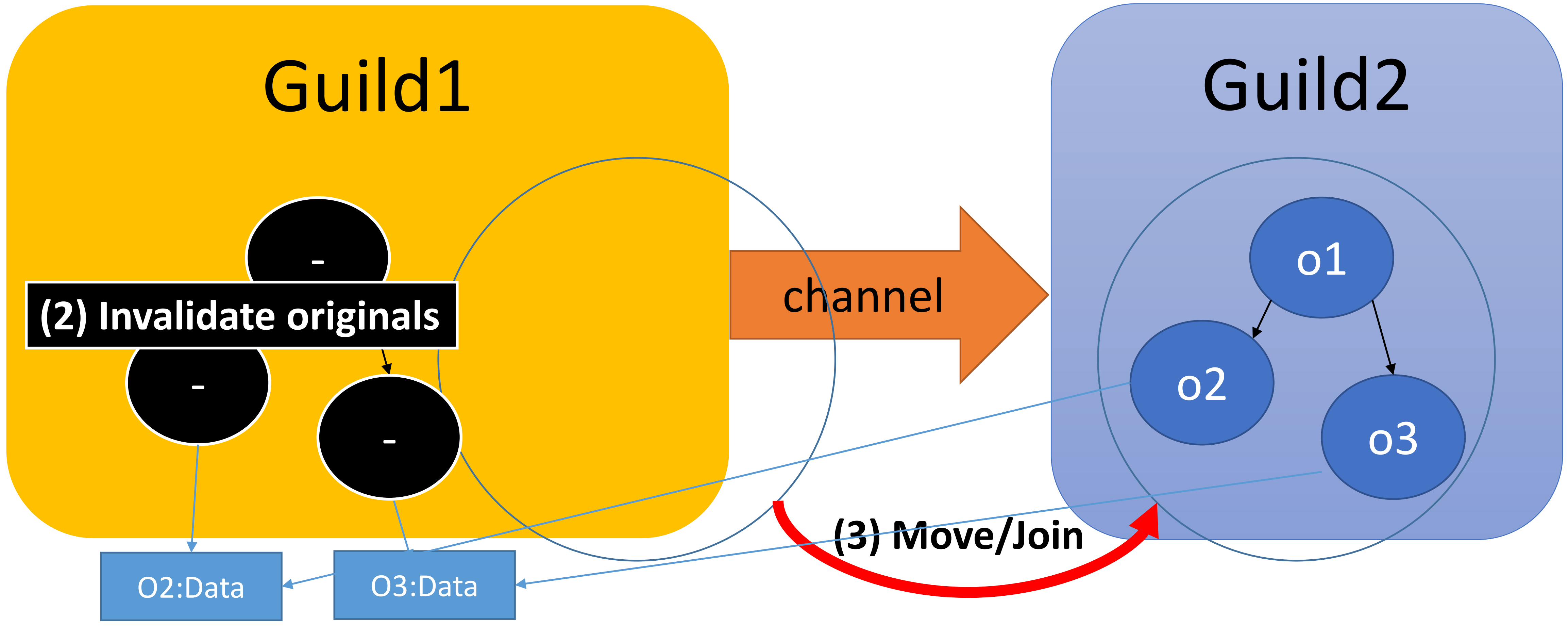


Ruby global data

Keep compatibility with Ruby 2

- 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

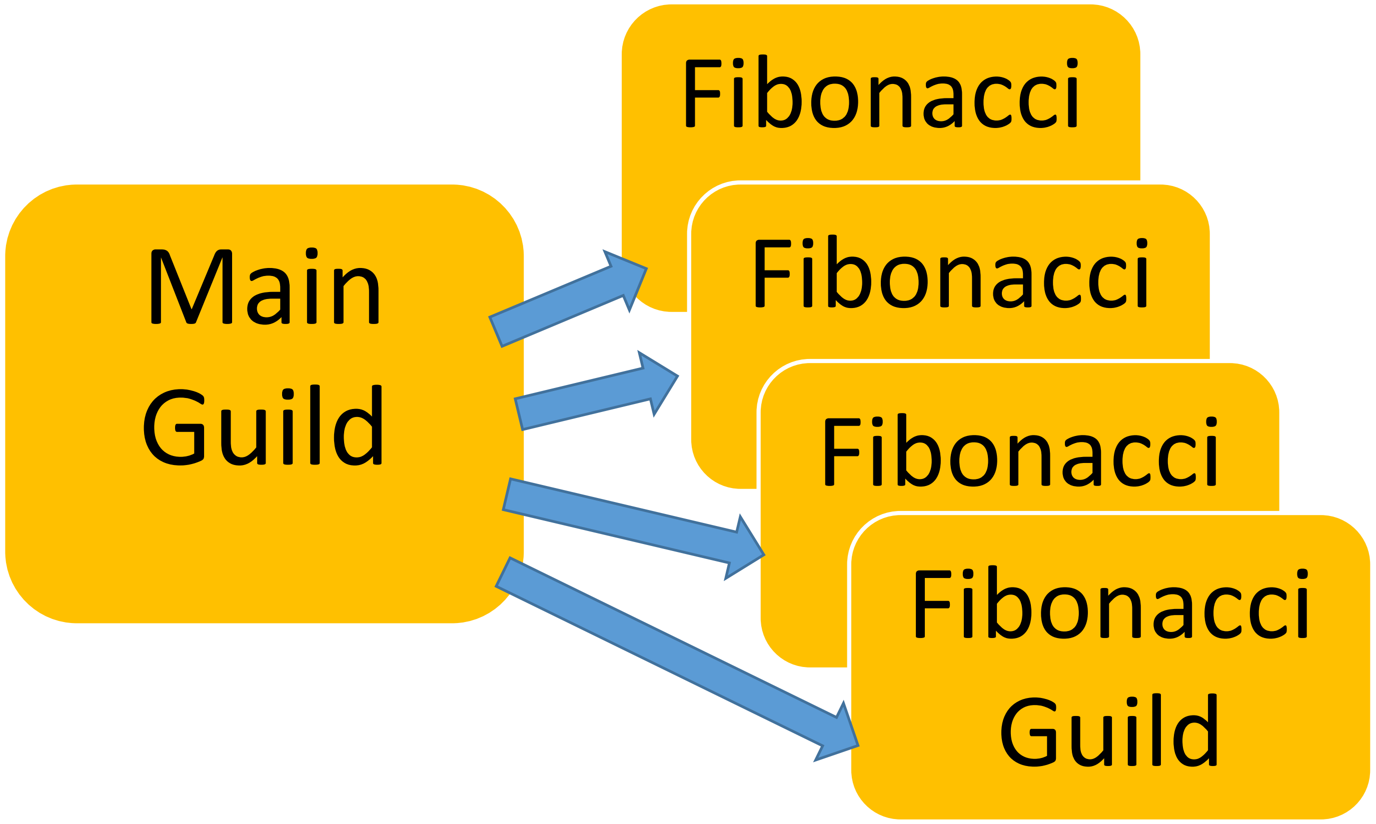
