Practical Concurrent and Parallel Programming XI

Message Passing II

Raúl Pardo

Exam date preferences

- You may have noticed that the span of exam dates for the course is very large

- If you have unmovable hard constraints you are welcome to let us know (just send an email to any member of the teaching team with an explanation for the constraint)
  - Although we will do our best to accommodate constraints, ***<u>we do not guarantee that your constrains will be met</u>***

- The more constraints we receive the harder it will be to meet them
  - So please be sensible in assessing whether you have a good reason to send us a constraint

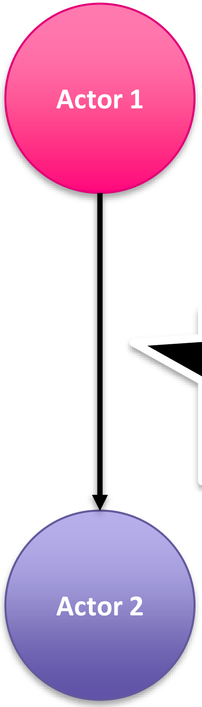
- You will hear more about this in coming lectures

Agenda

- Actors model (revisited)
    - Broadcaster
    - Primer
- Dynamic topology
- Fault-tolerance
    - Supervision
- Adaptive load balancing
    - Scatter-Gather
- Changing behaviour

Actors model (revisited)

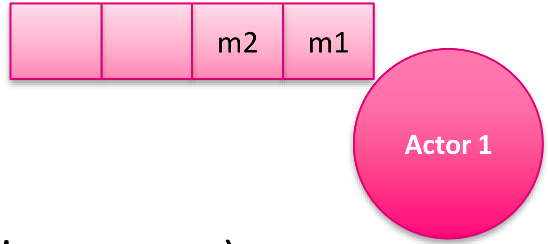
- An actor can be seen as a sequential unit of computation
    - Although, formally the model allows for parallelism within the actor, one can safely assume that there are not concurrency issues within the actor.
- Actors can send messages to other actors



The arrow indicates the direction of communication

Actors model (revisited)

- An actor is an abstraction of a process (in the OS sense)
  - It can execute computation
  - It can create new actors (sub-processes)



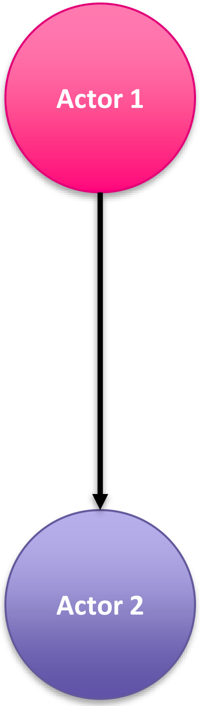
- Actors *do not share memory*
  - They only have access to:
    - Their *local state* (local memory)
    - Their *mailbox* (multiset of fixed size with “received” messages)

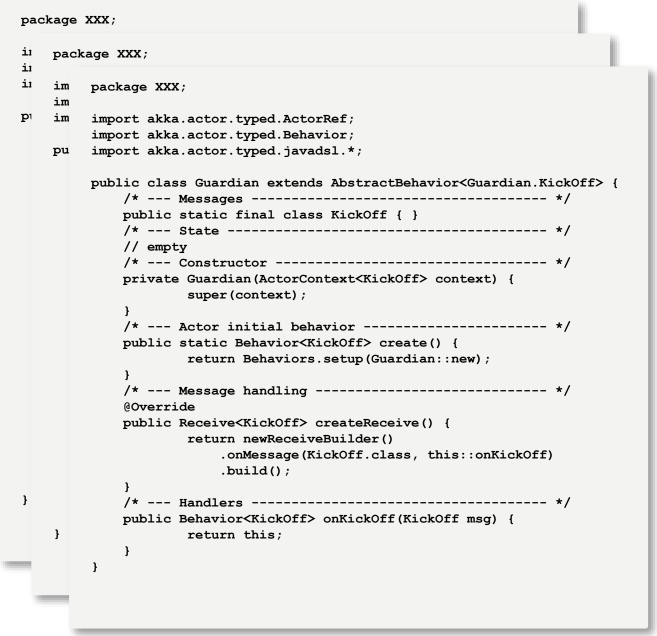
- Upon receiving a message an actor can
  - *send asynchronous messages* to other actors
  - *create new actors*
  - *change its behaviour* (local state and/or message handlers)

Actors model vs Akka implementation

- Do not confuse the Actors model with the technicalities of its implementation in Java (Akka)

- Before writing code, it is helpful to have a clear picture of the design of the system in terms of the basic rules from the previous slide





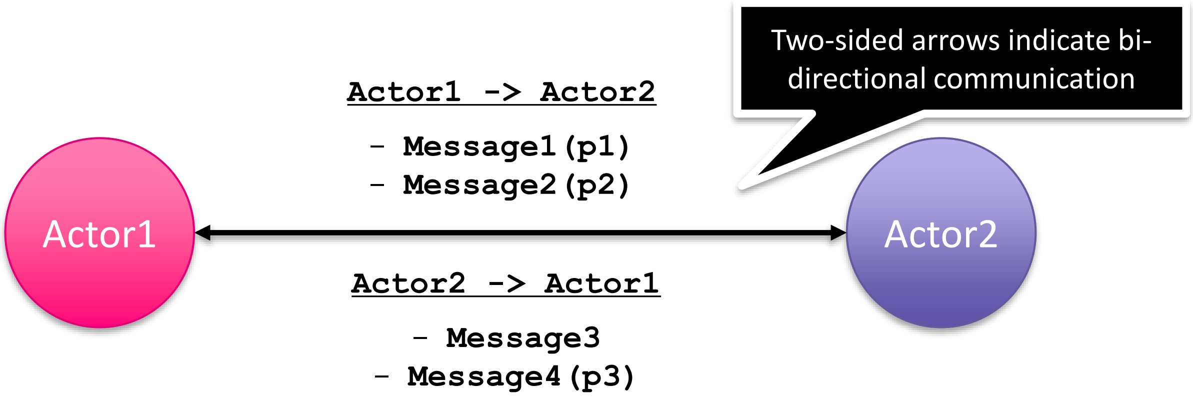
```java
package XXX;

import akka.actor.typed.ActorRef;
import akka.actor.typed.Behavior;
import akka.actor.typed.javadsl.*;

public class Guardian extends AbstractBehavior<Guardian.KickOff> {
    /* --- Messages --------------------------------------- */
    public static final class KickOff { }
    /* --- State ------------------------------------------ */
    // empty
    /* --- Constructor ------------------------------------ */
    private Guardian(ActorContext<KickOff> context) {
            super(context);
    }
    /* --- Actor initial behavior ------------------------- */
    public static Behavior<KickOff> create() {
            return Behaviors.setup(Guardian::new);
    }
    /* --- Message handling ------------------------------- */
    @Override
    public Receive<KickOff> createReceive() {
            return newReceiveBuilder()
                .onMessage(KickOff.class, this::onKickOff)
                .build();
    }
    /* --- Handlers --------------------------------------- */
    public Behavior<KickOff> onKickOff(KickOff msg) {
            return this;
    }
}
```

Advise: Implementing an Actors system

- Although the Actors model is simple, implementing actors systems may feel overwhelming
  - Chains of messages may force you to jump between files when implementing the behaviour of the actors in the system
- Tip: Focus on a message and message handler at a time



Two-sided arrows indicate bi-directional communication

Actor1 -> Actor2

- Message1(p1)
- Message2(p2)

Actor2 -> Actor1

- Message3
- Message4(p3)

Advise: Implementing an Actors system

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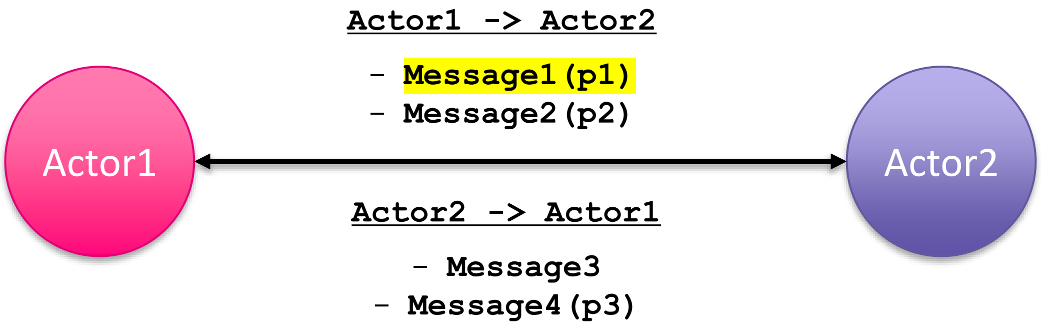

Actor1 -> Actor2

- Message1(p1)
- Message2(p2)

Actor2 -> Actor1

- Message3
- Message4(p3)

First, focus on the messages that actor 2 receives. More precisely, first implement the handler for Message1(p1): add elements to state if necessary, new auxiliary functions.

If new messages are sent to other actors, simply define the messages class in the corresponding actors, but do not implement the handler yet.

Advise: Implementing an Actors system

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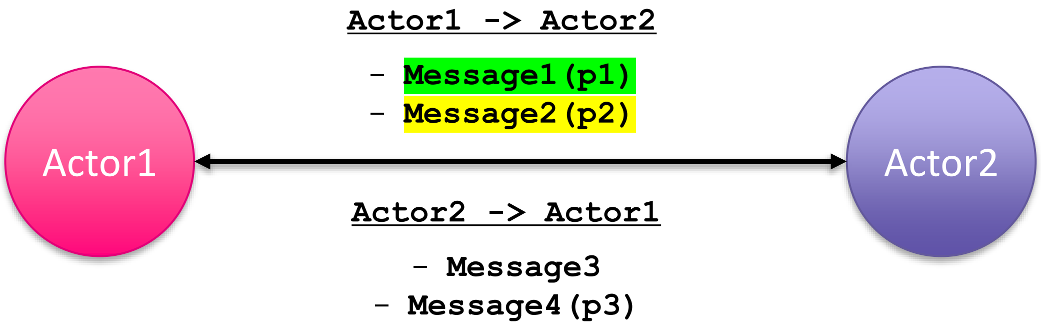

Actor1 -> Actor2

- Message1 (p1)
- Message2 (p2)

Actor2 -> Actor1

- Message3
- Message4 (p3)

Then continue with Message2 and so on…

Advise: Implementing an Actors system

- Although the Actors model is simple, implementing actors systems may feel overwhelming
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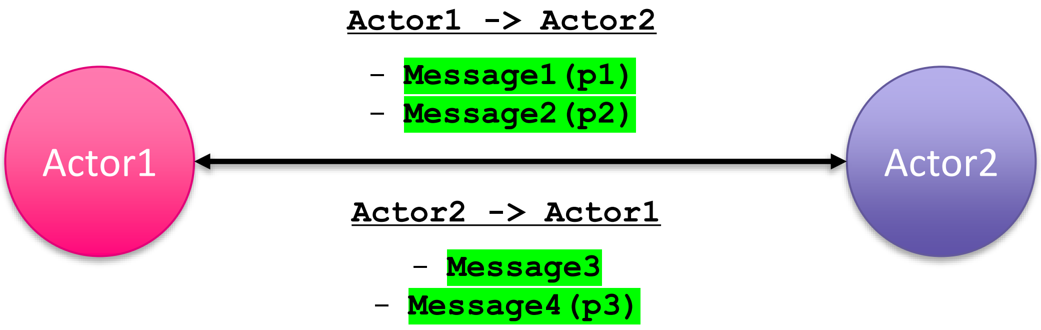
- Tip: Focus on a message and message handler at a time



Et voilà!

Template to start the system

```
package XXX;
import akka.actor.typed.ActorSystem;
import java.io.IOException;

public class Main {

    public static void main(String[] args) {

         // actor system
         final ActorSystem<Guardian.KickOff> guardian =
             ActorSystem.create(Guardian.create(), “XXX_system");

         // init message
         guardian.tell(new Guardian.KickOff());

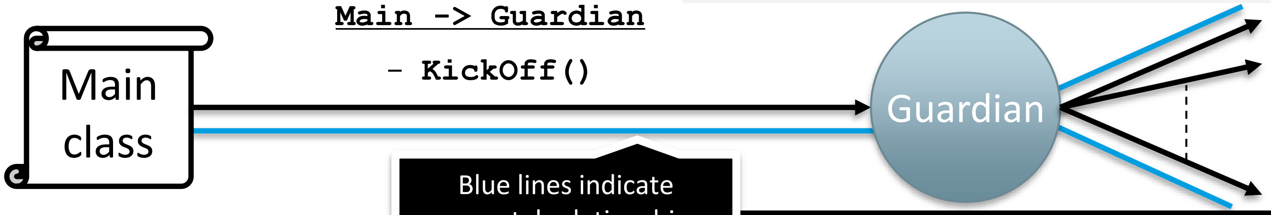
         // wait until user presses enter
         try {
             System.out.println(">>> Press ENTER to exit <<<");
             System.in.read();
         }
         catch (IOException e) {
             System.out.println("Error " + e.getMessage());
             e.printStackTrace();
         } finally {
             guardian.terminate();
         }
    }
}
```

The Main class simply creates the guardian and starts it with a kickoff message

```
package XXX;

import akka.actor.typed.ActorRef;
import akka.actor.typed.Behavior;
import akka.actor.typed.javadsl.*;

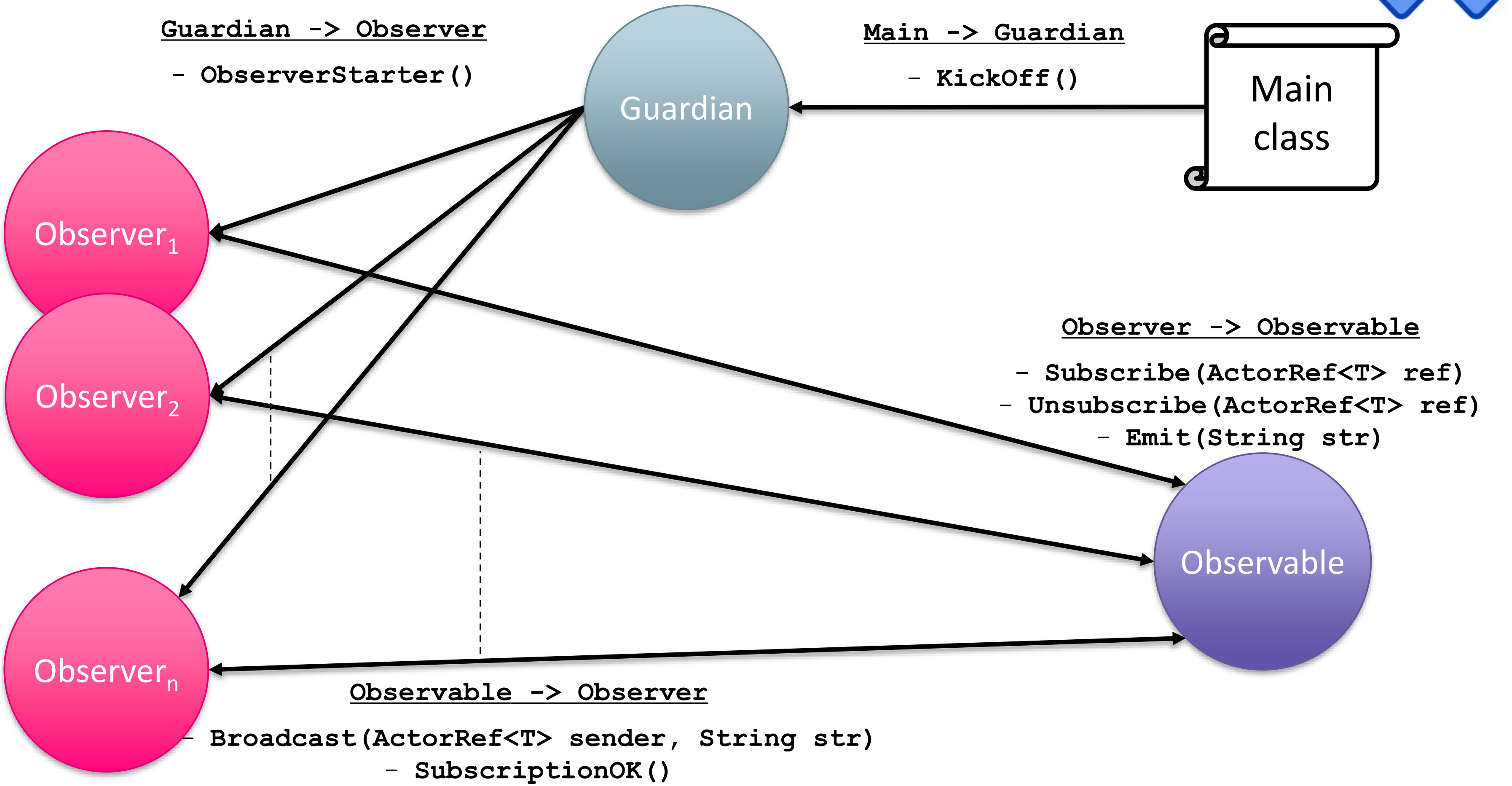
public class Guardian extends AbstractBehavior<Guardian.KickOff> {
    /* --- Messages ------------------------------------- */
    public static final class KickOff { }
    /* --- State ---------------------------------------- */
    // empty
    /* --- Constructor ---------------------------------- */
    private Guardian(ActorContext<KickOff> context) {
         super(context);
    }
    /* --- Actor initial behavior ----------------------- */
    public static Behavior<KickOff> create() {
         return Behaviors.setup(Guardian::new);
    }
    /* --- Message handling ----------------------------- */
    @Override
    public Receive<KickOff> createReceive() {
         return newReceiveBuilder()
             .onMessage(KickOff.class, this::onKickOff)
             .build();
    }
    /* --- Handlers ------------------------------------- */
    public Behavior<KickOff> onKickOff(KickOff msg) {
         // do all initialization tasks, e.g., spawn actors,
         // sending starting messages, etc.
         return this;
    }
}
```



Blue lines indicate parental relationship (who spawned who)

In the handler for the kickoff message the system is deployed by the guardian. It creates initial actors, and sends them start messages if necessary

Broadcaster + Guardian + Main (revisited)



Guardian -> Observer

- ObserverStarter()

Main -> Guardian

- KickOff()

Observer -> Observable

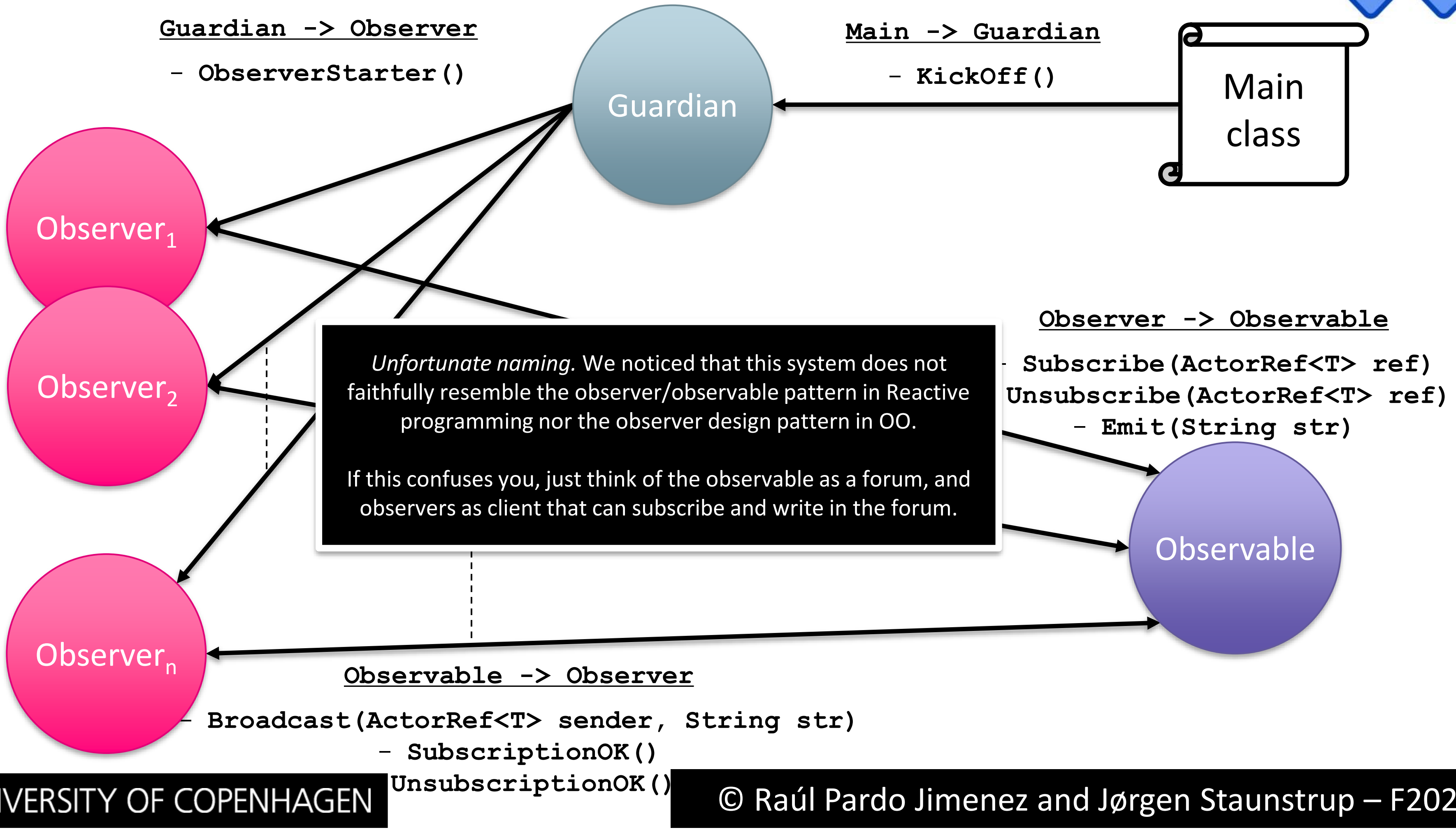
- Subscribe(ActorRef<T> ref)
- Unsubscribe(ActorRef<T> ref)
- Emit(String str)

