PRACTICAL CONCURRENT
- & -
PARALLEL PROGRAMMING

~~Riko~~
~~**JAKOB**~~

Claus
BRABRAND

PRACTICAL CONCURRENT - & - PARALLEL PROGRAMMING

MESSAGE PASSING CONCURRENCY I / II

Claus Brabrand

(((brabrand@itu.dk)))

Associate Professor, Ph.D.

(((Dept. of Computer Science)))

IT University of Copenhagen

Introduction

Problem:

- Sharing && Mutability!

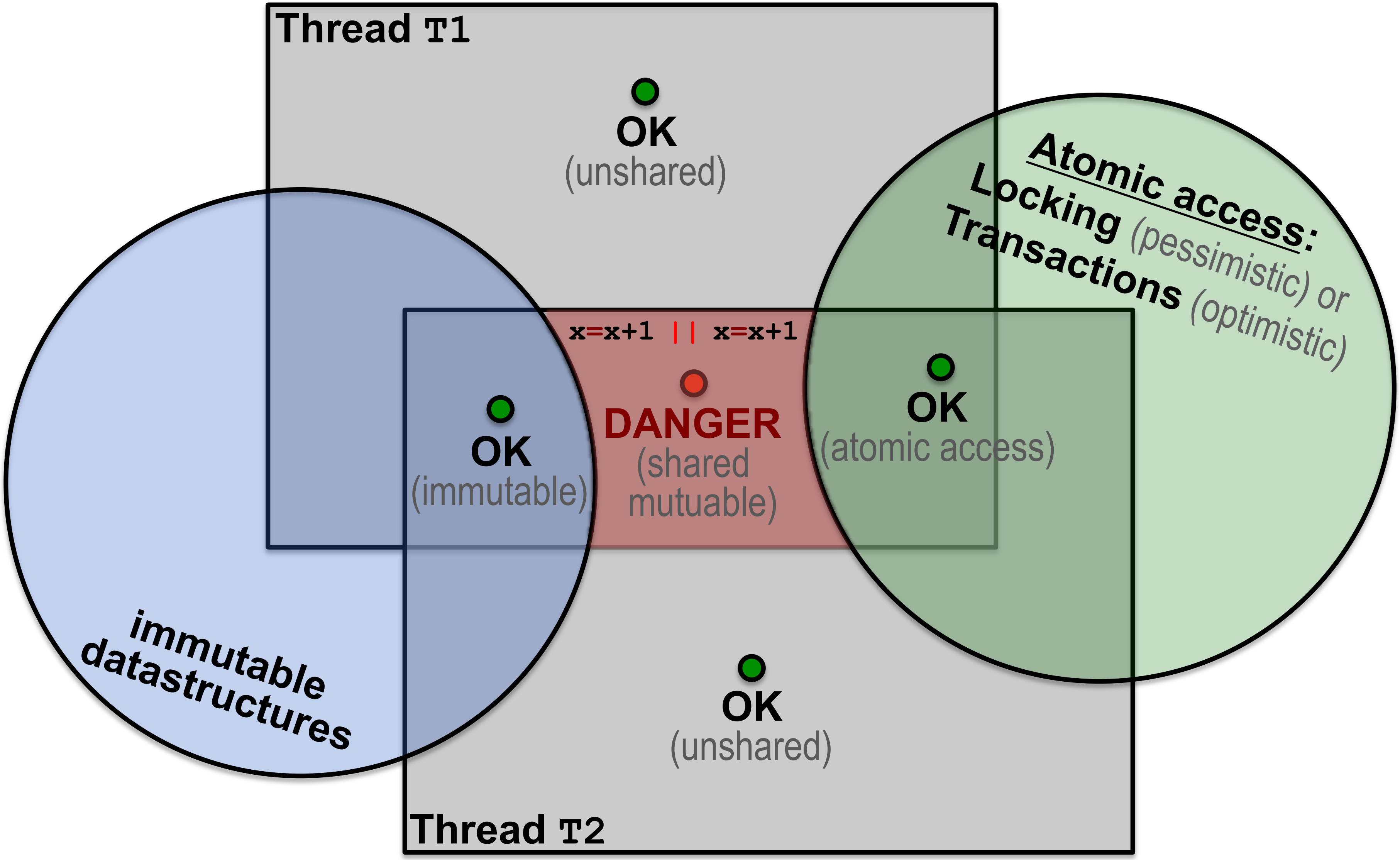
Solutions:

- 1) Atomic access (shared res.): "synchronized"
  - a) Locking (pessimistic concurrency)
  - b) Transactions (optimistic concurrency)
- 2) Eliminate mutability: "final"
  - E.g., functional programming
- 3) Eliminate sharing...: *message passing concurrency*

PROBLEM:
Sharing && Mutability!

SOLUTIONS:

1) atomic access!
   locking or transactions
   NB: avoid deadlock!
2) avoid mutability!
3) avoid sharing...



PROBLEM:

Sharing && Mutability!

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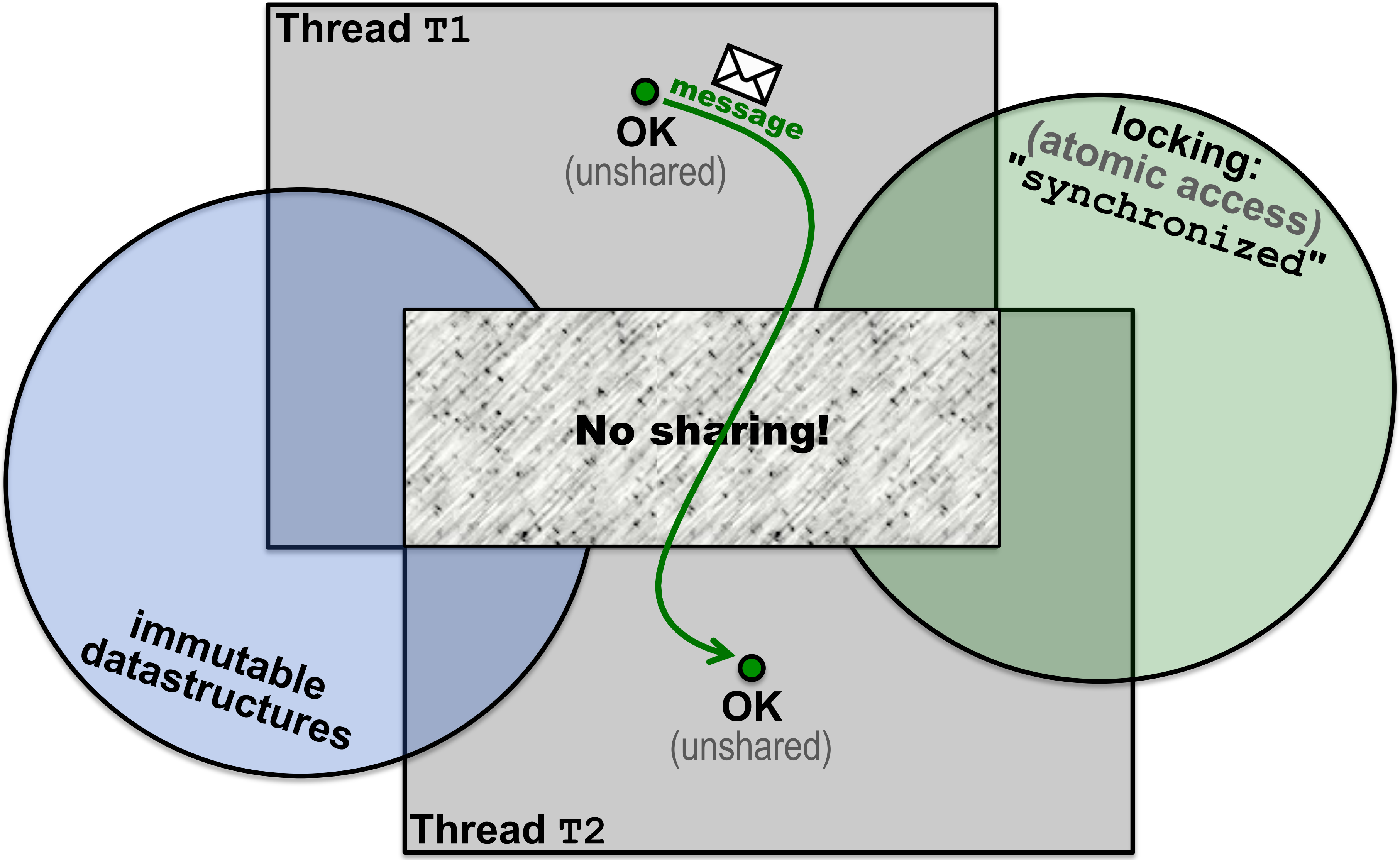
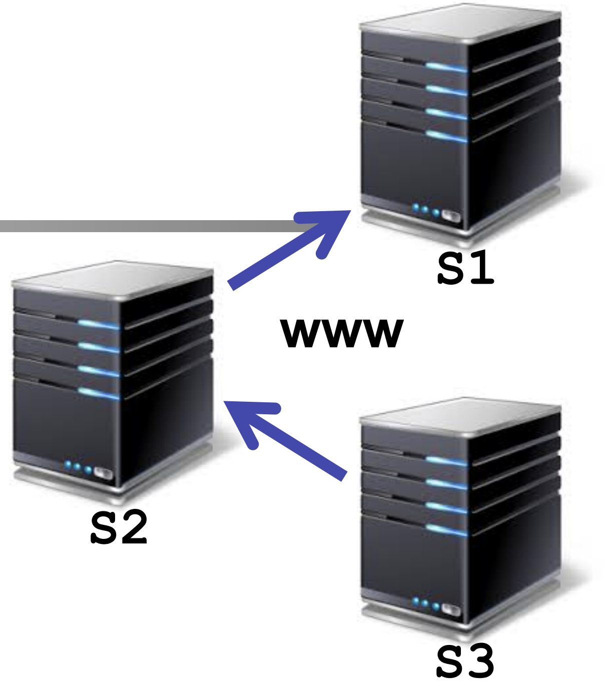
1) atomic access!
   locking or transactions
   NB: avoid deadlock!
2) avoid mutability!
3) avoid sharing...



World Wide Web...

