Robust Erlang

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Genesis of Erlang

- **Problem:** telephony systems in the late 1980s
  - Digital
  - More and more complex
  - Highly concurrent
  - Hard to get right
- **Approach:** a group at Ericsson research programmed POTS in different languages

”Plain Old Telephony System”

- **Solution:** nicest was *functional programming* —but not concurrent
- Erlang designed in the early 1990s

Mid 1990s: the AXD 301

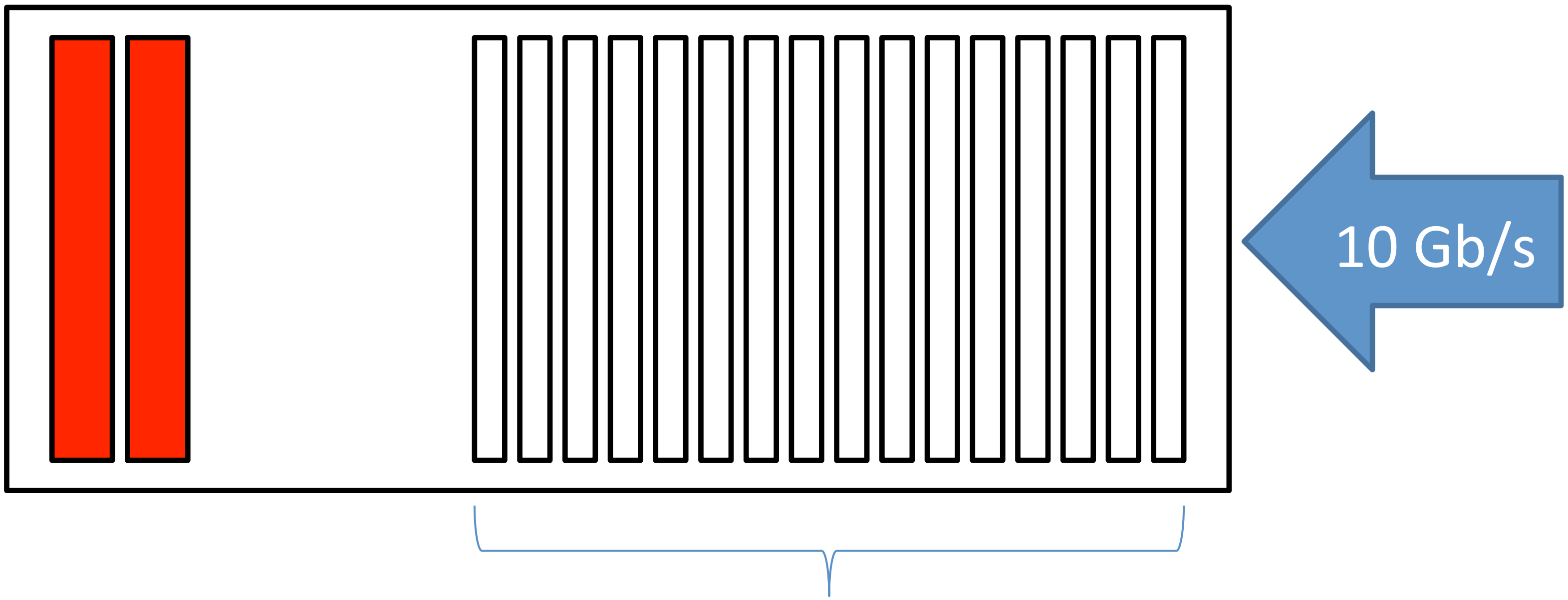
- ATM switch (telephone backbone), released in 1998

- First *big* Erlang project

- Born out of the ashes of a disaster!

AXD301 Architecture

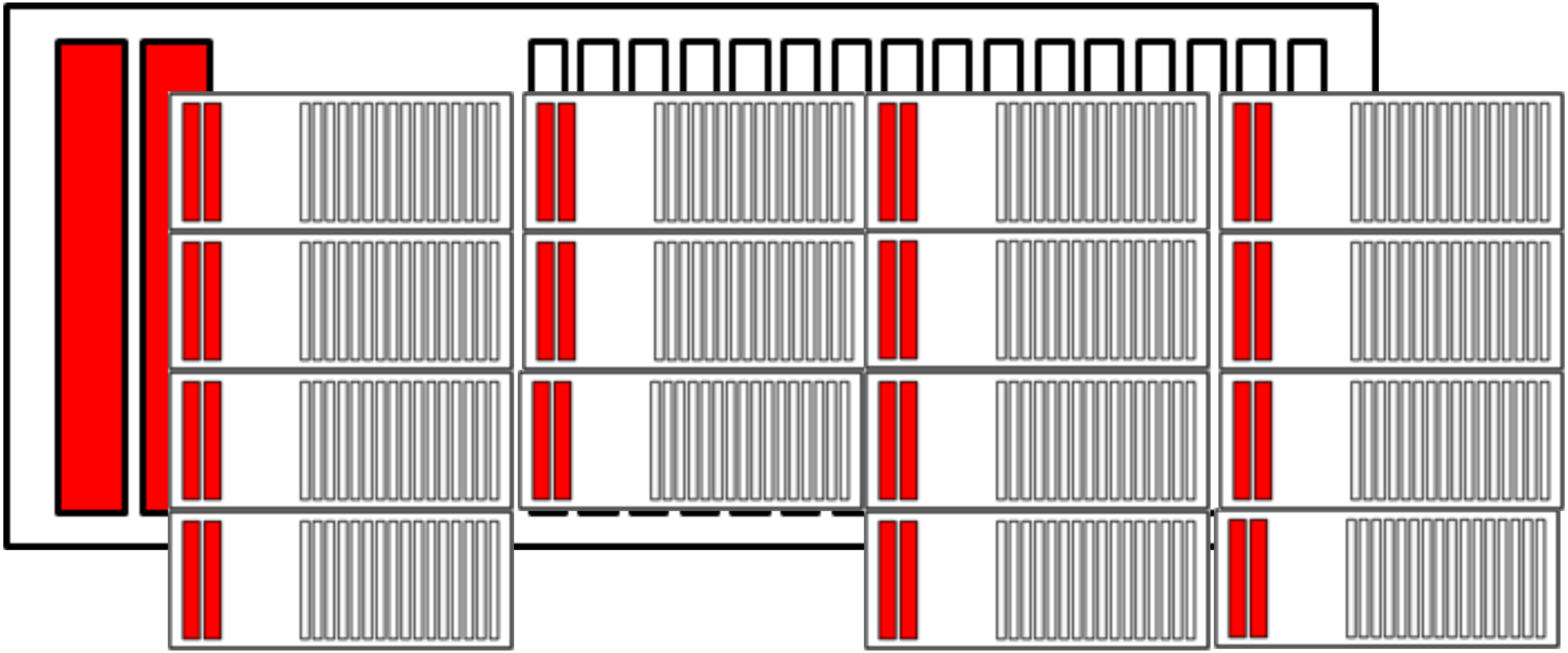
Subrack



10 Gb/s

1,5 million LOC
of Erlang

16 data boards
2 million lines of C++



- 160 Gbits/sec (240,000 simultaneous calls!)
- 32 distributed Erlang nodes
- Parallelism vital from the word go