Observable -> Observer

- Broadcast(ActorRef<T> sender, String str)
- SubscriptionOK()

UnsubscriptionOK()

Broadcaster + Guardian + Main (revisited)



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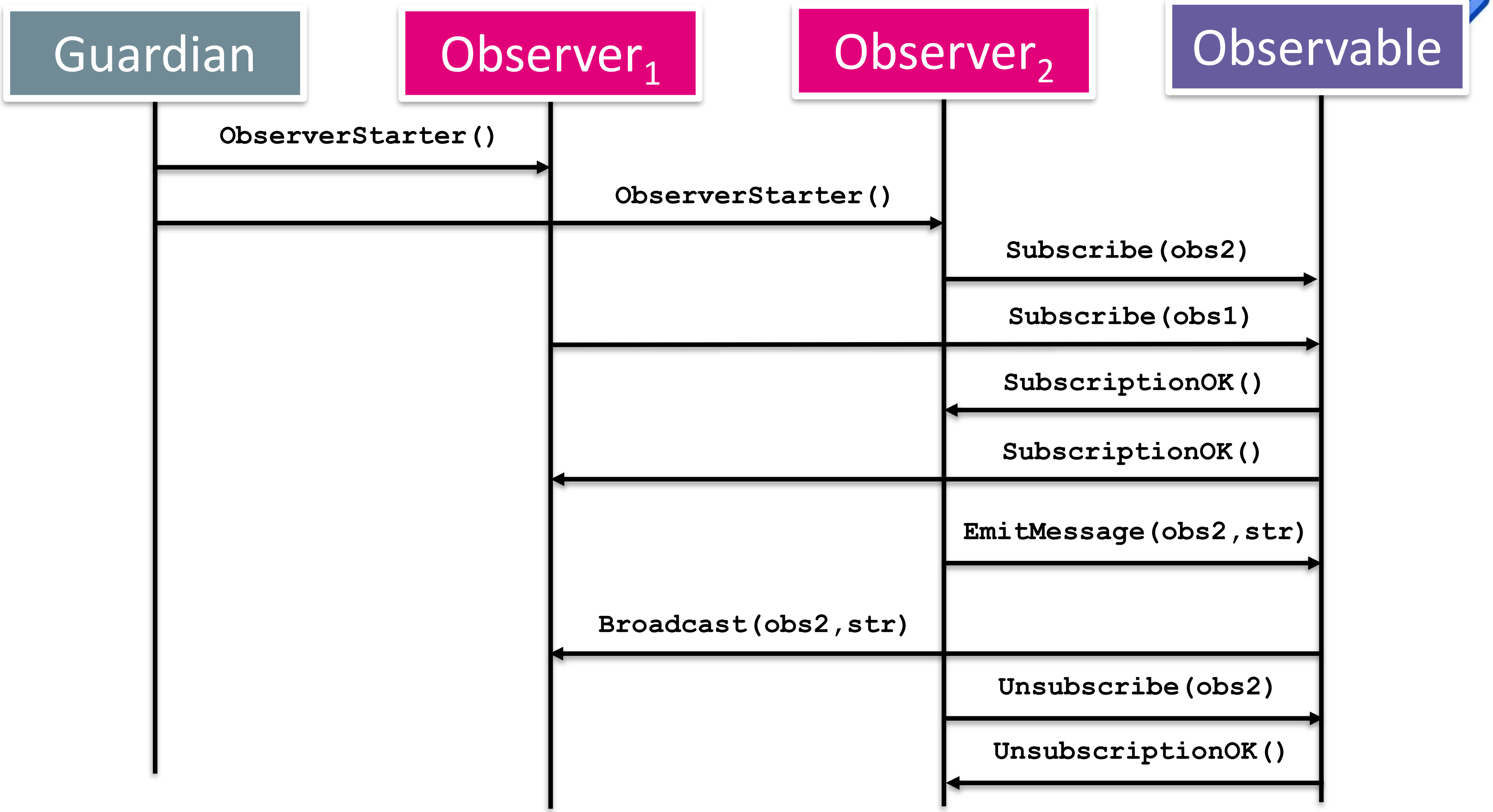
Observable -> Observer

- Broadcast(ActorRef<T> sender, String str)
- SubscriptionOK()
- UnsubscriptionOK()

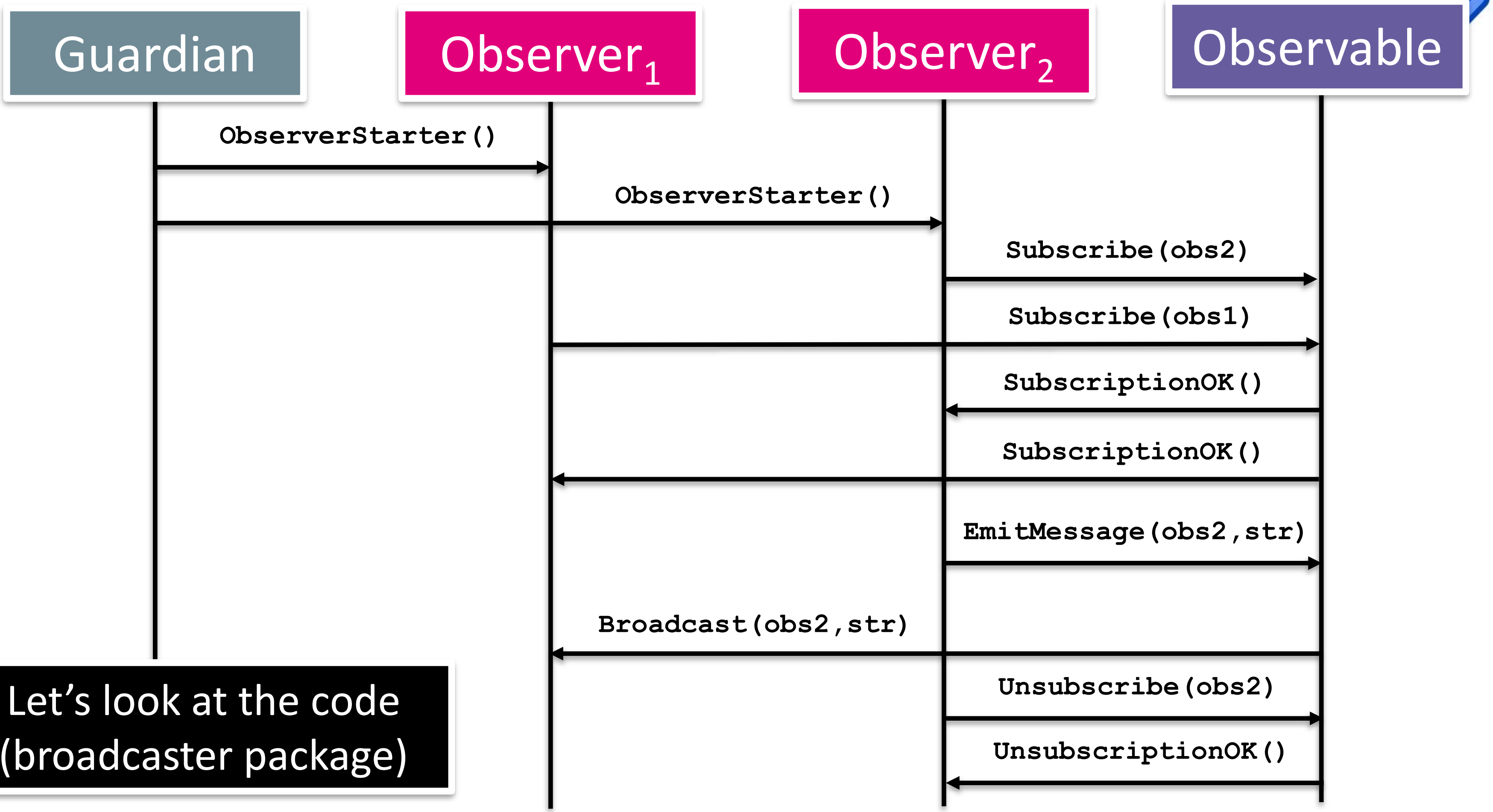
Unfortunate naming. We noticed that this system does not faithfully resemble the observer/observable pattern in Reactive programming nor the observer design pattern in OO.

If this confuses you, just think of the observable as a forum, and observers as client that can subscribe and write in the forum.

Primer – execution example (revisited)



Primer – execution example (revisited)



Let’s look at the code (broadcaster package)

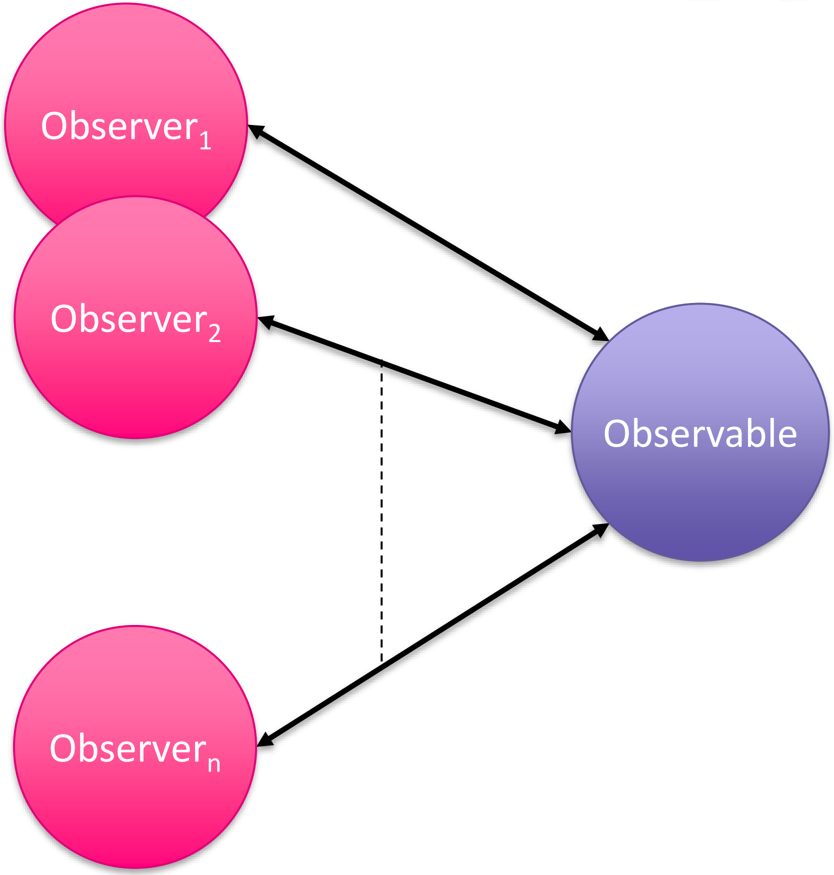
Broadcaster interesting executions

Assuming FIFO mailboxes (Akka's default)

- Consider this execution

1. Observer1 sends Subscription to observable
2. Observer2 sends Subscription to observable
3. …

What actor will receive first SubscriptionOK?



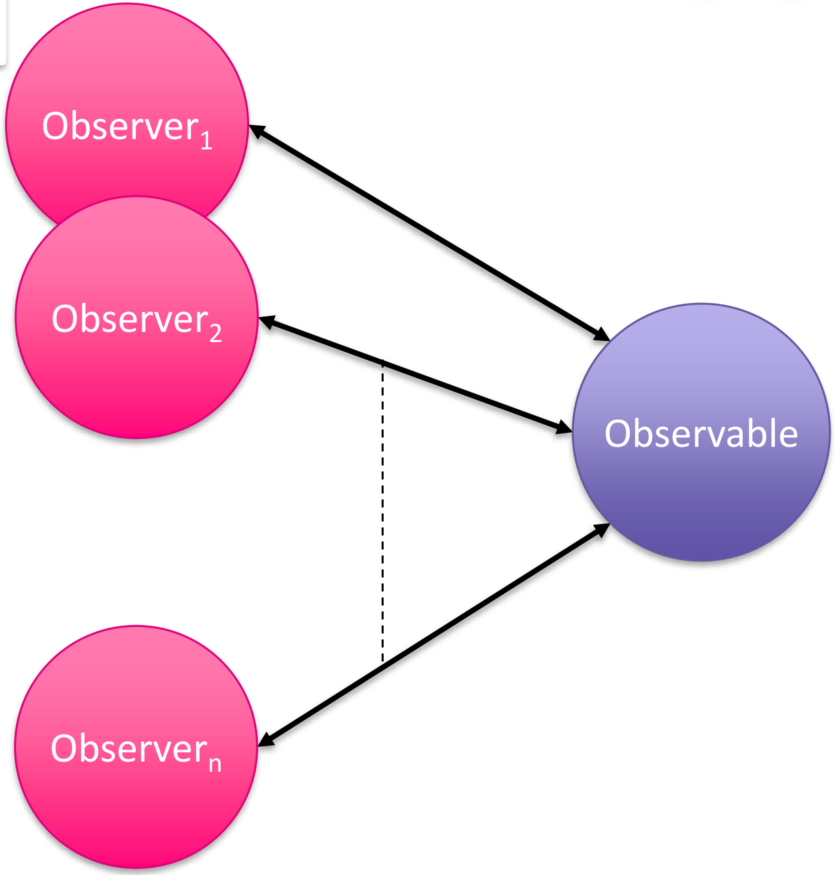
Broadcaster interesting executions

Assuming FIFO mailboxes (Akka’s default)

- Consider this execution

1. Observer1 sends Subscription to observable
2. Observable replies SubscriptionOK to observer1
3. Observer1 emits message to observable
4. Observer2 sends Subscription to observable
5. …

Can observer2 receive the message sent by observer1 in step 3?



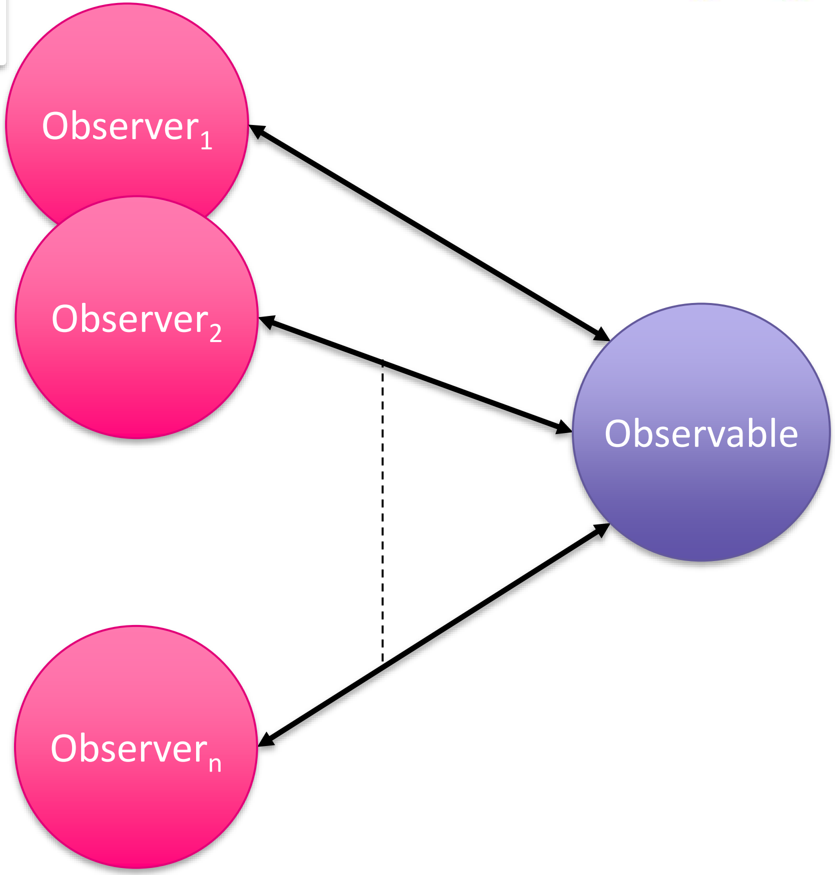
Broadcaster interesting executions

Assuming FIFO mailboxes (Akka's default)

- Consider this execution

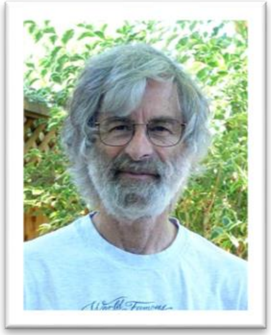
1. Observer1 send Subscription to observable
2. Observable replies SubscriptionOK to observer1
3. Observer1 emits message to observable
4. Observer2 sends Subscription to observable
5. Observable replies SubscriptionOK to observer2
6. …

Can observer2 receive the message sent by observer1 in step 3?



Happened-before in distributed systems

- Note that in the previous questions the behaviour of the systems depends on the reception of messages

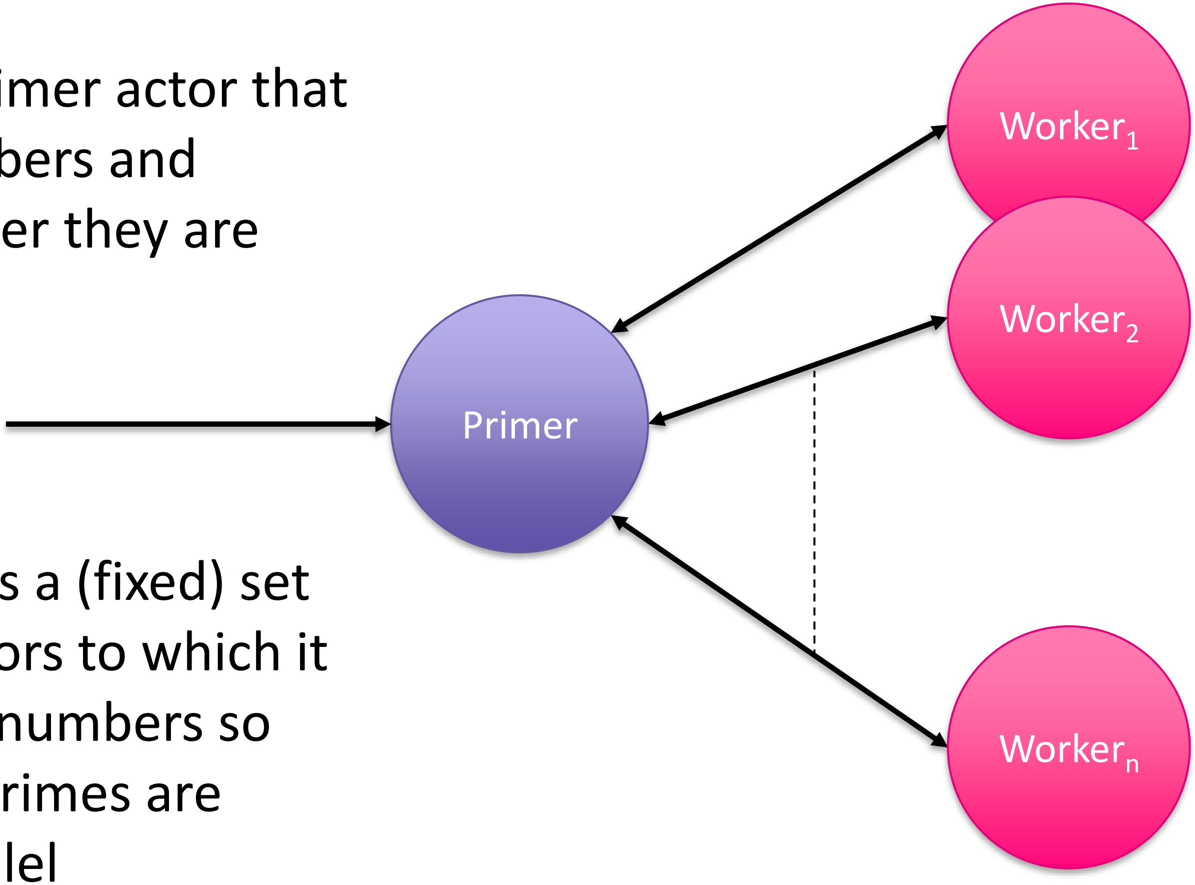


- Thus, the happened-before relation defined by Lamport is useful in reasoning about actor systems
  - An action *a* happens-before an action *b* if they belong to the same actor and *a* was executed before *b*
  - A send(m) action happens-before its corresponding receive(m)

