Robust Erlang
(PFP Lecture 11)

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Genesis of Erlang

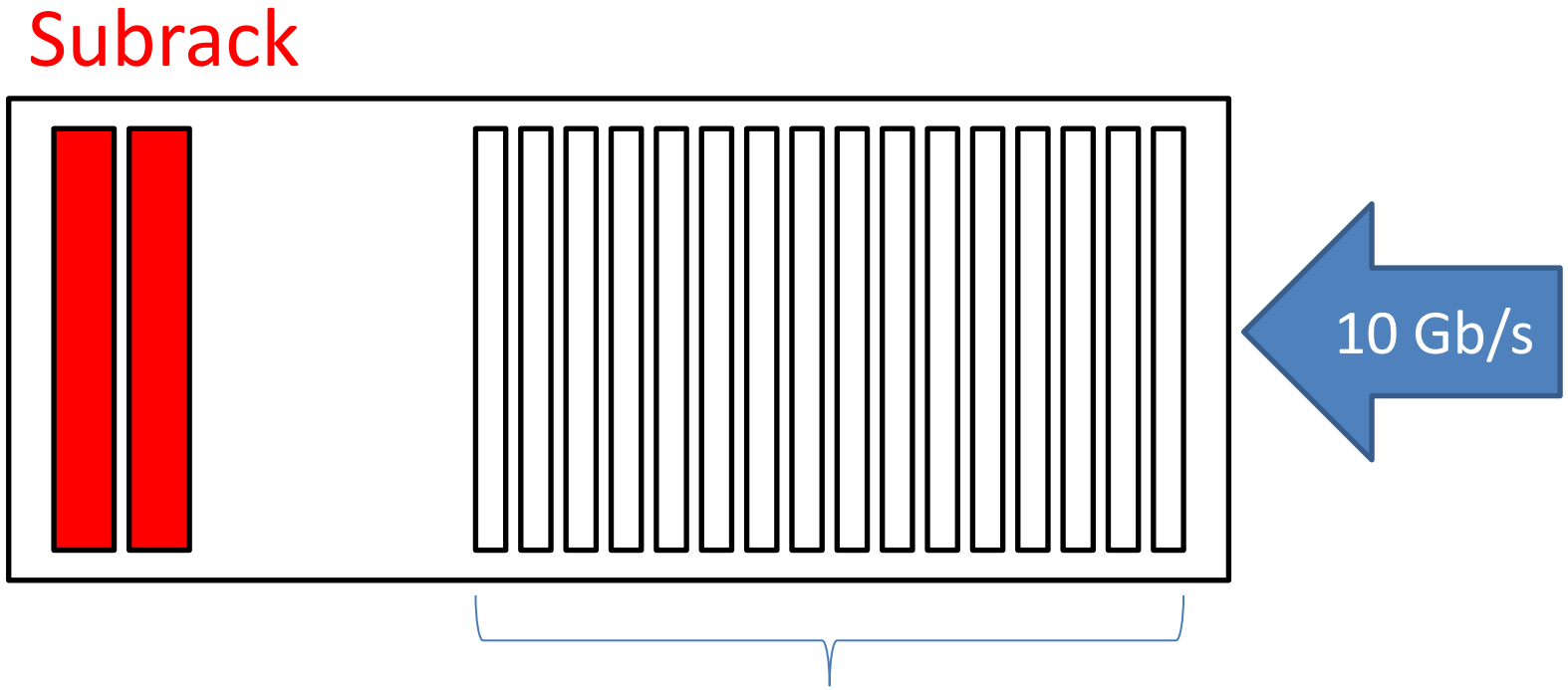
- **Problem:** telephony systems in the late 1980s
  - Digital
  - More and more complex
  - Highly concurrent
  - Hard to get right
- **Approach:** a group at Ericsson research programmed POTS in different languages
- **Solution:** nicest was *functional programming*—but not concurrent
- Erlang designed in the early 1990s

”Plain Old Telephony System”