Typical Applications Today

Invoicing services for web shops—European market leader, in 18 countries

Distributed no-SQL database serving e.g. Denmark and the UK's medicine card data

Messaging services. See http://www.wired.com/2015/09/whatsapp-serves-900-million-users-50-engineers/

What do they all have in common?

- Serving *huge* numbers of clients through parallelism

- Very high demands on *quality of service:* these systems should work *all* of the time

AXD 301 Quality of Service

- 7 nines reliability!
  - Up 99,99999% of the time
- Despite
  - Bugs
    - (10 bugs per 1000 lines is *good*)
  - Hardware failures
    - Always something failing in a big cluster
    - Avoid *any* SPOF

Example: Area of a Shape

```
area({square,X}) -> X*X;
area({rectangle,X,Y}) -> X*Y.
```

```
8> test:area({rectangle,3,4}).
12
9> test:area({circle,2}).
** exception error: no function clause matching test:area({circle,
2}) (test.erl, line 16)
10>
```

What do we do about it?

Defensive Programming

Anticipate a possible error

```
area({square,X}) -> X*X;
area({rectangle,X,Y}) -> X*Y;
area(_) -> 0.
```

Return a plausible result.

```
11> test:area({rectangle,3,4}).
12
12> test:area({circle,2}).
0
```

No crash any more!

Plausible Scenario

- We write lots more code manipulating shapes
- We add circles as a possible shape
  - But we forget to change area!

<LOTS OF TIME PASSES>

- We notice something doesn't work for circles
  - We silently substituted the wrong answer
- We write a special case *elsewhere* to "work around" the bug

Handling Error Cases

- Handling errors often accounts for > ⅔ of a system's code
  - Expensive to construct and maintain
  - Likely to contain > ⅔ of a system's bugs
- Error handling code is often poorly tested
  - Code coverage is usually << 100%
- ⅔ of system crashes are caused by *bugs in the error handling code*

But what can we do about it?

Don’t Handle Errors!

LET IT CRASH!

Stopping a malfunctioning program

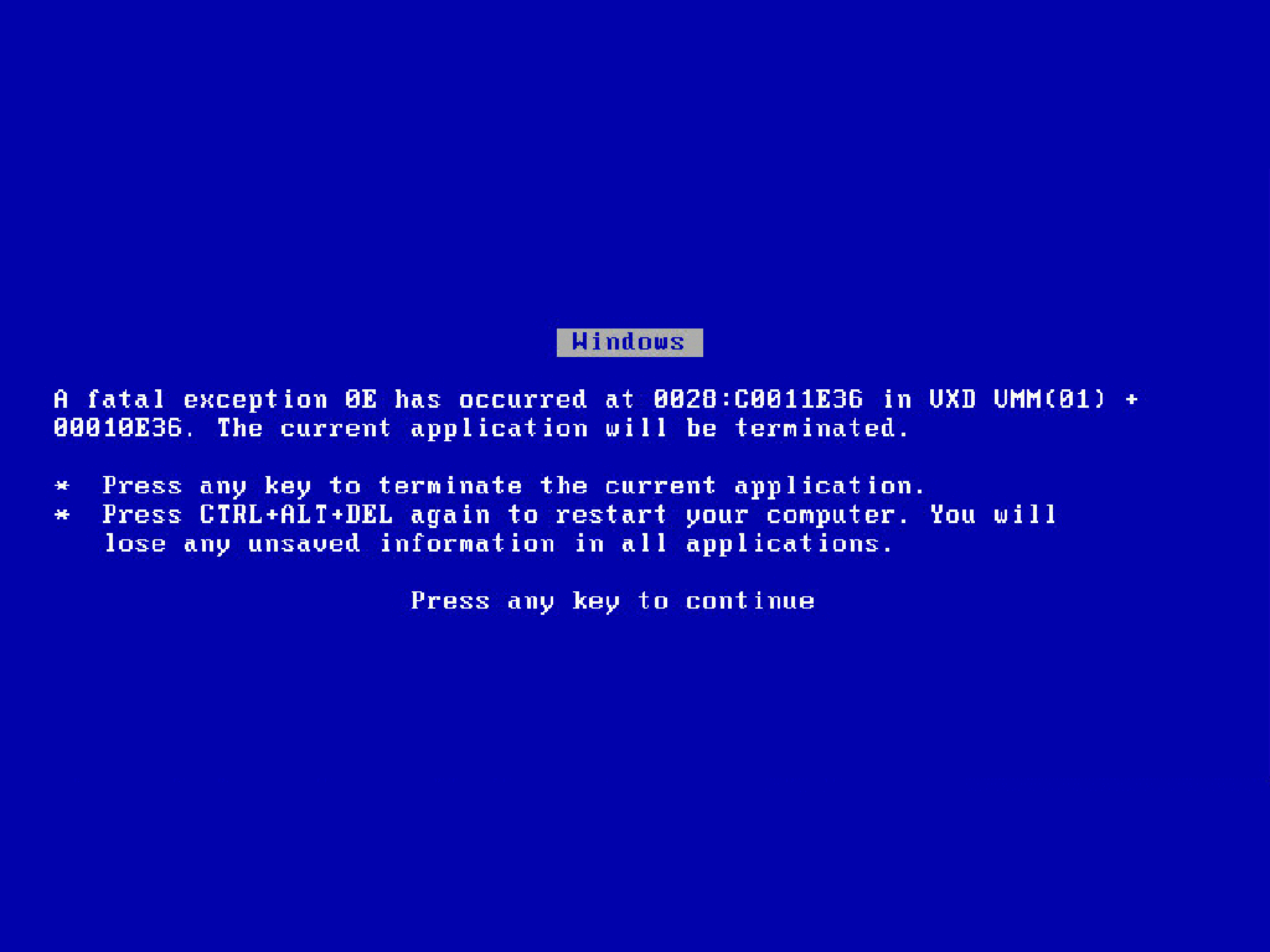
…is better than …

Letting it continue and wreak untold damage

Let it crash… locally

- **Isolate** a failure within one process!
  - No shared memory between processes
  - No mutable data
  - One process cannot cause another to fail