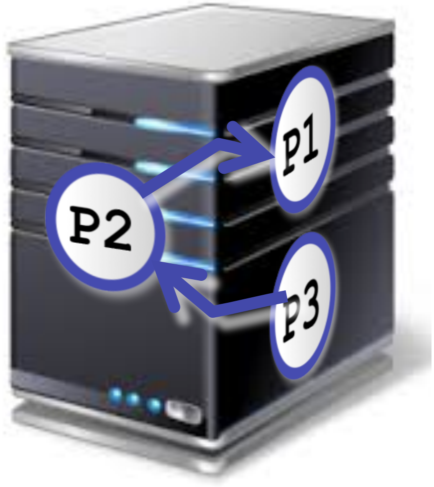


In a distributed setting, there's no shared memory:

- Communication is achieved *via "message passing"*
  - (between concurrently executing servers)

Message Passing Concurrency:

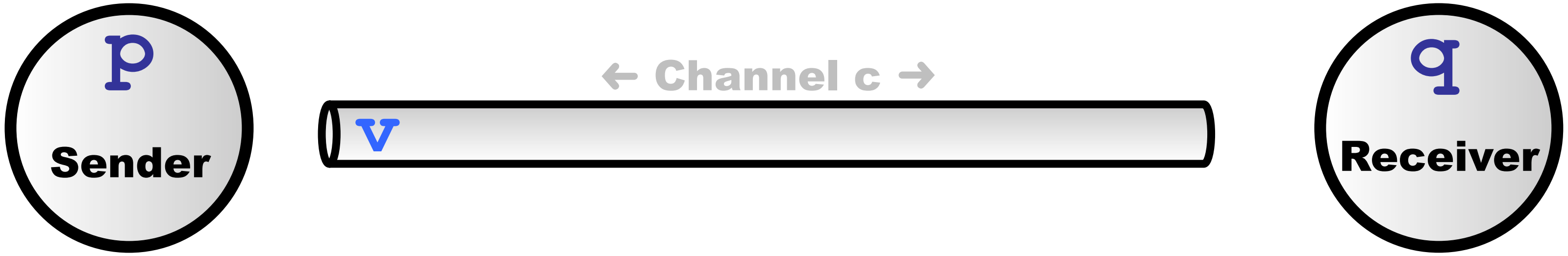
- Same idea (*message passing*) usable in non-distributed setting:
  - (between processes, inside a server)



Forms of Message Passing

- **Operations:**
  - `send`
  - `receive`
- **Symmetry:**
  - symmetric (send and receive)
  - asymmetric (send xor receive)
- **Synchronicity:**
  - synchronous (e.g., phone)
  - asynchronous (e.g., email)
  - rendez-vous (e.g., barrier)
- **Buffering:**
  - unbuffered (e.g., blocking)
  - buffered (e.g., non-blocking)
- **Multiplicity:**
  - one-to-one
  - one-to-many (or many-to-one)
  - many-to-many
- **Addressing:**
  - direct (naming processes)
  - indirect (naming addresses)
- **Reception:**
  - unconditional (all messages)
  - selective (only certain msgs)
- **Anonymity:**
  - anonymous
  - non-anonymous

Synchronous
Message Passing !



Send:

```
send v to q ;
```

- Sender process `p` ***sends*** value `v` to receiver process `q`
- Sending process `p` ***blocked*** until process `q` receives `v`

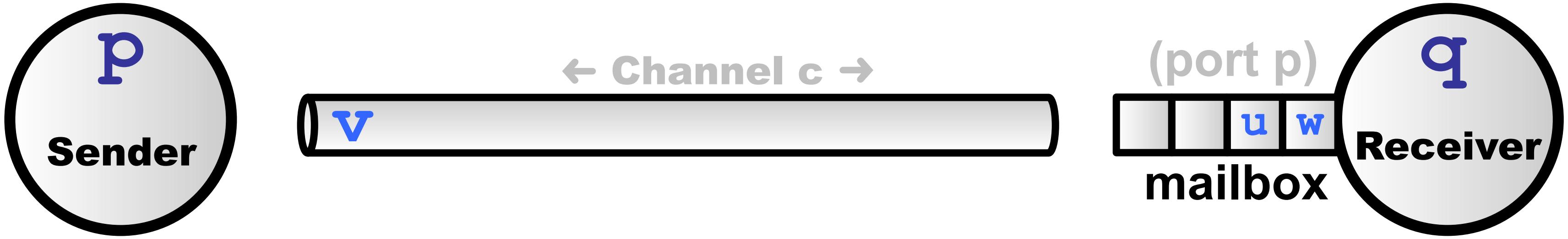
Receive:

```
v = receive();
```

- Receiver process `q` attempts to ***receive*** a value `v`
- Receiver process `q` is ***blocked*** until value received

- **Synchronous** (i.e., no message buffering)**!**

Asynchronous Message Passing !



Send:

```
send v to q;
```

- Sender process p ***sends*** value v to process q's mailbox
- Sending process p ***continues after sending***

Receive:

```
v = receive();
```

- Receiver process q attempts to ***receive*** v from its inbox
- Receiver process q is ***blocked*** until inbox is non-empty

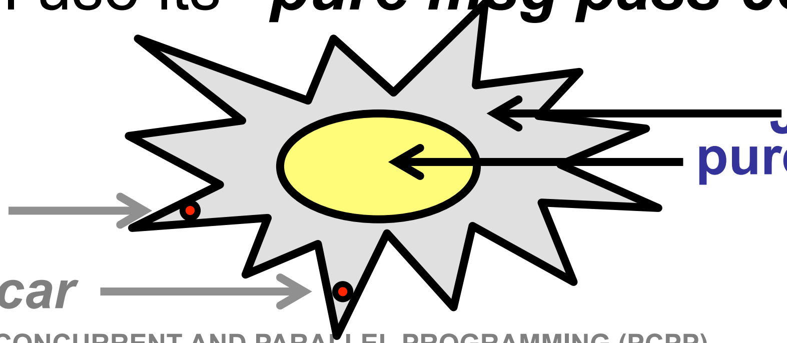
- **Asynchronous** (i.e., messages are buffered)!

Philosophy & Expectations !

- **ERLANG:**
  - We'll use as message passing ***specification language***
  - You have to-be-able-to ***read*** simple **ERLANG** programs
    - (i.e., not ***write***, nor ***modify***)

- **JAVA+AKKA:**
  - We'll use as msg passing ***implementation language***
  - You have 2-b-a-2 ***read/write/modify*** **JAVA+AKKA** p's
  - However, we'll use its ***"pure msg pass core"*** only **!**

NB: we're **not** going to use all of its fantazilions of functions!



make toast

wash your car

JAVA+AKKA

pure msg pass core

An ERLANG Tutorial

"Concurrent Programming in ERLANG"

(Joe Armstrong, Robert Virding, Claes Wikström, Mike Williams)

[Ericsson 1994]

ERLANG

- Named after Danish mathematician **Agner Krarup ERLANG:**

  ...credited for inventing:

  - ***traffic engineering***
  - ***queueing theory***
  - ***telephone network analysis***

[http://en.wikipedia.org/wiki/Agner_Krarup_Erlang]

- **The ERLANG language:**

  [http://en.wikipedia.org/wiki/Erlang_%28programming_language%29]

  - **by Ericsson in 1986** (**Er**icsson **Lang**uage? **:-)**)

The ERLANG Language (1986)

- Functional language with...:
  - ***message passing concurrency* !!!**
  - ***garbage collection***
  - ***eager evaluation***
  - ***single assignment***
  - ***dynamic typing***

> ***"Though all concurrency is explicit in ERLANG, processes communicate using message passing instead of shared variables, which removes the need for explicit locks."***
>
> ***-- Wikipedia***

- Designed by **`Ericsson`** to support...:
  distributed, fault-tolerant, soft-real-time, non-stop applications
- It supports ***"hot swapping":***
  - i.e., code can be changed without stopping a system!

Hello World

- Hello World (in ERLANG)

```
% hello world program:
-module(helloworld).
-export([start/0]).

start() ->
    io:fwrite("Hello world!\n").
```

An **actor** named "start" taking zero arguments (i.e., arity zero)

- Output:

```
Hello world!
```

- Try it out:

[www.tutorialspoint.com/compile_erlang_online.php]

Screenshot

Online ERLANG Compiler

- Online ERLANG Compiler:

  [www.tutorialspoint.com/compile_erlang_online.php]

- Documentation:

  [http://www.erlang.org/doc/man/io.html]

- Simple usage:
  - One module called: `helloworld`
  - Export one function called: `start/0`
  - Call *your code* from `start()` and `io:write` output

```
-module(helloworld).
-export([start/0]).

yourcode(...) -> ...

start() -> Val = yourcode(...),   % single assign: unchangable!
           io:write(Val).         % NB: use fwrite for strings!
```

Factorial

- Factorial
  (in ERLANG)

```
% factorial program:
-module(mymath).
-export([start/0, factorial/1]).

factorial(0) -> 1;
factorial(N) -> N * factorial(N-1).

start() -> io:write(factorial(6)).
```

- Usage:

```
> mymath:factorial(6).
720
```

```
> mymath:factorial(25).
15511210043330985984000000
```

- Try it out:

  [www.tutorialspoint.com/compile_erlang_online.php]

Modularization: Import / Export

- Factorial (in ERLANG)

```
-module(mymath).
-export([double/1]).

double(X) -> times(X, 2).  % public

times(X, N) -> X * N.      % private
```

- Usage:

```
> mymath:double(10).
20
```

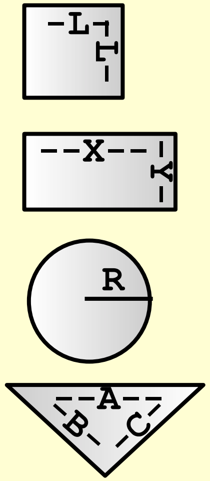
```
> mymath:times(5,2).
** undef'd fun': mymath:double/2 **
```

- Try it out:

  [www.tutorialspoint.com/compile_erlang_online.php]

Pattern Matching

```
-module(mymath).
-export([area/1]).

area( {square, L} ) ->                         % patterns in purple!
    L * L;
area( {rectangle, X, Y} ) ->
    X * Y;
area( {circle, R} ) ->
    3.14159 * R * R;
area( {triangle, A, B, C} ) ->
    S = (A + B + C)/2,                         % immutable assignment
    math:sqrt(S*(S-A)*(S-B)*(S-C)).
```



```
> Thing = {triangle, 6, 7, 8}.
{triangle,6,7,8}
> mymath:area(Thing).
20.3332
```

Values (with lists and tuples)

- Numbers: 42, -99, 3.1415, 6.626e-34, ...
- Atoms: abc, hello_world, 'with space',...
- Tuples: {}, { 1, 2, 3 }, { { x, 1}, { 2, y, 3 } }
- Lists: [], [1, 2, 3], [[x, 1], [2, y, 3]]

String (really just list of characters)

```
PCPP =
   {course, "Practical Concurrent and Parallel Programming",
      {master, 7.5, { fall, 2017 } }
      { teachers, [ 'Riko Jacob', 'Claus Brabrand' ] },
      { students, [ aaa, bbb, ccc, ... ] }
   }
```

- Recall: ***dynamically typed***

Lists: member/2

- [H|T] is (standard) ***"head-tail constructor":***
  - H is the ***head***; i.e., *the first element* (one element)
  - T is the ***tail***; i.e., *the rest of the list* (zero-or-more)

```
-module(mylists).
-export([member/2]).

member( X, [] ) -> false;
member( X, [X|_] ) -> true;
member( X, [_|T] ) -> member(X, T).
```

...for list construction de-construction

```
> mylists:member(3, [1,3,2]).
true
```

```
> mylists:member(4, [1,3,2]).
false
```

Lists: `append/2`

- `[H|T]` is (standard) ***"head-tail constructor"*:**
  - `H` is the ***head***; i.e., *the first element* (one element)
  - `T` is the ***tail***; i.e., *the rest of the list* (zero-or-more)

```
-module(mylists).
-export([append/2]).

append( [], L ) -> L;
append( [H|L1], L2 ) -> [H|append(L1, L2)].
```

...for list construction de-construction and re-construction

```
> mylists:append([], [a,b])
[a,b]
```

```
> mylists:append([1,2], [3,4])
[1,2,3,4]
```

Message Passing in ERLANG!