Mid 1990s: the AXD 301

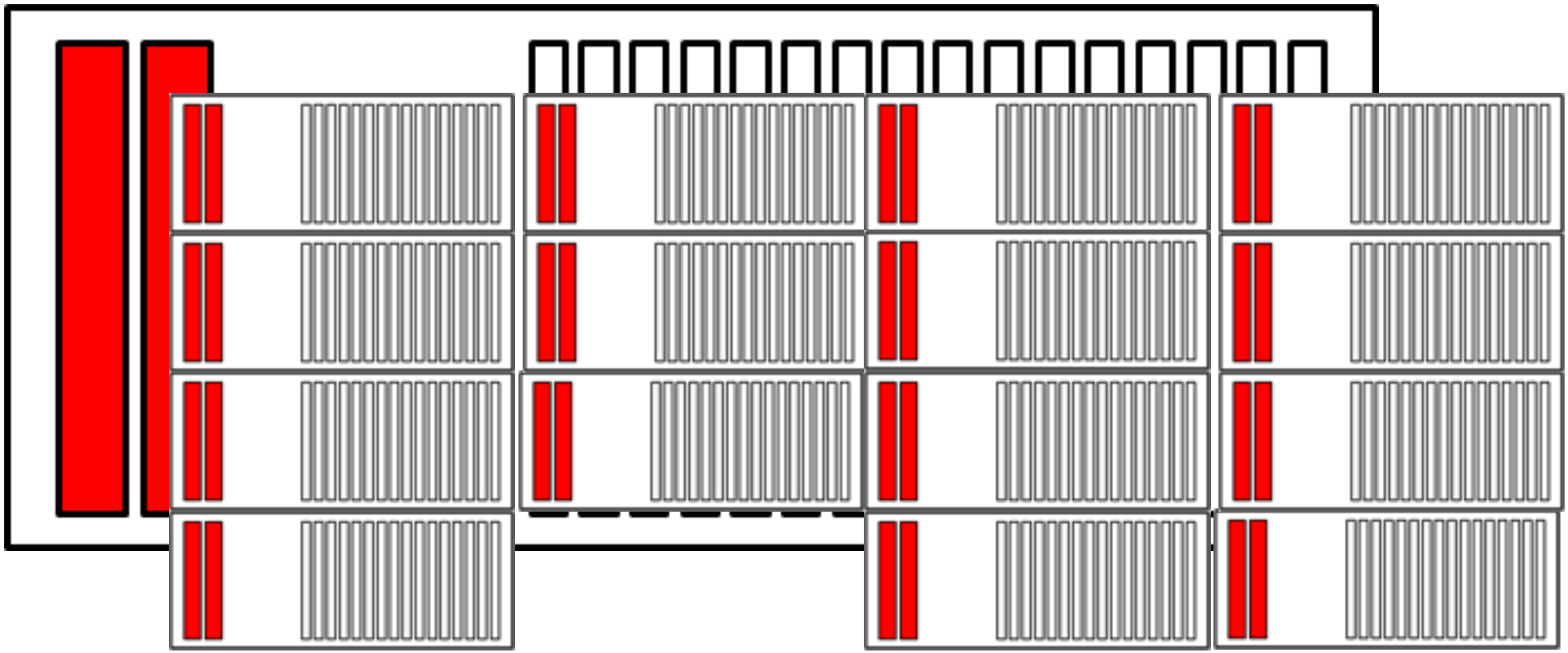
- ATM switch (telephone backbone), released in 1998
- First *big* Erlang project
- Born out of the ashes of a disaster!

AXD301 Architecture



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

Facebook Chat

Invoicing services for web shops—in 6 countries!

Distributed no-SQL database serving e.g. all Denmark's medicine card data

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!