- *One* client may experience a failure… but the rest of the system keeps going



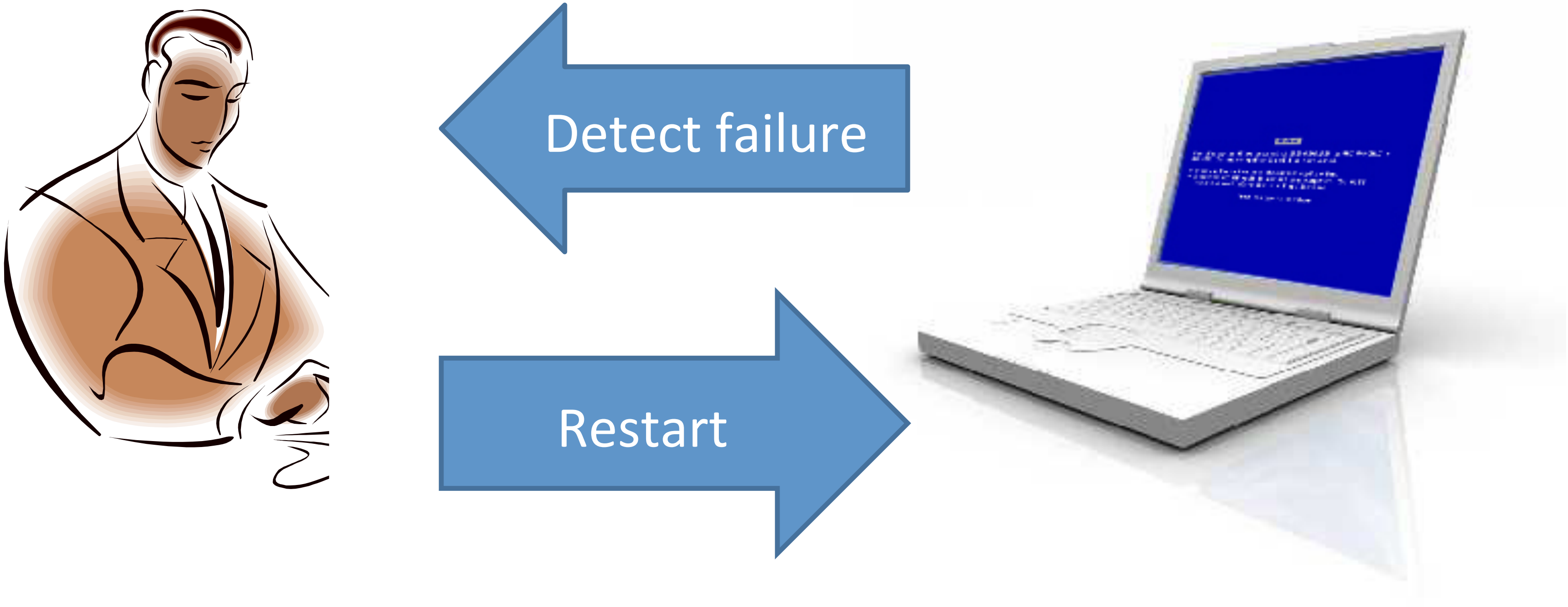
```
                              Windows

A fatal exception 0E has occurred at 0028:C0011E36 in VXD VMM(01) +
00010E36. The current application will be terminated.

*  Press any key to terminate the current application.
*  Press CTRL+ALT+DEL again to restart your computer. You will
   lose any unsaved information in all applications.

                      Press any key to continue
```