Actor: Send / Receive / Spawn

- **Send:**
  - `Pid ! M` // Message M is sent to process Pid
  - `Pid ! {some, {complex, structured, [m,s,g]}, 42}`
- **Receive:**

  -
    ```
    receive
       pattern1 -> ...
       ;
       pattern2 -> ...
    end
    ```

    ```
    receive
       {init,N} when N>0 -> ...
       ;
       {init,N} -> ...
    end
    ```
- **Spawn:**
  - `MyActorId = spawn(mymodule,myactor,[a,r,g,s])`

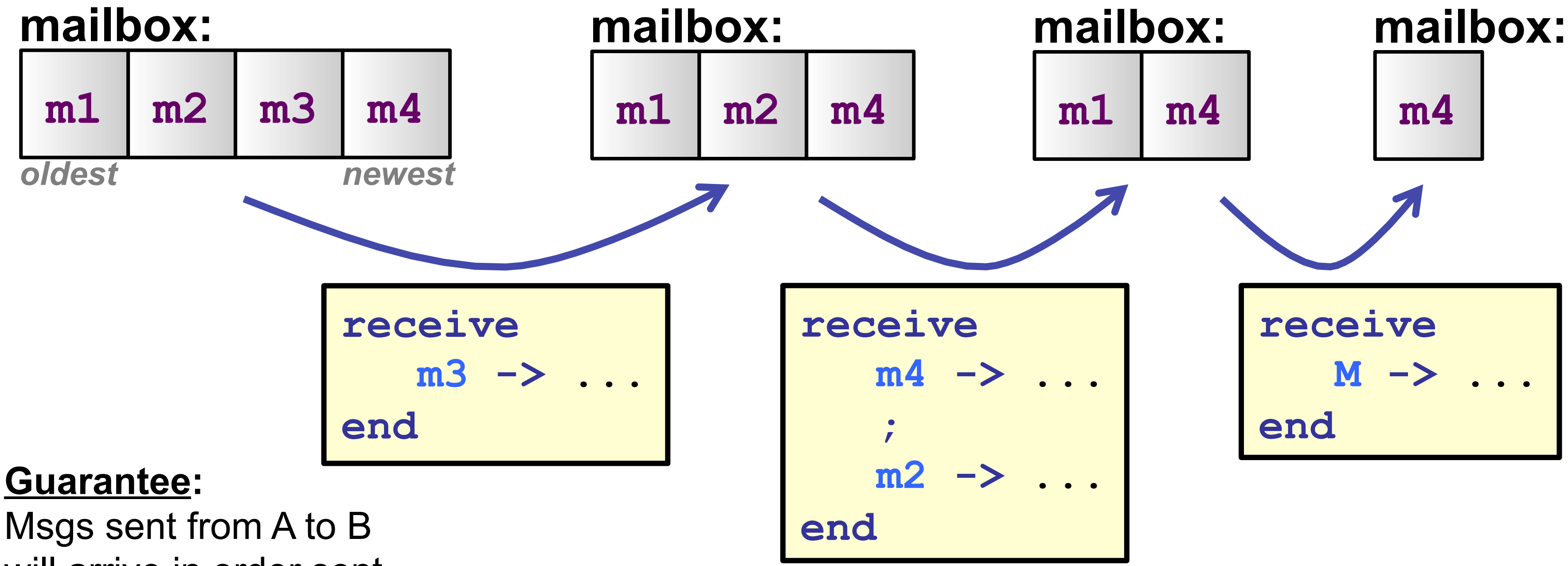
Order of Receiving Messages

- **Semantics:**

```
for (M: message) {
   for (P: pattern) {
      M~P (i.e., M matches P)?
   }
}
```

This is what happens inside each actor.

- **Example:**



mailbox:
m1 m2 m3 m4
oldest *newest*

```
receive
   m3 -> ...
end
```

mailbox:
m1 m2 m4

```
receive
   m4 -> ...
   ;
   m2 -> ...
end
```

mailbox:
m1 m4

```
receive
   M -> ...
end
```

mailbox:
m4

Guarantee:
Msgs sent from A to B
will arrive in order sent

5 Examples (ERLANG & JAVA+AKKA)

1) HelloWorld:

The "Hello World" of message passing; one message is sent to ***one actor***.

2) Ecco:

A ***person actor*** sends a msg to an ***ecco actor*** that responds with three suffix messages (used for ye olde "hvad drikker møller" kids joke).

3) Broadcast:

Three ***person actors*** unsubscribe/subscribe to a ***broadcast actor*** that forwards subsequent incoming msgs to subscribed persons.

4) Primer:

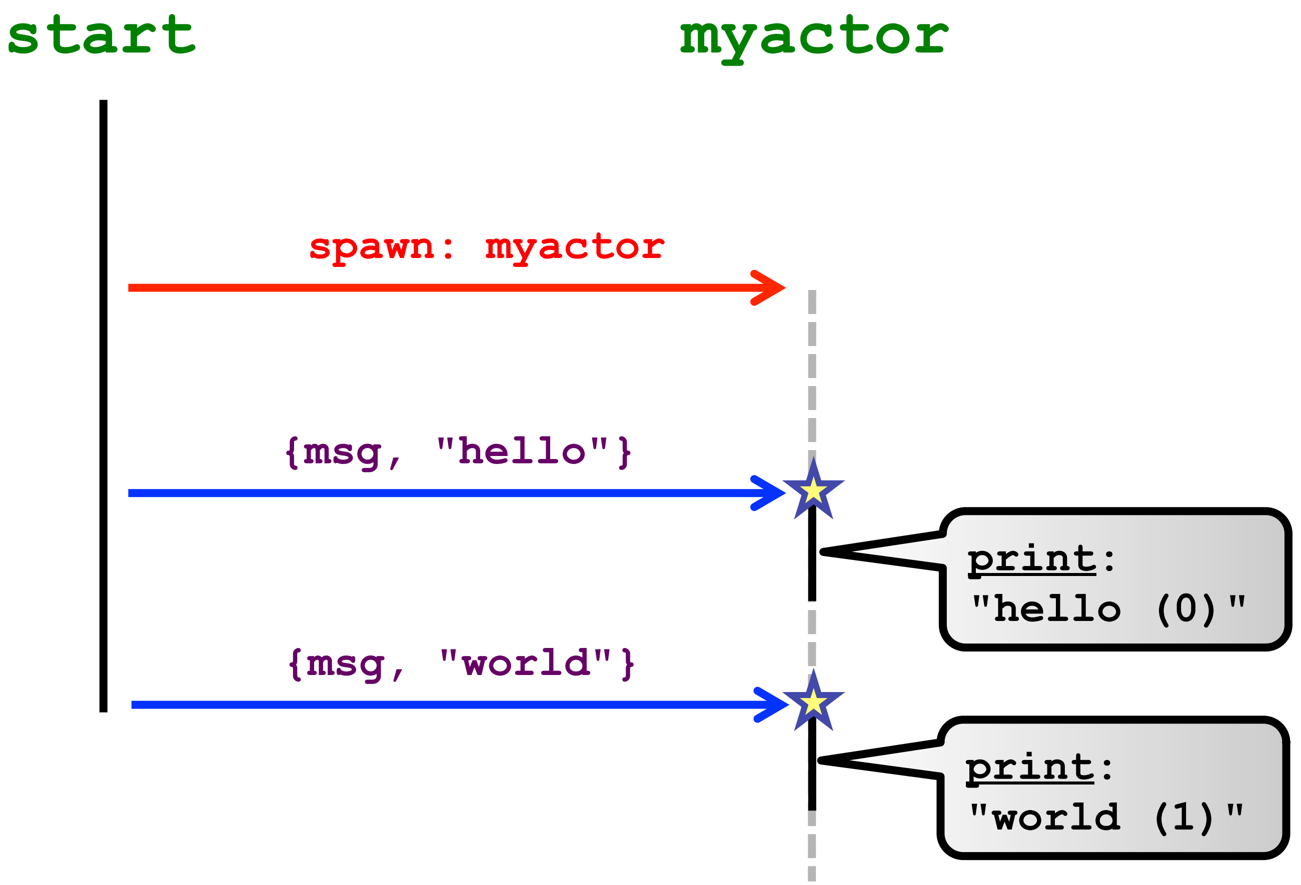
An ***actor primer*** is created that when initialized with **`N=7`** creates a **`list[]`** of that many ***slave actors*** to factor primes for it. Main bombards the prime actor with msgs (**`p ∈ [2..100]`**) that are evenly distributed among the slaves according to **`list[p%n]`**.

5) ABC: // ~earlier in course

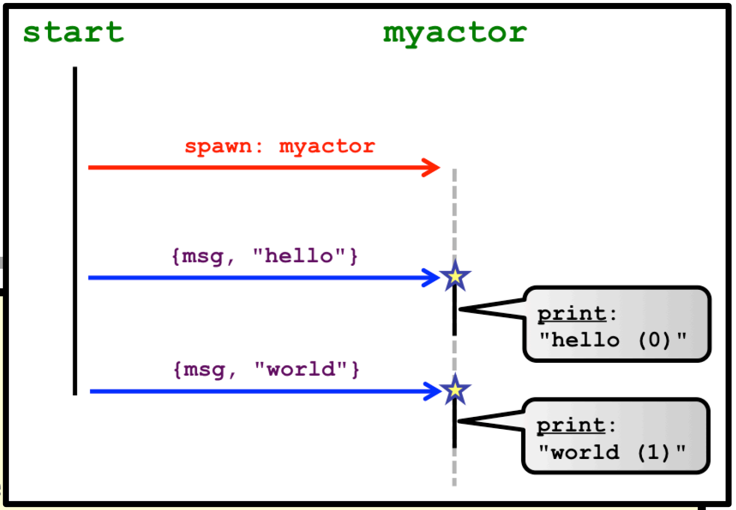
Two ***clerk actors*** each bombard a ***bank actor*** with 100 transfer-random-amount-x-from-an-account-to-other-account msgs. The banks transfer the money by sending deposit(+x) to one ***account actor*** and deposit(-x) to the other ***account actor***. (The system is called ABC as in Account/Bank/Clerk.)

1) HelloWorld

LEGEND:
send, receive, msgs
actors, spawn, rest.



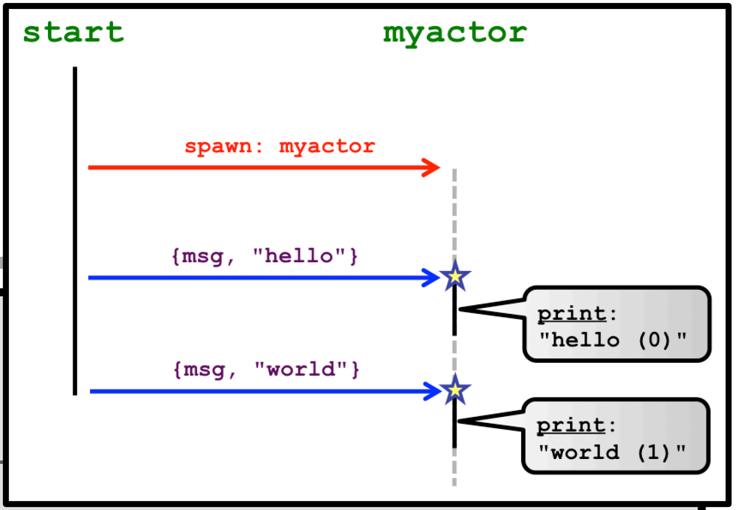
1) HelloWorld.erl