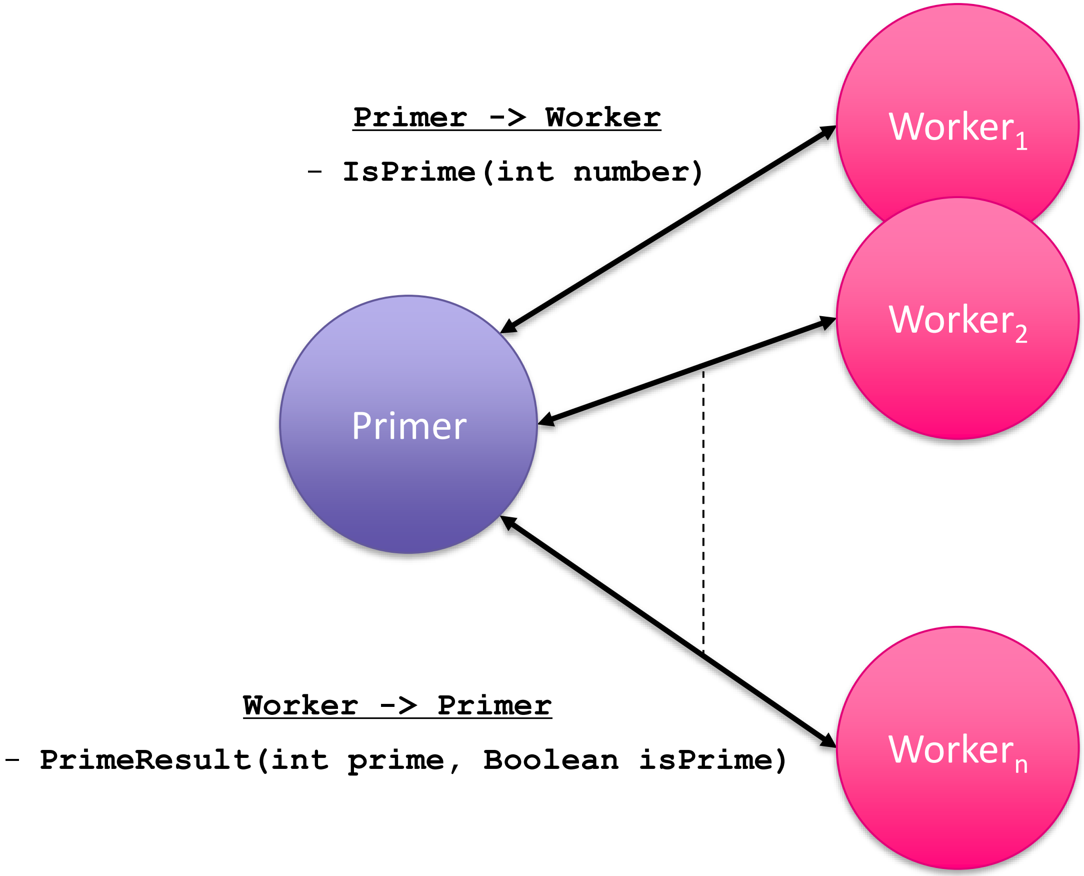
- Note the similarity with the happens-before relation of the Java memory model
  - We reason about message exchange instead of locking (inherent coordination problems remain, i.e., “semantic” deadlock & starvation)
  - Visibility issues disappear as actors only access local memory

Primer

- Consider a Primer actor that receives numbers and checks whether they are prime
- The actor uses a (fixed) set of worker actors to which it forwards the numbers so that several primes are check in parallel



Primer



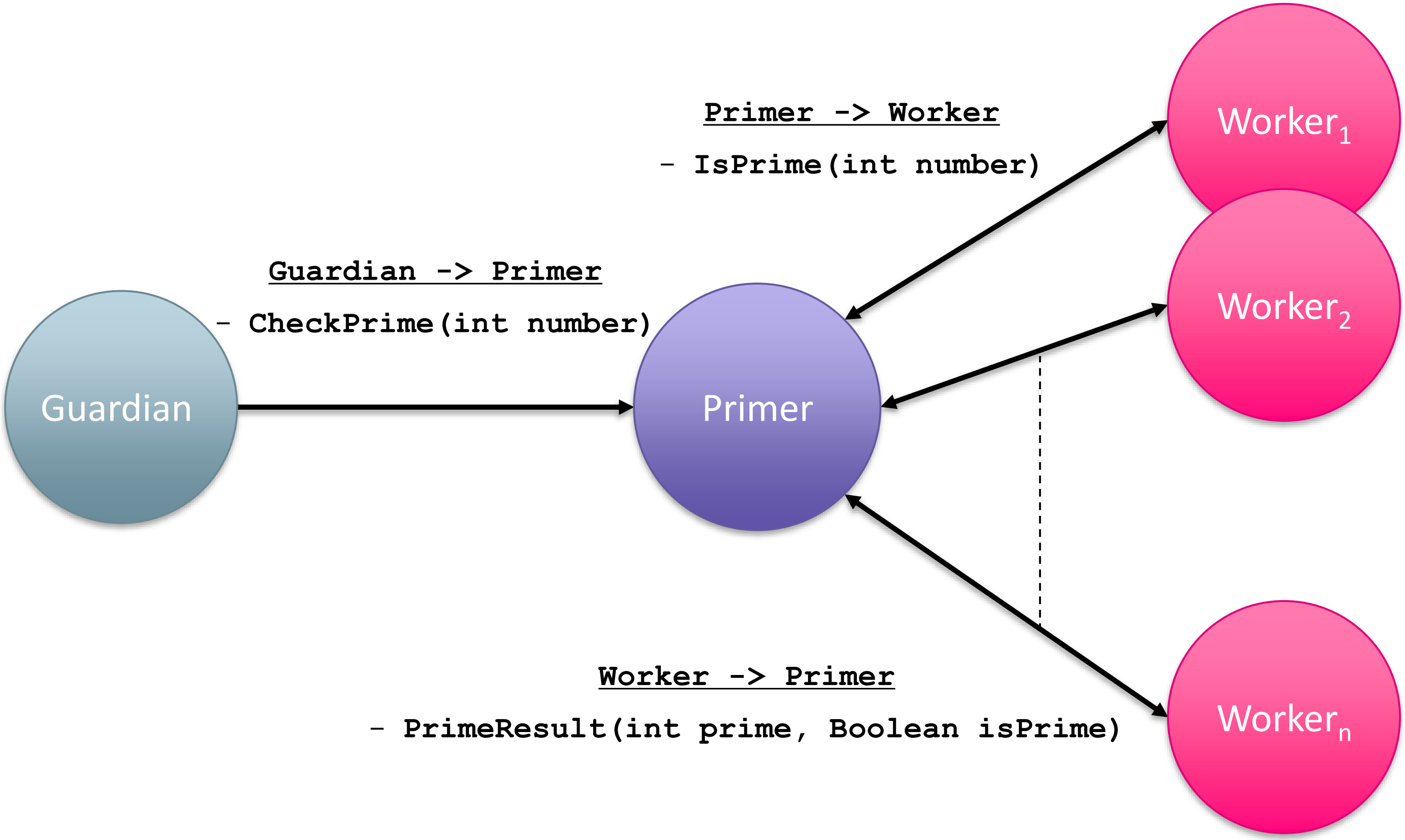
Primer -> Worker

- `IsPrime(int number)`

Worker -> Primer

- `PrimeResult(int prime, Boolean isPrime)`

Primer



Primer -> Worker

- `IsPrime(int number)`

Guardian -> Primer

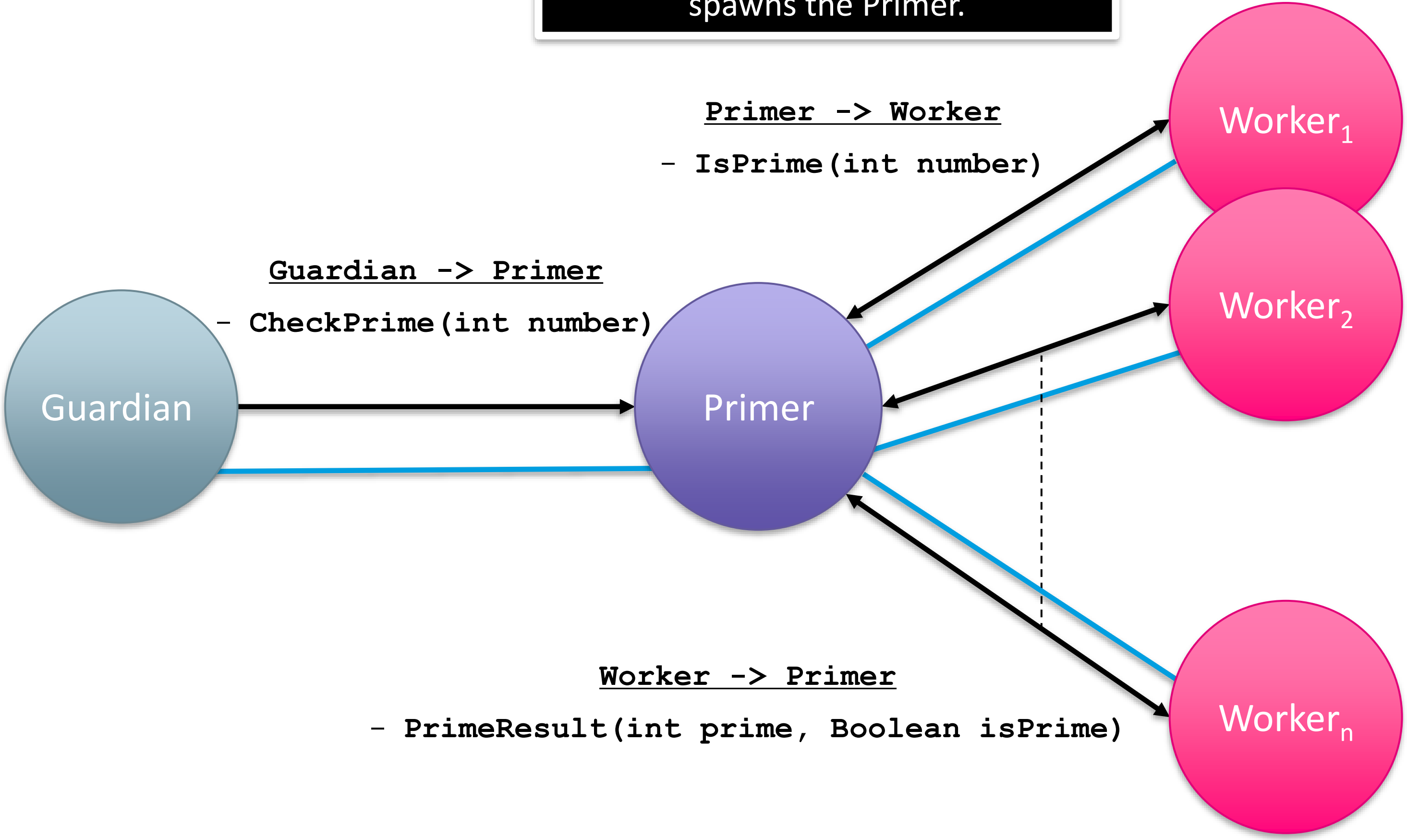
- `CheckPrime(int number)`

Worker -> Primer

- `PrimeResult(int prime, Boolean isPrime)`

Primer

The Primer is in charge of spawning the workers. As usual, the guardian spawns the Primer.



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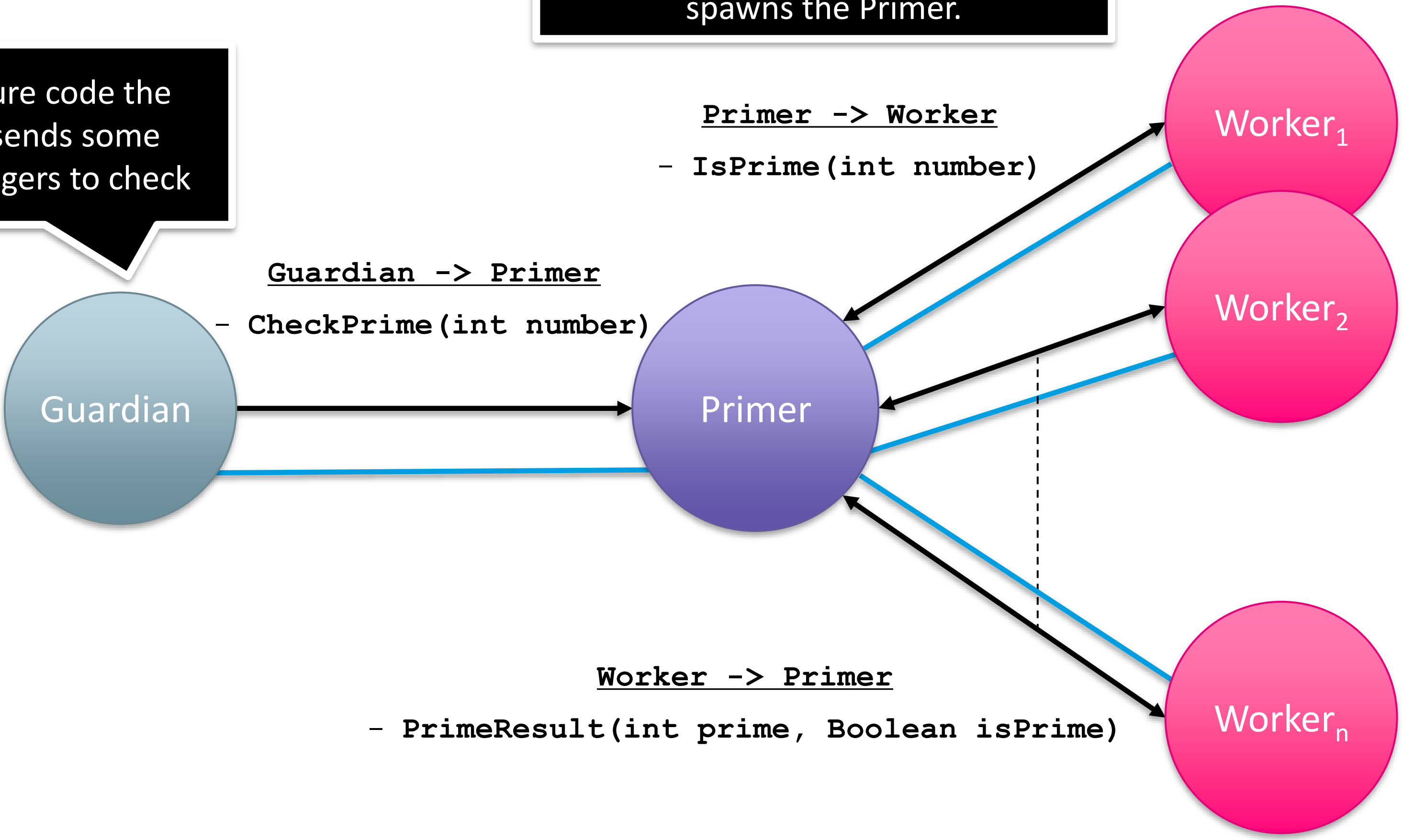
In the lecture code the guardian sends some random integers to check



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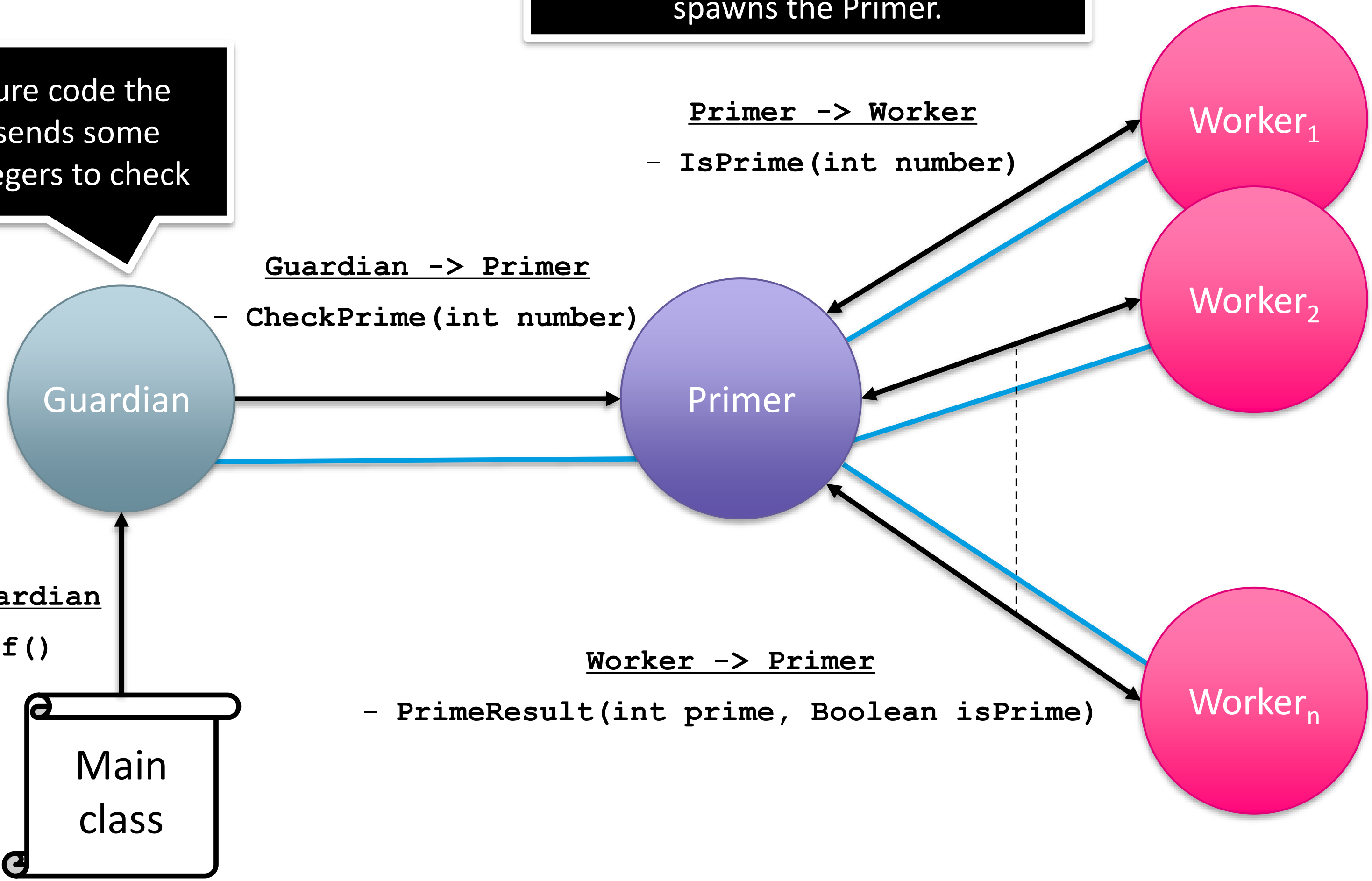


Main -> Guardian

- KickOff()

Guardian -> Primer

- CheckPrime(int number)

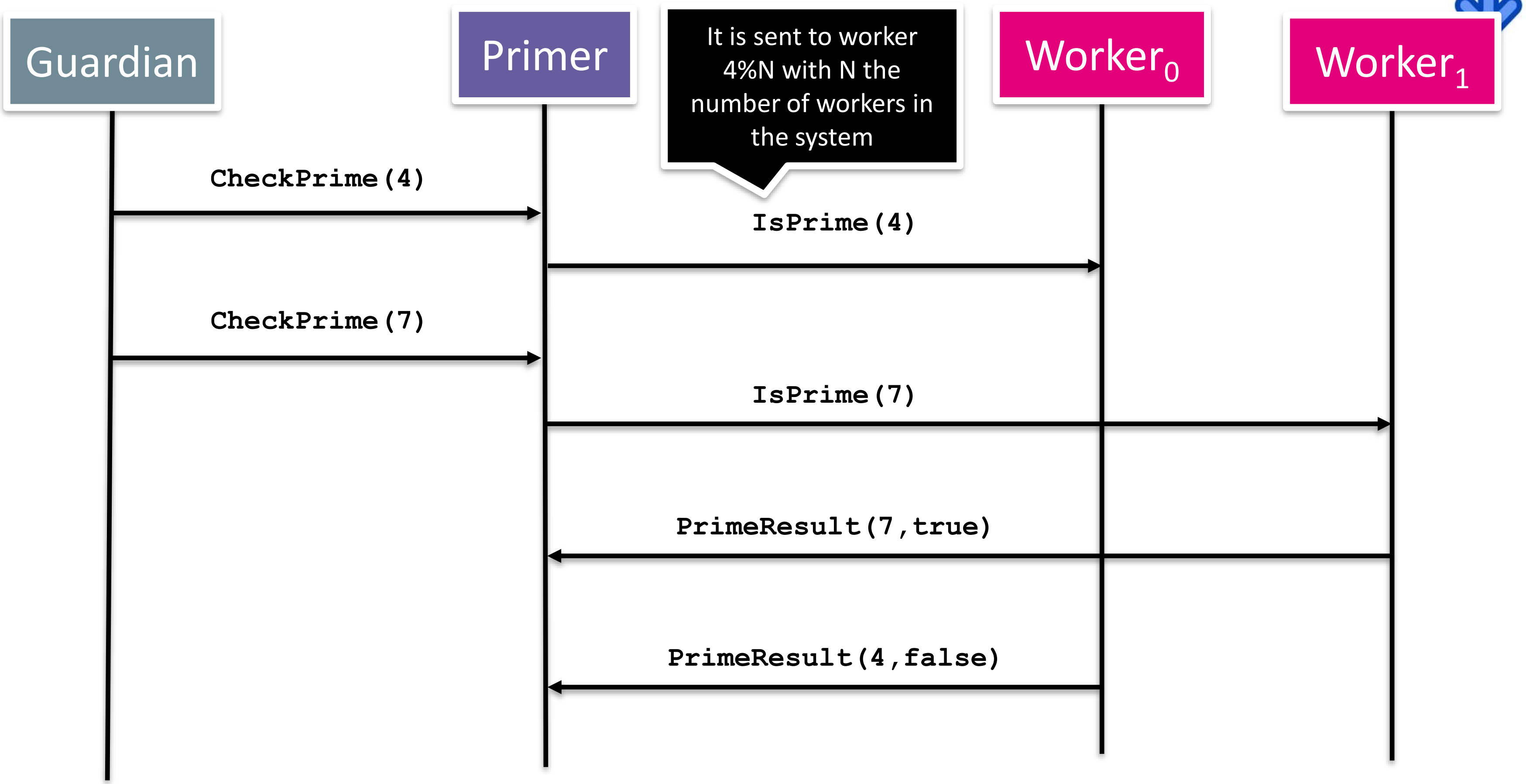
Primer -> Worker

- IsPrime(int number)

