Message Passing

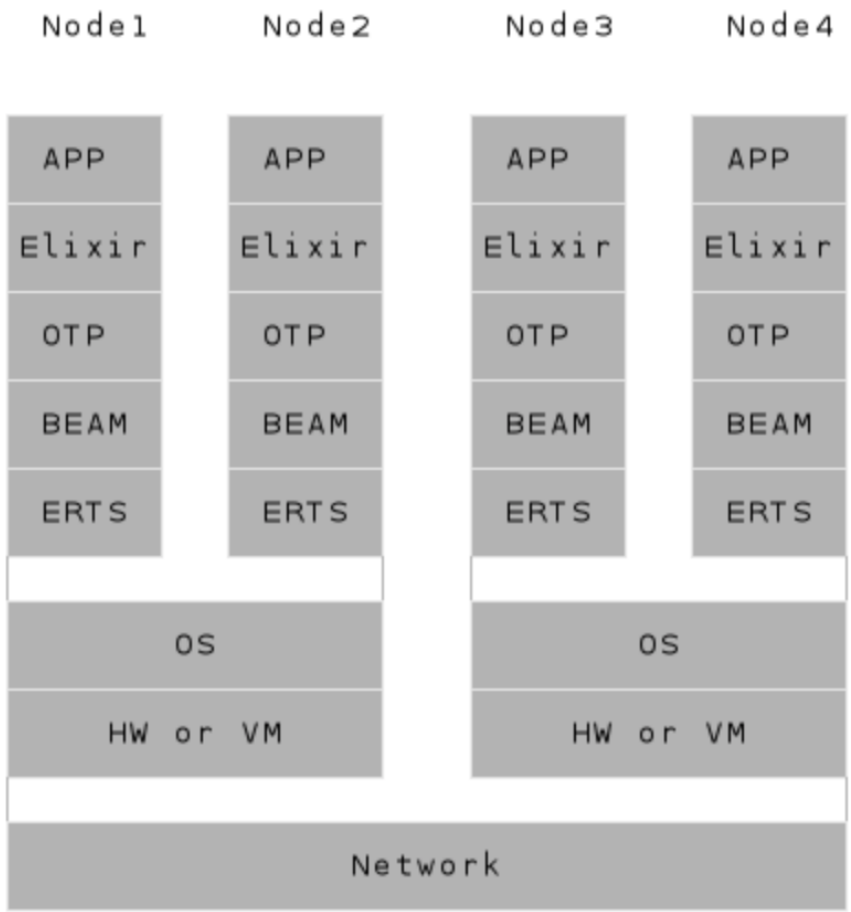
CS511

Interaction Models

- Previously
  - Shared memory (low-level, non-structured)
  - Semaphores (low-level, non-structured)
  - Monitors (popular, structured, encapsulate synchronization)
- So what's the problem with monitors?
  - Highly centralized (un/blocking processes, maintaining queues of blocked processes, encapsulating data)
  - For modern, distributed architectures, need for less centralized solution
  - Turn to interaction through communication rather than sharing

Erlang System

- Consists of a number of distributed Erlang runtime systems communicating with each other (instances of the VM)



Nodes and Processes in Erlang

- Each such runtime system is called a node
  - node name is an atom `name@host`
    - `name` is the name given by the user
    - `host` is the full host name if long names are used, or the first part of the host name if short names are used
- The name of a node may be consulted using `node()`

```
1> node().
nonode@nohost
```

Processes and Communication in Erlang

- A process in a node has
  - a process id (pid)

```
1> self().
<0.78.0>
```

  - its own memory (a mailbox, a heap and a stack); and
  - a process control block (PCB) with information about the process.
- Message passing between processes at different nodes, as well as links and monitors, are transparent when pids are used
  - Registered names, however, are local to each node.
- Format of a PID:
  - node id where process lives; 0 if node is local
  - process index itelf (index into process table)
  - serial which increases every time MAXPROCS has been reached.

Erlang System

Message Passing

Exceptions

Links and Monitors

The Message Passing Model

- No shared memory
  - A process sends a message
  - Another process receives the message
- Operations:

```
receive(Var);
send(PID,msg);
```

  - `receive` blocks until a message is available in the mailbox
  - `send(PID,msg)` is non-blocking; it sends message `msg` to process `PID`
- This model is the asynchronous communication model and is the one used in Erlang

A Simple Echo Server

- Process `echo` will receive a message and then send it back to the sender
- After that it will continue to wait for a new message
- It may be stopped by sending it the `stop` message

```
1 echo() ->
2     receive
3         {From, Msg} ->
4             From ! {Msg},
5             echo();
6         stop -> true
7     end.
```

- Processes are created using `spawn/1` and `spawn/3`

A Simple Echo Server (cont.)

```
1  -module(echo).
2  -export([start/0]).
3
4  echo() ->
5      receive
6          {From, Msg} ->
7              From ! {Msg},
8              echo();
9          stop -> true
10     end.
11
12 start() ->
13     Pid = spawn(fun echo/0), % Returns pid of a new process
14        % started by the application of echo/0 to []
15     Token = "Hello Server!",      % Sending tokens to the server
16     Pid ! {self(), Token},
17     io:format("Sent ~s~n",[Token]),
18     receive
19        {Msg} ->
20             io:format("Received ~s~n", [Msg])
21     end,
22     Pid ! stop.      % Stop server
```