```
-module(helloworld).
-export([start/0,myactor/1]).

myactor(Count) ->  %% can have (local) state
   receive
      {msg, Msg} ->
         io:fwrite(Msg ++ " ("),
         io:write(Count),
         io:fwrite(")\n"),
         myactor(Count + 1)
   end.

start() ->
   MyActor = spawn(helloworld, myactor, [0]),
   MyActor ! {msg, "hello"},
   MyActor ! {msg, "world"}.
```

```
hello (0)
world (1)
```

1) HelloWorld.java



```
import java.io.*;
import akka.actor.*;

// -- MESSAGE ------------

class MyMessage implements Serializable { // must be Serializable:
    public final String s;
    public MyMessage(String s) { this.s = s; }
}

// -- ACTOR ----------------------------------------------

class MyActor extends UntypedActor {
    private int count = 0; // can have (local) state: "myactor(Count) -> ..."

    public void onReceive(Object o) throws Exception { // reacting to message:
        if (o instanceof MyMessage) {
            MyMessage message = (MyMessage) o;
            System.out.println(message.s + " (" + count + ")");
            count++;
        }
    }
}
```

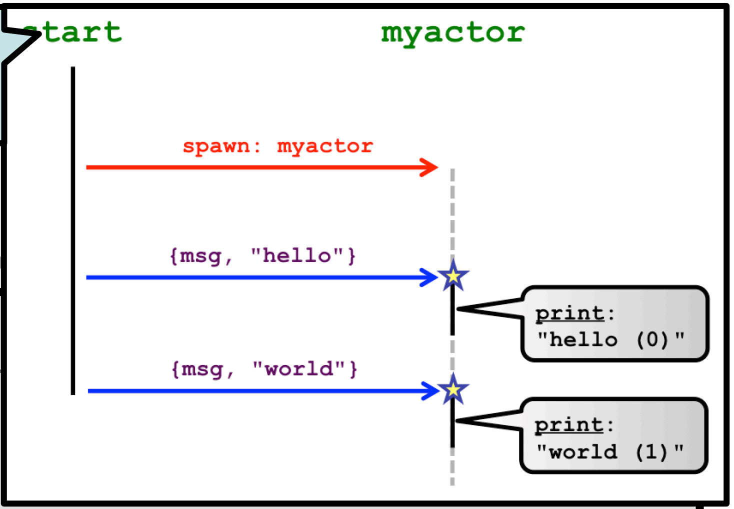
In JAVA+AKKA, we want to pass immutable msgs

Otherwise, we're back to shared mutable!

```
hello (0)
world (1)
```

1) HelloWorld.java

In JAVA+AKKA, the `main()` thread is NOT an actor !



start

myactor

spawn: myactor

{msg, "hello"}

print: "hello (0)"

{msg, "world"}

print: "world (1)"

In JAVA+AKKA, the `main()` thread is NOT an actor !

```java
// -- MAIN -------------                ---------------

public class HelloWorld {
    public static void main(String[] args) {
        final ActorSystem system = ActorSystem.create("HelloWorldSystem");

        final ActorRef myactor =
            system.actorOf(Props.create(MyActor.class), "myactor");

        myactor.tell(new MyMessage("hello"), ActorRef.noSender());

        myactor.tell(new MyMessage("world"), ActorRef.noSender());

        try {
            System.out.println("Press return to terminate...");
            System.in.read();
        } catch(IOException e) {
            e.printStackTrace();
        } finally {
            system.shutdown();
        }
    }
}
```

```
hello (0)
world (1)
```

1) HelloWorld.java

Download:
scala.jar
akka-actor.jar

- Compile:

```
javac -cp scala.jar:akka-actor.jar HelloWorld.java
```

- Run:

```
java -cp scala.jar:akka-actor.jar:akka-config.jar:. HelloWorld
```

- Output:

```
hello (0)
world (1)
```

EXERCISE: HelloWorld Variant

```
-module(helloworld).
-export([start/0,myactor/1]).

myactor(X) ->
   receive
      {msg, Msg} ->
         io:fwrite(Msg ++ " ("),
         io:fwrite(X),
         io:fwrite(")\n"),
         myactor(X ++ Msg)
   end.