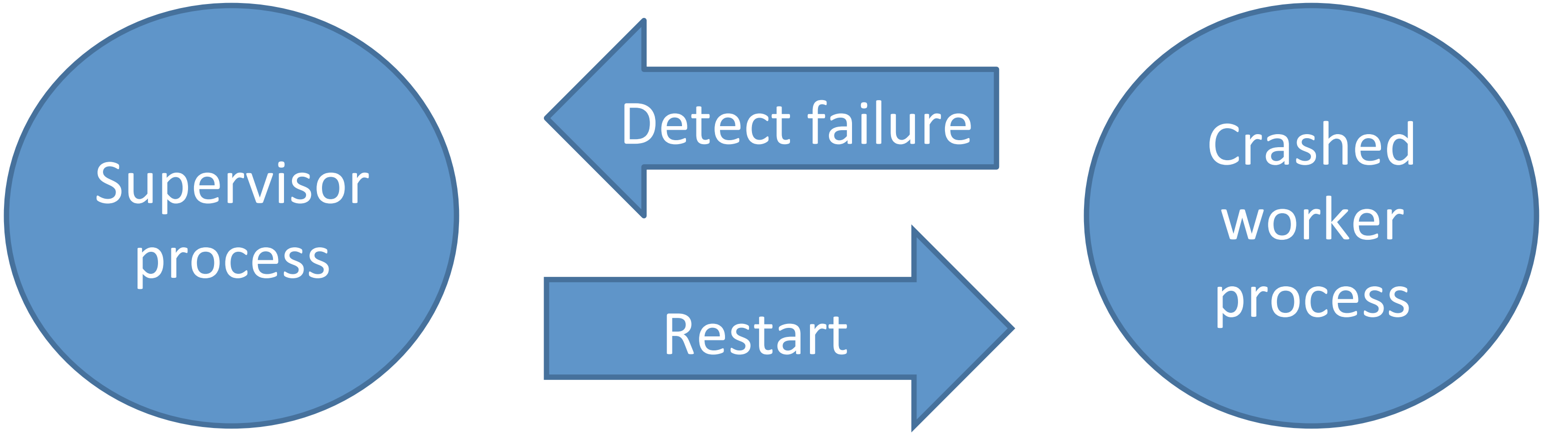
We know what to do…



Detect failure

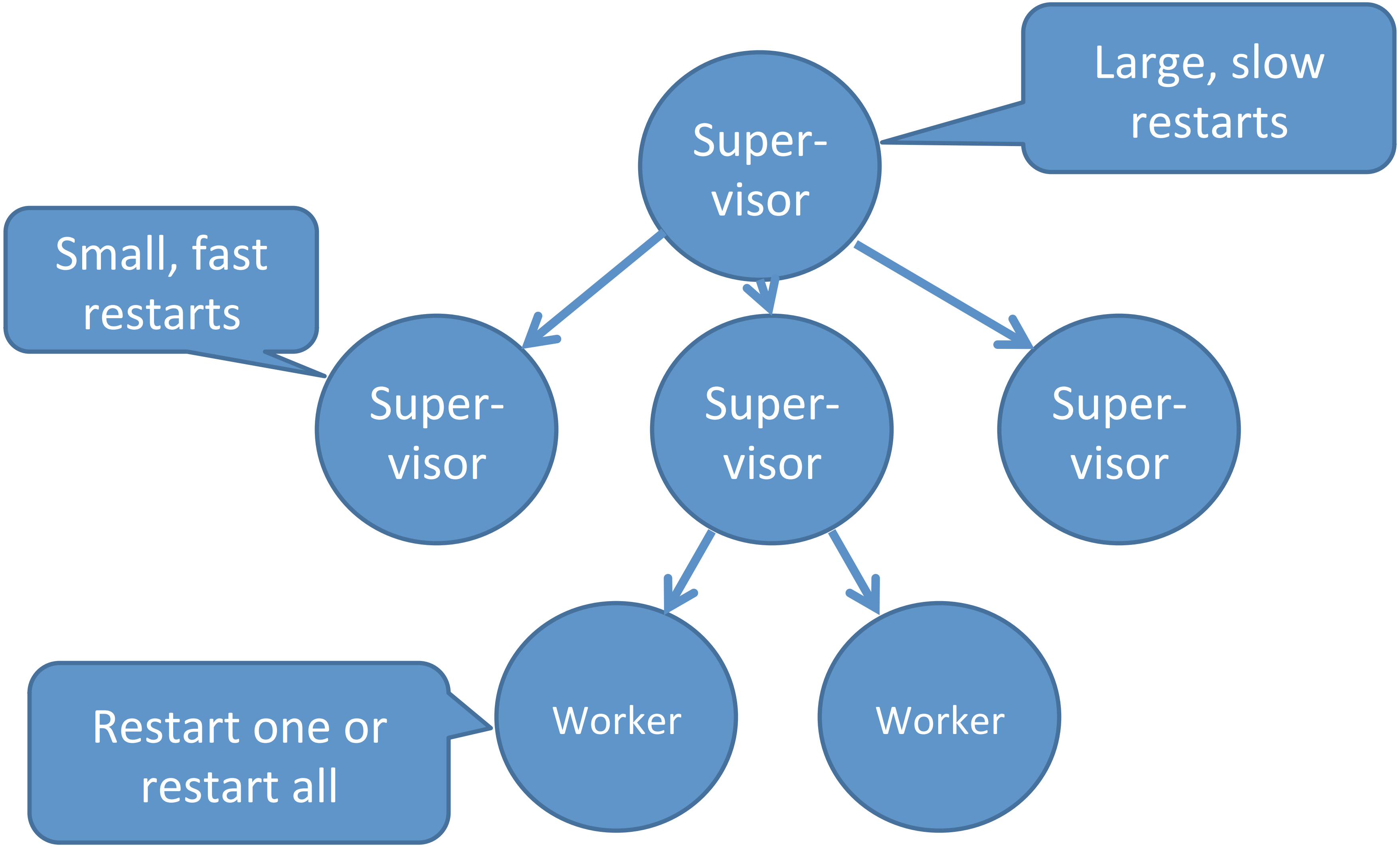
Restart

Using Supervisor Processes



- Supervisor process is *not* corrupted
  - One process *cannot* corrupt another
- Large grain error handling
  - simpler, smaller code