A Simple Echo Server

```
1> echo:start( ).
Sent Hello Server!
Received Hello Server!
stop
```

If we export `echo/0` we can spawn from the interpreter:

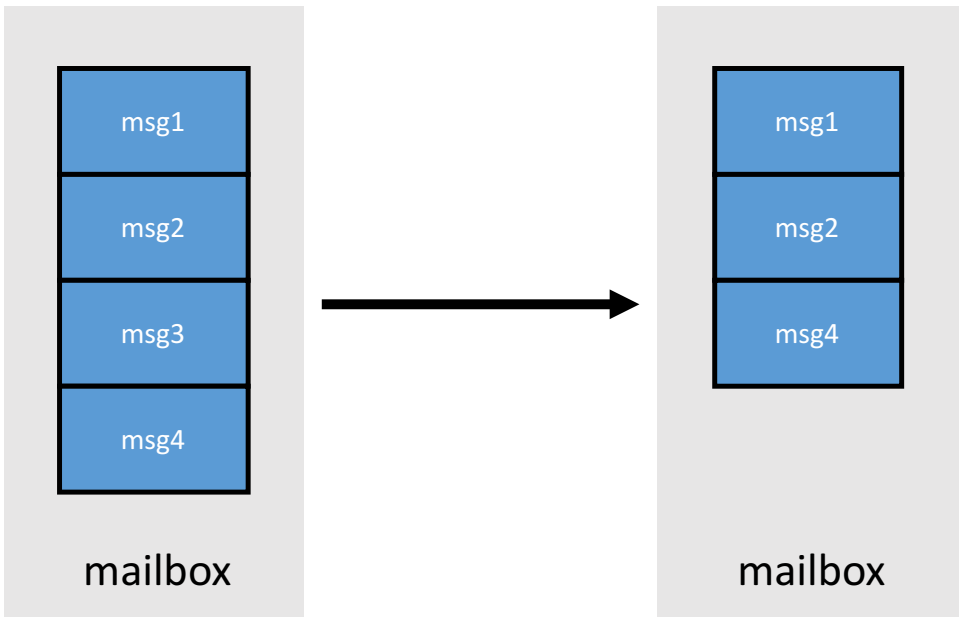
```
59> X=spawn(fun echo:echo/0).
<0.198.0>
60> X!{self(),"hello"}.
{<0.60.0>,"hello"}
61> X.
<0.198.0>
```

Note: the value of a send is the value of the message

Reacting to Multiple Messages

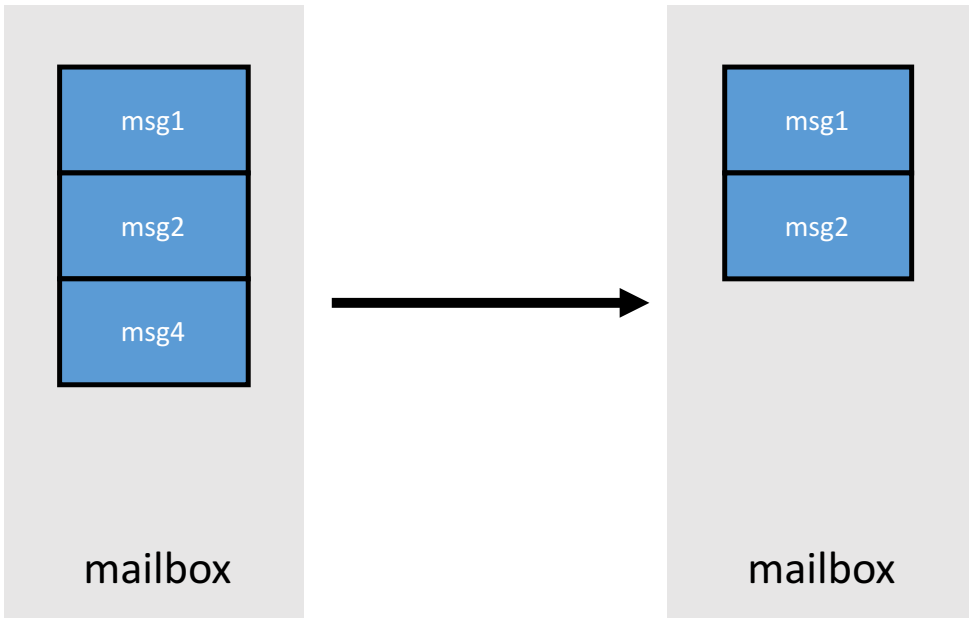
- Erlang "listens" for messages from different senders
- In which order will they be processed?
- Can we force an order?
- A receive statement tries to find a match as early in the mailbox as it can

```
1 receive
2     msg3 -> 42
3 end
```