start() ->
   MyActor = spawn(helloworld, myactor, [""]),
   MyActor ! {msg, "aaa"},
   MyActor ! {msg, "bbb"},
   MyActor ! {msg, "ccc"}.
```

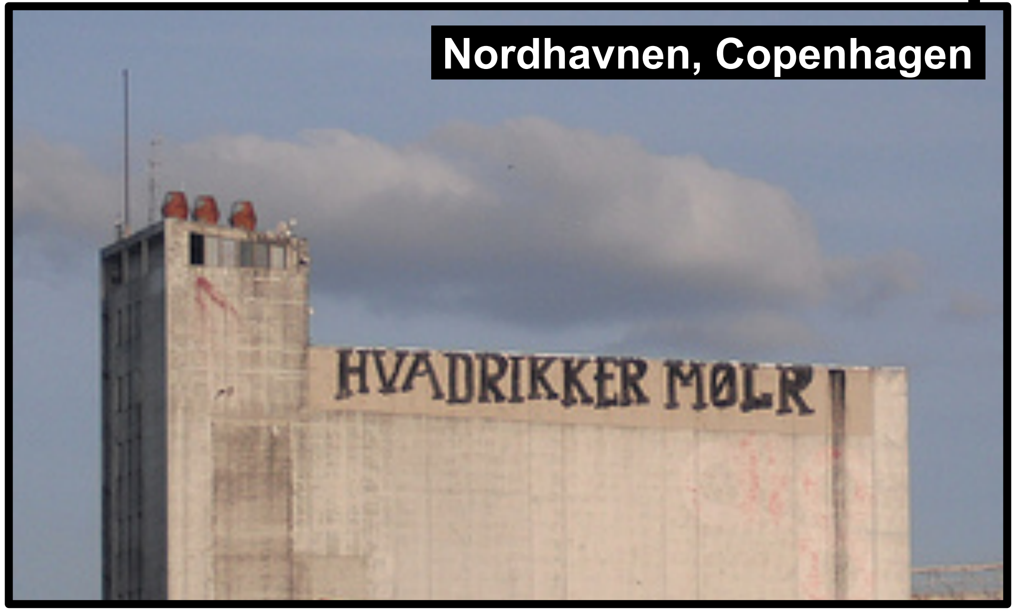
EXERCISE:

1) What does this program do?
2) Run this Erlang program
3) Adapt this program to Java
4) Run your Java program

2) Ecco

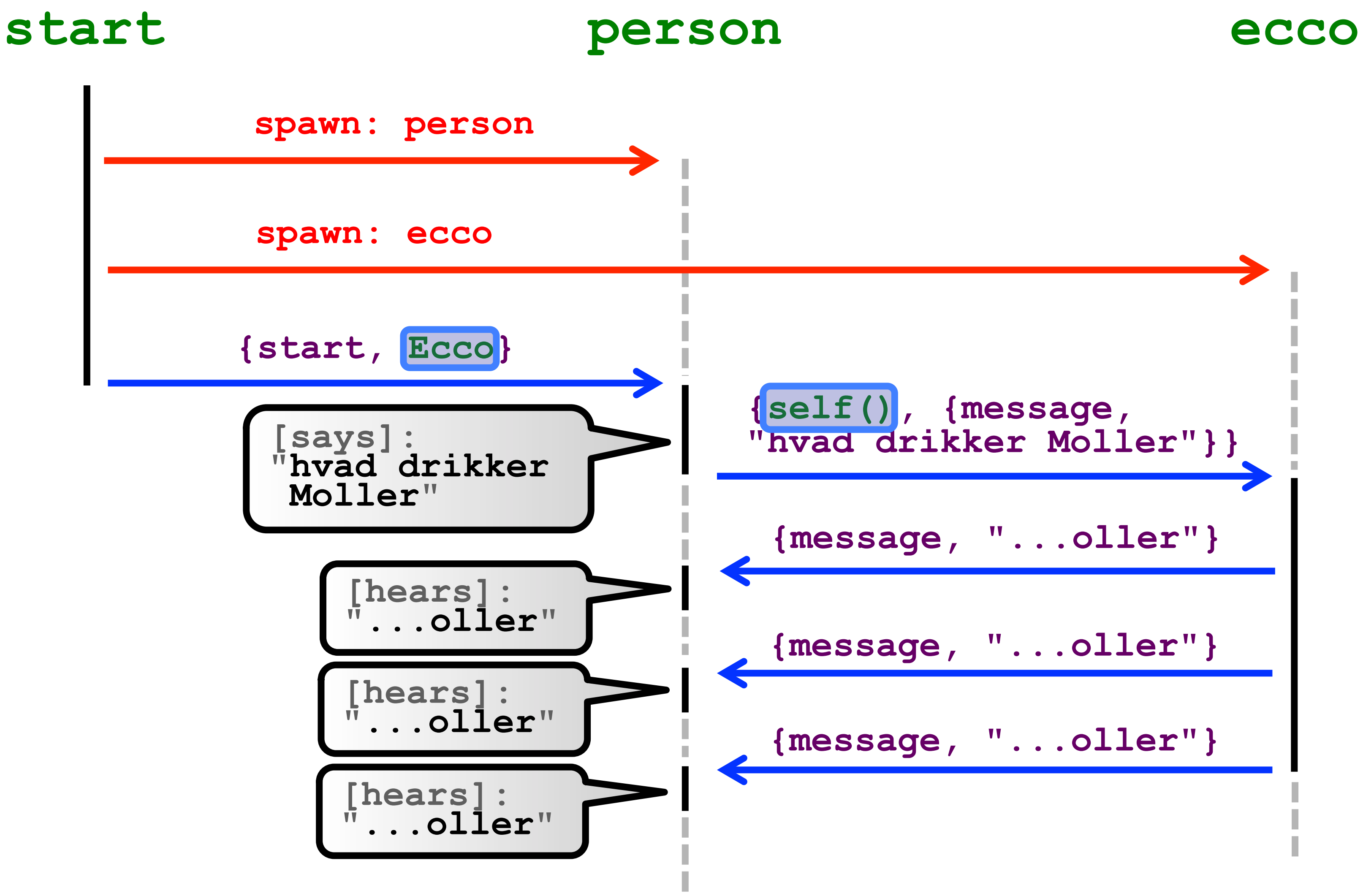
- From Old Danish Kids Joke:
  - [http://www.tordenskjoldssoldater.dk/ekko.html]

- Huge graffiti in Nordhavnen, Copenhagen:



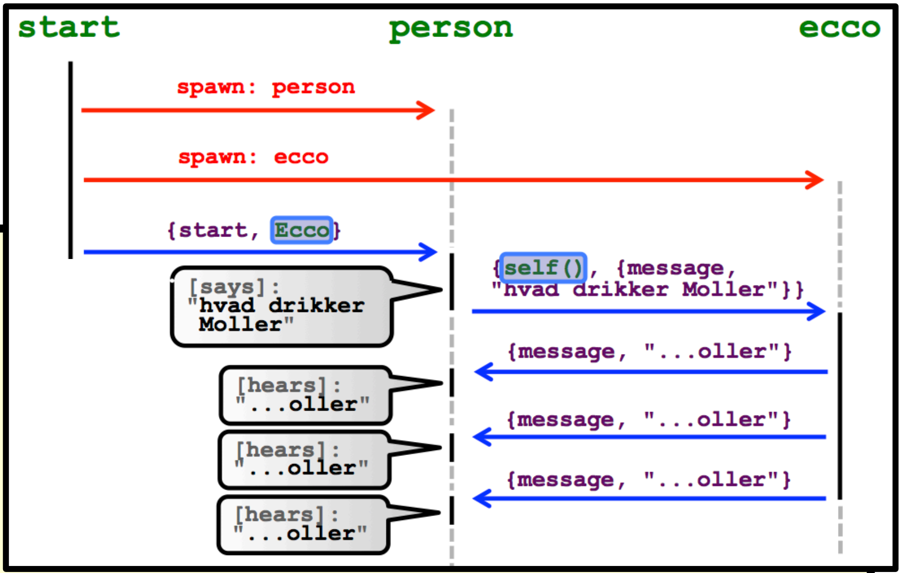
[https://www.flickr.com/photos/unacivetta/5745925102/]

2) Ecco


start
person
ecco
spawn: person
spawn: ecco
{start, Ecco}
[says]: "hvad drikker Moller"
{self(), {message, "hvad drikker Moller"}}
{message, "...oller"}
[hears]: "...oller"
{message, "...oller"}
[hears]: "...oller"
{message, "...oller"}
[hears]: "...oller"

2) Ecco.erl

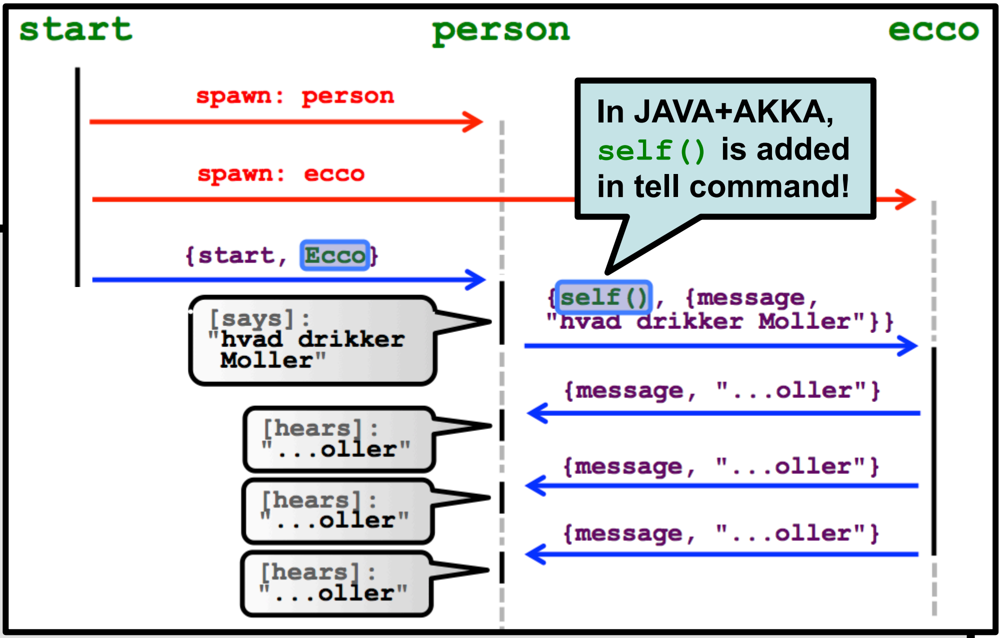
```
-module(helloworld).
-export([start/0,person/0,ecco/0]).

person() ->
   receive
      {start,Pid} ->
         S = "hvad drikker Moller",
         io:fwrite("[says]:  " ++ S ++ "\n"),
         Pid ! {self(), {message,S}} ;
      {message, S} ->
         io:fwrite("[hears]: " ++ S ++ "\n")
   end,
   person().

ecco() ->
   receive
      {Sender,{message,S}} ->
         Sub = substr(S),
         Sender ! {message,Sub},
         Sender ! {message,Sub},
         Sender ! {message,Sub},
         ecco()
   end.

start() ->
   Person = spawn(helloworld,person,[]),
   Ecco = spawn(helloworld,ecco,[]),
   Person ! {start,Ecco}.
```



```
substr(S) when length(S) < 6 -> "..." ++ S;
substr([_|T]) -> substr(T).
```

```
[says]:   hvad drikker Moller
[hears]:  ...oller
[hears]:  ...oller
[hears]:  ...oller
```

2) Ecco.java



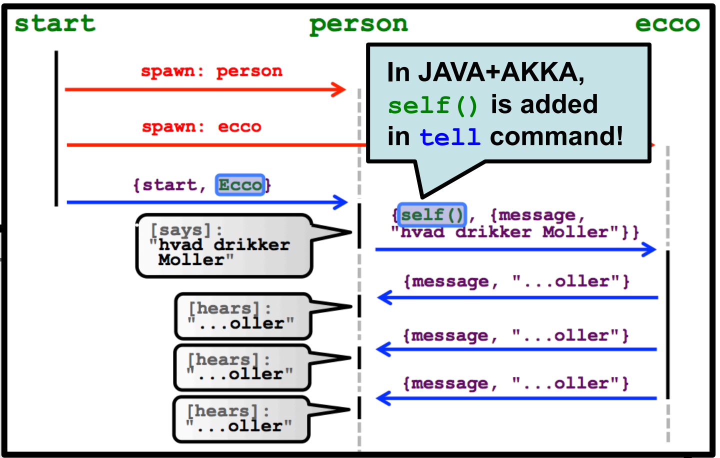
In JAVA+AKKA, self() is added in tell command!

```
import java.io.*;
import akka.actor.*;









// -- MESSAGES -------------------------------------------

class StartMessage implements Serializable {
    public final ActorRef ecco;
    public StartMessage(ActorRef ecco) {
        this.ecco = ecco;
    }
}

class Message implements Serializable {
    public final String s;
    public Message(String s) {
        this.s = s;
    }
}
```

Used for...:
person ← ecco
...and also for:
person → ecco

```
[says]:   hvad drikker Moller
[hears]:  ...oller
[hears]:  ...oller
[hears]:  ...oller
```

2) Ecco.java



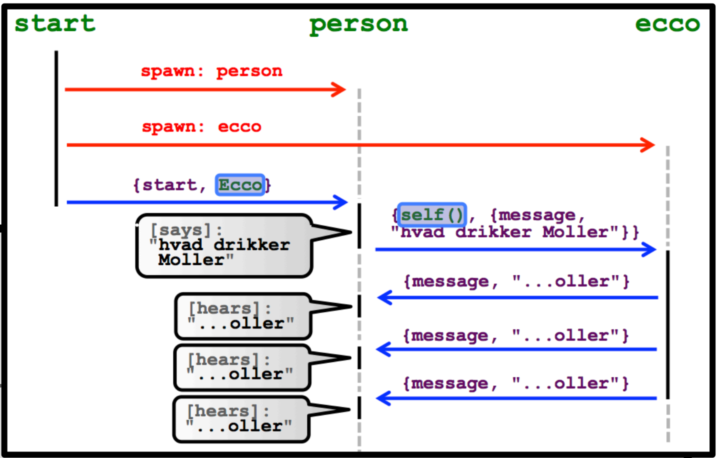
In JAVA+AKKA, self() is added in tell command!