Worker -> Primer

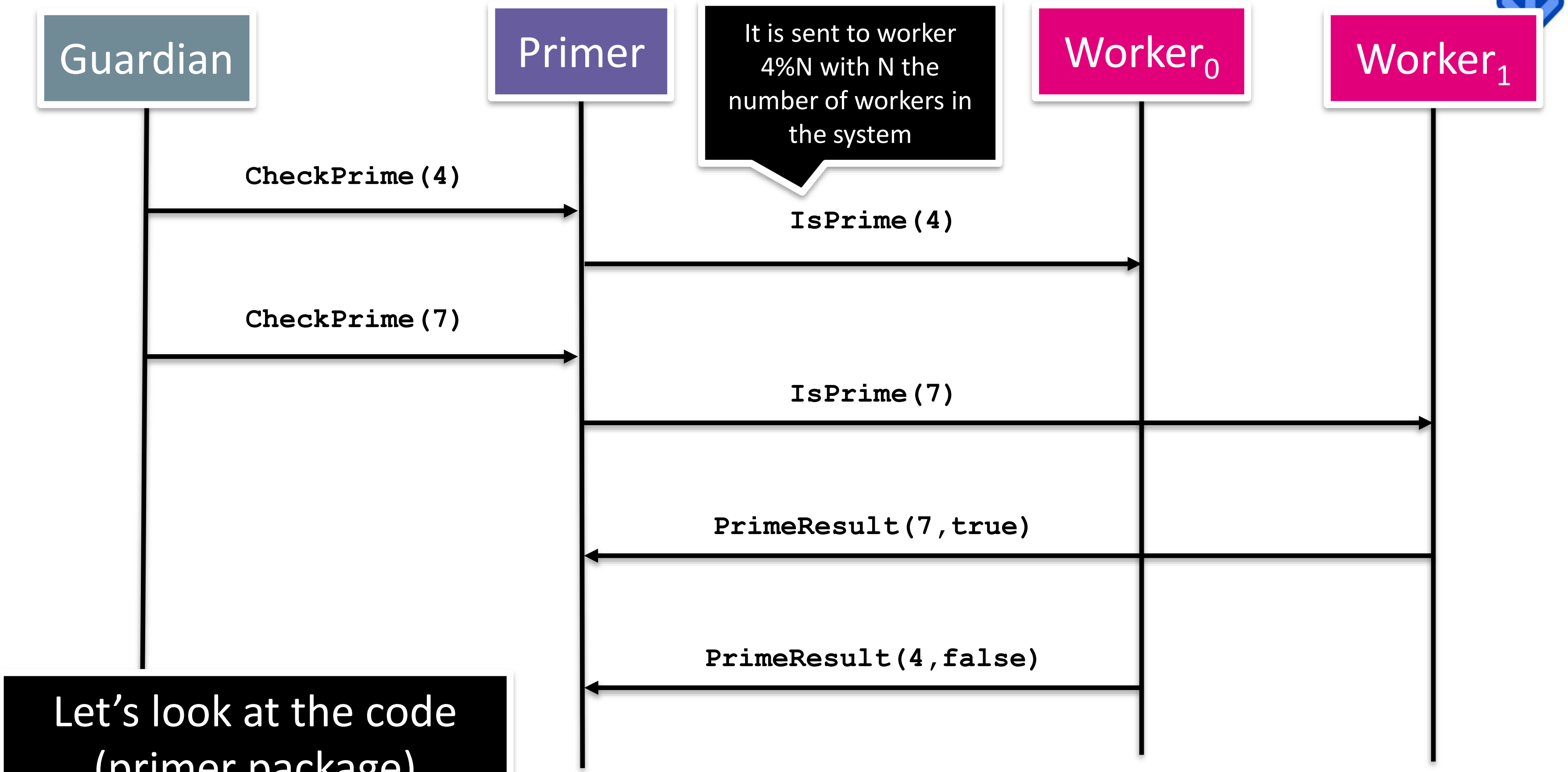
- PrimeResult(int prime, Boolean isPrime)

Primer – execution example



It is sent to worker 4%N with N the number of workers in the system

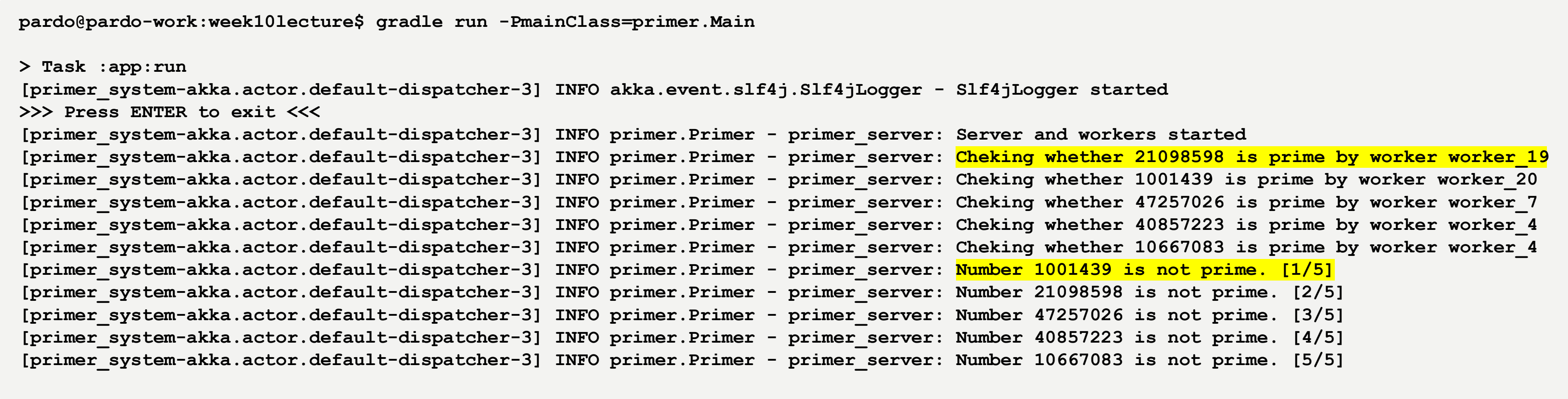
Primer – execution example



Let's look at the code (primer package)

Primer – Printing order

- Note that the printing order of the results does not correspond to the order of sending the requests



```
pardo@pardo-work:week10lecture$ gradle run -PmainClass=primer.Main

> Task :app:run
[primer_system-akka.actor.default-dispatcher-3] INFO akka.event.slf4j.Slf4jLogger - Slf4jLogger started
>>> Press ENTER to exit <<<
[primer_system-akka.actor.default-dispatcher-3] INFO primer.Primer - primer_server: Server and workers started
[primer_system-akka.actor.default-dispatcher-3] INFO primer.Primer - primer_server: Cheking whether 21098598 is prime by worker worker_19
[primer_system-akka.actor.default-dispatcher-3] INFO primer.Primer - primer_server: Cheking whether 1001439 is prime by worker worker_20
[primer_system-akka.actor.default-dispatcher-3] INFO primer.Primer - primer_server: Cheking whether 47257026 is prime by worker worker_7
[primer_system-akka.actor.default-dispatcher-3] INFO primer.Primer - primer_server: Cheking whether 40857223 is prime by worker worker_4
[primer_system-akka.actor.default-dispatcher-3] INFO primer.Primer - primer_server: Cheking whether 10667083 is prime by worker worker_4
[primer_system-akka.actor.default-dispatcher-3] INFO primer.Primer - primer_server: Number 1001439 is not prime.  [1/5]
[primer_system-akka.actor.default-dispatcher-3] INFO primer.Primer - primer_server: Number 21098598 is not prime.  [2/5]
[primer_system-akka.actor.default-dispatcher-3] INFO primer.Primer - primer_server: Number 47257026 is not prime.  [3/5]
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[primer_system-akka.actor.default-dispatcher-3] INFO primer.Primer - primer_server: Number 10667083 is not prime.  [5/5]
```

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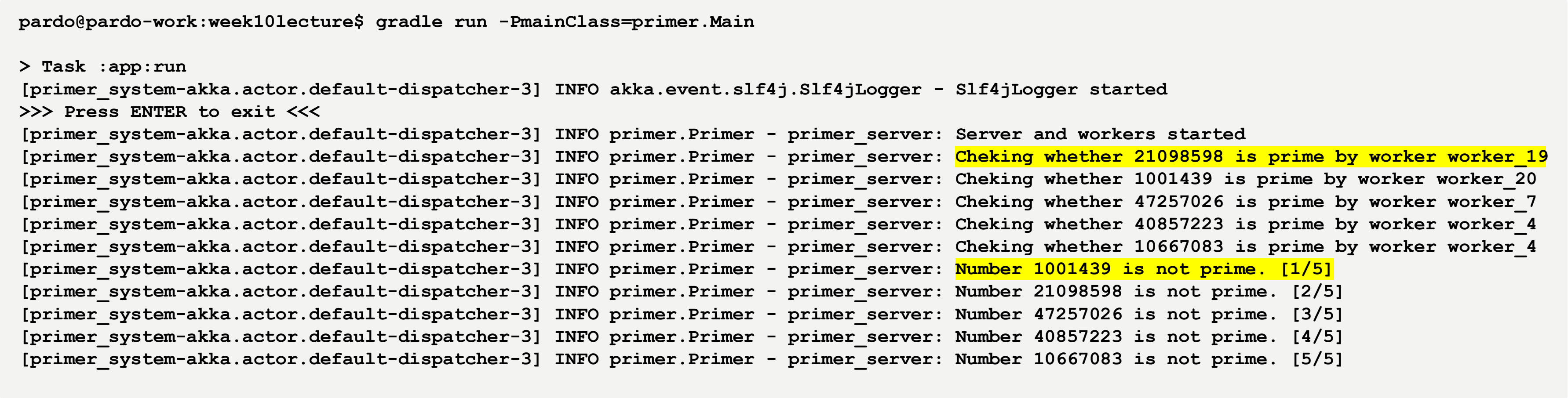

```
pardo@pardo-work:week10lecture$ gradle run -PmainClass=primer.Main

> Task :app:run
[primer_system-akka.actor.default-dispatcher-3] INFO akka.event.slf4j.Slf4jLogger - Slf4jLogger started
>>> Press ENTER to exit <<<
[primer_system-akka.actor.default-dispatcher-3] INFO primer.Primer - primer_server: Server and workers started
[primer_system-akka.actor.default-dispatcher-3] INFO primer.Primer - primer_server: Cheking whether 21098598 is prime by worker worker_19
[primer_system-akka.actor.default-dispatcher-3] INFO primer.Primer - primer_server: Cheking whether 1001439 is prime by worker worker_20
[primer_system-akka.actor.default-dispatcher-3] INFO primer.Primer - primer_server: Cheking whether 47257026 is prime by worker worker_7
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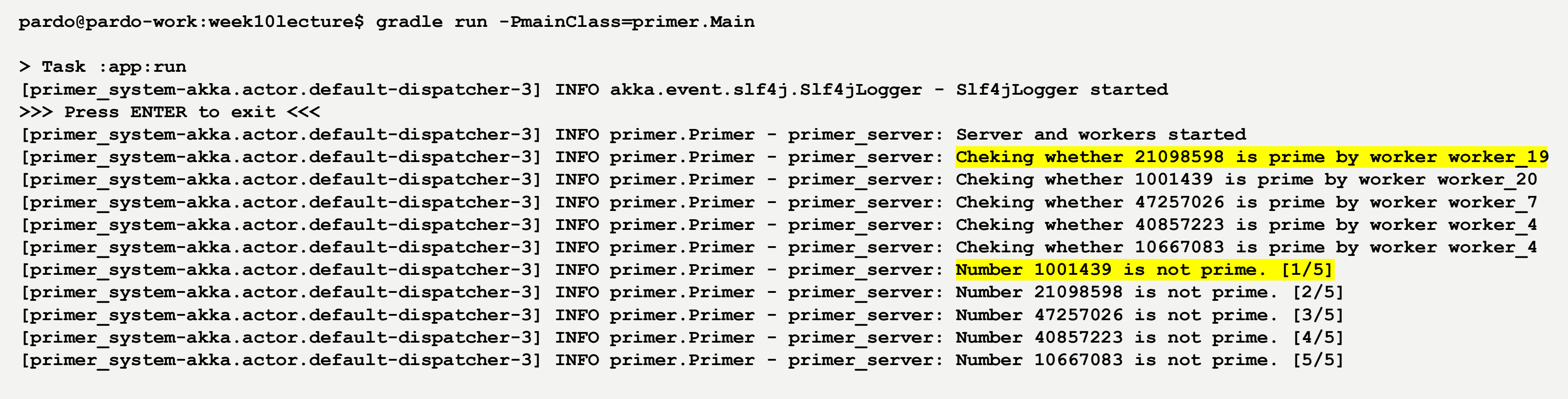
```

How can this ordering happen?

Primer – Printing order

- Note that the printing order of the results does not correspond to the order of sending the requests