Interpreter process global data

- 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

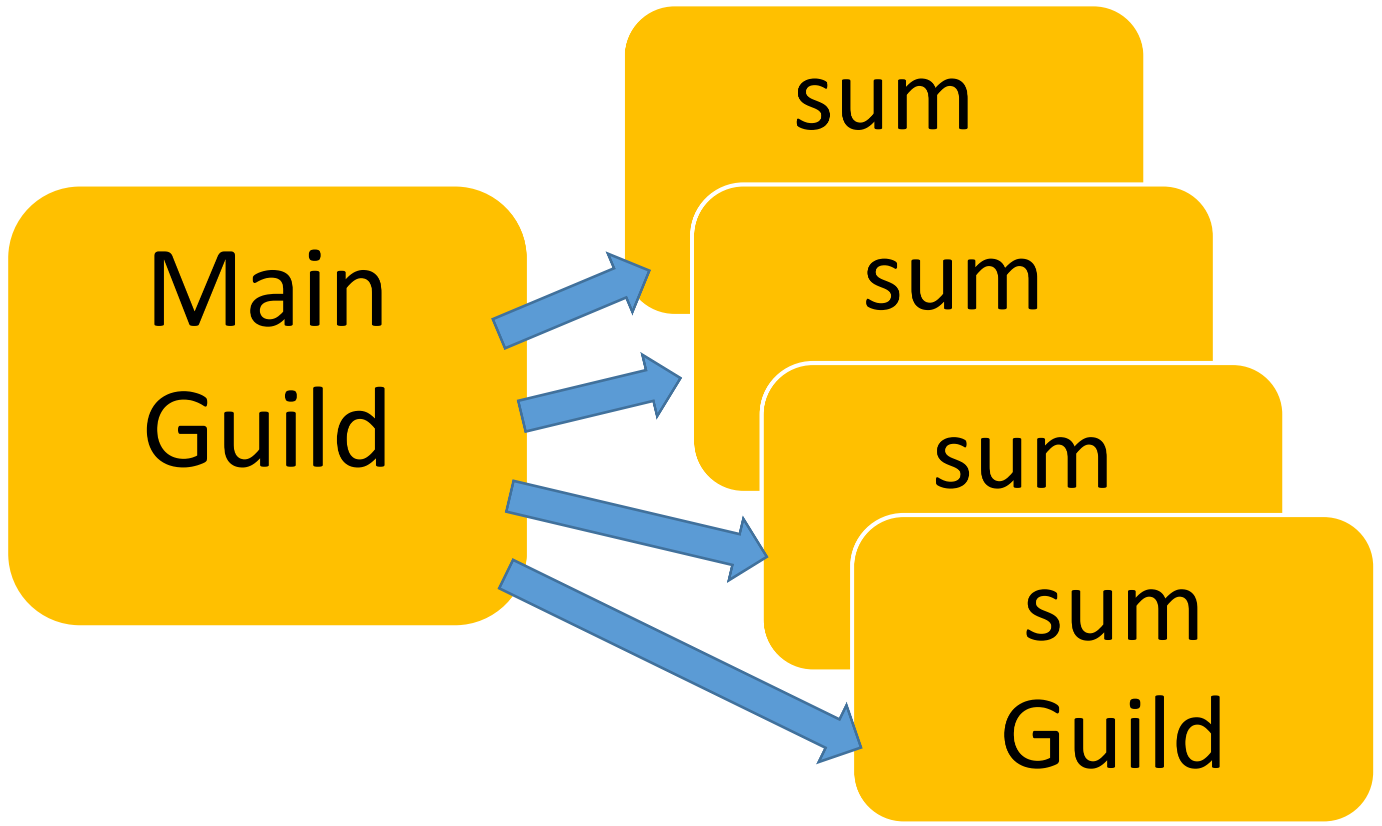
Performance evaluation
Simple numeric task in parallel