```
// -- ACTORS -----------------------------------------------

class PersonActor extends UntypedActor {
    public void onReceive(Object o) throws Exception {
        if (o instanceof StartMessage) {
            StartMessage start = (StartMessage) o;
            ActorRef ecco = start.ecco;
            String s = "hvad drikker moller";
            System.out.println("[says]:   " + s);
            ecco.tell(new Message(s), getSelf());
        } else if (o instanceof Message) {
            Message m = (Message) o;
            System.out.println("[hears]: " + m.s);
        }
    }
}

class EccoActor extends UntypedActor {
    public void onReceive(Object o) throws Exception {
        if (o instanceof Message) {
            Message m = (Message) o;
            String s = m.s;
            Message reply;
            if (s.length()>5) reply = new Message("..." + s.substring(s.length()-5));
            else reply = new Message("...");
            getSender().tell(reply, getSelf());
            getSender().tell(reply, getSelf());
            getSender().tell(reply, getSelf());
        }
    }
}
```

Here, could also have been: ActorRef.noSender()

```
[says]:   hvad drikker Moller
[hears]:  ...oller
[hears]:  ...oller
[hears]:  ...oller
```

2) Ecco.java



```
// -- MAIN ---------------------------------------

public class Ecco {
    public static void main(String[] args) {
        final ActorSystem system = ActorSystem.create("EccoSystem");

        final ActorRef person =
            system.actorOf(Props.create(PersonActor.class), "person");

        final ActorRef ecco =
            system.actorOf(Props.create(EccoActor.class), "ecco");

        person.tell(new StartMessage(ecco), ActorRef.noSender());

        try {
            System.out.println("Press return to terminate...");
            System.in.read();
        } catch(IOException e) {
            e.printStackTrace();
        } finally {
            system.shutdown();
        }
    }
}
```

```
[says]:   hvad drikker Moller
[hears]:  ...oller
[hears]:  ...oller
[hears]:  ...oller
```

2) Ecco.java

- **Compile:**

```
javac -cp scala.jar:akka-actor.jar Ecco.java
```

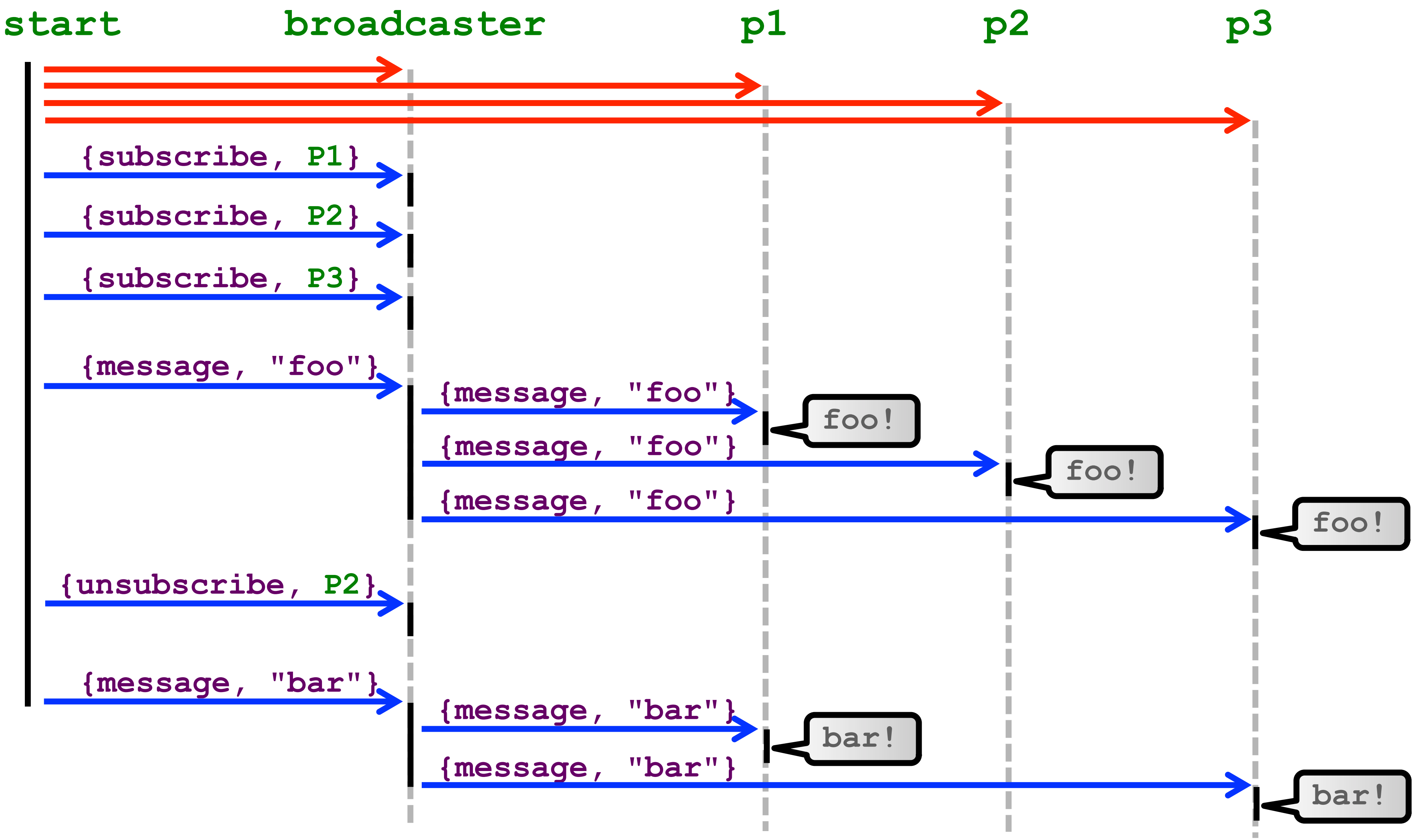
- **Run:**

```
java -cp scala.jar:akka-actor.jar:akka-config.jar:. Ecco
```

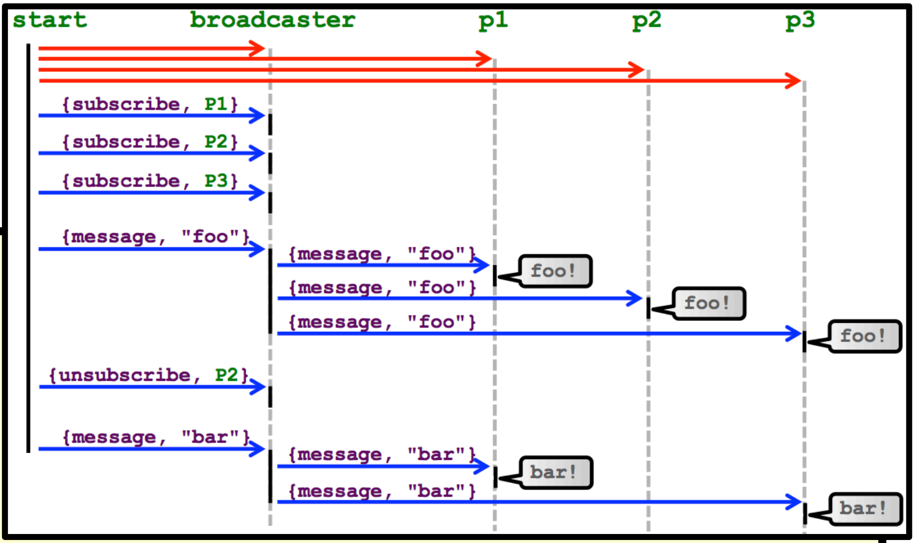
- **Output:**

```
Press return to terminate...
[says]:  hvad drikker moller
[hears]: ...oller
[hears]: ...oller
[hears]: ...oller
```

3) Broadcast


start
broadcaster
p1
p2
p3
{subscribe, P1}
{subscribe, P2}
{subscribe, P3}
{message, "foo"}
{message, "foo"}
foo!
{message, "foo"}
foo!
{message, "foo"}
foo!
{unsubscribe, P2}
{message, "bar"}
{message, "bar"}
bar!
{message, "bar"}
bar!

3) Broadcast.erl

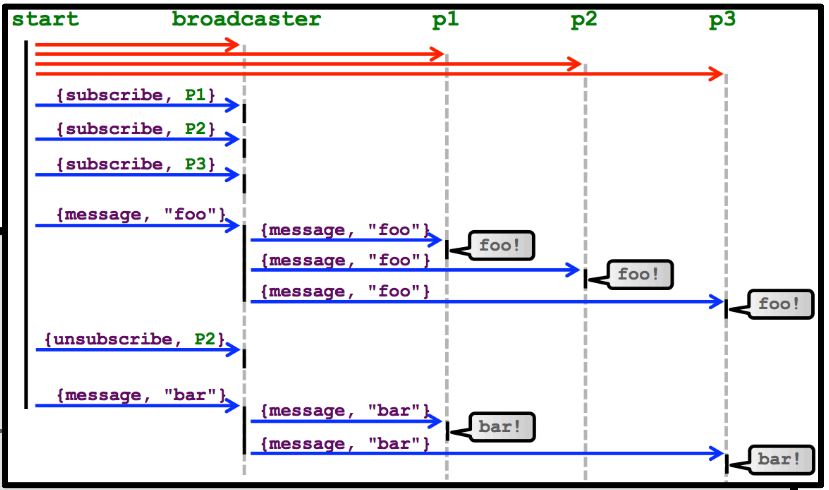


```
-module(helloworld).
-export([start/0,person/0,broadcaster/1]).

person() ->
   receive
     {message,M} ->
        io:fwrite(M ++ "\n"),
        person()
   end.

broadcast([],_) -> true;
broadcast([Pid|L],M) ->
    Pid ! {message,M},
    broadcast(L,M).

broadcaster(L) ->
    receive
       {subscribe,Pid} ->
          broadcaster([Pid|L]) ;
       {unsubscribe,Pid} ->
          broadcaster(lists:delete(Pid,L)) ;
       {message,M} ->
          broadcast(L,M),
          broadcaster(L)
    end.
```

```
start() ->
  Broadcaster = spawn(helloworld,broadcaster,[[]]),
  P1 = spawn(helloworld,person,[]),
  P2 = spawn(helloworld,person,[]),
  P3 = spawn(helloworld,person,[]),
  Broadcaster ! {subscribe,P1},
  Broadcaster ! {subscribe,P2},
  Broadcaster ! {subscribe,P3},
  Broadcaster ! {message,"Purses half price!"},
  Broadcaster ! {unsubscribe,P2},
  Broadcaster ! {message,"Shoes half price!!"}.
```

```
purses half price!
purses half price!
purses half price!
shoes half price!!
shoes half price!!
```

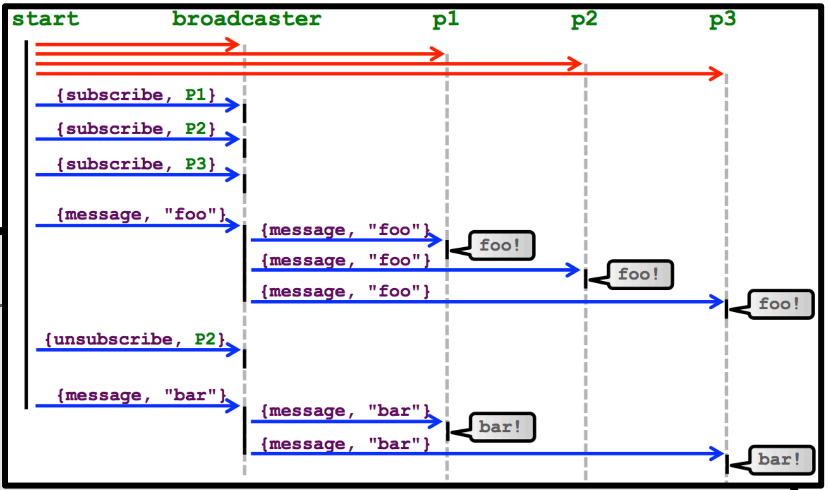
3) Broadcast.java



```
import java.util.*;
import java.io.*;
import akka.actor.*;

// -- MESSAGES ---------------------------------

class SubscribeMessage implements Serializable {
    public final ActorRef subscriber;
    public SubscribeMessage(ActorRef subscriber) {
         this.subscriber = subscriber;
    }
}

class UnsubscribeMessage implements Serializable {
    public final ActorRef unsubscriber;
    public UnsubscribeMessage(ActorRef unsubscriber) {
         this.unsubscriber = unsubscriber;
    }
}

class Message implements Serializable {
    public final String s;
    public Message(String s) {
         this.s = s;
    }
}
```