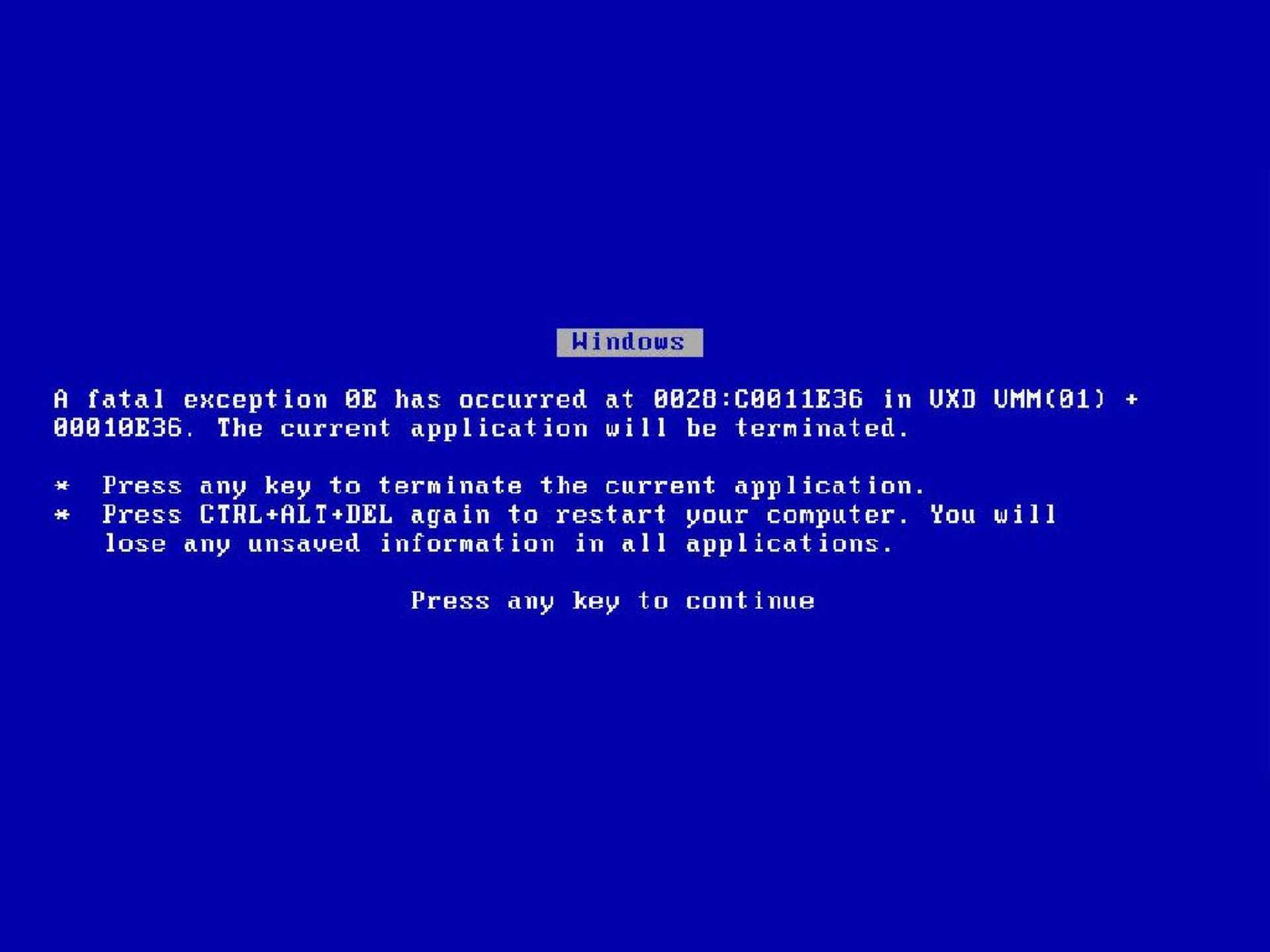
Stopping a malfunctioning program

…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

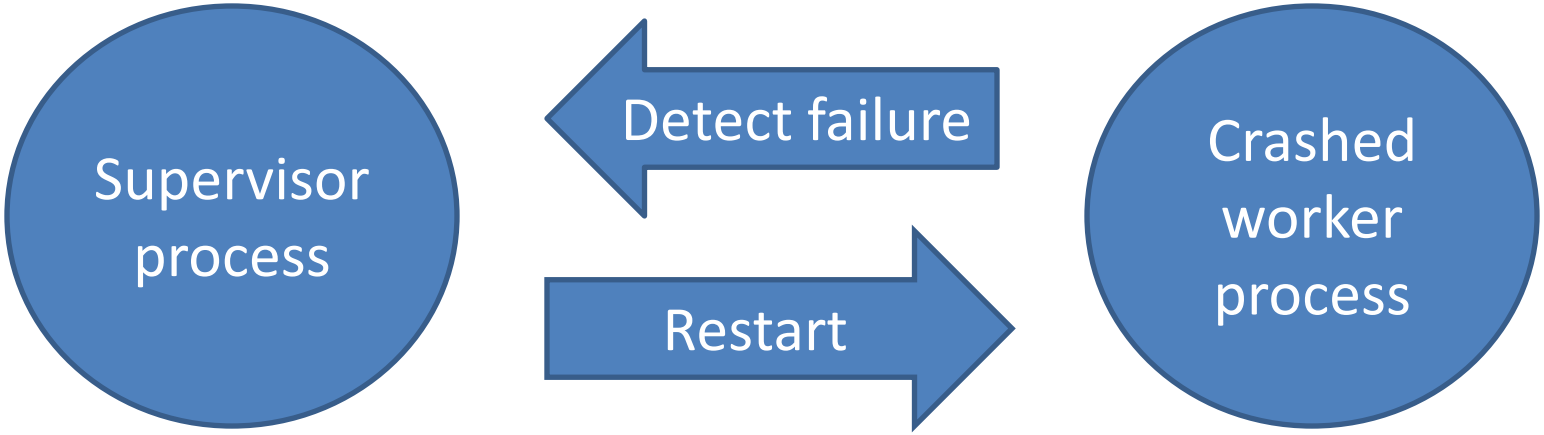

Windows
A fatal exception 0E has occurred at 0028:C0011E36 in VXD VMM(01) +
00010E36. The current application will be terminated.
* Press any key to terminate the current application.
* Press CTRL+ALT+DEL again to restart your computer. You will
lose any unsaved information in all applications.
Press any key to continue