Reacting to Multiple Messages

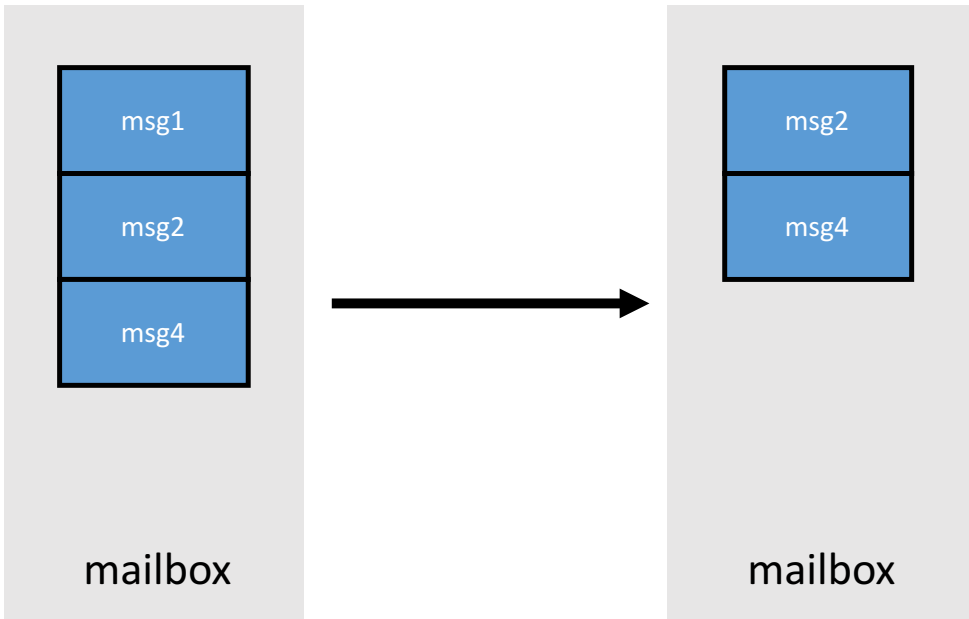
```
1 receive
2     msg4 -> 42
3 end
```



Reacting to Multiple Messages

Waiting for multiple messages

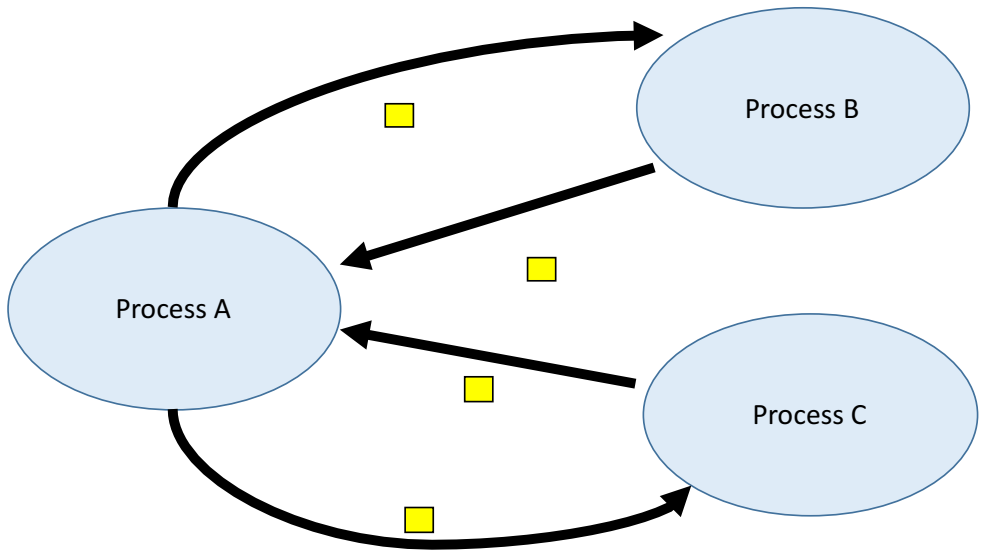
```
1 receive
2     msg4 -> 42;
3     _    -> 41
4 end
```



- The oldest message is tried against every pattern of the receive until one of them matches

Sources of Multiple Messages

Multiple messages can come from different processes



- How do we know who sent a message?
- Distinguish the source by Pids

Sources of Multiple Messages

```
1  -module(echo2).
2  -export([start/0]).
3
4  echo() ->
5      receive
6       {From, Msg} ->
7              timer:sleep(rand:uniform(100)),
8              From ! {Msg},
9              echo();
10         stop ->
11             true
12     end.
13
14 % continued on next slide...
```

- `timer:sleep(N)` sleeps a process for `N` milliseconds
- `rand:uniform(N)` produces a random integer between 1 and N

Sources of Multiple Messages

```
1  start() ->
2      PidB = spawn(fun echo/0),
3      PidC = spawn(fun echo/0),
4
5      % sending tokens
6      Token = 42,
7      PidB ! {self(), Token},
8      io:format("Sent~w~n",[Token]),
9      Token2 = 41,
10     PidC ! {self(), Token2},
11     io:format("Sent~w~n",[Token2]),
12
13     % receive message
14     receive
15         {Msg} ->
16                 io:format("Received ~w~n", [Msg])
17     end,
18
19     % stop echo-servers
20     PidB ! stop,
21     PidC ! stop.
```

Sources of Multiple Messages

- How do we know who sent a message?
- Distinguish the source by Pids

```
1  -module(echo2).
2  -export([start/0]).
3
4  echo() ->
5      receive
6       {From, Msg} ->
7              timer:sleep(rand:uniform(100)),
8              From ! {self(), Msg},
9              echo();
10         stop ->
11             true
12     end.
13
14 % continued on next slide...
```