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[primer_system-akka.actor.default-dispatcher-3] INFO primer.Primer - primer_server: Cheking whether 47257026 is prime by worker worker_7
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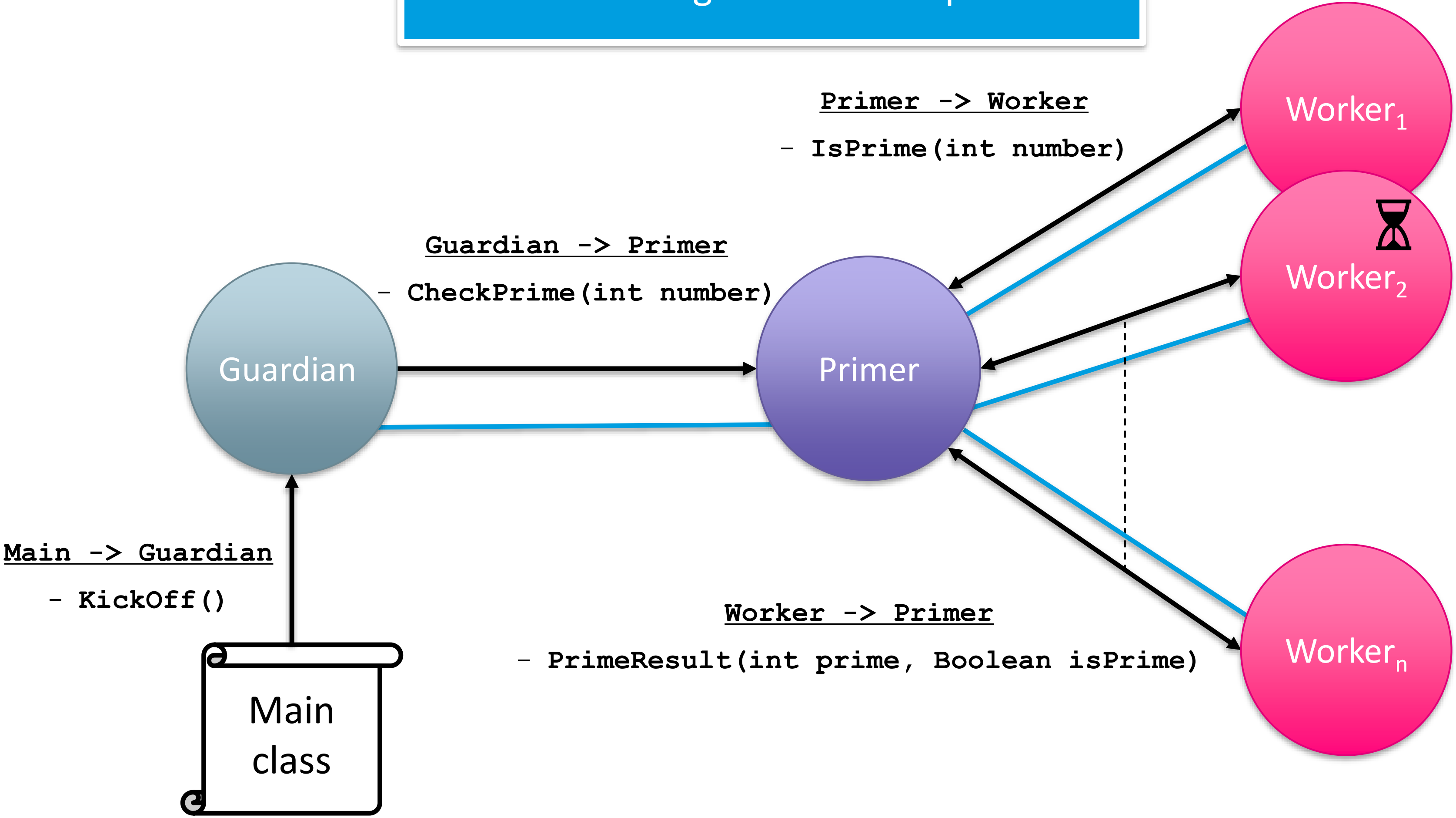
```

How would you change the system to print the results in the same order as they arrived?

Primer

What happens if one of the workers gets stuck working on a difficult prime?



Actors systems with *dynamic* topology

Don’t be shy, spawn actors!

- The Actors model encourages creating many actors that perform small tasks and communicate with each other

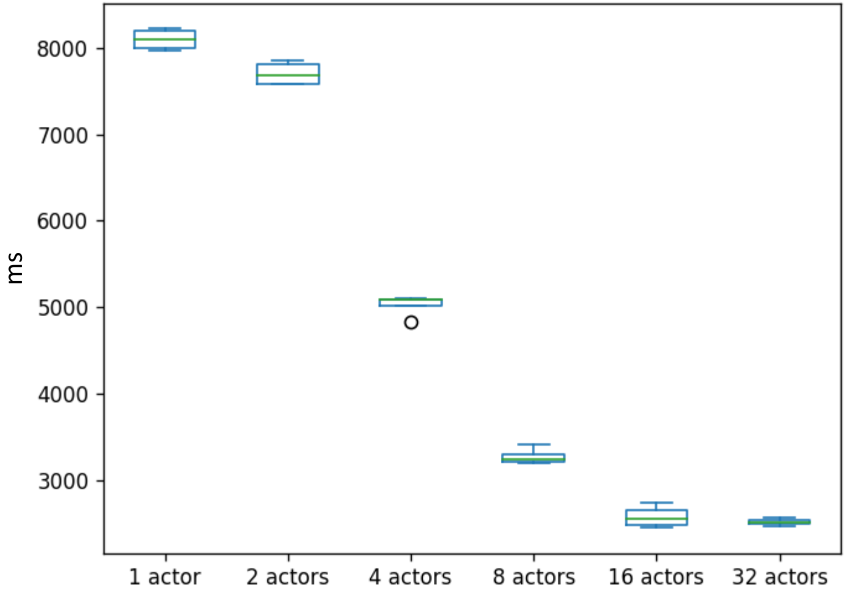
Do more actors improve performance?

- As usual, performance depends on the HW

- These are the results of running the primer to check 1 million numbers between 1 billion and Integer.MAX_VALUE.
  - Not very strong statistics (4 runs for each number of actors).

- Akka implements actors systems using a ForkJoinPool (a version of the ThreadPool, which is more efficient for tasks with low dependencies)

- However, actor systems can be distributed among many JVMs and computers
  - We are not limited to a single computer throughput
  - See Akka cluster

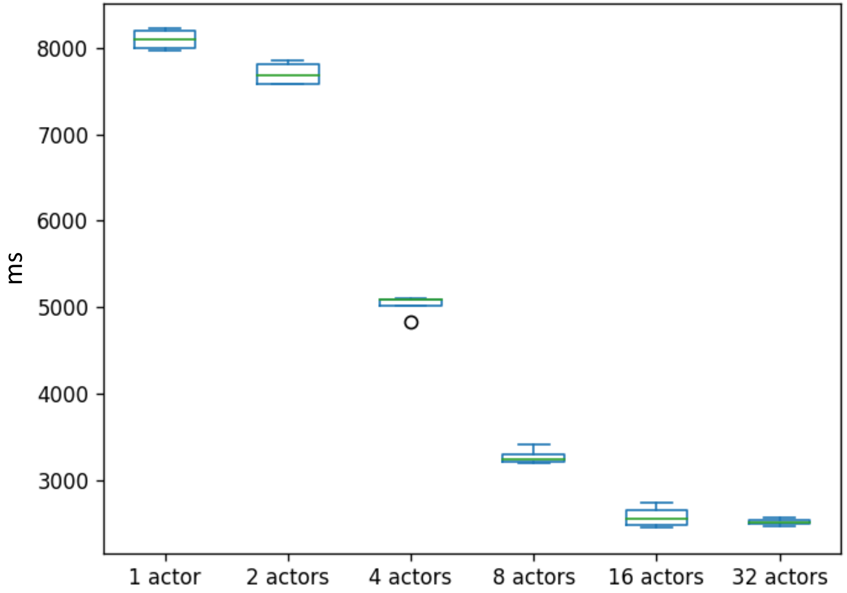


Do more actors improve performance?

That said, distributing computation among actors makes it easy to implement fault-tolerant systems and adaptive load-balancing

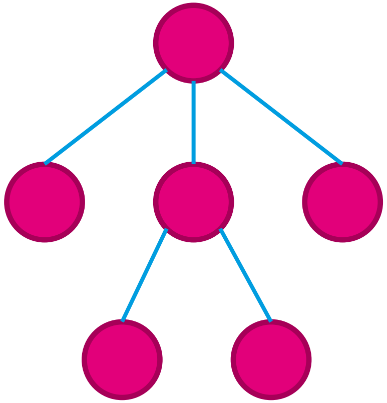
- Akka implements actors systems using a ForkJoinPool (a version of the ThreadPool, which is more efficient for tasks with low dependencies)

- However, actor systems can be distributed among many JVMs and computers
  - We are not limited to a single computer throughput
  - See Akka cluster



Topology (Actor hierarchy)

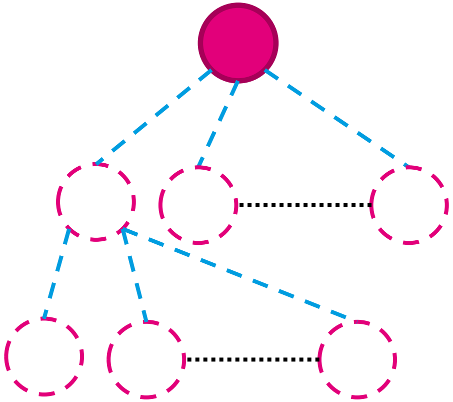
- We use the term *topology* to refer to the parental structure of actors in the system
  - In Akka, this structure is a tree, and it is called a *hierarchy*.
- The systems we have seen so far feature a *static* topology
  - They spawn the actors in the system during initialization and they never change



Solid lines and actors represent elements that are created during initialization and never change

Dynamic topology

- Actor systems with static topology may not exploit computational resources effectively
  - As we saw, the system may slow down if some actors are consuming excessive computational resources
  - Actors may also crash, and the system should be able to recover from this (fault-tolerance)
- The advantages of the actors model are better exploited when the system can adaptively decide the number of workers
- Actors should be seen as *nice co-workers*
  - *A group of computational resources that collaborate to achieve a common goal*



Dashed lines and actors represent elements that may be created dynamically (on-demand, after initialization)

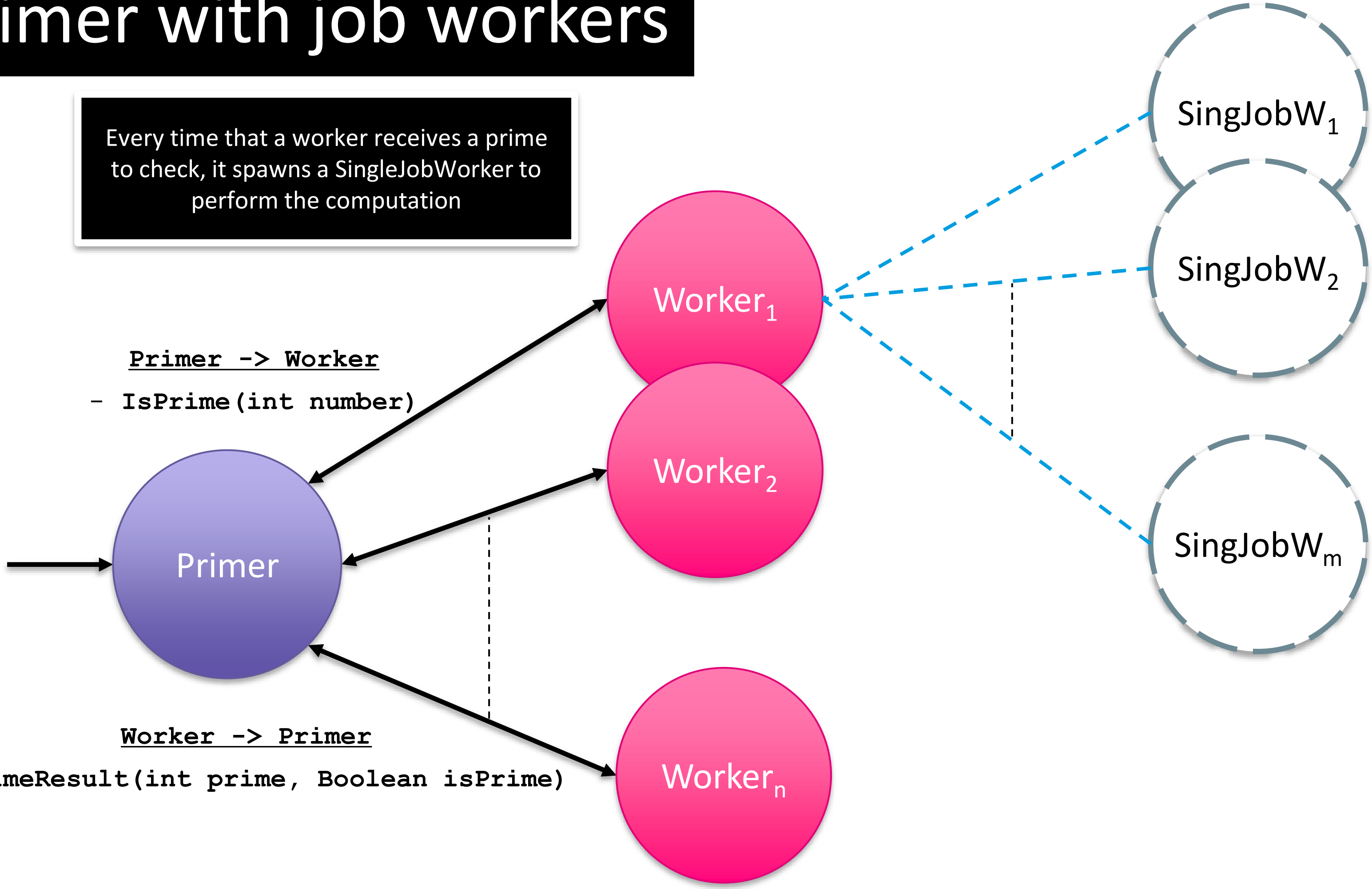
Primer with job workers

- To avoid excessive delays by primes that are difficult to check, we extend the system with dedicated actors whose only task is to check the prime

- After these dedicated actors have finished the computation they report the result and terminate the execution

Primer with job workers

Every time that a worker receives a prime to check, it spawns a SingleJobWorker to perform the computation



Primer -> Worker

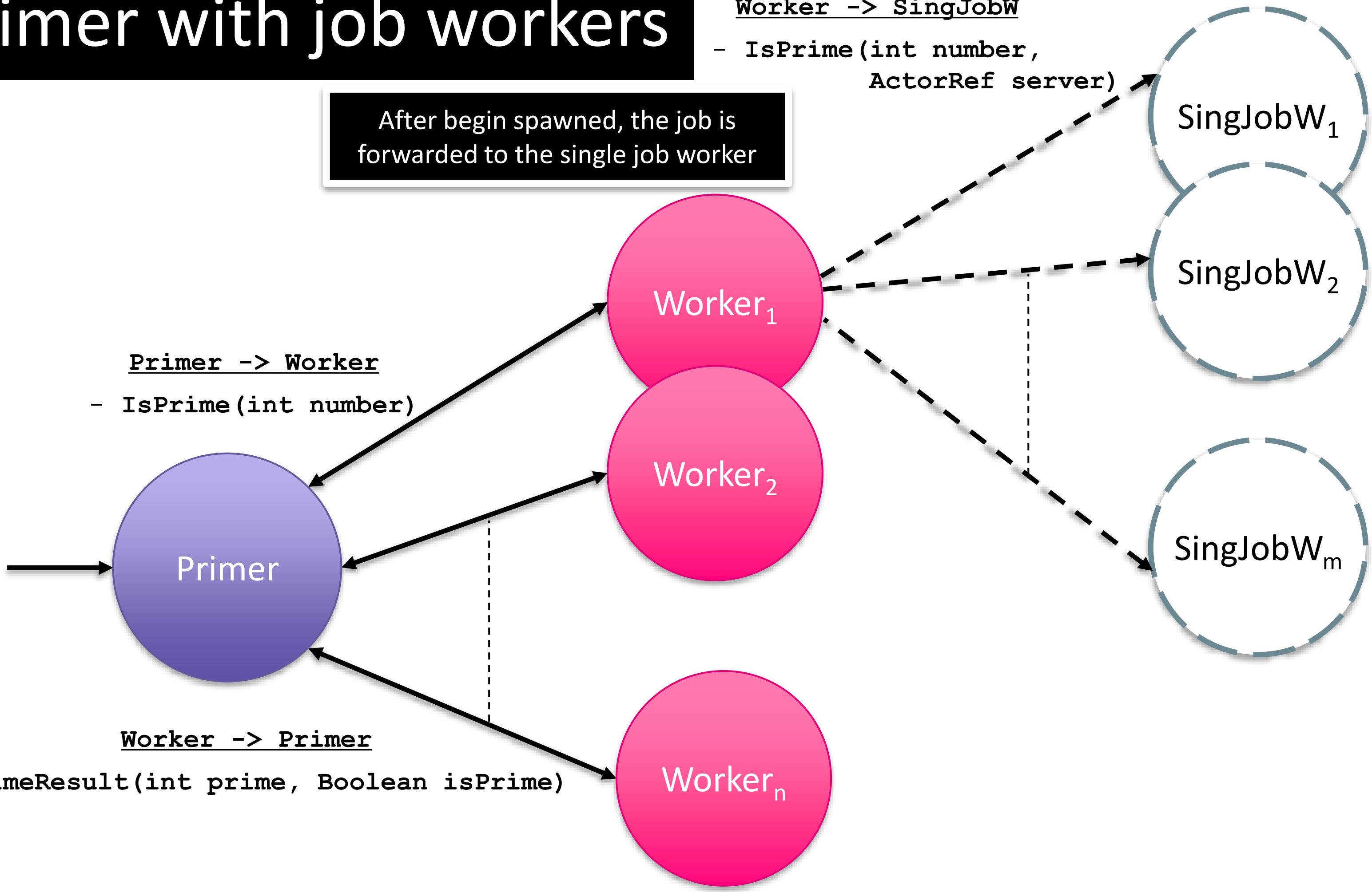
```
- IsPrime(int number)
```

Worker -> Primer

```
- PrimeResult(int prime, Boolean isPrime)
```

Primer with job workers

After begin spawned, the job is forwarded to the single job worker



Worker -> SingJobW

```
- IsPrime(int number,
          ActorRef server)
```

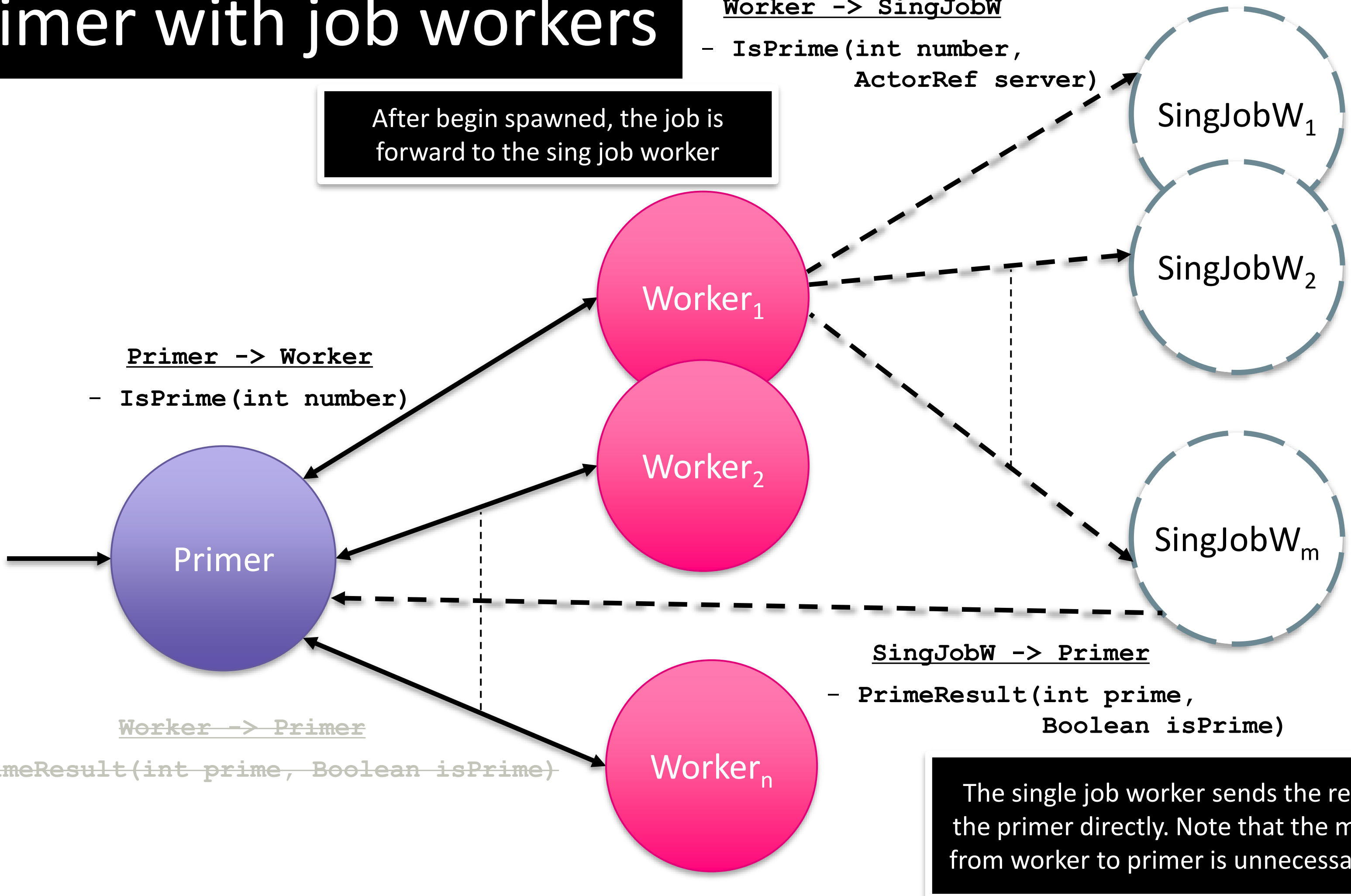
Primer -> Worker

```
- IsPrime(int number)
```

Worker -> Primer

```
- PrimeResult(int prime, Boolean isPrime)
```

Primer with job workers



Worker -> SingJobW

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After begin spawned, the job is forward to the sing job worker

Primer -> Worker

```
- IsPrime(int number)
```

~~Worker -> Primer~~

~~- PrimeResult(int prime, Boolean isPrime)~~

SingJobW -> Primer

```
- PrimeResult(int prime,
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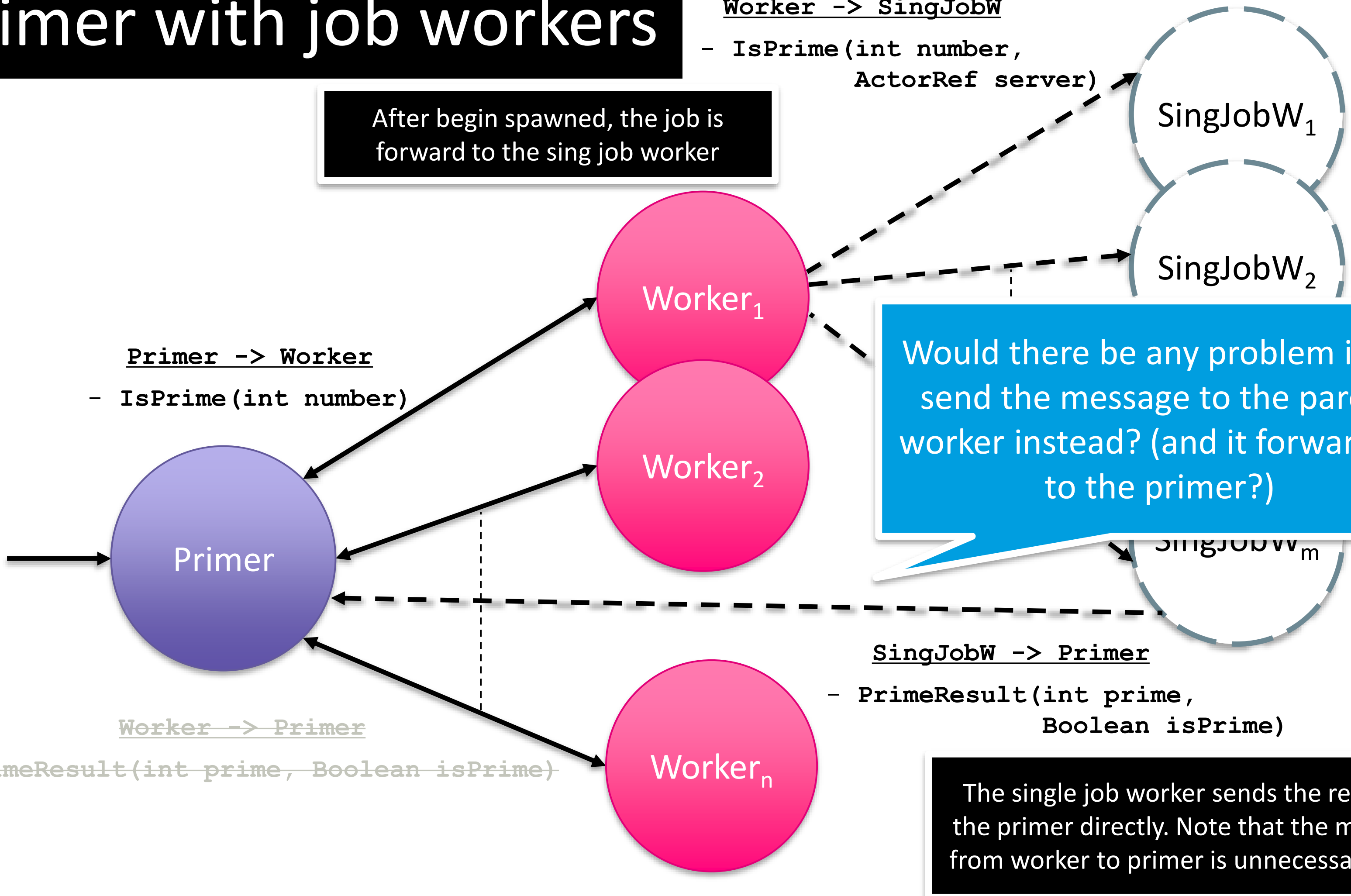
```

The single job worker sends the result to the primer directly. Note that the message from worker to primer is unnecessary now.

Primer with job workers

After begin spawned, the job is forward to the sing job worker



Worker -> SingJobW

- IsPrime(int number,
  ActorRef server)

Primer -> Worker

- IsPrime(int number)

~~Worker -> Primer~~

~~- PrimeResult(int prime, Boolean isPrime)~~

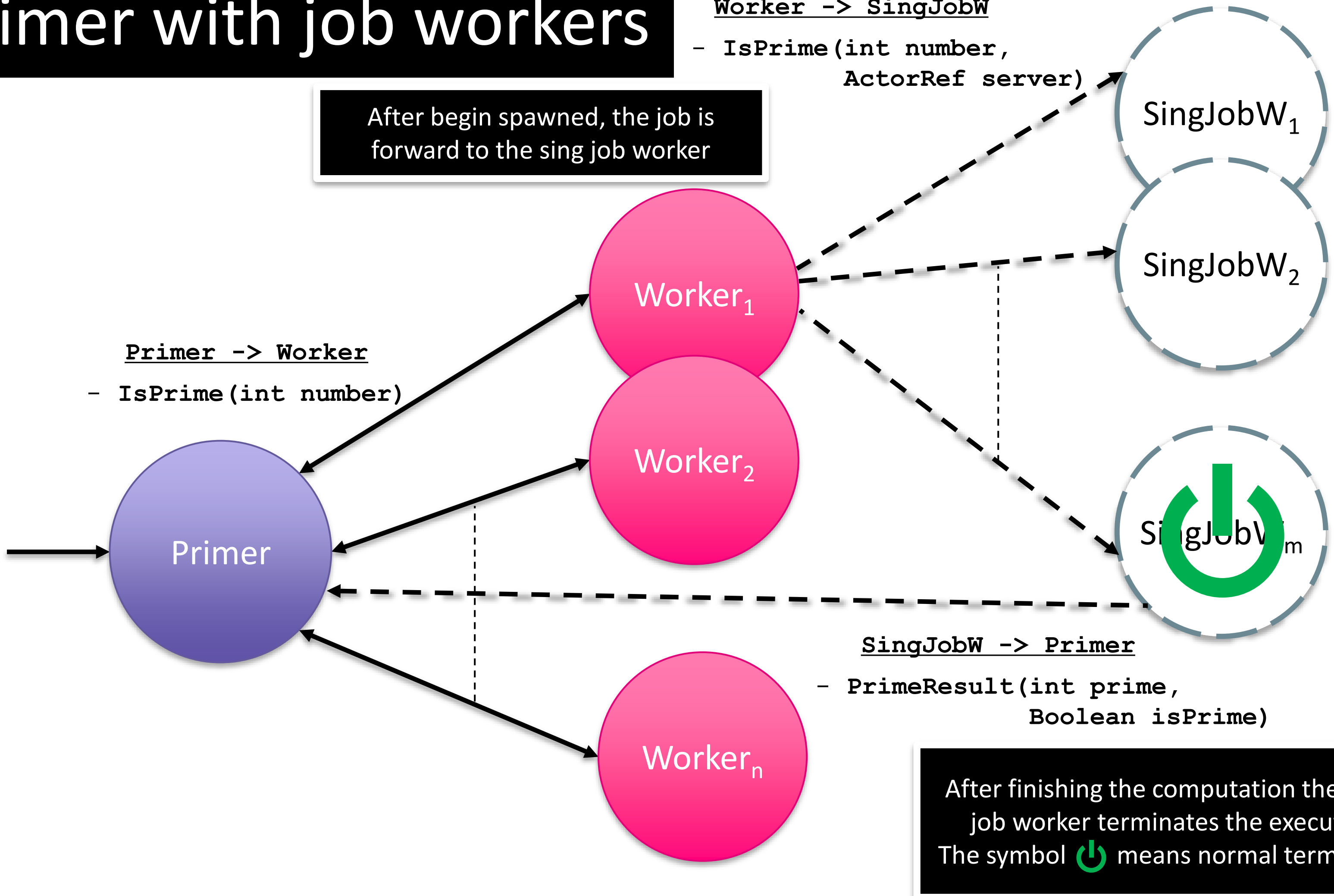
SingJobW -> Primer

- PrimeResult(int prime,
  Boolean isPrime)

Would there be any problem if we send the message to the parent worker instead? (and it forwards it to the primer?)

The single job worker sends the result to the primer directly. Note that the message from worker to primer is unnecessary now.

Primer with job workers



After begin spawned, the job is forward to the sing job worker

Worker -> SingJobW