	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

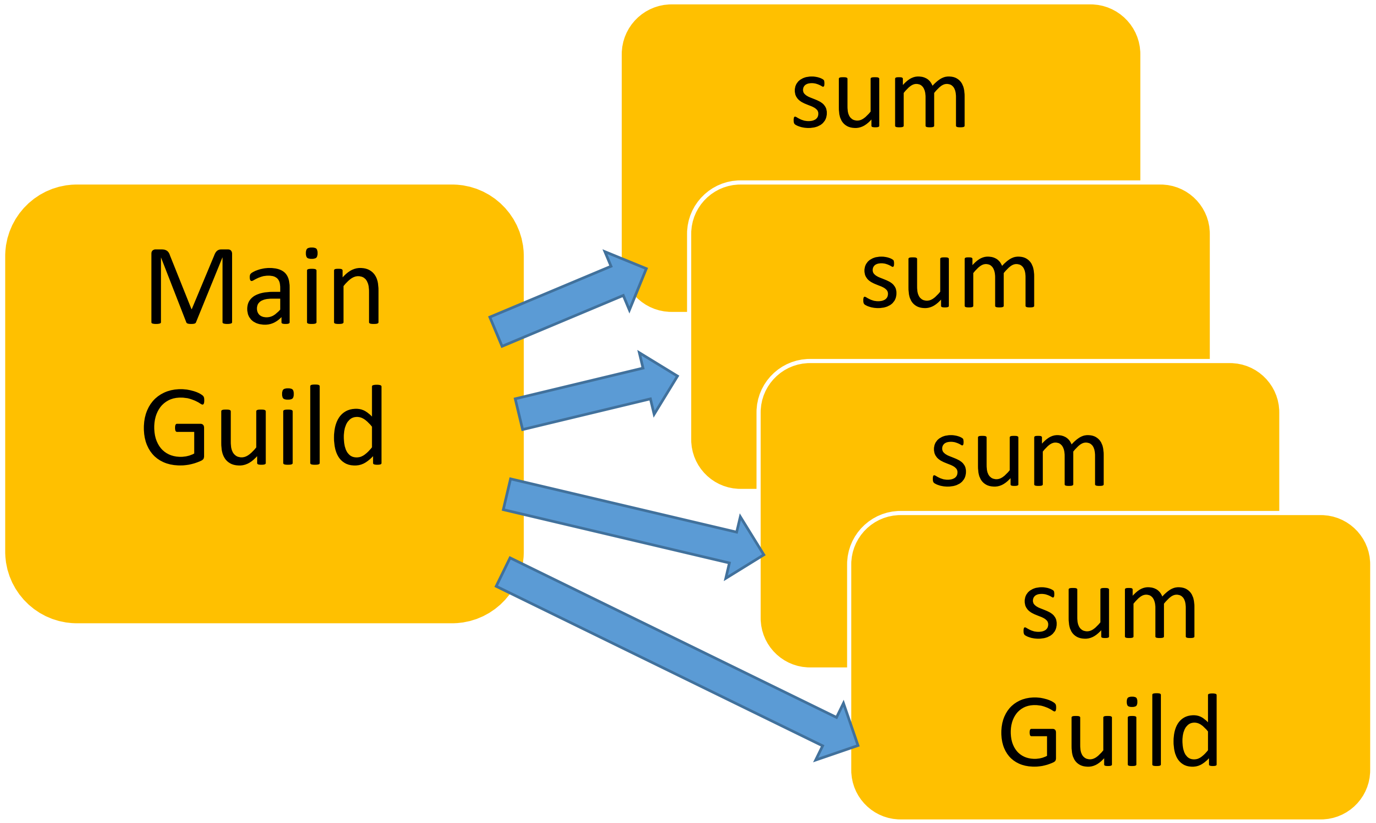


	Execution time (sec)
Single-Guild	1.00
Multi/ref	0.64
Multi/move	4.29
Multi/copy	5.16

Too slow!!
Because “move” need to check all of elements

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

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.

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"***)

Approach comparison

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

Summary

- One goal of Ruby 3: better concurrency support
- Guild: Isolate objects between guilds
    - Objects belong to one guild
    - Threads belong to different guilds can ***run parallel***
    - Communication using ***“transfer membership”***
- No implementation (just idea)

Thank you for your attention

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