```
purses half price!
purses half price!
purses half price!
shoes half price!!
shoes half price!!
```

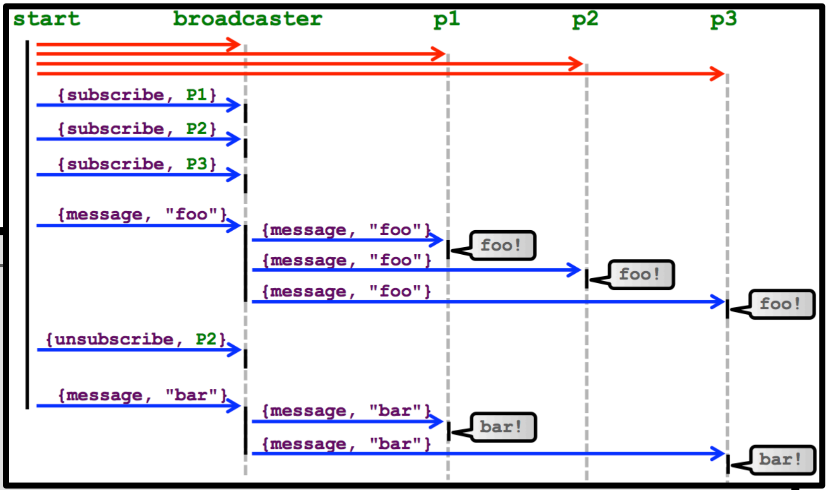
3) Broadcast.java



```
// -- ACTORS -----------------------------------

class BroadcastActor extends UntypedActor {
    private List<ActorRef> list =
        new ArrayList<ActorRef>();

    public void onReceive(Object o) throws Exception {
         if (o instanceof SubscribeMessage) {
             list.add(((SubscribeMessage) o).subscriber);
         } else if (o instanceof UnsubscribeMessage) {
             list.remove(((UnsubscribeMessage) o).unsubscriber);
         } else if (o instanceof Message) {
             for (ActorRef person : list) {
                  person.tell(o, getSelf());
             }
         }
    }
}

class PersonActor extends UntypedActor {
    public void onReceive(Object o) throws Exception {
         if (o instanceof Message) {
             System.out.println(((Message) o).s);
         }
    }
}
```

```
purses half price!
purses half price!
purses half price!
shoes half price!!
shoes half price!!
```

3) Broadcast.java



```
// -- MAIN ---------------------------------------

public class Broadcast {
    public static void main(String[] args) {
        final ActorSystem system =
            ActorSystem.create("EccoSystem");
        final ActorRef broadcaster =
            system.actorOf(Props.create(BroadcastActor.class), "broadcaster");
        final ActorRef p1 = system.actorOf(Props.create(PersonActor.class), "p1");
        final ActorRef p2 = system.actorOf(Props.create(PersonActor.class), "p2");
        final ActorRef p3 = system.actorOf(Props.create(PersonActor.class), "p3");
        broadcaster.tell(new SubscribeMessage(p1), ActorRef.noSender());
        broadcaster.tell(new SubscribeMessage(p2), ActorRef.noSender());
        broadcaster.tell(new SubscribeMessage(p3), ActorRef.noSender());
        broadcaster.tell(new Message("purses half price!"), ActorRef.noSender());
        broadcaster.tell(new UnsubscribeMessage(p2), ActorRef.noSender());
        broadcaster.tell(new Message("shoes half price!!"), ActorRef.noSender());
        try {
            System.out.println("Press return to terminate...");
            System.in.read();
        } catch(IOException e) {
            e.printStackTrace();
        } finally {
            system.shutdown();
        }
    }
}
```

```
purses half price!
purses half price!
purses half price!
shoes half price!!
shoes half price!!
```

3) Broadcast.java

- Compile:

```
javac -cp scala.jar:akka-actor.jar Broadcast.java
```

- Run:

```
java -cp scala.jar:akka-actor.jar:akka-config.jar:. Broadcast
```

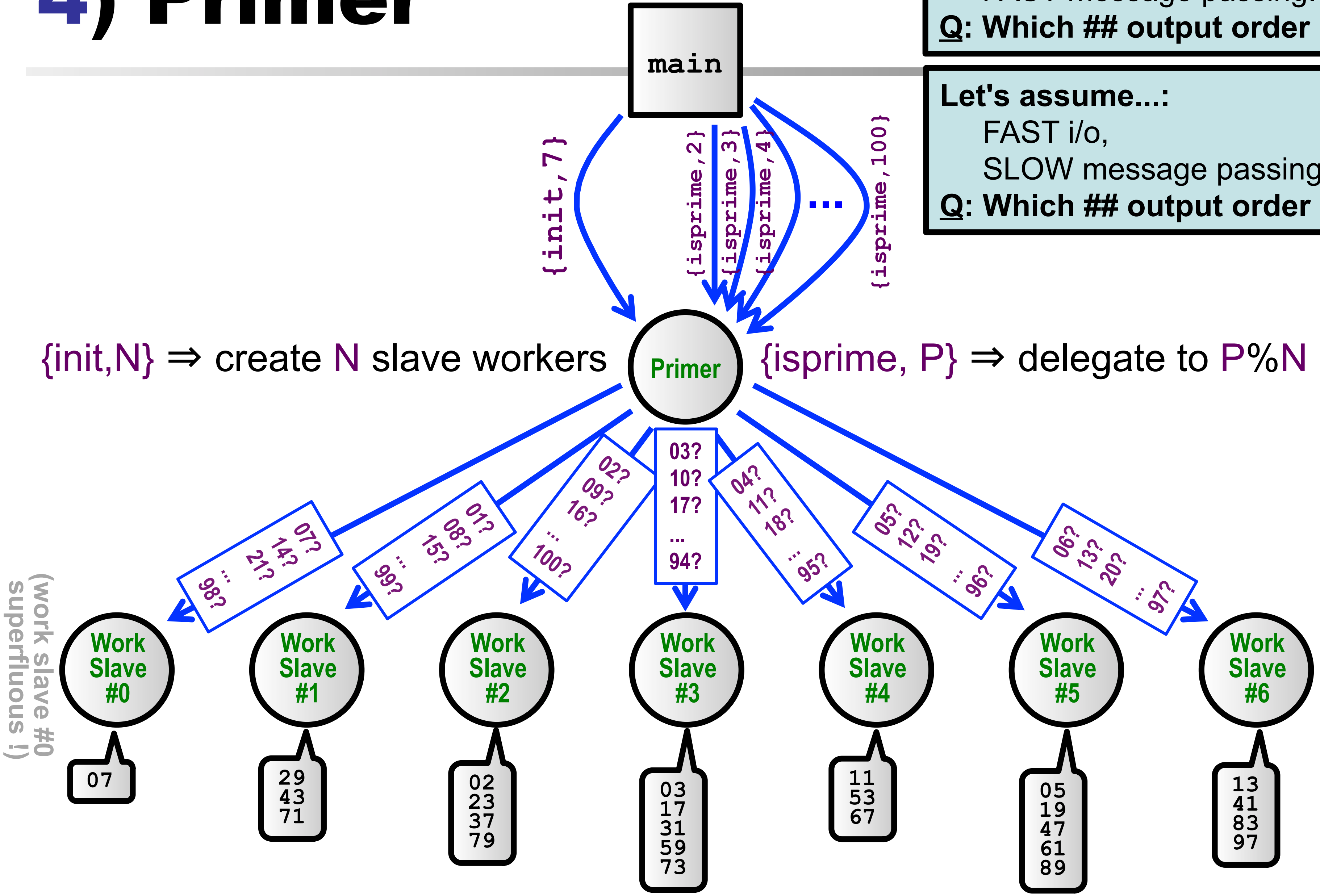
- Output:

```
purses half price!
purses half price!
purses half price!
shoes half price!!
shoes half price!!
```

4) Primer

Let's assume...:
SLOW i/o,
FAST message passing.
Q: Which ## output order ??

Let's assume...:
FAST i/o,
SLOW message passing.
Q: Which ## output order ??



main

{init,7}

{isprime,2}

{isprime,3}

{isprime,4}

...

{isprime,100}

{init,N} ⇒ create N slave workers

Primer

{isprime, P} ⇒ delegate to P%N :-)

07? 14? 21? ... 98?

01? 08? 15? ... 99?

02? 09? 16? ... 100?

03? 10? 17? ... 94?

04? 11? 18? ... 95?

05? 12? 19? ... 96?

06? 13? 20? ... 97?

Work Slave #0

Work Slave #1

Work Slave #2

Work Slave #3

Work Slave #4

Work Slave #5

Work Slave #6

(work slave #0 superfluous !)

07

29
43
71

02
23
37
79

03
17
31
59
73

11
53
67

05
19
47
61
89

13
41
83
97

4) Primer.erl

Slave

```
-module(helloworld).
-export([start/0,slave/1,primer/1]).

is_prime_loop(N,K) ->
   K2 = K * K, R = N rem K,
   case (K2 =< N) and (R /= 0) of
      true  -> is_prime_loop(N, K+1);
      false -> K
   end.

is_prime(N) ->
K = is_prime_loop(N,2),
   (N >= 2) and (K*K > N).

n2s(N) ->
   lists:flatten(io_lib:format("~p",[N])).

slave(Id) ->
   receive
      {isprime, N} ->
         case is_prime(N) of
           true -> io:fwrite("(" ++
n2s(Id) ++ ") " ++ n2s(N) ++ "\n");
           false -> []
         end,
         slave(Id)
   end.
```

Primer

```
create_slaves(Max,Max) -> [];
create_slaves(Id,Max) ->
   Slave = spawn(helloworld,slave,[Id]),
   [Slave|create_slaves(Id+1,Max)].

primer(Slaves) ->
   receive
      {init, N} when N=<0 ->
         throw({nonpositive,N}) ;
      {init, N} ->
         primer(create_slaves(0,N)) ;
      {isprime, _} when Slaves == [] ->
         throw({uninitialized}) ;
      {isprime, N} when N=<0 ->
         throw({nonpositive,N}) ;
      {isprime, N} ->
         SlaveId = N rem length(Slaves),
         lists:nth(SlaveId+1, Slaves)
            ! {isprime,N},
         primer(Slaves)
   end.

spam(_, N, Max) when N>=Max -> true;
spam(Primer, N, Max) ->
   Primer ! {isprime, N},
   spam(Primer, N+1, Max).

start() ->
   Primer =
      spawn(helloworld, primer, [[]]),
   Primer ! {init,7},
   spam(Primer, 2, 100).
```

4) Primer.java

```
import java.util.*;
import java.io.*;
import akka.actor.*;