Sources of Multiple Messages

```
1  start() ->
2      PidB = spawn(fun echo/0),
3      PidC = spawn(fun echo/0),
4
5      % sending tokens
6      Token = 42,
7      PidB ! {self(), Token},
8      io:format("Sent~w~n",[Token]),
9      Token2 = 41,
10     PidC ! {self(), Token2},
11     io:format("Sent~w~n",[Token2]),
12
13     % receive messages
14     receive
15         {PidB, Msg} ->
16                 io:format("Received from B: ~w~n", [Msg]) ;
17         {PidC, Msg} ->
18                 io:format("Received from C: ~w~n", [Msg])
19     end,
20
21     % stop echo-servers
22     PidB ! stop,
23     PidC ! stop.
```

Sources of Multiple Messages

```
11> echo2:start().
Sent42
Sent41
Received from B: 42
stop
12> echo2:start().
Sent42
Sent41
Received from B: 42
stop
13> echo2:start().
Sent42
Sent41
Received from C: 41
stop
14> echo2:start().
Sent42
Sent41
Received from B: 42
stop
```

Sources of Multiple Messages

Multiple messages can come from the same processes

- Send several messages of the same shape and continue computing
- When receiving the responses, how can the code match them to the appropriate request?
- BIF `make_ref` provides globally unique reference objects (references for short) different from every other object in the Erlang system including remote nodes
- References can be used to uniquely identify messages

Sources of Multiple Messages

```
1  -module(echo3).
2  -export([start/0]).
3
4  echo() ->
5      receive
6          {From, Ref, Msg} ->
7              From ! {self(), Ref, Msg},
8              echo();
9          stop ->
10             true
11     end.
12
13 % continues in next slide...
```

Sources of Multiple Messages

```
1  start() ->
2      PidB = spawn(fun echo/0),
3      % sending tokens
4      Token = 42,
5      Ref = make_ref(),
6      PidB ! {self(), Ref, Token},
7      io:format("Sent~w~n",[Token]),
8      Token2 = 41,
9      Ref2 = make_ref(),
10     PidB ! {self(), Ref2, Token2},
11     io:format("Sent~w~n",[Token2]),
12     % receive messages
13     receive
14         {PidB, Ref2, Msg} ->
15               io:format("Received 41? ~w~n", [Msg]) ;
16         {PidB, Ref, Msg} ->
17               io:format("Received 42? ~w~n", [Msg])
18
19     end,
20
21     % stop echo-servers
22     PidB ! stop.
```

Selective Receive

- Clauses can have guards
- Guards must be composed of terminating functions (BIFs)

```
1 receive
2   {Pid, Ref, N} when N>0 -> ...
```

Timeouts

```
1  f(Pid) ->
2      receive
3          {Pid, Msg} -> Msg
4      after 3000 ->
5          timeout
6  end.
```

- The after part will be triggered if 3000 milliseconds have passed without receiving a message that matches the pattern.
- Other uses

```
1  sleep(T) ->
2      receive
3      after T ->
4          ok
5  end.
6
7  flush() ->
8      receive
9        _ -> flush()
10     after 0 ->
11       ok
12 end.
```

Exercise

- Implement a semaphore
- Use the `when` clause

Template that you can start from:

```
1 -module(semaphore).
2 -compile(export_all).
3
4 make_semaphore(Permits) ->
5 spawn(?MODULE,semaphore,[Permits]).
6
7 % complete
```

- `?MODULE`: macro that refers to the name of the current module

A Semaphore

```
1  -module(semaphore).
2  -compile(export_all).
3
4  make_semaphore(Permits) ->
5      spawn(?MODULE,semaphore,[Permits]).
6
7  semaphore(0) ->
8      receive
9          {From,Ref,release} ->
10             semaphore(1)
11     end;
12 semaphore(P) when P>0 ->
13     receive
14         {From,Ref,release} ->
15             From!{self(),Ref,ok},
16             semaphore(P+1);
17         {From,Ref,acquire} ->
18             From!{self(),Ref,ok},
19             semaphore(P-1)
20     end.
```

- `semaphore` could be specified as a FSM

Semaphore - Print “a” before “b”

```
1  start() ->
2      S = make_semaphore(0),
3      spawn(?MODULE,p1,[S]),
4      spawn(?MODULE,p2,[S]).
5
6  release(S) ->  % could be included in semaphore module
7      R = make_ref(),
8      S!{self(),R,release},
9      receive
10         {S,R,ok} ->
11             done
12     end.
13
14 p1(S) ->
15     io:format("a"),
16     release(S).
17
18 p2(S) ->  %  acquire is inlined
19     R = make_ref(),
20     S!{self(),R,acquire},
21     receive
22         {S,R,ok} ->
23             io:format("b")
24     end.
```

Erlang System

Message Passing

Exceptions

Links and Monitors

Three Kinds of Exceptions

- Errors
  - Ends the execution in the current process and includes a stack trace of the last functions
  - Errors are the means for a function to stop its execution when you can't expect the calling code to handle what just happened
- Throws
  - Used for cases that the programmer can be expected to handle (`try...catch`).
- Exits
  - Same as errors except used to signal abnormal termination between processes.
  - More lightweight than errors in that stack trace not included

Note: `try...catch` actually can catch them all

Errors – Example

```
1> erlang:error(badarith).
** exception error: bad argument in an arithmetic expression
2> erlang:error(custom_error).
** exception error: custom_error
3> catch(1+a).
{'EXIT',{badarith,[{erlang,'+',[1,a],[]},
       {erl_eval,do_apply,6,[{file,"erl_eval.erl"},{line,681}]},
       {erl_eval,expr,5,[{file,"erl_eval.erl"},{line,434}]},
       {shell,exprs,7,[{file,"shell.erl"},{line,686}]},
       {shell,eval_exprs,7,[{file,"shell.erl"},{line,642}]},
       {shell,eval_loop,3,[{file,"shell.erl"},{line,627}]}]}
```

Erlang System

Message Passing

Exceptions

Links and Monitors

Links

- Pid1 can be linked to Pid2 by calling `link(Pid2)`
  - Creates a two-way link
- Terminating processes emit exit signals to all linked processes, which can terminate as well or handle the exit in some way.
- This feature can be used to build hierarchical program structures where some processes are supervising other processes, for example, restarting them if they terminate abnormally.