```
– IsPrime(int number,
          ActorRef server)
```

Primer -> Worker

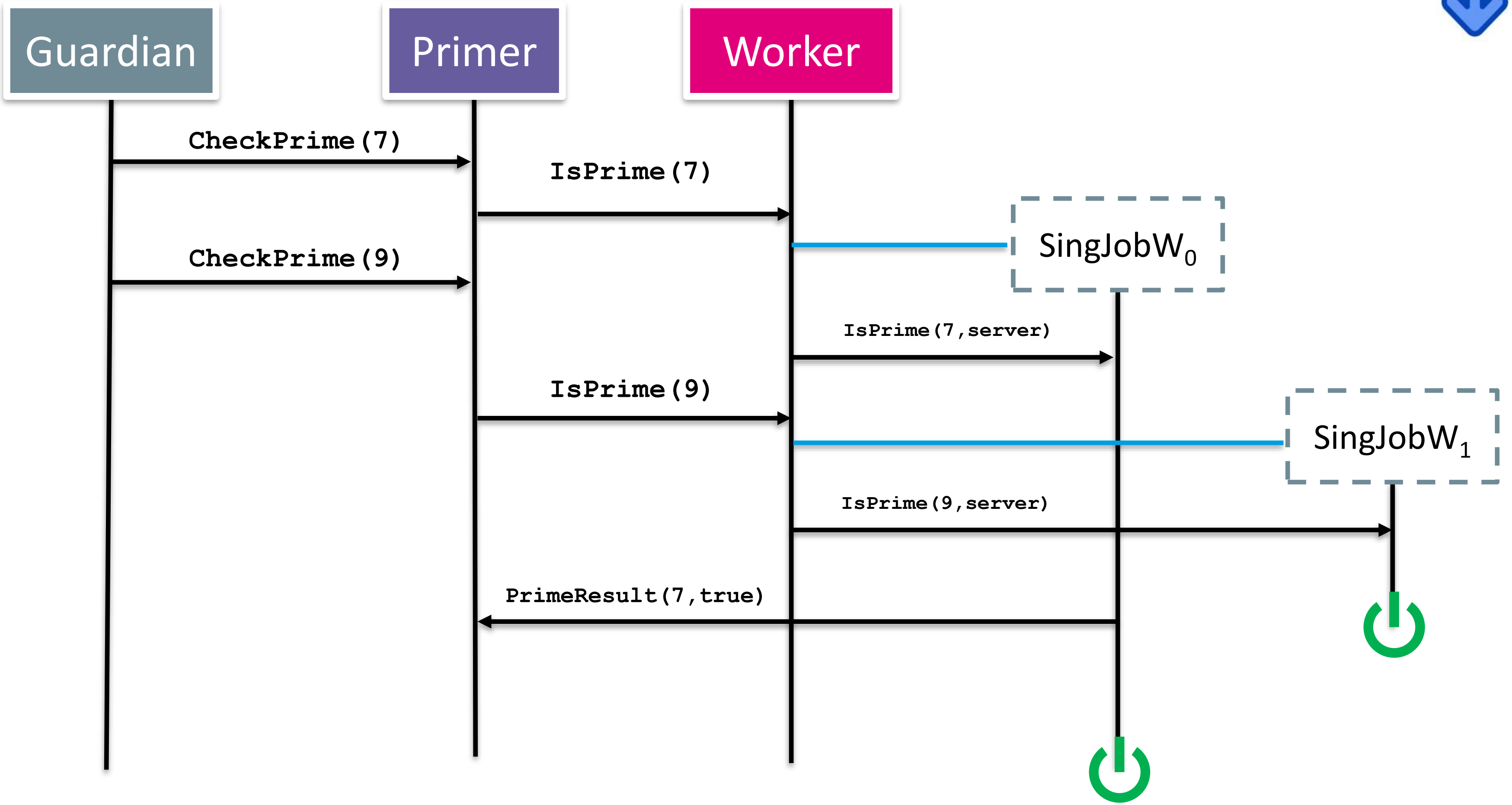
```
– IsPrime(int number)
```

SingJobW -> Primer

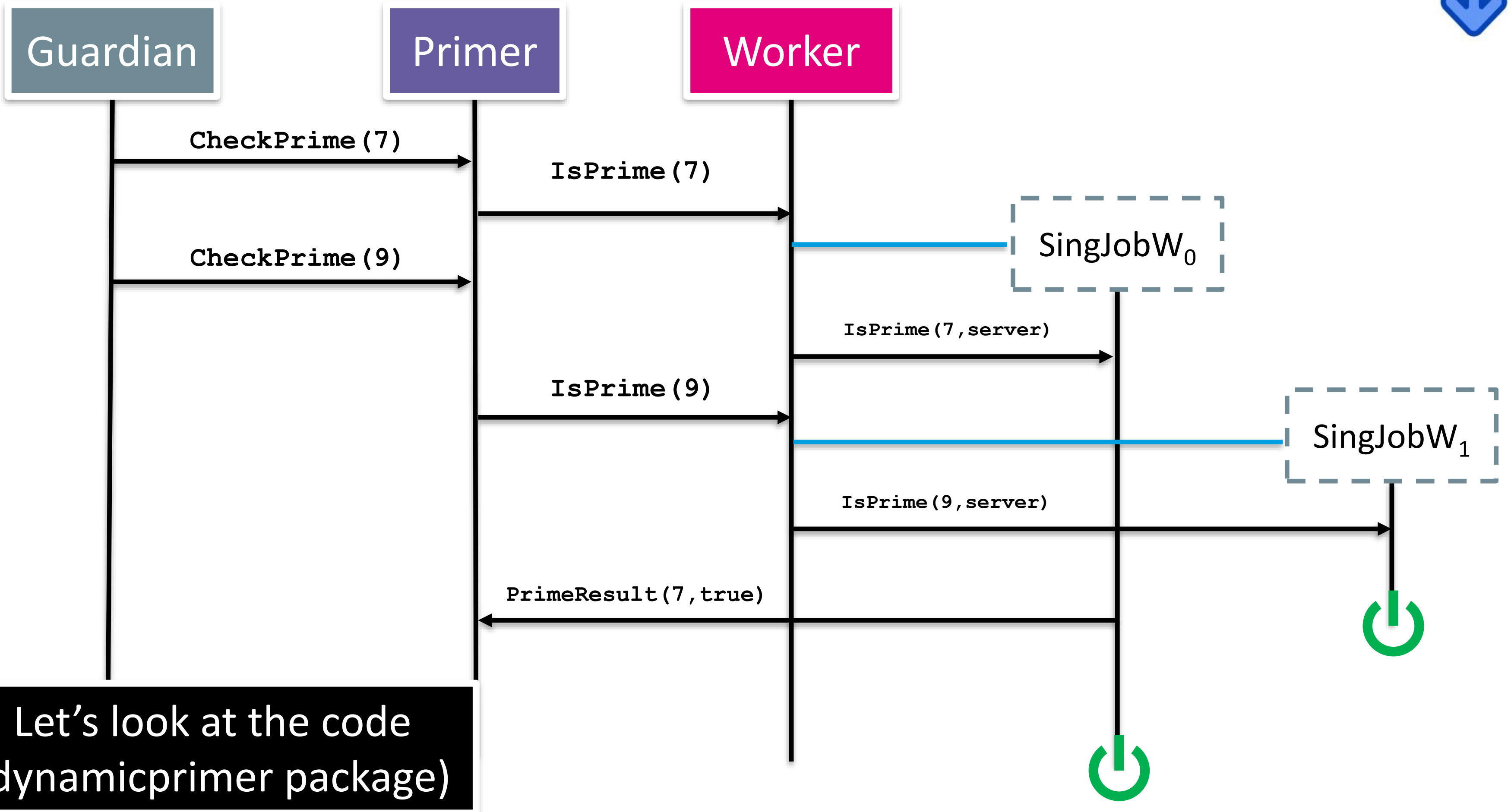
```
– PrimeResult(int prime,
              Boolean isPrime)
```

After finishing the computation the single job worker terminates the execution. The symbol ⏻ means normal termination

Primer with job workers – execution example

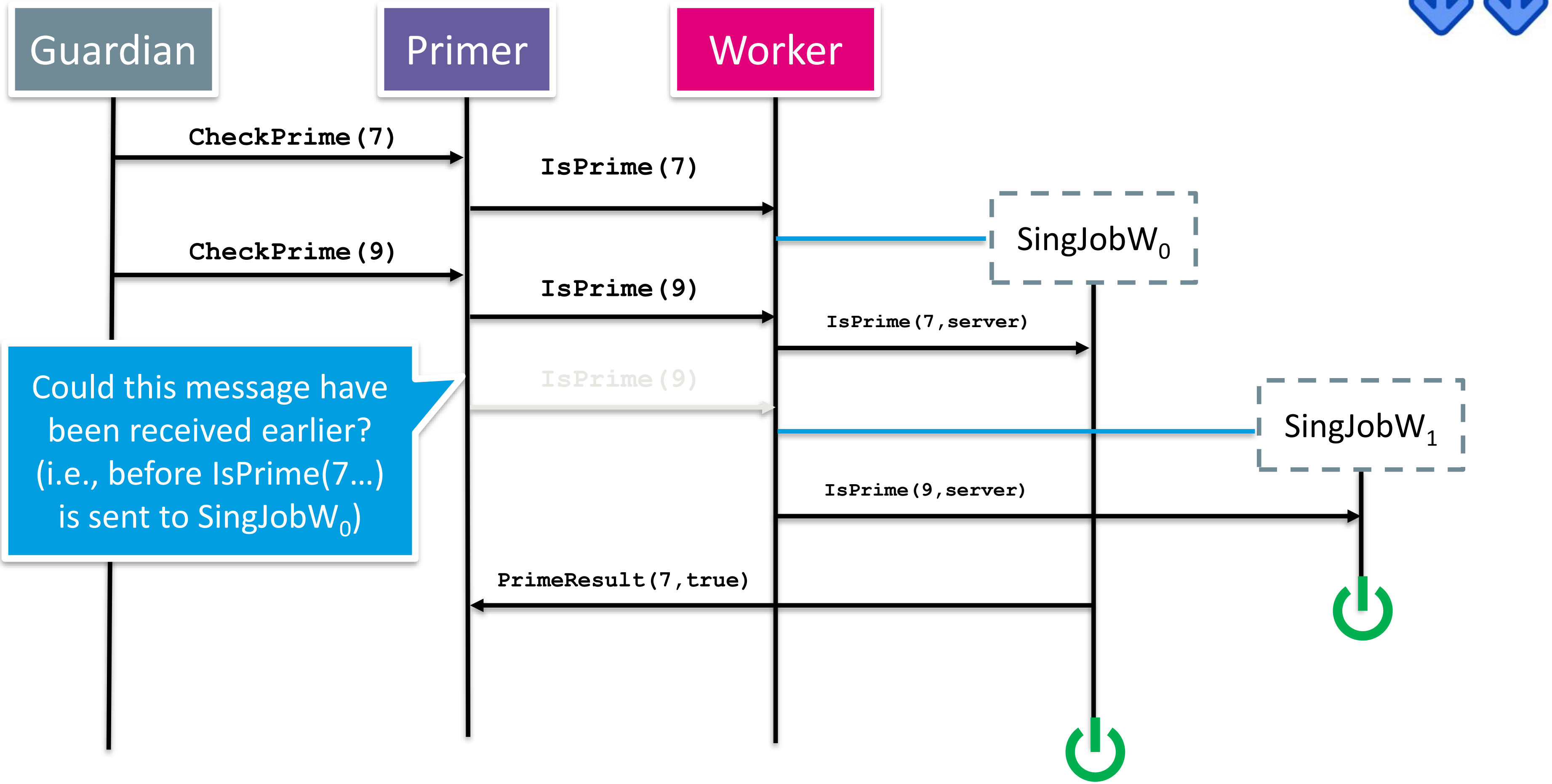


Primer with job workers – execution example



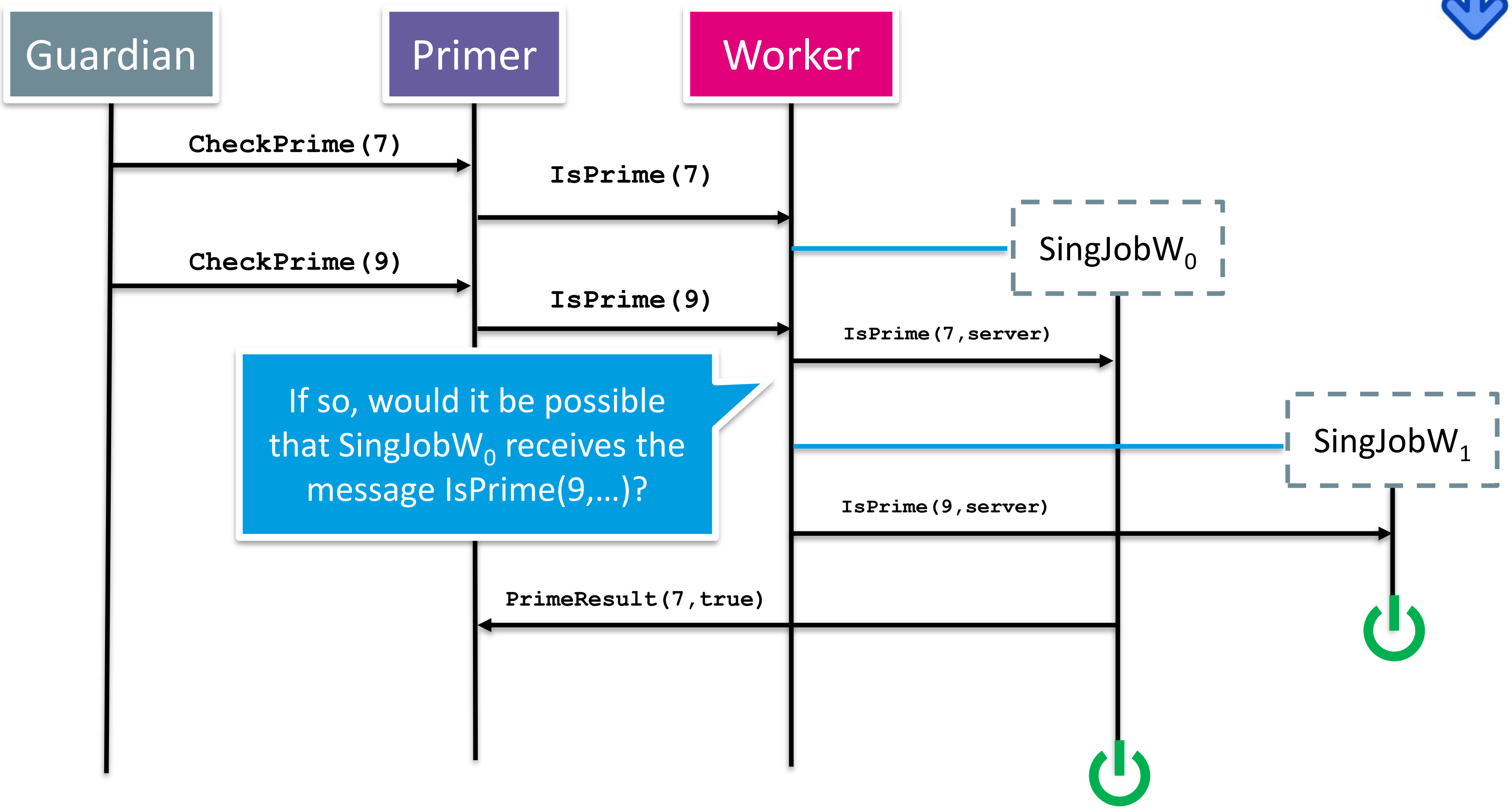
Let's look at the code (dynamicprimer package)

Primer with job workers – execution example



Could this message have been received earlier? (i.e., before IsPrime(7…) is sent to SingJobW_0)

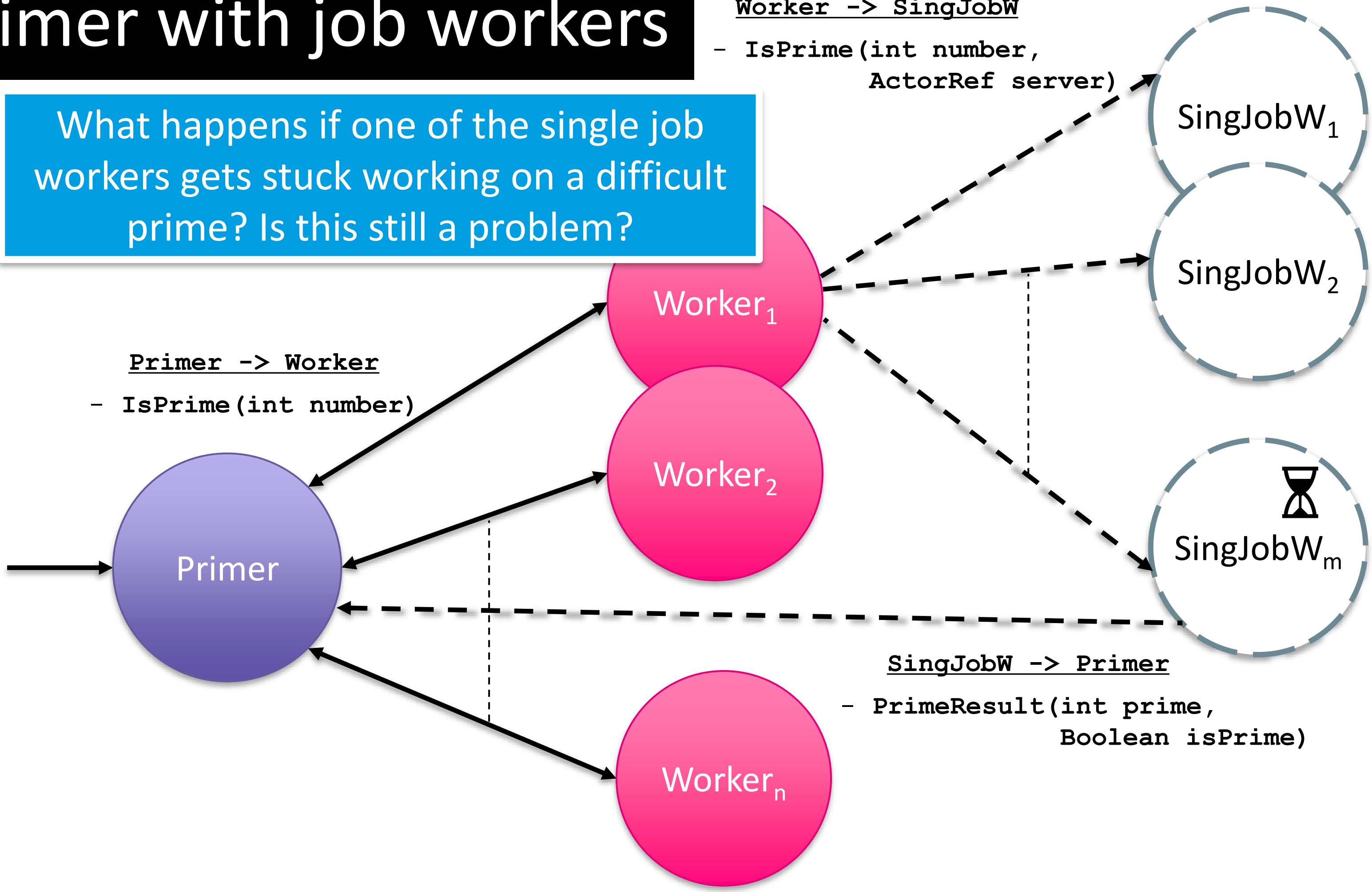
Primer with job workers – execution example



If so, would it be possible that SingJobW$_0$ receives the message IsPrime(9,…)?

Primer with job workers

What happens if one of the single job workers gets stuck working on a difficult prime? Is this still a problem?



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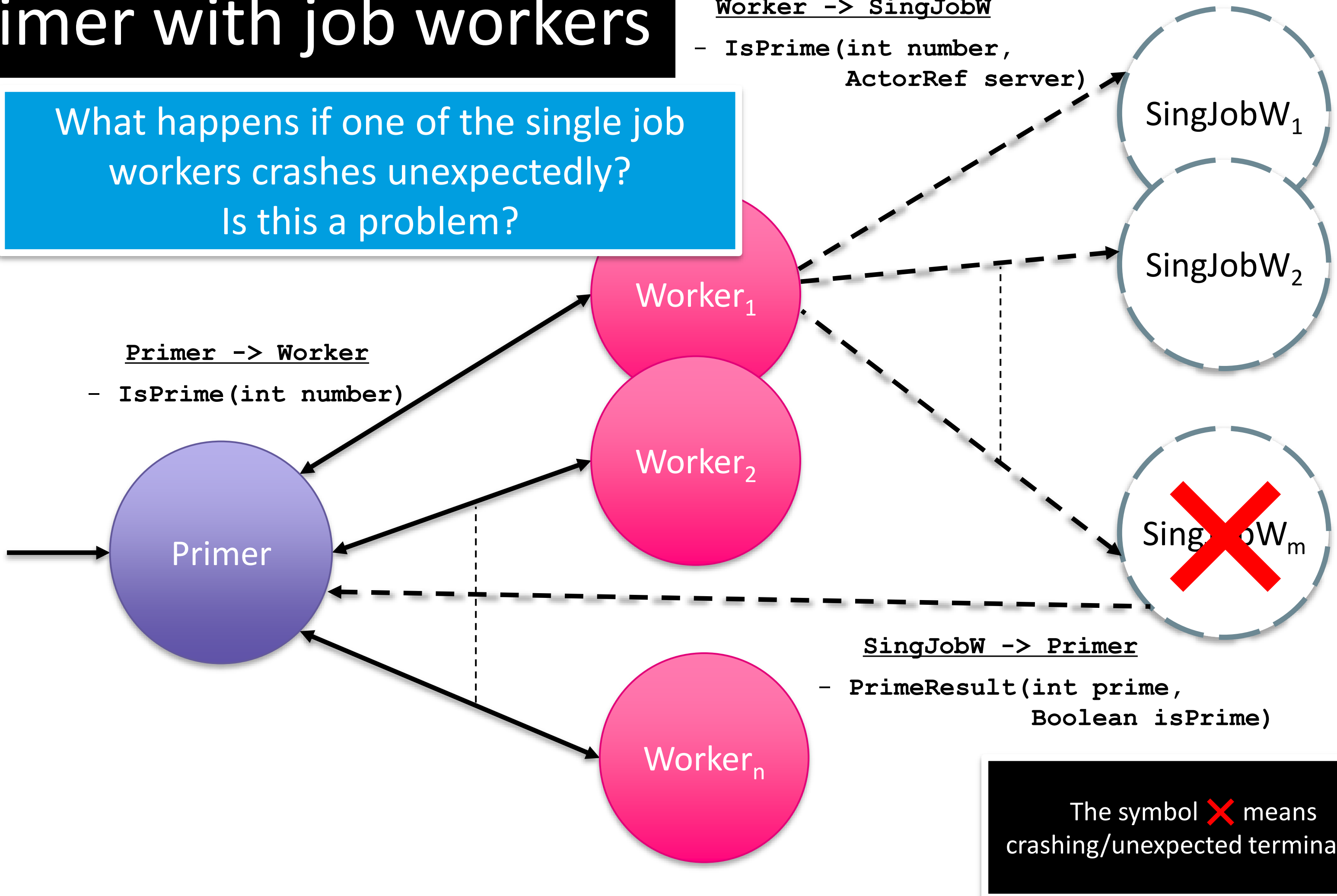
Primer with job workers



What happens if one of the single job workers crashes unexpectedly?
Is this a problem?

Worker -> SingJobW

- IsPrime(int number,
  ActorRef server)

Primer -> Worker

- IsPrime(int number)

SingJobW -> Primer

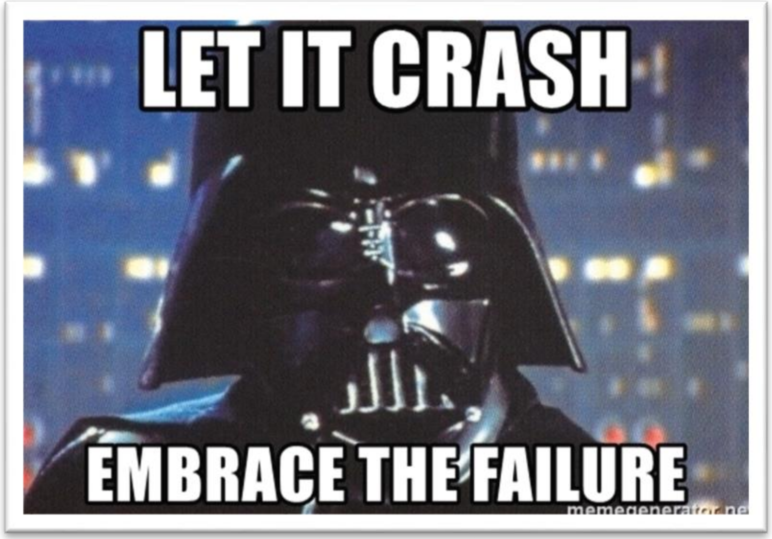
- PrimeResult(int prime,
  Boolean isPrime)

The symbol ✕ means crashing/unexpected termination

Fault-tolerance in Akka

Let it crash! model

- Actor libraries and programming languages encourage a *let it crash* programming model
- Do not put effort into sanitizing inputs or ensuring that actors never crash
  - Assume that things will fail
- Develop actors systems ensuring that if an actors crashes the system can recover
- Specially useful in distributed systems when you cannot predict what type of message you will receive



Supervision in Akka

- Akka implements supervision mechanisms to react to failures

- We focus on the closest to what may be defined in the actors model
  - Children inform their parents when they terminate or fail

- Actors may use the function **`watch(ActorRef<T> actor)`** to supervise their children

- If an actor is being supervised by a (parent) watcher, it sends to the watcher
  - A **`ChildFailed`** signal, if it crashed due to an exception
  - A **`Terminated`** signal, if it terminates normally

But ChilFailed extends from Terminated

Handling signals in Akka

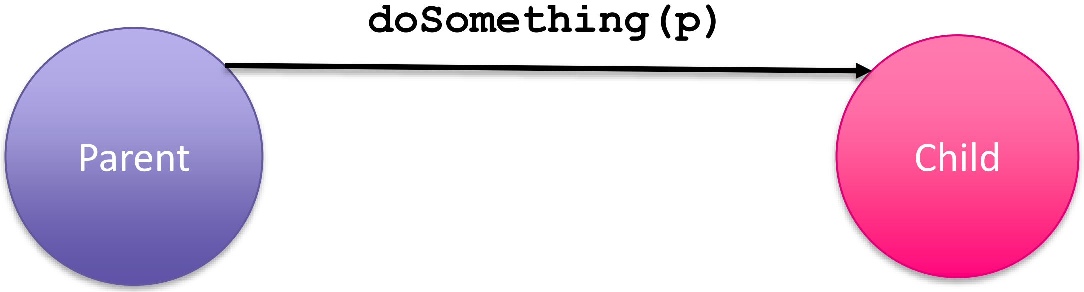
- A *signal* can be seen as a message that is automatically sent by Akka
- For a watcher to handle signals, it needs to extend the message handler with **`onSignal(Signal.class, Function f)`**