// -- MESSAGES --------------------------------------------------

class InitializeMessage implements Serializable {
    public final int number_of_slaves;
    public InitializeMessage(int number_of_slaves) {
         this.number_of_slaves = number_of_slaves;
    }
}

class IsPrimeMessage implements Serializable {
    public final int number;
    public IsPrimeMessage(int number) {
         this.number = number;
    }
}
```

4) Primer.java

```
// -- SLAVE ACTOR -----------------------------------------------------

class SlaveActor extends UntypedActor {
    private boolean isPrime(int n) {
        int k = 2;
        while (k * k <= n && n % k != 0) k++;
        return n >= 2 && k * k > n;
    }

    private int delay(int n) {
        int res = 0;
        for (int i=0; i<10000000*n; i++) {
            res = res + i;
        }
        return res;
    }

    public void onReceive(Object o) throws Exception {
        if (o instanceof IsPrimeMessage) {
            int p = ((IsPrimeMessage) o).number;
            if (delay(p)==p) System.out.println("will not happen: ");
            if (isPrime(p)) System.out.println("(" + p%7 + ")  " + p);
        }
    }
}
```

artificial delay

// artificial delay

4) Primer.java

```
// -- PRIME ACTOR ----------------------------------------------------
class PrimeActor extends UntypedActor {
    List<ActorRef> slaves;

    private List<ActorRef> createSlaves(int n) {
        List<ActorRef> slaves = new ArrayList<ActorRef>();
        for (int i=0; i<n; i++) {
            ActorRef slave =
                getContext().actorOf(Props.create(SlaveActor.class), "p" + i);
                slaves.add(slave);
        }
        return slaves;
    }

    public void onReceive(Object o) throws Exception {
        if (o instanceof InitializeMessage) {
            InitializeMessage init = (InitializeMessage) o;
            int n = init.number_of_slaves;
            if (n<=0) throw new RuntimeException("*** non-positive number!");
            slaves = createSlaves(n);
            System.out.println("initialized (" + n + " slaves ready to work)!");
        } else if (o instanceof IsPrimeMessage) {
            if (slaves==null) throw new RuntimeException("*** uninitialized!");
            int n = ((IsPrimeMessage) o).number;
            if (n<=0) throw new RuntimeException("*** non-positive number!");
            int slave_id = n % slaves.size();
            slaves.get(slave_id).tell(o, getSelf());
        }
    }
}
```

4) Primer.java

```java
// -- MAIN ---------------------------------------------------

public class Primer {
    private static void spam(ActorRef primer, int min, int max) {
        for (int i=min; i<max; i++) {
            primer.tell(new IsPrimeMessage(i), ActorRef.noSender());
        }
    }

    public static void main(String[] args) {
        final ActorSystem system = ActorSystem.create("PrimerSystem");
        final ActorRef primer =
            system.actorOf(Props.create(PrimeActor.class), "primer");
        primer.tell(new InitializeMessage(7), ActorRef.noSender());
        try {
            System.out.println("Press return to initiate...");
            System.in.read();
            spam(primer, 2, 100);
            System.out.println("Press return to terminate...");
            System.in.read();
        } catch(IOException e) {
            e.printStackTrace();
        } finally {
            system.shutdown();
        }
    }
}
```

4) Primer.java

- Compile:

```
javac -cp scala.jar:akka-actor.jar Primer.java
```

- Run:

```
java -cp scala.jar:akka-actor.jar:akka-config.jar:. Primer
```

- Output:

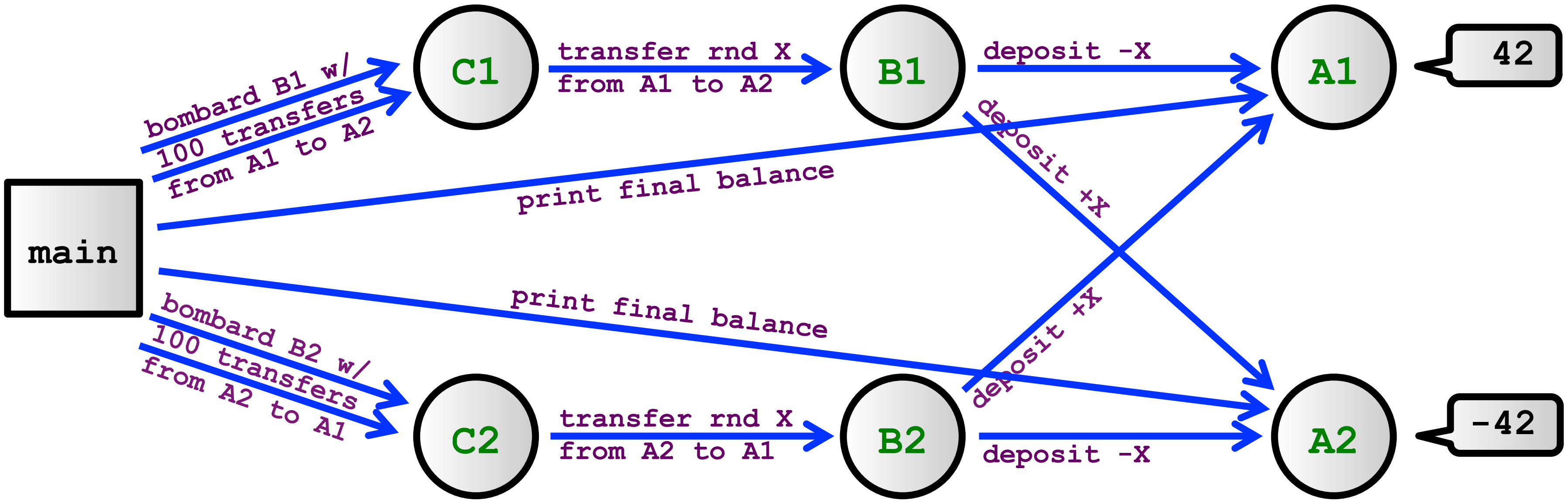
```
press return to initiate...
initialized (7 slaves ready to work)!

(2) 2
(3) 3
Press return to terminate...
(0) 7
(5) 5
(4) 11
(6) 13
(3) 17
(5) 19
(2) 23
(1) 29
(3) 31
```

```
(2) 37
(6) 41
(1) 43
(5) 47
(4) 53
(3) 59
(5) 61
(4) 67
(1) 71
(3) 73
(2) 79
(6) 83
(5) 89
(6) 97
```

Mandatory Hand-in Exercise

For Message Passing

5) ABC (Clerk / Bank / Account)


main
C1
C2
B1
B2
A1
A2
bombard B1 w/ 100 transfers from A1 to A2
bombard B2 w/ 100 transfers from A2 to A1
transfer rnd X from A1 to A2
transfer rnd X from A2 to A1
deposit -X
deposit +X
deposit +X
deposit -X
print final balance
print final balance
42
-42

5) ABC.erl

```
-module(helloworld).
-export([start/0,
         account/1,bank/0,clerk/0]).

%% -- BASIC PROCESSING -------------------
n2s(N) -> lists:flatten( %% int2string
   io_lib:format("~p", [N])). %% HACK!

random(N) -> random:uniform(N) div 10.

%% -- ACTORS ----------------------------

account(Balance) ->
   receive
      {deposit,Amount} ->
         account(Balance+Amount) ;
      {printbalance} ->
         io:fwrite(n2s(Balance) ++ "\n")
   end.

bank() ->
   receive
      {transfer,Amount,From,To} ->
         From ! {deposit,-Amount},
         To ! {deposit,+Amount},
         bank()
   end.
```

```
ntransfers(0,_,_,_) -> true;
ntransfers(N,Bank,From,To) ->
   R = random(100),
   Bank ! {transfer,R,From,To},
   ntransfers(N-1,Bank,From,To).

clerk() ->
   receive
      {start,Bank,From,To} ->
         random:seed(now()),
         ntransfers(100,Bank,From,To),
         clerk()
   end.


start() ->
   A1 = spawn(helloworld,account,[0]),
   A2 = spawn(helloworld,account,[0]),
   B1 = spawn(helloworld,bank,[]),
   B2 = spawn(helloworld,bank,[]),
   C1 = spawn(helloworld,clerk,[]),
   C2 = spawn(helloworld,clerk,[]),
   C1 ! {start,B1,A1,A2},
   C2 ! {start,B2,A2,A1},
   timer:sleep(1000),
   A1 ! {printbalance},
   A2 ! {printbalance}.
```

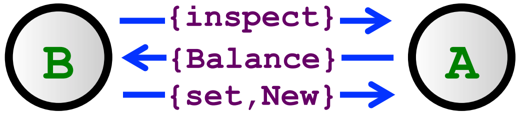
5) ABC.java (Skeleton)

```
import java.util.Random;   import java.io.*;   import akka.actor.*;

// -- MESSAGES --------------------------------------------------
class StartTransferMessage implements Serializable { /* TODO */ }
class TransferMessage implements Serializable { /* TODO */ }
class DepositMessage implements Serializable { /* TODO */ }
class PrintBalanceMessage implements Serializable { /* TODO */ }

// -- ACTORS ----------------------------------------------------
class AccountActor extends UntypedActor { /* TODO */ }
class BankActor extends UntypedActor { /* TODO */ }
class ClerkActor extends UntypedActor { /* TODO */ }

// -- MAIN ------------------------------------------------------
public class ABC { // Demo showing how things work:
    public static void main(String[] args) {
        final ActorSystem system = ActorSystem.create("ABCSystem");

        /* TODO (CREATE ACTORS AND SEND START MESSAGES) */

        try {
            System.out.println("Press return to inspect...");
            System.in.read();

            /* TODO (INSPECT FINAL BALANCES) */

            System.out.println("Press return to terminate...");
            System.in.read();
        } catch(IOException e) {
            e.printStackTrace();
        } finally {
            system.shutdown();
        }
    }
}
```

MANDATORY HAND-IN!

a) Implement ABC.java
(as close to **ABC**.erl as possible,
but without using "tail-recursion")

b) Answer question:
What happens if we replace
{deposit, ±Amount} w/ the msgs?:



```
*** OUTPUT ***
Press return to inspect...
Press return to terminate...
Balance = 42
Balance = -42
```

Thx!

Questions?

Four Conditions ⇔ Deadlock !

1) Mutual exclusion condition (aka. "Serially reusable resources"):

- Processes involved share resources which they use under mutual exclusion.

2) Hold-and-wait condition (aka. "Incremental acquisition"):

- Processes hold on to resources already allocated to them while waiting to acquire additional resources.

3) No pre-emption condition:

- Resources cannot be "pre-empted" (i.e., forcibly withdrawn) once acquired by a process, but are only released voluntarily.

4) Circular-wait condition (aka. "Wait-for cycle"):

- a circular chain (cycle) of processes exists such that each process holds a resource which its successor in the cycle is waiting to acquire.

[Magee & Kramer]