Note: Some comments on monitors are present at the end of these set of slides

Example

```
1  -module(linkmon).
2  -compile(export_all).
3
4  myproc() ->
5      timer:sleep(2000),
6      exit(reason).
```

In the shell:

```
1  > c(linkmon).
2  {ok,linkmon}
3  > self().
4  <0.79.0>
5  > spawn(fun linkmon:myproc/0).
6  <0.75.0>
7  > self().
8  <0.79.0>
9  > link(spawn(fun linkmon:myproc/0)).
10 true
11 ** exception error: reason
12 > self().
13 <0.83.0>
```

Another Example

```
1  chain(0) ->
2    receive
3      _ -> ok
4    after 2000 ->
5      exit("chain dies here")
6    end;
7
8  chain(N) ->
9    Pid = spawn(fun() -> chain(N-1) end),
10   link(Pid),
11   receive
12     _ -> ok
13   end.
```

In the shell:

```
1> c(linkmon).
{ok,linkmon}
2> link(spawn(linkmon, chain, [3])).
true
** exception error: "chain dies here"
```

Another Example (cont.)

```
[shell] == [3] == [2] == [1] == [0]
[shell] == [3] == [2] == [1] == *dead*
[shell] == [3] == [2] == *dead*
[shell] == [3] == *dead*
[shell] == *dead*
*dead, error message shown*
[shell] <-- restarted
```

- After the process running `linkmon:chain(0)` dies, the error is propagated down the chain of links until the shell process itself dies because of it.
- The crash could have happened in any of the linked processes
  - because links are bidirectional, you only need one of them to die for the others to follow suit.

On Number of Links and Linking

- Links cannot be stacked.
  - Calling `link/1` multiple times for the same two processes, will still create only one link between them
  - A single call to `unlink/1` will be enough to tear it down.
- `link(spawn(Function))` or `link(spawn(M,F,A))` happens in more than one step. In some cases, it is possible for a process to die before the link has been set up and then provoke unexpected behavior.
  - `spawn_link/1-3` spawns and links as an atomic operation

Trapping Exit Signals

- In order to be reliable, an application needs to be able to both kill and restart a process quickly.
  - Links convenient for the killing part but restarting is missing.
- When a linked process terminates, it terminates with an exit reason that is sent through a special message known as an exit signal
  - Eg. exit signal with exit reason `"chain dies here"`

```
exit("chain dies here")
```

Trapping Exit Signals

- The default behaviour when a process receives an exit signal with an exit reason other than normal, is to terminate and in turn emit exit signals with the same exit reason to its linked processes.
- System processes: normal processes, except they can convert exit signals to regular messages.
  - Done by calling `process_flag(trap_exit, true)` in a running process.
- Allows a process to react to exit signals

Chain Example Revisited

Chain example with a system process at the beginning

```
1> process_flag(trap_exit, true).
true
2> spawn_link(fun() -> linkmon:chain(3) end).
<0.49.0>
3> receive X -> X end.
{'EXIT',<0.49.0>,"chain dies here"}
```

Description of behavior:

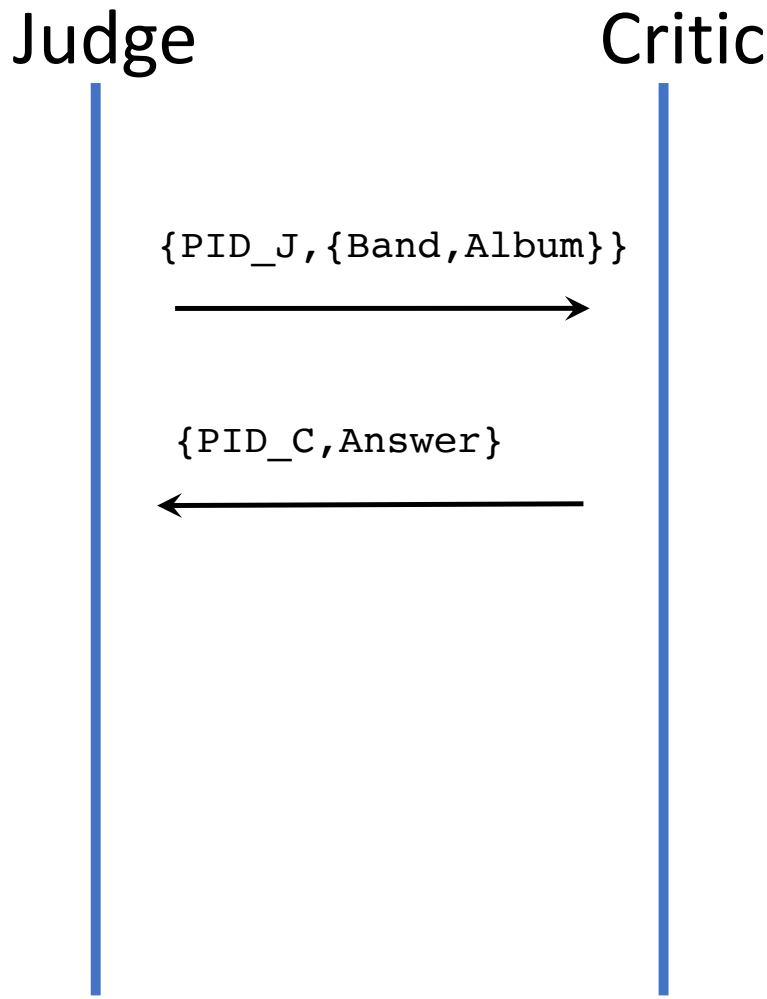
```
[shell] == [3] == [2] == [1] == [0]
[shell] == [3] == [2] == [1] == *dead*
[shell] == [3] == [2] == *dead*
[shell] == [3] == *dead*
[shell] <-- {'EXIT,Pid,"chain dies here"} -- *dead*
[shell] <-- still alive!
```