Supervision Trees

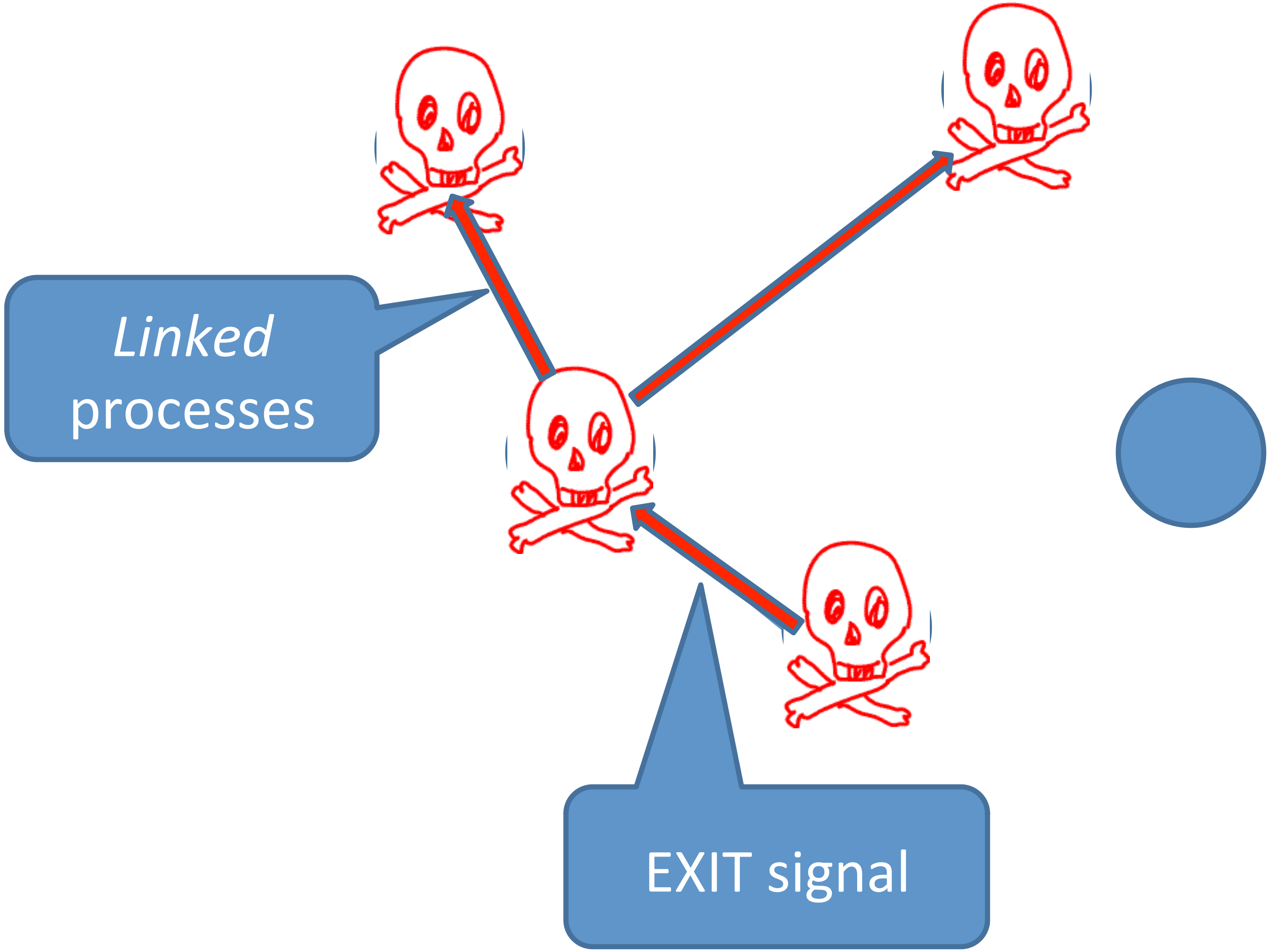


Large, slow restarts

Small, fast restarts

Restart one or restart all

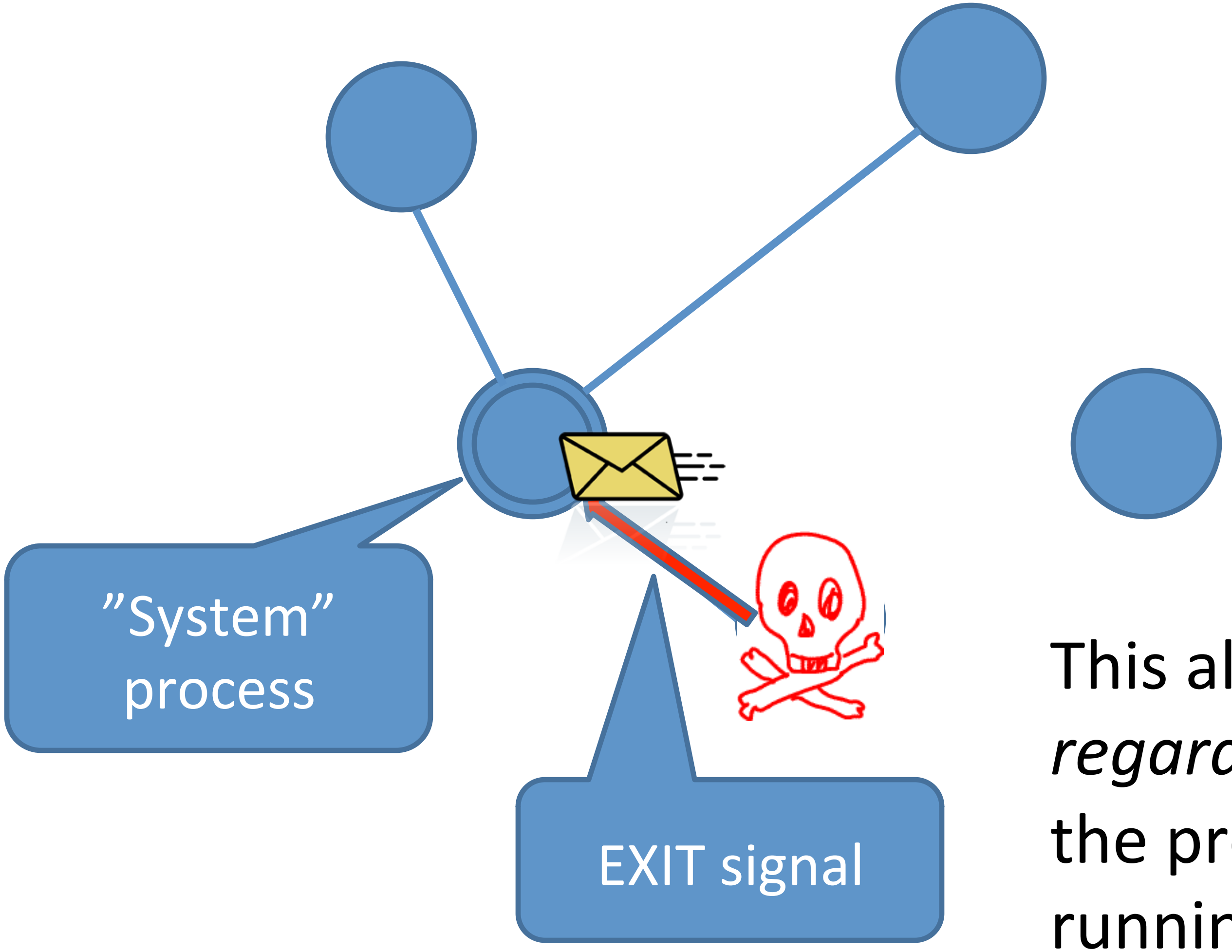
Detecting Failures: Links



Linked processes

EXIT signal

Linked Processes



”System” process

EXIT signal

This all works *regardless* of where the processes are running☺

Creating a Link

- link(Pid)
  - Create a link between self() and Pid
  - When one process exits, an *exit signal* is sent to the other
  - Carries an *exit reason* (`normal` for successful termination)

- unlink(Pid)
  - Remove a link between self() and Pid

Two ways to spawn a process

- spawn(F)
  - Start a new process, which calls F().
- spawn_link(F)
  - Spawn a new process *and link to it atomically*

Trapping Exits

- An exit signal causes the recipient to exit also
  - Unless the reason is `normal`
- …unless the recipient is a *system process*
  - Creates a message in the mailbox: `{’EXIT’,Pid,Reason}`
  - Call `process_flag(trap_exit,true)` to become a system process