We know what to do…

Detect failure

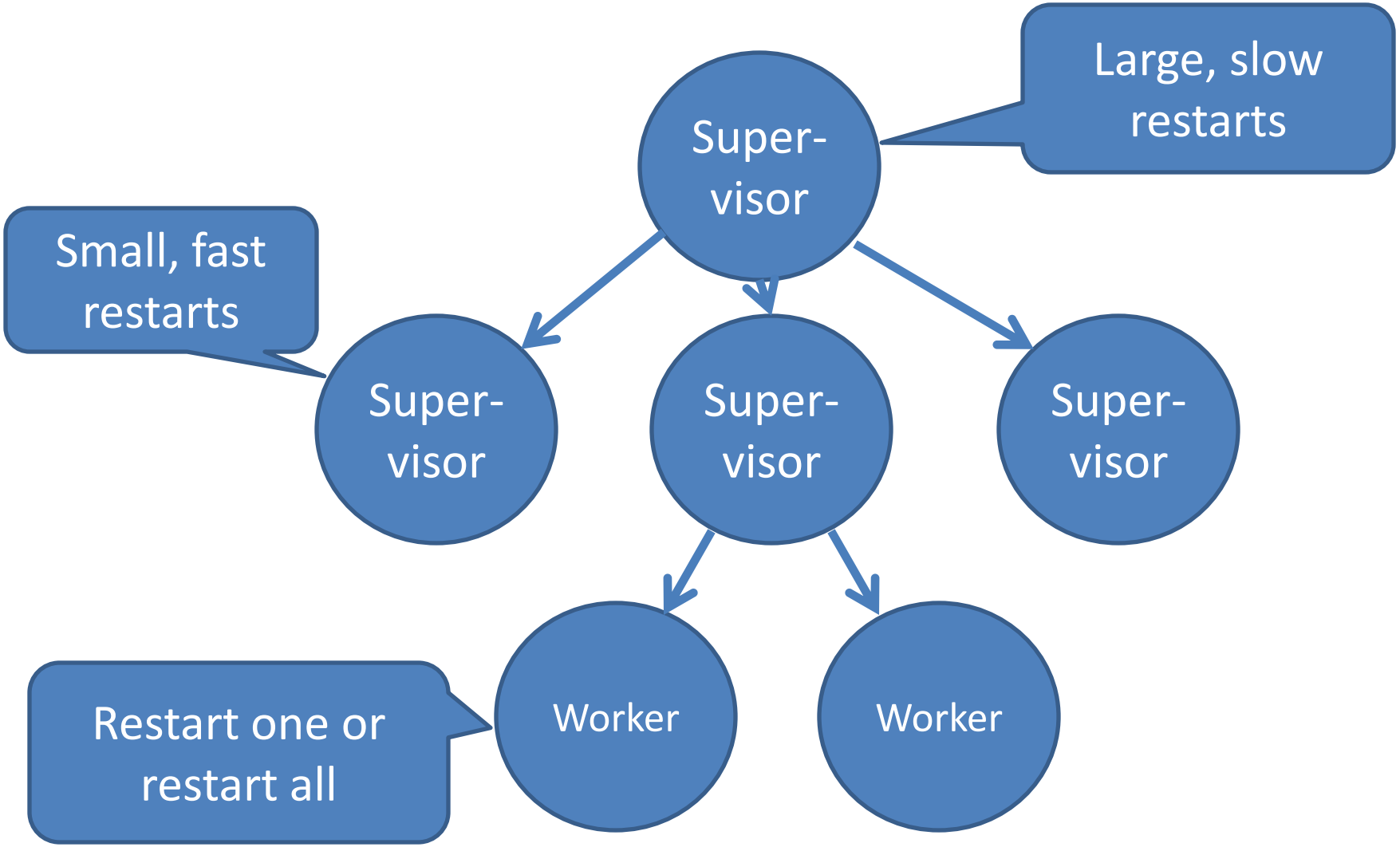
Restart

Using Supervisor Processes

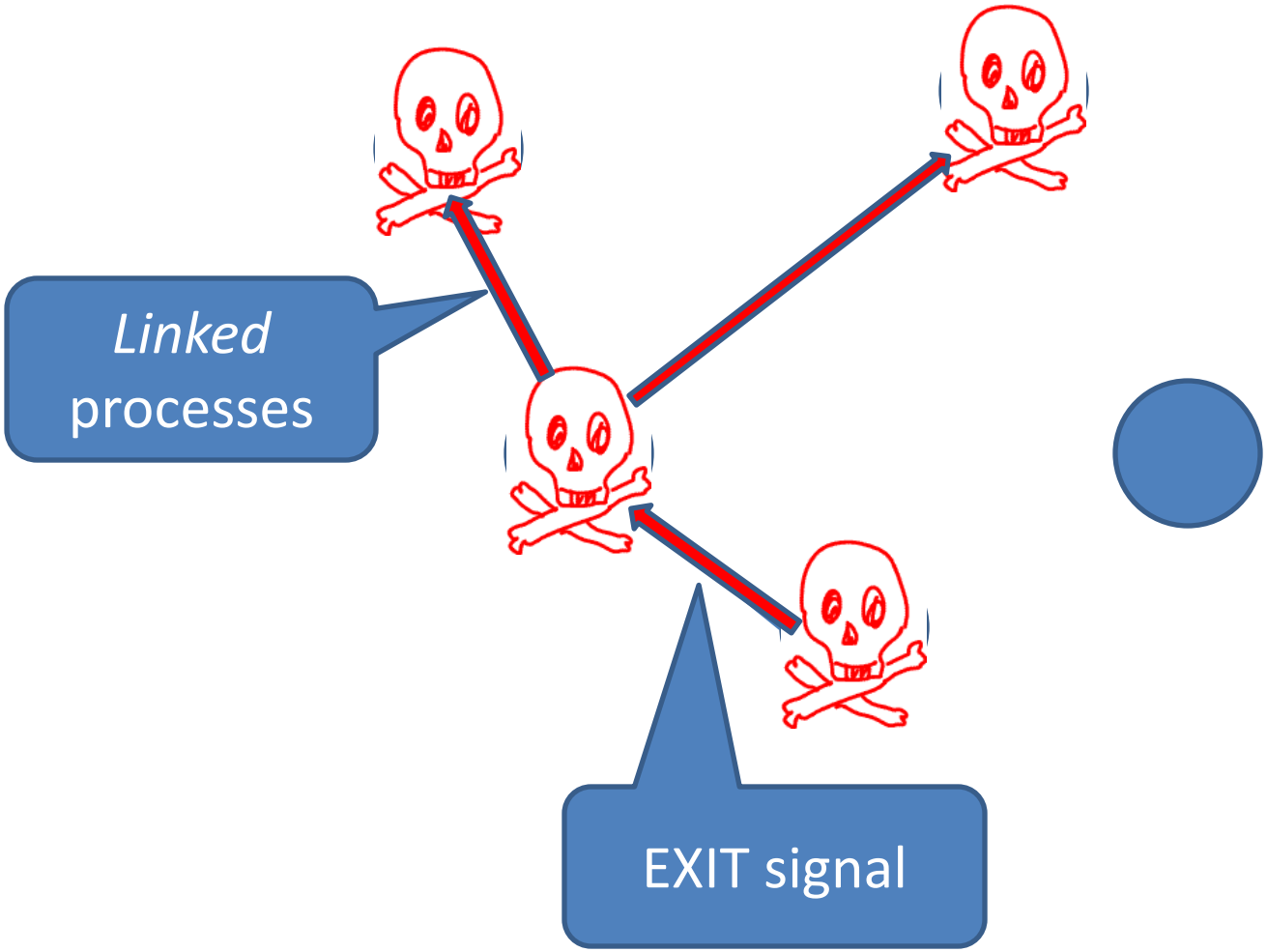


- Supervisor process is *not* corrupted
  - One process *cannot* corrupt another
- Large grain error handling
  - simpler, smaller code