Kill Reason

- Acts as a special signal that can't be trapped.
- Ensures any process you terminate with it will be dead.
  - A last resort, when everything else has failed.
- As the kill reason can never be trapped, it needs to be changed to `killed` when other processes receive the message.
  - Otherwise, every other process linked to it would in turn die for the same kill reason and would in turn kill its neighbors, and so on.
  - This explains why `exit(kill)` looks like `killed` when received from another linked process.

```
1 > spawn_link(fun() -> exit(kill) end).
2 ** exception exit: killed
```

MSC for Critic Example



Restarting Processes

```
1  start_critic() ->
2      spawn(?MODULE, critic, []).
3
4  judge(Pid, Band, Album) ->
5    Pid ! {self(), {Band, Album}},
6      receive
7        {Pid, Criticism} -> Criticism
8        after 2000 ->
9          timeout
10   end.
11
12 critic() ->
13   receive
14     {From, {"Rage Against the Turing Machine", "Unit Testify"}} ->
15       From ! {self(), "They are great!"};
16     {From, {"System of a Downtime", "Memoize"}} ->
17       From ! {self(), "They're not Johnny Crash but they're good."
18     {From, {"Johnny Crash", "The Token Ring of Fire"}} ->
19       From ! {self(), "Simply incredible."};
20    {From, {_Band, _Album}} ->
21       From ! {self(), "They are terrible!"}
22   end,
23   critic().
```

Restarting Processes

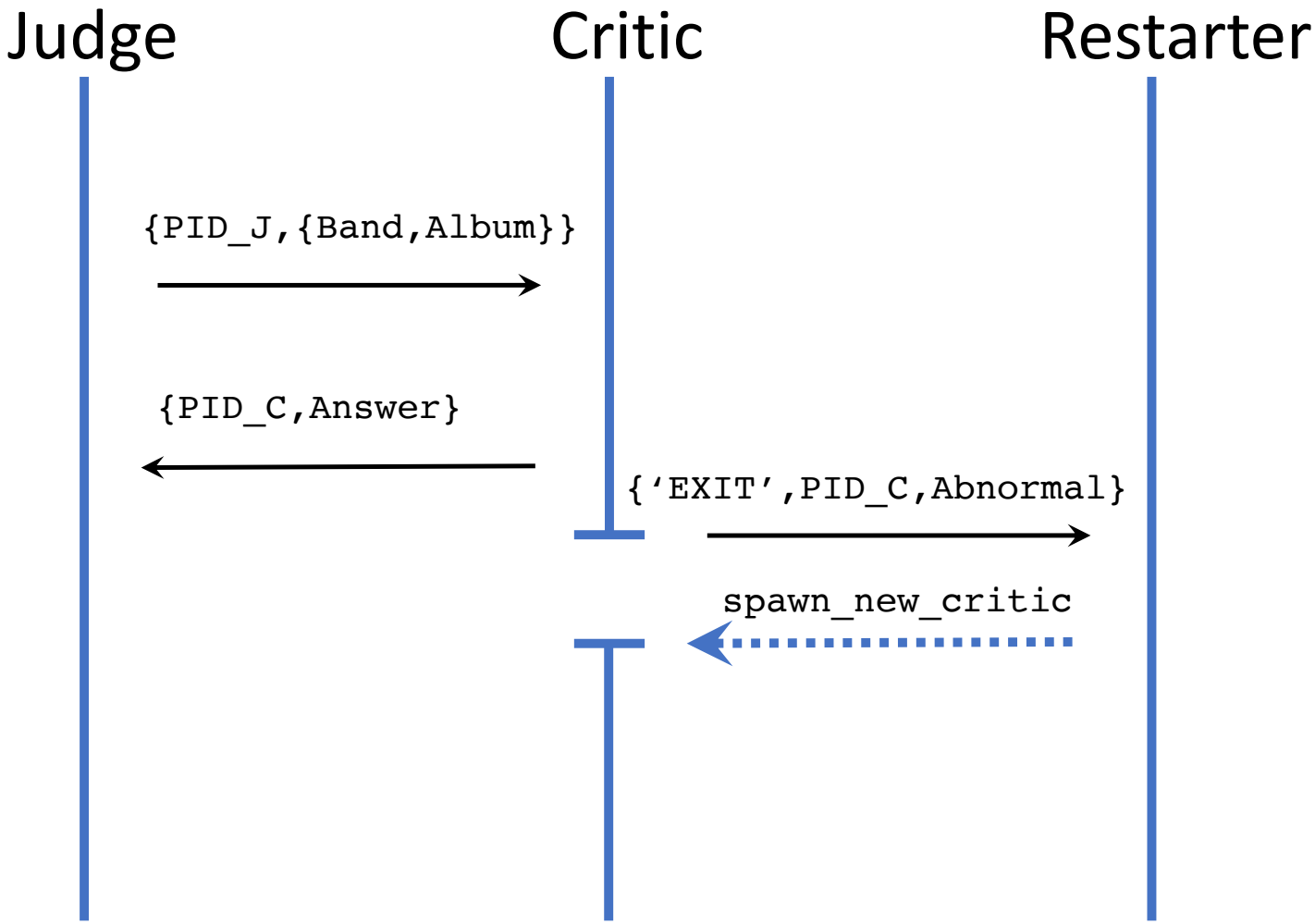
```
1> c(linkmon).
{ok,linkmon}
2> Critic = linkmon:start_critic().
<0.47.0>
3> linkmon:judge(Critic, "Genesis", "The Lambda Lies Down on Broad
"They are terrible!"
```