```
/* --- Message handling ---------------------------- */
@Override
public Receive<T> createReceive() {
    return newReceiveBuilder()
      .onMessage(Message.class, this::onMessage)
      // Here order matters `ChildFailed extends Terminated`
      .onSignal(ChildFailed.class, this::onChildFailed)
      .onSignal(Terminated.class, this::onTerminated)
      .build();
}
```

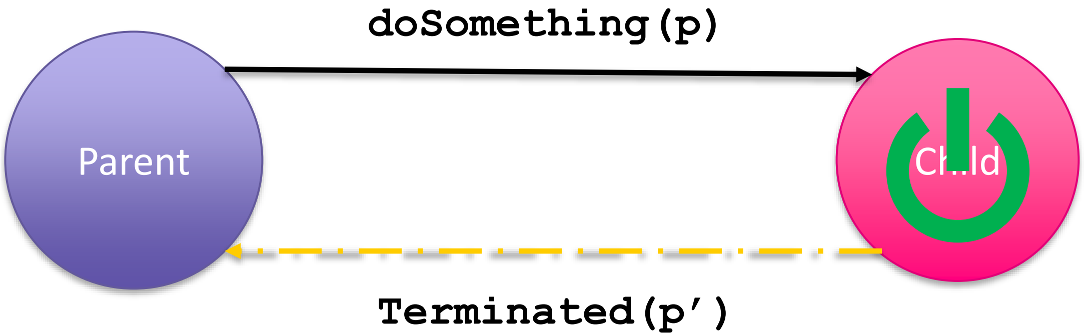
Note I: When processing a message/signal, the message handler picks the handler that first matches the class of the message.

Note II: Since ChildFailed extends Terminated, if onSignal(Terminated,…) appears before onSignal(ChildFailed,…), when a ChildFailed signal arrives, the latter onSignal will not be triggered.

Actor supervision (graphically)

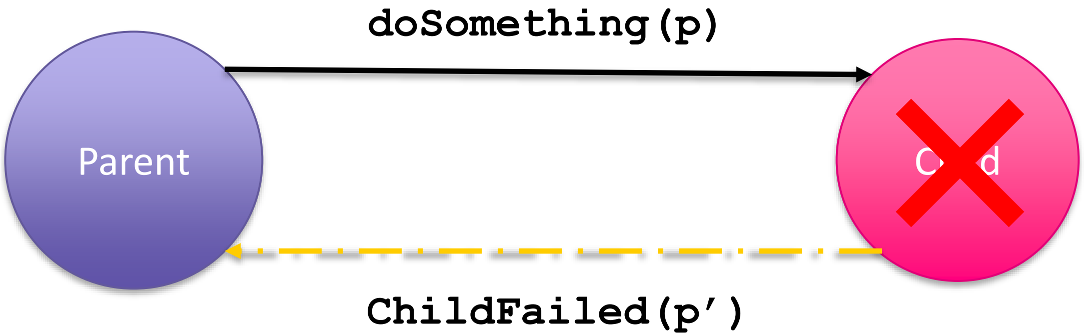


Actor supervision (graphically)



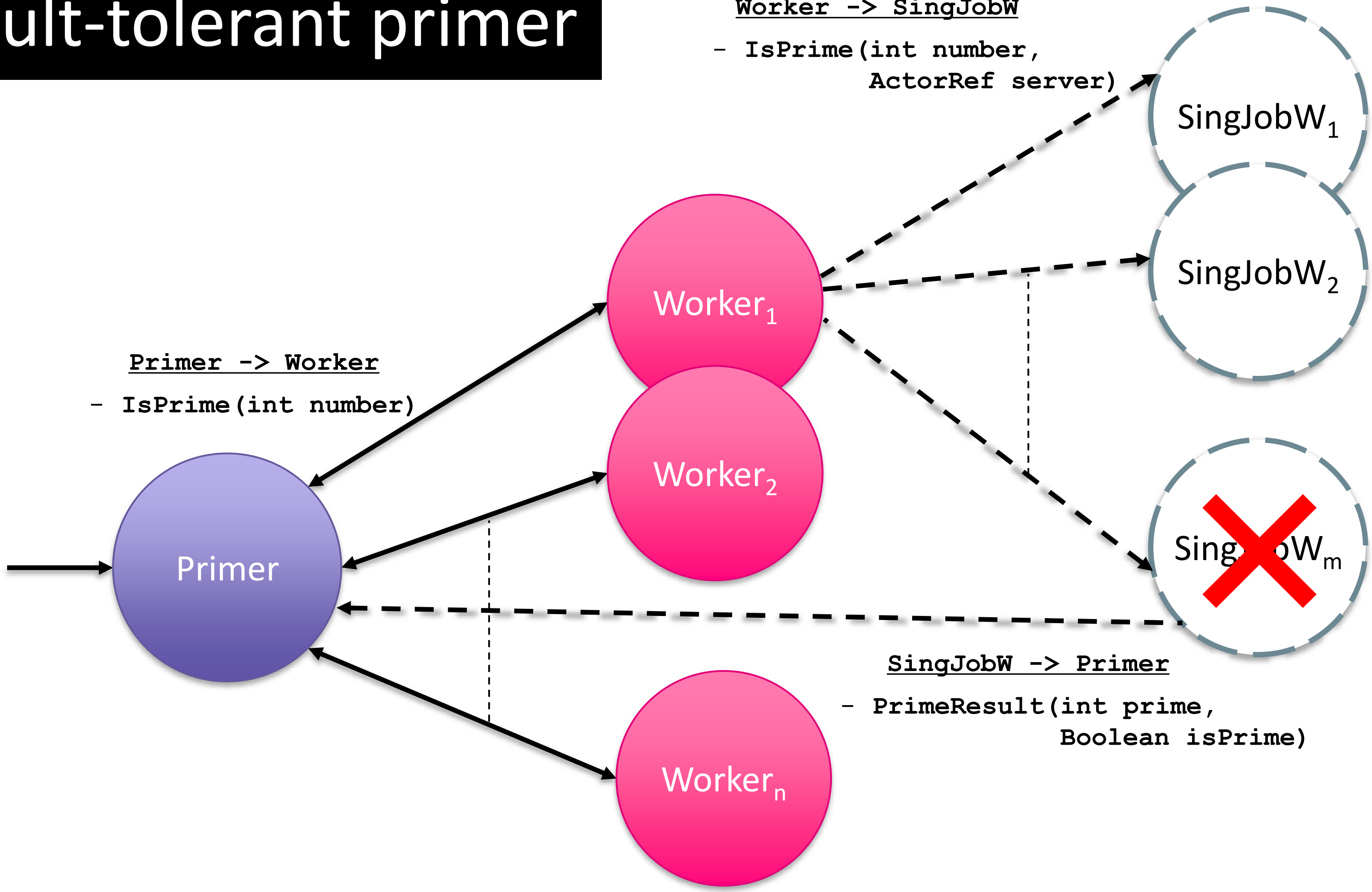
The dashed-dotted yellow arrow indicates the sending of a signal. These are sent automatically by Akka as part of the supervision functionality. If the child finishes normally, it sends a Terminated signal.

Actor supervision (graphically)



If the child finishes with an exception, it sends a ChildFailed signal.

Fault-tolerant primer



Worker -> SingJobW

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Primer -> Worker

- IsPrime(int number)

SingJobW -> Primer

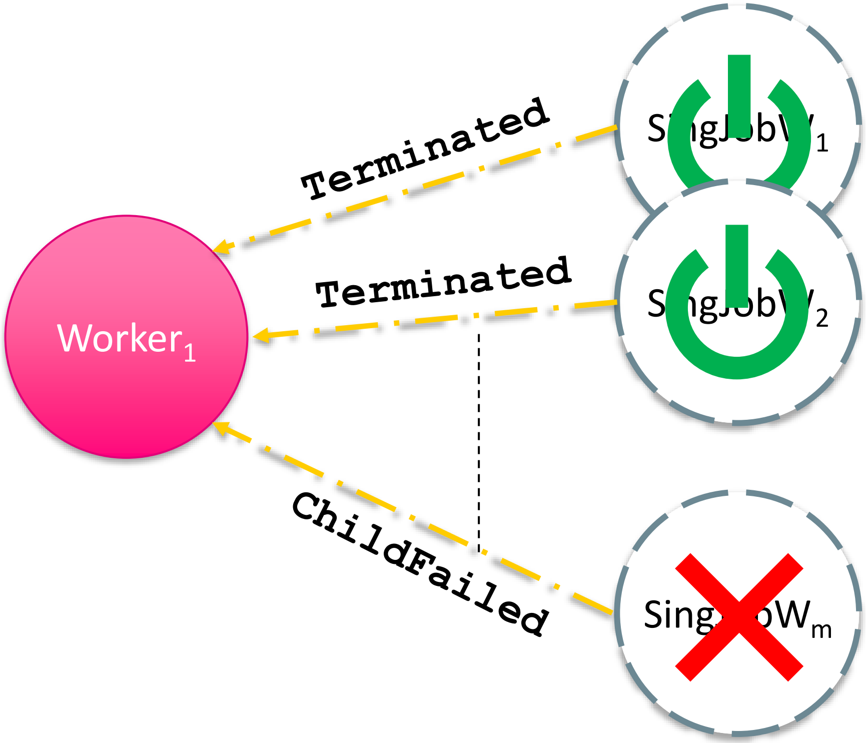
- PrimeResult(int prime,
  Boolean isPrime)

Fault-tolerant primer

- We extend the primer to handle the case when a single job worker fails

- To this end, the worker needs to:

1. Watch all the actors it spawns
2. Handle ChildFailed signals
   - The handler spawns a new worker and sends the number again to check whether it is prime
3. Handle Terminated signals
   - No more computation needed, we can mark the number as checked



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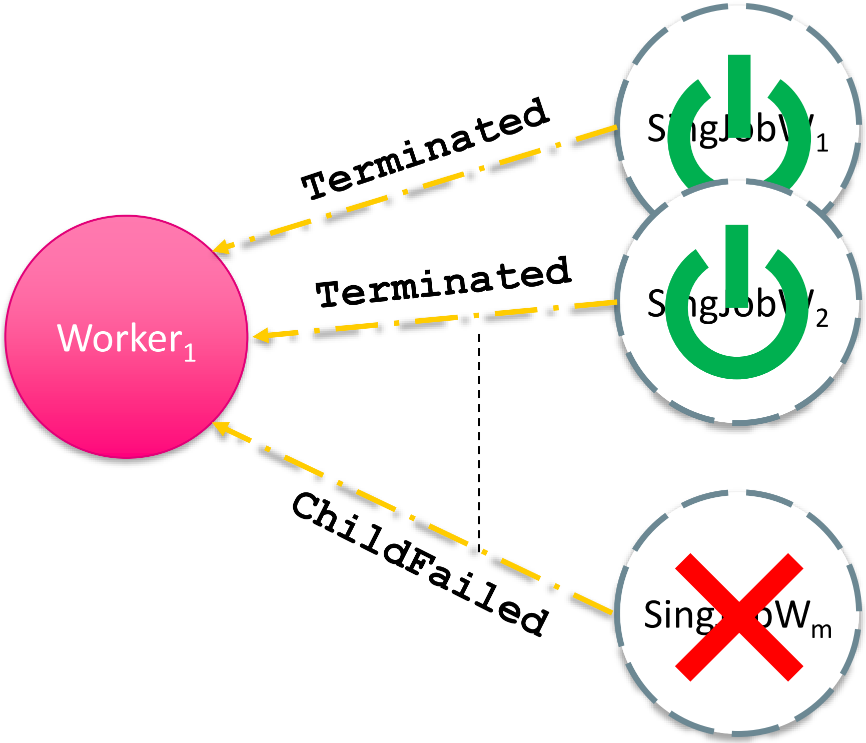
Do we need to extend the state of Worker actors to handle fault-tolerance?



Fault-tolerant primer

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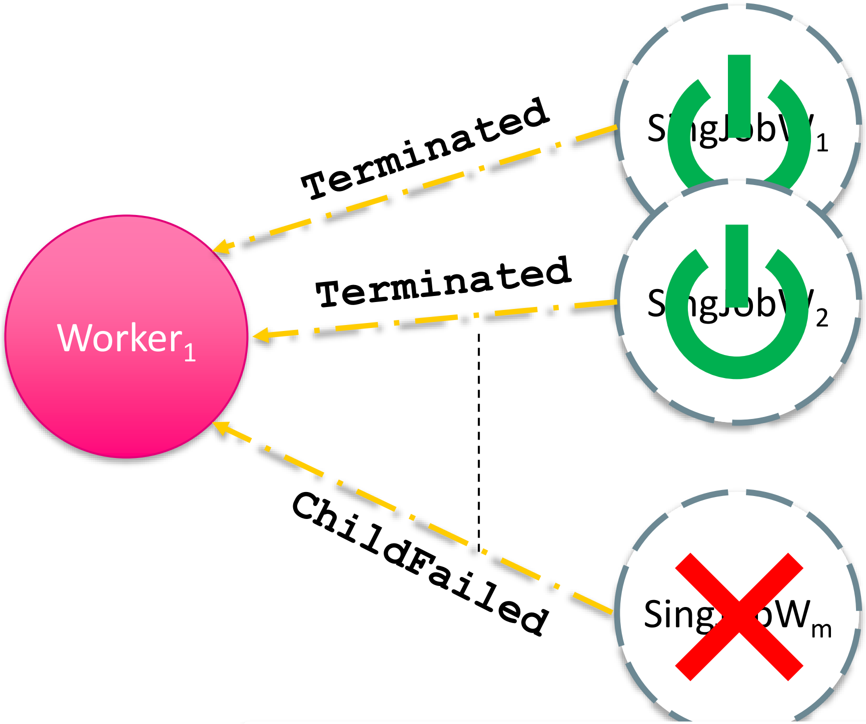


Let's look at the code (faulttolerantprimer package)

Adaptive load balancing

Adaptive load balancing

- *Load balancing* refers to the process of distributing a set of tasks over a set of resources (computing units), with the aim of making their overall processing more efficient. [Wikipedia]

- In the (static) primer system, we indiscriminately spawned processes to perform tasks
  - This may cause sending tasks to busy workers while other idle workers could be processing them

- There exists some patterns that aim at distributing computation fairly among actors.
  - For instance, the scatter-gather pattern

Scatter-Gather systems

- Scatter-Gather is a common design patter in distributed systems that can be easily implemented with actors

- Typically, the level of scattering (i.e., number of spawned actors) depends on the size of the problem to solve (dynamic load balancing)
  - But it can also be limited by other factors, e.g., CPU or memory usage

- A scatter-gather systems contains two main type of actors
  - Scatterer: if possible, it splits computation in smaller units. Otherwise, it may perform a processing step in the atomic piece of data and send it to a gatherer.
  - Gatherer: Receives pieces of data from scatterers, and combines them into a single piece of data performing

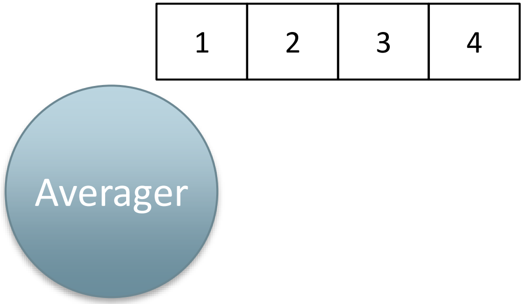
Average and scatter-gather

- A problem for which this pattern is suitable is computing the average of a list of numbers

- Given a set of natural numbers $a_1, a_2, \ldots, a_n$, the average is $\frac{1}{n}\sum_i a_i$
  - Note that this is equivalent to $\sum_i \frac{a_i}{n}$