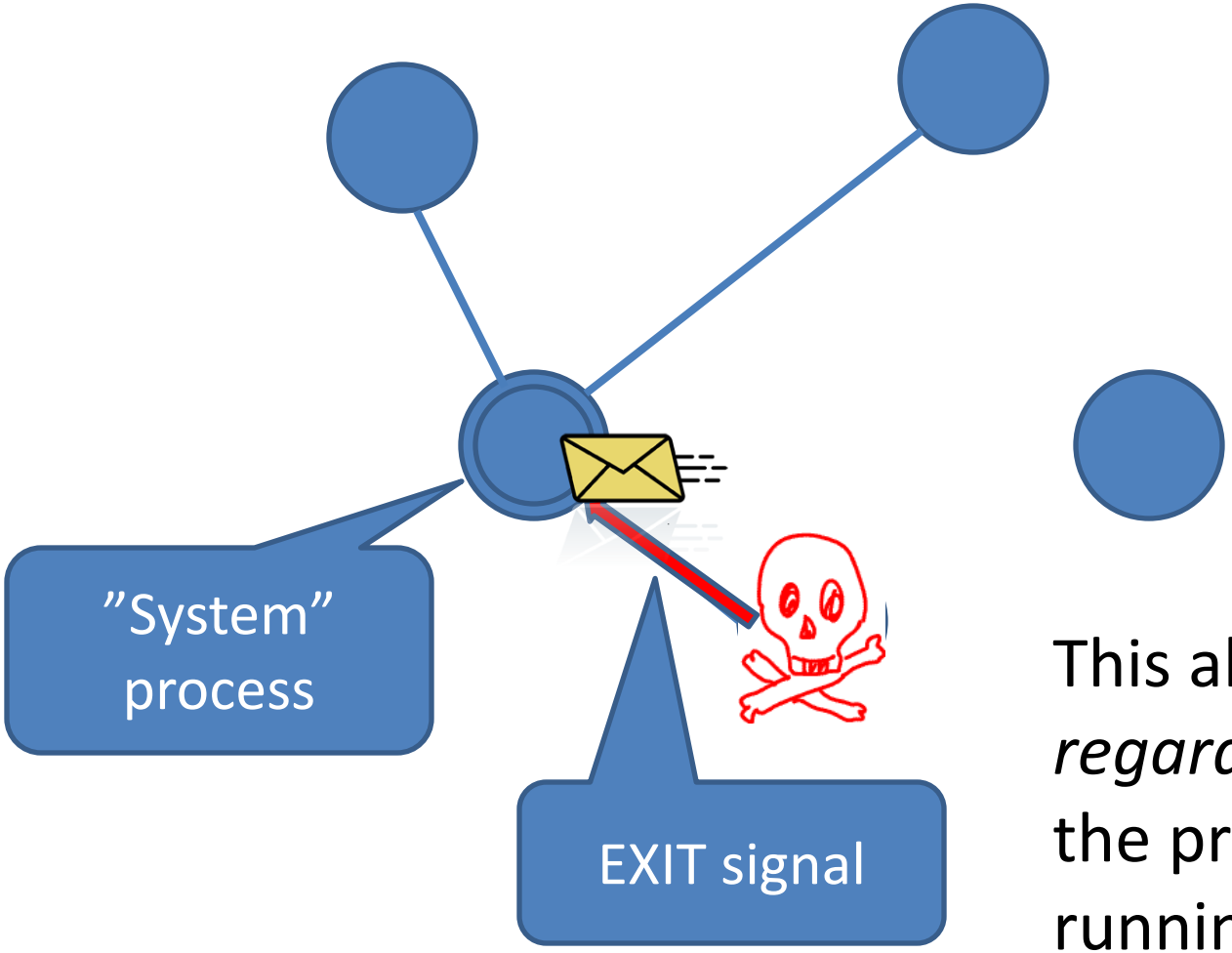
Supervision Trees



Detecting Failures: Links



Linked Processes



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

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