An On-Exit Handler

- Specify a function to be called when a process terminates

```
on_exit(Pid,Fun) ->
  spawn(fun() -> process_flag(trap_exit,true),
                 link(Pid),
                 receive
                   {'EXIT',Pid,Why} -> Fun(Why)
                 end
         end).
```

Testing on_exit

```
5> Pid = spawn(fun()->receive N -> 1/N end end).
<0.55.0>
6> test:on_exit(Pid,fun(Why)->
           io:format("***exit: ~p\n",[Why]) end).
<0.57.0>
7> Pid ! 1.
***exit: normal
1
8> Pid2 = spawn(fun()->receive N -> 1/N end end).
<0.60.0>
9> test:on_exit(Pid2,fun(Why)->
         io:format("***exit: ~p\n",[Why]) end).
<0.62.0>
10> Pid2 ! 0.
=ERROR REPORT==== 25-Apr-2012::19:57:07 ===
Error in process <0.60.0> with exit value:
{badarith,[{erlang,'/',[1,0],[]}]}
***exit: {badarith,[{erlang,'/',[1,0],[]}]}
0
```

A Simple Supervi

Real supervisors won’t restart too often—pass the failure up the hierarchy

- Keep a server alive at all times
  - Restart it whenever it terminates

```
keep_alive(Fun) ->
    Pid = spawn(Fun),
    on_exit(Pid,fun(_) -> keep_alive(Fun) end).
```

- Just one problem…

How will anyone ever communicate with Pid?

The Process Registry

- Associate *names* (atoms) with pids
- Enable other processes to find pids of servers, using
  - register(Name,Pid)
    - Enter a process in the registry
  - unregister(Name)
    - Remove a process from the registry
  - whereis(Name)
    - Look up a process in the registry

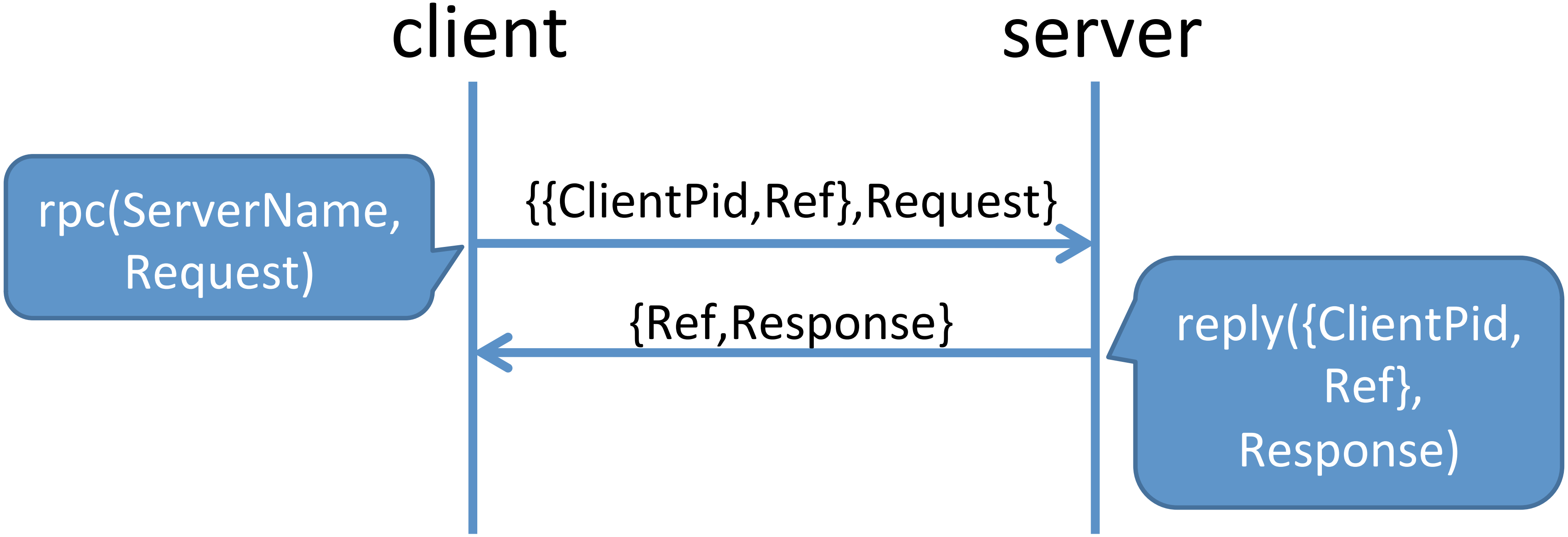
A Supervised Divider

```
divider() ->
  keep_alive(fun() -> register(divider,self()),
                      receive
                            N ->  io:format("~n~p~n",[1/N])
                      end
             end).
```

```
4> divider ! 0.
=ERROR REPORT==== 25-Apr-2012::20:05:20 ===
Error in process <0.43.0> with exit value: {badarith,
[{test,'-divider/0-fun-0-',0,
          [{file,"test.erl"},{line,34}]}]}
0
5> divider ! 3.
0.3333333333333333
3
```

Supervisors supervise servers

- At the leaves of a supervision tree are processes that service requests
- Let’s decide on a protocol



rpc/reply

```
rpc(ServerName,Request) ->
    Ref = make_ref(),
    ServerName ! {{self(),Ref},Request},
    receive
        {Ref,Response} ->
            Response
    end.

reply({ClientPid,Ref},Response) ->
    ClientPid ! {Ref,Response}.
```

Example Server

```
account(Name,Balance) ->
  receive
    {Client,Msg} ->
        case Msg of
          {deposit,N} ->
              reply(Client,ok),
              account(Name,Balance+N);
          {withdraw,N} when N=<Balance ->
              reply(Client,ok),
              account(Name,Balance-N);
          {withdraw,N} when N>Balance ->
              reply(Client,{error,insufficient_funds}),
              account(Name,Balance)
        end
  end.
```

eply

Change the state

A Generic Server

- Decompose a server into…
  - A *generic* part that handles client—server communication
  - A *specific* part that defines functionality for this particular server
- Generic part: receives requests, sends replies, recurses with new state
- Specific part: *computes* the replies and new state