We now kill the `Critic` process

```
4> exit(Critic, solar_storm).
true
5> linkmon:judge(Critic, "Genesis", "A trick of the Tail Recursion
timeout
```

We need a "supervisor" process to keep critics alive

MSC for Critic Example



Restarting Processes

```
1  start_critic2() ->
2  spawn(?MODULE, restarter, []).
3
4  restarter() ->
5    process_flag(trap_exit, true),
6    Pid = spawn_link(?MODULE, critic, []),
7    receive
8      {'EXIT', Pid, normal} -> % not a crash
9        ok;
10     {'EXIT', Pid, shutdown} -> % manual termination, not a crash
11       ok;
12     {'EXIT', Pid, _} ->
13   restarter()
14 end.
```

Problem: Pid of the critic is part of internal state, it is not known

```
1> c(linkmon).
{ok,linkmon}
2> linkmon:start_critic2().
<0.48.0>
3> linkmon:judge(?????, "Genesis", "The Lambda Lies Down on Broadw
```

Restarting Processes

- We can name a process, using an atom, rather than use its pid via `erlang:register/2`
- If a process dies, it will automatically lose its name or you can also use `unregister/1`
- You can get a list of all registered processes with `registered/0` or a more detailed one with the shell command `regs()`.

```
1  restarter() ->
2    process_flag(trap_exit, true),
3    Pid = spawn_link(?MODULE, critic, []),
4    register(critic, Pid),
5    receive
6      {'EXIT', Pid, normal} -> % not a crash
7        ok;
8      {'EXIT', Pid, shutdown} -> % manual termination, not a crash
9        ok;
10     {'EXIT', Pid, _} ->
11       restarter()
12   end.
```

What about the judge?

Restarting a Process

```
1 judge2(Band, Album) ->
2   critic ! {self(), {Band, Album}},
3   Pid = whereis(critic),
4   receive
5     {Pid, Criticism} -> Criticism
6   after 2000 ->
7     timeout
8   end.
```

Restarting a Process

```
1> linkmon:start_critic2().
<0.58.0>
2> whereis(critic).
<0.59.0>
3> linkmon:judge2("Genesis", "A trick of the Tail Recursion").
"They are terrible!"
4> exit(whereis(critic),solar_storm).
true
5> linkmon:judge2("Genesis", "A trick of the Tail Recursion").
"They are terrible!"
6> whereis(critic).
<0.63.0>
```

Race Conditions due to Shared State

- `critic` is stored in a shared registry
- There are processes that read it such as `judge2`
- And processes that write to it such as `restarter`
- Race conditions are therefore possible

Race Conditions due to Shared State – Example 1

1. `critic ! Message`
2. critic receives
3. critic replies
4. critic dies
5. whereis fails
6. critic is restarted
7. code crashes

```
1  judge2(Band, Album) ->
2    critic ! {self(), {Band, Album}},
3    %% critic dies at this point
4    %% register still not updated
5    Pid = whereis(critic), %% fails (returns undefined)
6    receive
7      {Pid, Criticism} -> Criticism  %% undefined!=Pid
8    after 2000 ->
9      timeout
10   end.
```

Race Conditions due to Shared State – Example 2

1. `critic ! Message`
2. critic receives
3. critic replies
4. critic dies
5. critic is restarted
6. whereis picks up wrong pid
7. message never matches

```
1  judge2(Band, Album) ->
2    critic ! {self(), {Band, Album}},
3    %% critic dies at this point
4    %% register updated with new Pid
5    Pid = whereis(critic), %% successful (but different Pid)
6    receive
7      {Pid, Criticism} -> Criticism  %% no match
8    after 2000 ->
9      timeout
10   end.
```

- Both may be solved by replacing the use of `whereis` (and Pid matching) to that of reference matching