- In a nutshell, we can have scatterer actors splitting computation and computing each factor $\frac{a_i}{n}$, and gatherers summing up the results

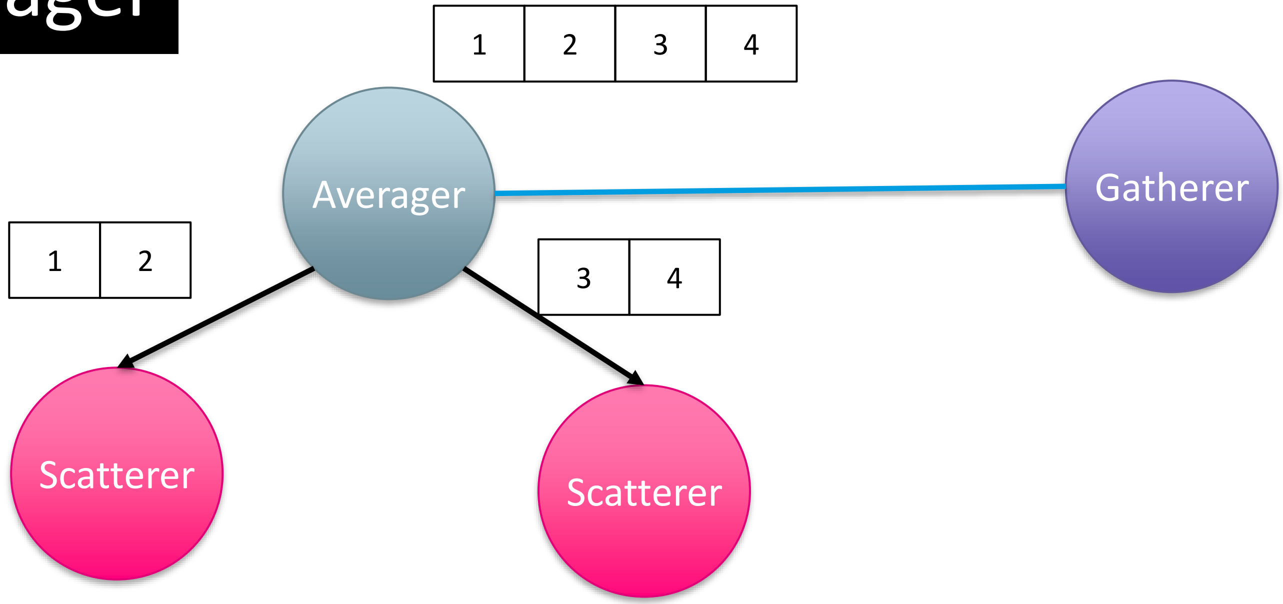
Averager



1	2	3	4

Consider a system that computes the average of a list of numbers

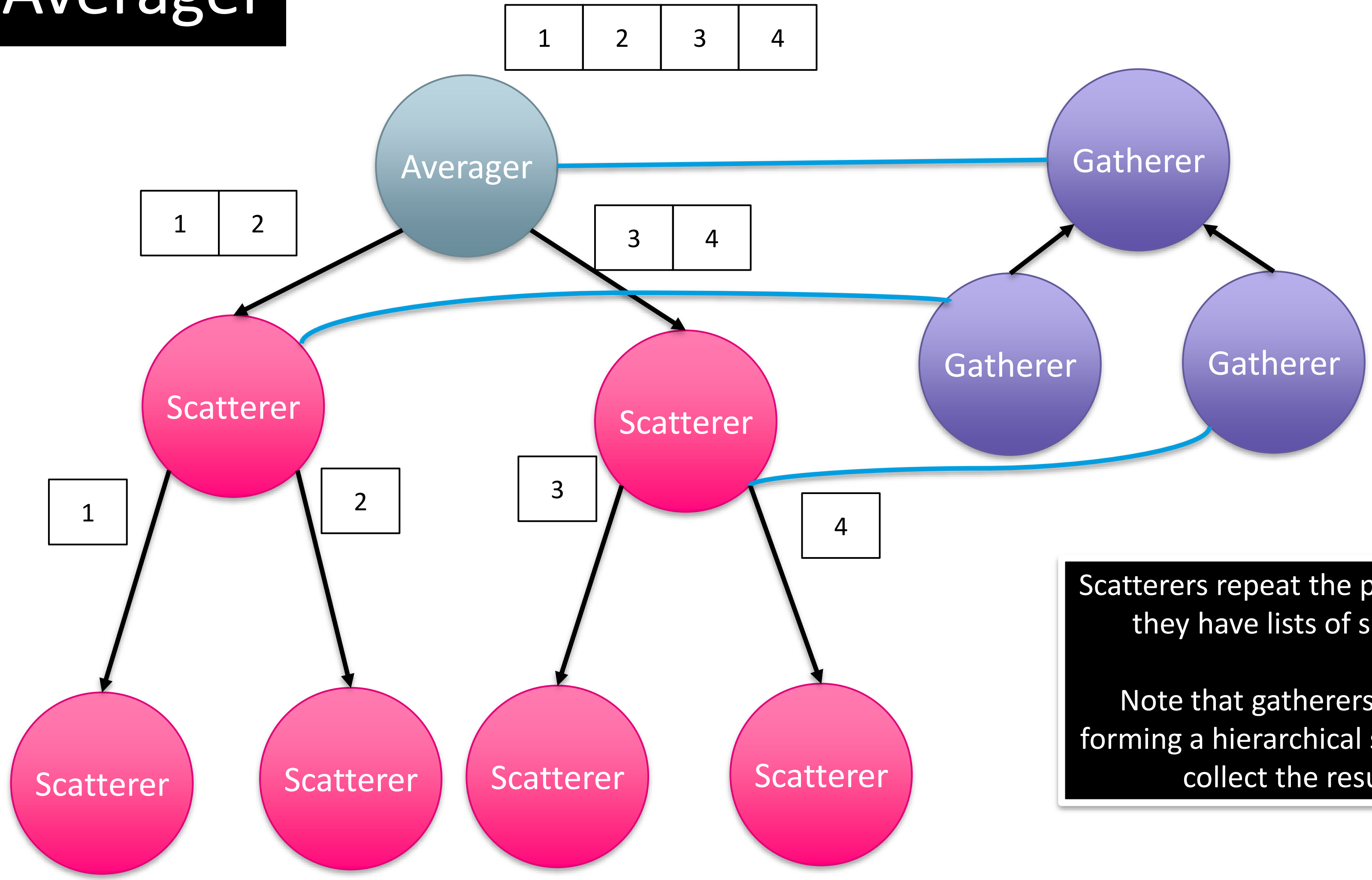
Averager



In the first step, we split the computation into two sublists, and assign them to separate scatterer workers.

Also, we spawn a gatherer worker that will receive merge the average of each sublist

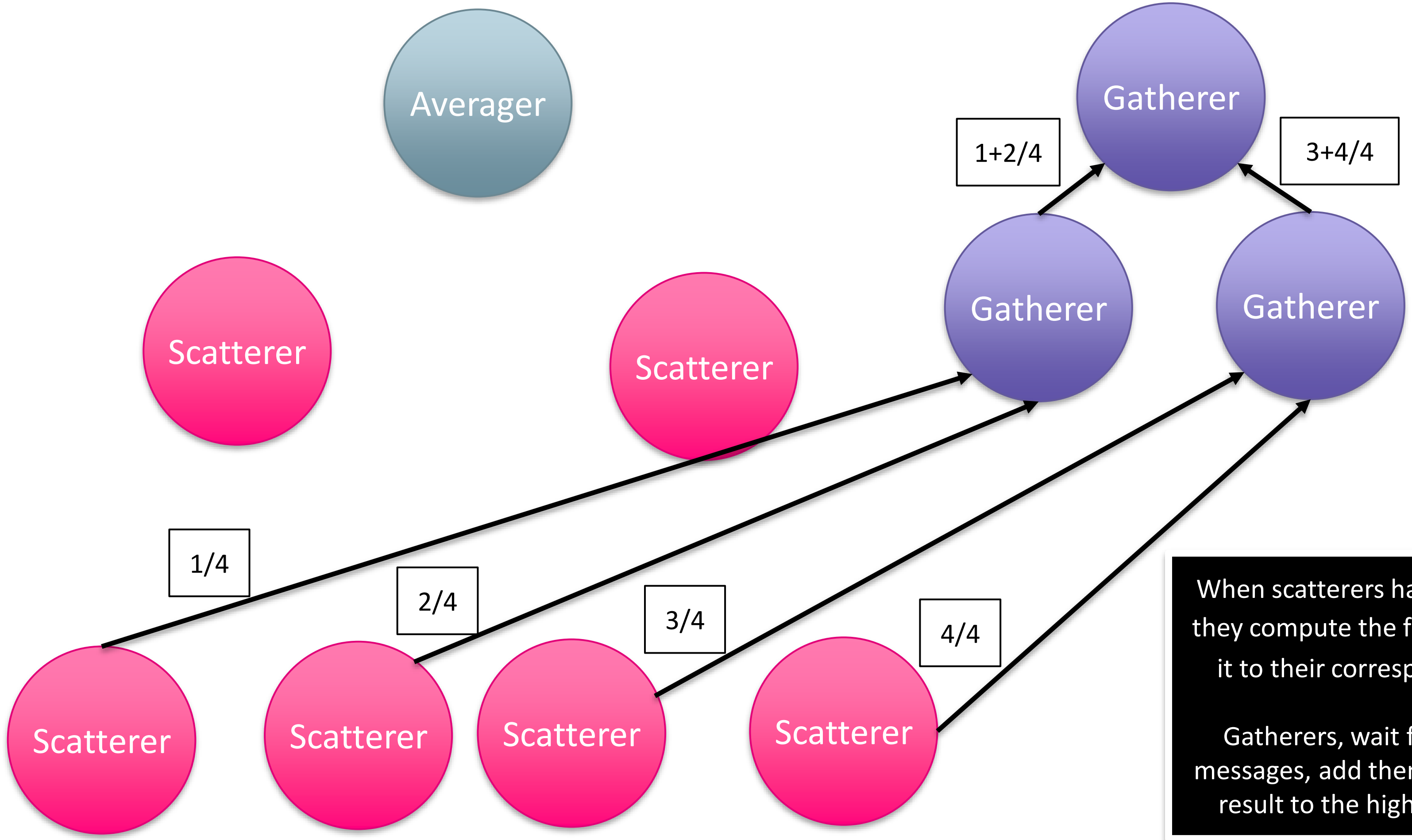
Averager



Scatterers repeat the process until they have lists of size one.

Note that gatherers are also forming a hierarchical structure to collect the results.

Averager

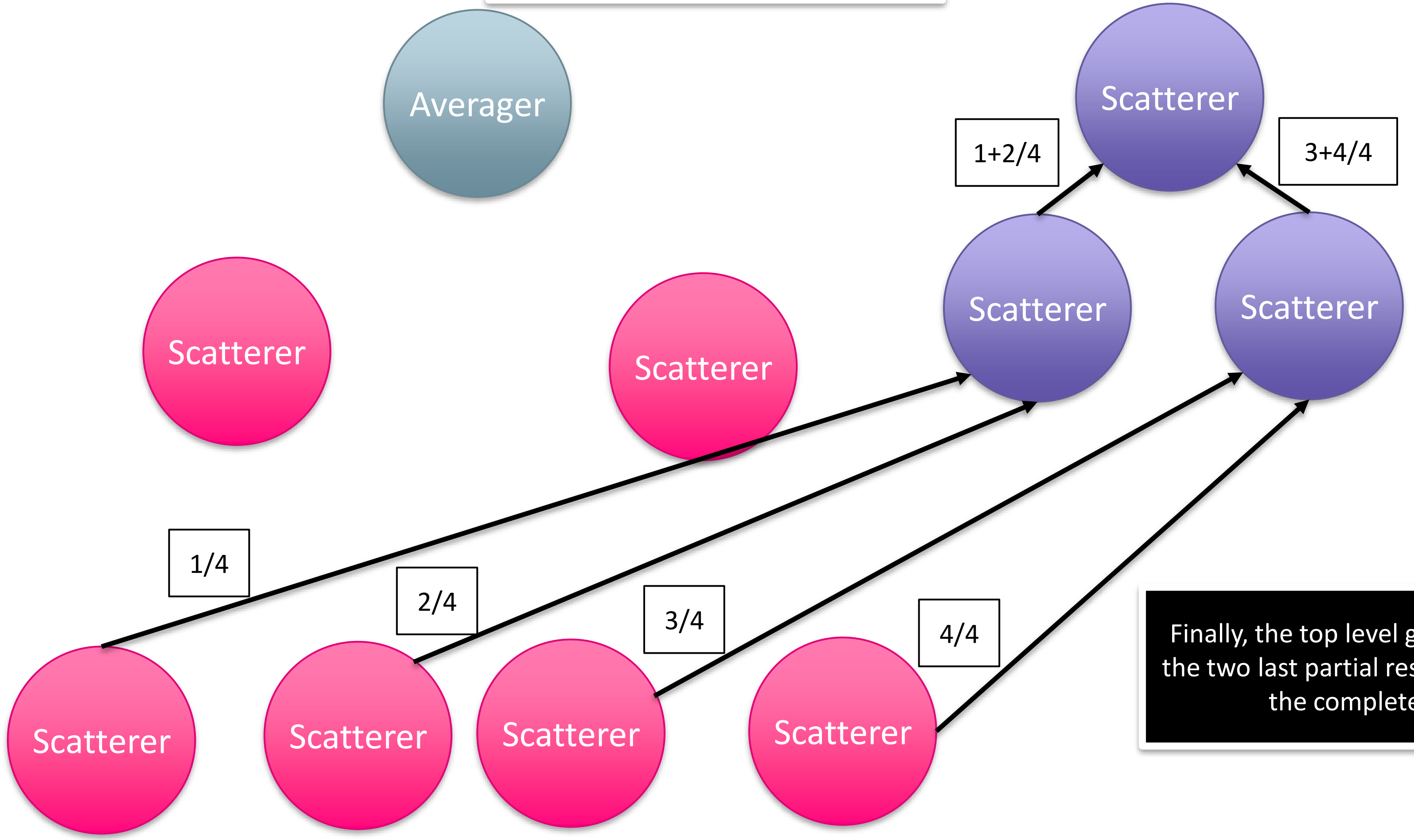


When scatterers have lists of size one they compute the fraction $\frac{a_i}{n}$ and send it to their corresponding gatherer.

Gatherers, wait for two scatterer messages, add them up, and send the result to the higher level gatherer

Averager

Proof by example ☺

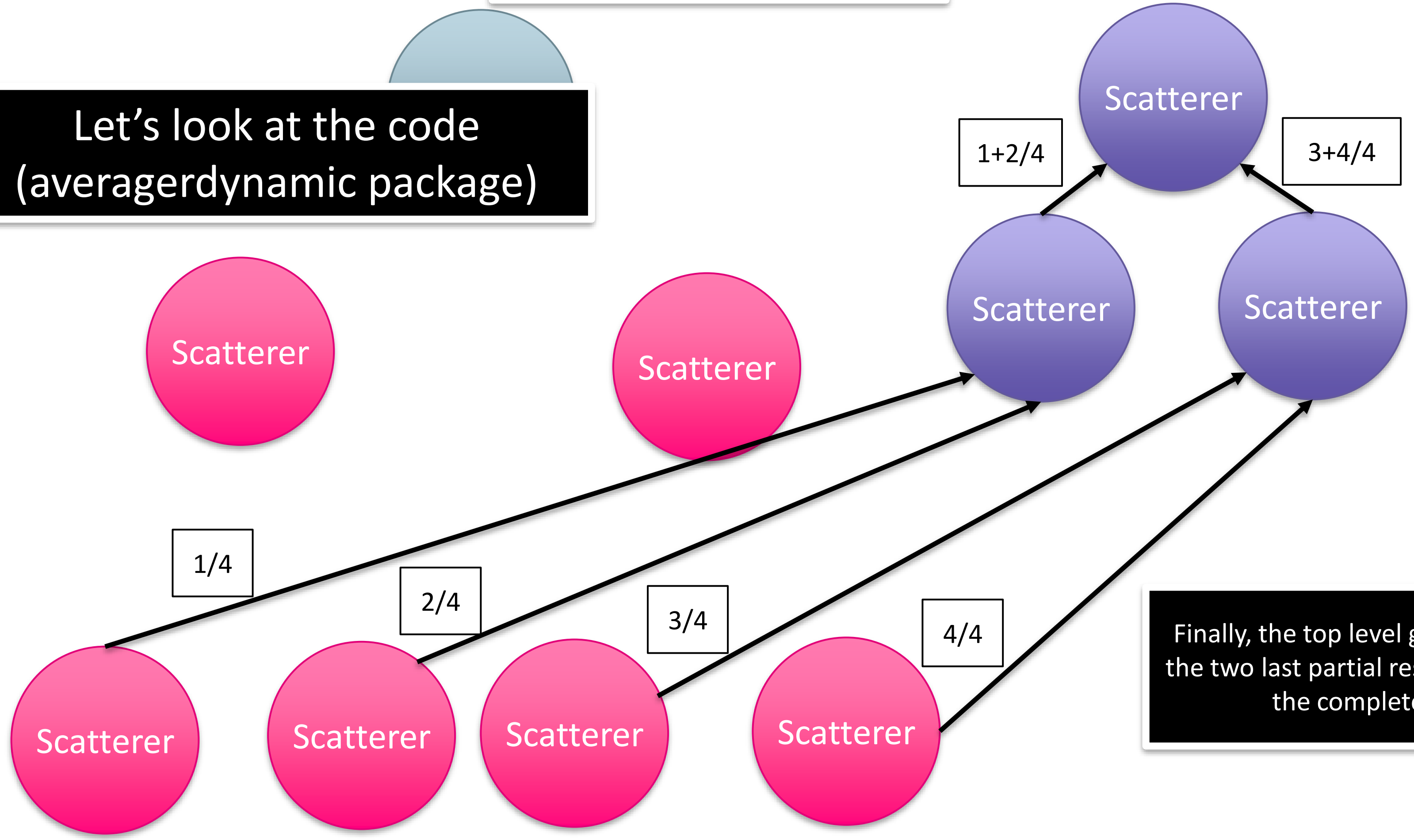


Finally, the top level gatherer adds up the two last partial results and outputs the complete result.

Averager

Proof by example ☺

Let’s look at the code (averagerdynamic package)



Finally, the top level gatherer adds up the two last partial results and outputs the complete result.

Other approaches to load balancing

- The size of the problem does not necessarily need to determine the distribution of computation

- One may have HW restrictions
  - As we saw, actors systems running in a single machine may not scale well beyond the number of processors

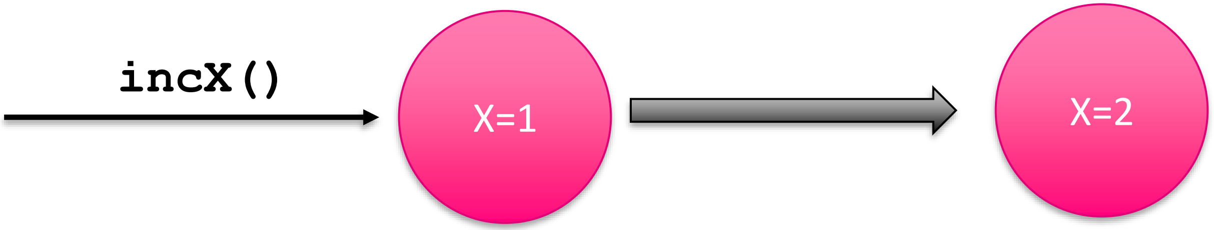
- Another example of adaptive load balancing are elastic systems
  - Elastic systems try to keep a number of active actors proportional to the workload
  - Several exercises for this week target implementing an elastic server

Changing behaviour

Actors with changing behaviour

- The actors model states that *"upon receiving a message an actor may change its behaviour"*

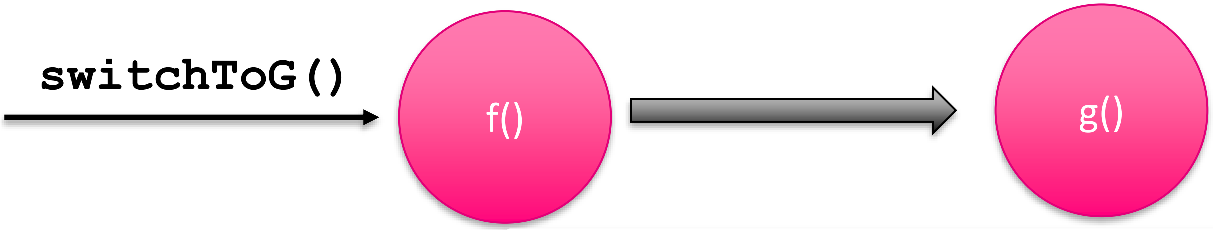
- So far we have considered change in behaviour as change in state



The actor receives a message and updates its internal state. The arrow ➡ models state transition

Actors with changing behaviour

- The actors model states that *“upon receiving a message an actor may change its behaviour”*
- However, actors may also change the *functions* to process messages (i.e., message handlers)



In this example, the actor that was executing f() when a message comes, now executes g(). The new function g() could be completely different, e.g., changing how messages are processed or even waiting for different type of messages!

Changing behaviour in Akka

- In Akka, we can change the behaviour of an actor by defining a function that returns the new behaviour
  - Like in the behaviour defined in createReceive()

- In fact, we have already done this when we return Behaviors.stopped() to terminate an actor

Averager with changing behaviour

- The packages averagerdynamic and averagerbehavior implement the same system, but the latter uses changing behaviour

- In averagerdynamic, we use a Boolean variable (**`receivedFirstNumber`**) to determine whether we have received the first or second GathererCommand message

- In averagebehavior, we define a new behaviour (**`waitForSecond`**) to which the actor transitions after receiving the first GathereCommand message.
  - In this way we can do without the Boolean variable mentioned above

Averager with changing behaviour

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Let’s look at the code
(averagerbehaviors package)

Agenda

- Actors model (revisited)
  - Broadcaster
  - Primer
- Dynamic topology
- Fault-tolerance
  - Supervision
- Adaptive load balancing
  - Scatter-Gather
- Changing behaviour