A Factored Server

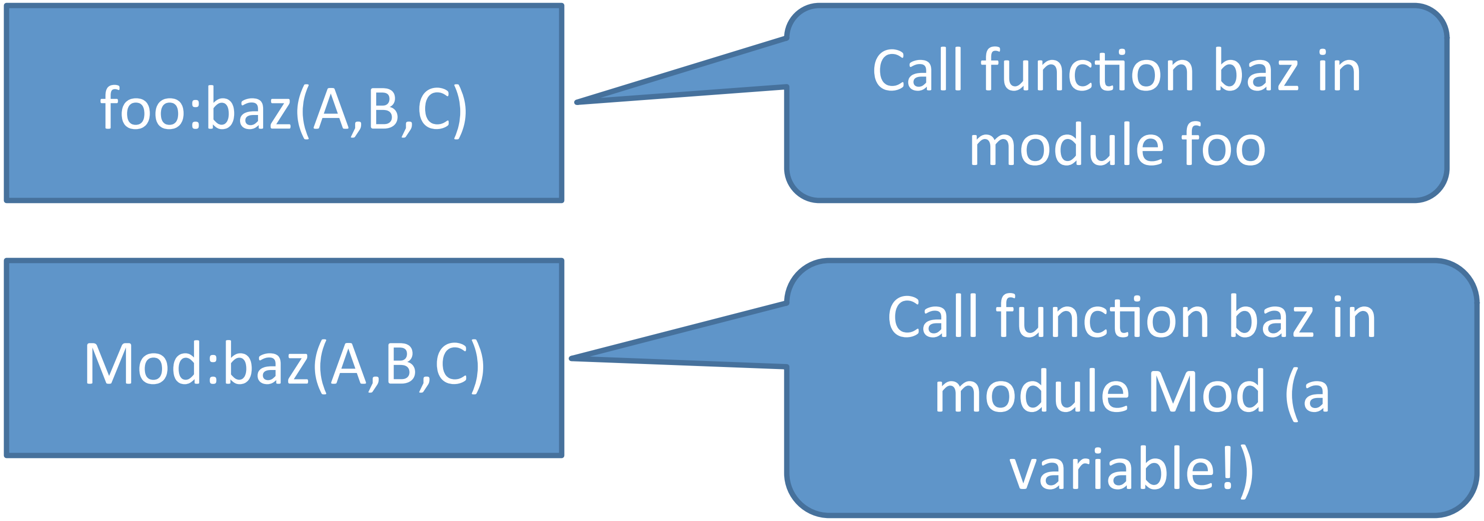
```
server(State) ->
   receive {Client,Msg} -> {Reply,NewState} = handle(Msg,State),
                           reply(Client,Pid,Reply),
                           server(NewState)
   end.
```

How do we parameterise the server on the callback?

```
handle(Msg,Balance) ->
   case Msg of
        {deposit,N}                          -> {ok, Balance+N};
        {withdraw,N} when N=<Balance -> {ok, Balance-N};
        {withdraw,N} when N>Balance   ->
           {{error,insufficient_funds}, Balance}
   end.
```

Callback Modules

- Remember:



foo:baz(A,B,C)

Call function baz in module foo

Mod:baz(A,B,C)

Call function baz in module Mod (a variable!)

- Passing a module *name* is sufficient to give access to a collection of ”callback” functions

A Generic Server

```
server(Mod,State) ->
    receive {Client,Msg} ->
            {Reply,NewState} = Mod:handle(Msg,State),
            reply(Client,Reply),
            server(Mod,NewState)
    end.
```

```
new_server(Name,Mod) ->
    keep_alive(fun() -> register(Name,self()),
                        server(Mod,Mod:init()) end).
```

The Bank Account Module

```
handle(Msg,Balance) ->
    case Msg of
            {deposit,N}                          -> {ok, Balance+N};
            {withdraw,N} when N=<Balance -> {ok, Balance-N};
            {withdraw,N} when N>Balance   ->
                                     {{error,insufficient_funds}, Balance}
    end.
init() -> 0.
```

- This is *purely sequential* (and hence easy) code
- This is all the application programmer needs to write

What Happens If…

- The client makes a bad call, and…
- The handle callback crashes?

Is this what
we want?

- The *server* crashes
- The *client* waits for ever for a reply

- Let’s make the *client* crash instead

Erlang Exception Handling

```
catch <expr>
```

- Evaluates to V, if <expr> evaluates to V
- Evaluates to {’EXIT’,Reason} if expr throws an exception with reason Reason

Generic S

```
server(Mod,State) ->
    receive
        {Pid,Msg} ->
            case catch Mod:hand
                {'EXIT',Reason} ->
                    reply(Name,Pid, {crash,Reason}),
                    server(Mod,. State );
                {Reply,NewState} ->
                    reply(Name,Pid, {ok,Reply}),
                    server(Mod,NewState)
            end
    end.
```

```
rpc(Name,Msg) ->
    …
    receive
        {Ref,{crash,Reason}} ->
            exit(Reason);
        {Ref,{ok,Reply}} ->
            Reply
    end.
```

What should we put here?

We don’t *have* a new state!

Transaction Semantics

- The Mk II server supports *transaction semantics*
  - When a request crashes, the *client* crashes…
  - …but the server state is restored to the state before the request

- Other clients are unaffected by the crashes

Hot Code Swapping

- Suppose we want to *change the code* that the server is running
  - It's sufficient to change the *module* that the callbacks are taken from

```
server(Mod,State) ->
    receive
        {Client, {code_change,NewMod}} ->
            reply(Client,{ok,ok}),
            server(NewMod,State);
        {Client,Msg} -> …
    end.
```

The State is not lost

Two Difficult Things Before Breakfast

- Implementing transactional semantics in a server
- Implementing dynamic code upgrade *without losing the state*

Why was it easy?