Adding References to Messages

```
1  judge2(Band, Album) ->
2    Ref = make_ref(),
3    critic ! {self(), Ref, {Band, Album}},
4    receive
5      {Ref, Criticism} -> Criticism
6    after 2000 ->
7      timeout
8    end.
9
10 critic2() ->
11   receive
12     {From, Ref, {"Rage Against the Turing Machine", "Unit Testify"
13       From ! {Ref, "They are great!"};
14     {From, Ref, {"System of a Downtime", "Memoize"}} ->
15       From ! {Ref, "They're not Johnny Crash but they're good."};
16     {From, Ref, {"Johnny Crash", "The Token Ring of Fire"}} ->
17       From ! {Ref, "Simply incredible."};
18     {From, Ref, {_Band, _Album}} ->
19       From ! {Ref, "They are terrible!"}
20   end,
21   critic2().
```

Appendix: More on Exceptions

Appendix: Monitors

Revisiting Exceptions – How Processes Trap Them

- `spawn_link(fun() ->ok end)`
  - Untrapped Result: Nothing
  - Trapped Result: `{'EXIT', <0.61.0>, normal}`
  - The process exited normally, without a problem.
- `spawn_link(fun() ->exit(reason) end)`
  - Untrapped Result: `** exception exit: reason`
  - Trapped Result: `{'EXIT', <0.55.0>, reason}`
  - The process has terminated for a custom reason.
- `spawn_link(fun() ->exit(normal) end)`
  - Untrapped Result: Nothing
  - Trapped Result: `{'EXIT', <0.58.0>, normal}`
  - Emulates process terminating normally.

Revisiting Exceptions

- `spawn_link(fun() ->1/0 end)`
  - Untrapped Result:

    ```
    Error in process <0.44.0> with exit value: {badarith, [{erlang, '/',
    ```
  - Trapped Result:

    ```
    {'EXIT', <0.52.0>, {badarith, [{erlang, '/', [1,0]}]}
    ```
- `spawn_link(fun() ->erlang:error(reason) end)`
  - Untrapped Result:

    ```
    Error in process <0.47.0> with exit value: {reason, [{erlang, apply,
    ```
  - Trapped Result:

    ```
    {'EXIT', <0.74.0>, {reason, [{erlang, apply, 2}]}}
    ```
  - Similar to 1/0.
- `spawn_link(fun() ->throw(rocks) end)`
  - Untrapped Result:

    ```
    Error in process <0.51.0> with exit value: {{nocatch, rocks}, [{erlan
    ```
  - Trapped Result:

    ```
    {'EXIT', <0.79.0>, {{nocatch, rocks}, [{erlang, apply, 2}]}}
    ```
  - Because the throw is never caught by a try ... catch, it bubbles up into an error, which in turn bubbles up into an EXIT. Without trapping exit, the process fails.

Revisiting Exceptions – the `exit/2` case

Allows a process to kill another one from a distance, safely

- `exit(self(), normal)`
  - Untrapped Result: `** exception exit: normal`
  - Trapped Result: `{'EXIT', <0.31.0>, normal}`
  - When not trapping exits, `exit(self(), normal)` acts the same as `exit(normal)`.
- `exit(spawn_link(fun() ->timer:sleep(50000) end), normal)`
  - Untrapped Result: nothing
  - Trapped Result: nothing
- `exit(spawn_link(fun() ->timer:sleep(50000) end), reason)`
  - Untrapped Result: `** exception exit: reason`
  - Trapped Result: `{'EXIT', <0.52.0>, reason}`

Revisiting Exceptions – the `exit/2` case

- `exit(spawn_link(fun() ->timer:sleep(50000) end), kill)`
  - Untrapped Result: `** exception exit: killed`
  - Trapped Result: `{'EXIT', <0.58.0>, killed}`
- `exit(self(), kill)`
  - Untrapped Result: `** exception exit: killed`
  - Trapped Result: `** exception exit: killed`
- `spawn_link(fun() ->exit(kill) end)`
  - Untrapped Result: `** exception exit: killed`
  - Trapped Result: `{'EXIT', <0.67.0>, kill}`

Monitors

- Special type of link with two differences
  - they are unidirectional,
  - can monitor via a registered name, and
  - they can be stacked.
- Allows a process to, unobtrusively, monitor another one
- Useful for when you have multiple libraries that you call and they all need to know whether a process is alive or not
  - You can stack links and remove them individually

Example

`erlang:monitor/2` sets up a monitor, where the first argument is the atom process and the second one is the pid

```
1> erlang:monitor(process, spawn(fun() -> timer:sleep(500) end)).
#Ref<0.0.0.77>
2> flush().
Shell got {'DOWN',#Ref<0.0.0.77>,process,<0.63.0>,normal}
ok
```

- When monitored process goes down, send message to monitor: `{'DOWN', MonitorReference, process, Pid, Reason}`.
- The reference allows you to demonitor the process.
  - Monitors are stackable, so it's possible to take more than one down.
  - References allow you to track each of them in a unique manner.

Example

Atomic function to spawn process while monitoring it:

```
3> {Pid, Ref} = spawn_monitor(fun() -> receive _ -> exit(boom) end
{<0.73.0>,#Ref<0.0.0.100>}
4> erlang:demonitor(Ref).
true
5> Pid ! die.
die
6> flush().
ok
```

- We demonitored the other process before it crashed hence no trace of it dying.