- Because all of the state is captured in a single value…
- …and the state is updated by a pure function

gen_server for real

- 6 call-backs
  - init
  - handle_call
  - handle_cast—messages with no reply
  - handle_info—timeouts/unexpected messages
  - terminate
  - code_change
- Tracing and logging, supervision, system messages…
- 70% of the code in real Erlang systems

OTP

- A handful of generic behaviours
  - gen_server
  - gen_fsm—traverses a finite graph of states
  - gen_event—event handlers
  - supervisor—tracks supervision tree+restart strategies

- And there are other more specialised behaviours…
  - gen_leader—leader election
  - …

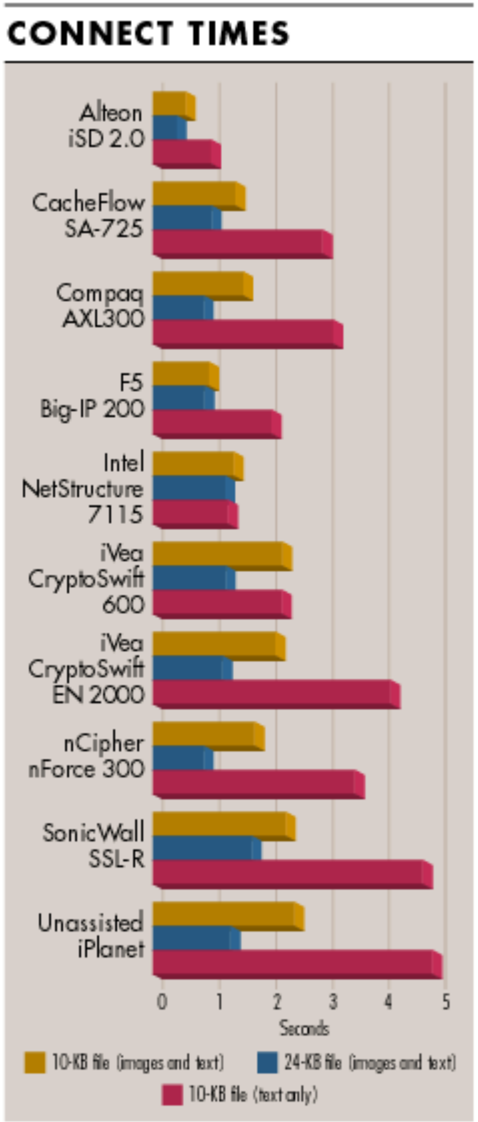
Erlang’s Secret

- Highly robust
- Highly scalable
- **Ideal for internet servers**

- 1998: Open Source Erlang (banned in Ericsson)
- First Erlang start-up: Bluetail
  - Bought by Alteon Websystems
    - Bought by Nortel Networks

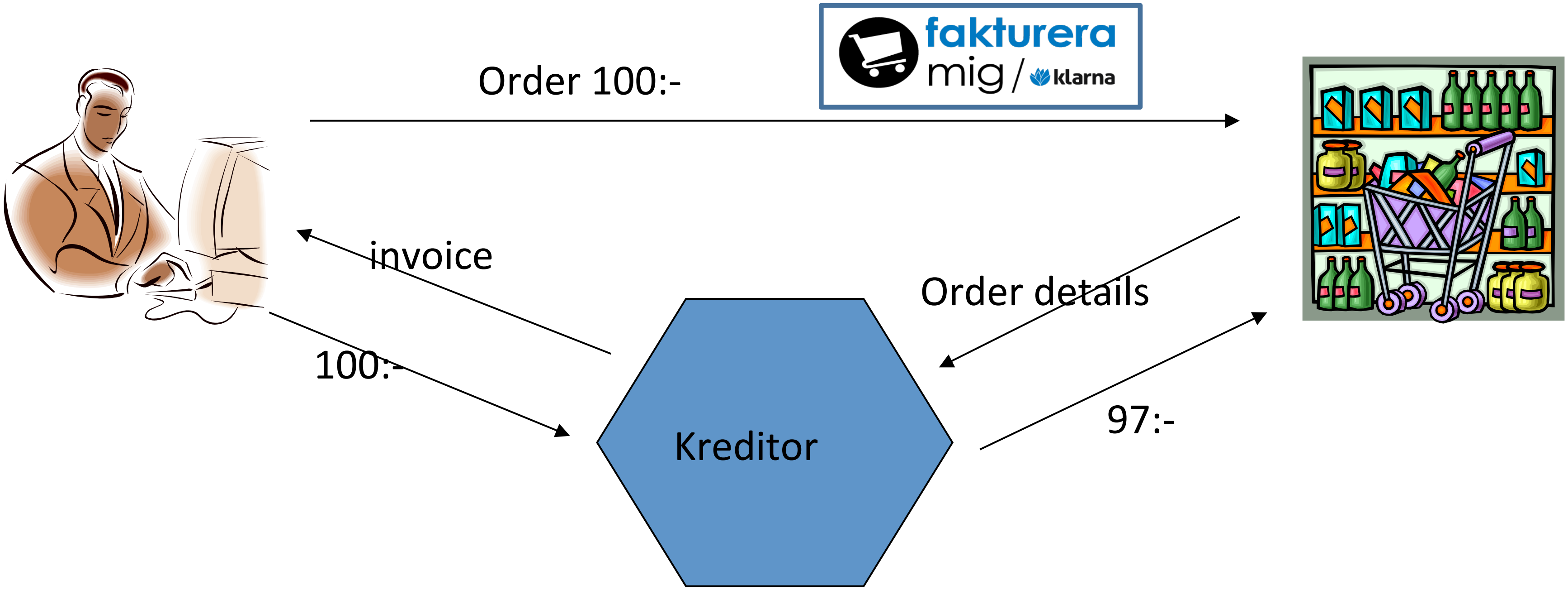
$140 million in <18 months

SSL Accelerator



- ”Alteon WebSystems' SSL Accelerator offers phenomenal performance, management and scalability.”
  – *Network Computing*

2004 Start-up: Kreditor



- New features every few weeks—never down
- ”Company of the year” in 2007
- Now over 1,400 people
- Market leader in Europe

Erlang Today

- Scaling well on multicores
  - 64 cores, no problem!
- Many companies, large and small
  - Amazon/Facebook/Nokia/Motorola/HP…
  - Ericsson recruiting Erlangers
  - No-sql databases (Basho, Hibari…)
  - Many many start-ups
- ”Erlang style concurrency” widely copied
  - Akka in Scala (powers Twitter), Cloud Haskell…

Erlang Events

- Erlang User Conference, Stockholm

- Erlang Factory
  - London
  - San Francisco
    - (btw: Youtube ”John Hughes Why Functional Programming Matters Erlang Factory 2016”)

- Erlang Factory Lite, ErlangCamp…

Summary

- Erlang’s fault-tolerance mechanisms and design approach reduce complexity of error handling code, help make systems robust
- OTP libraries simplify building robust systems
- Erlang fits internet servers like a glove—as many start-ups have demonstrated
- Erlang’s mechanisms have been widely copied
  - See especially Akka, a Scala library based on Erlang