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

```
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

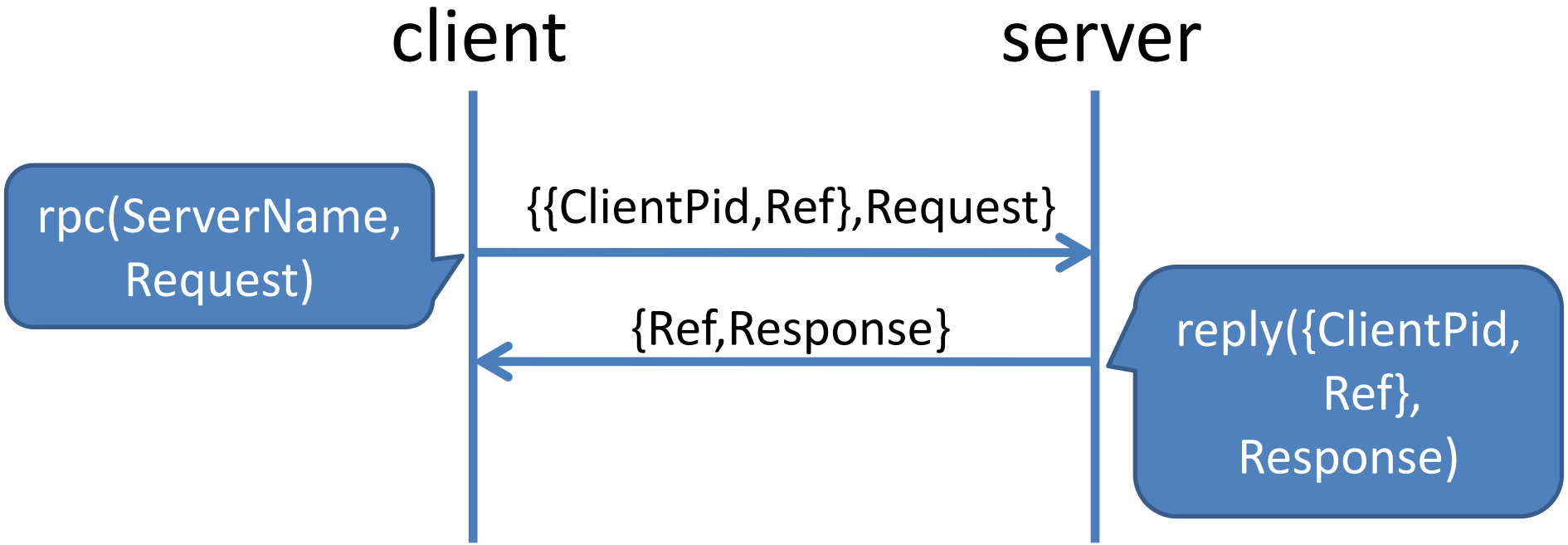
A Supervised Divider

```
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

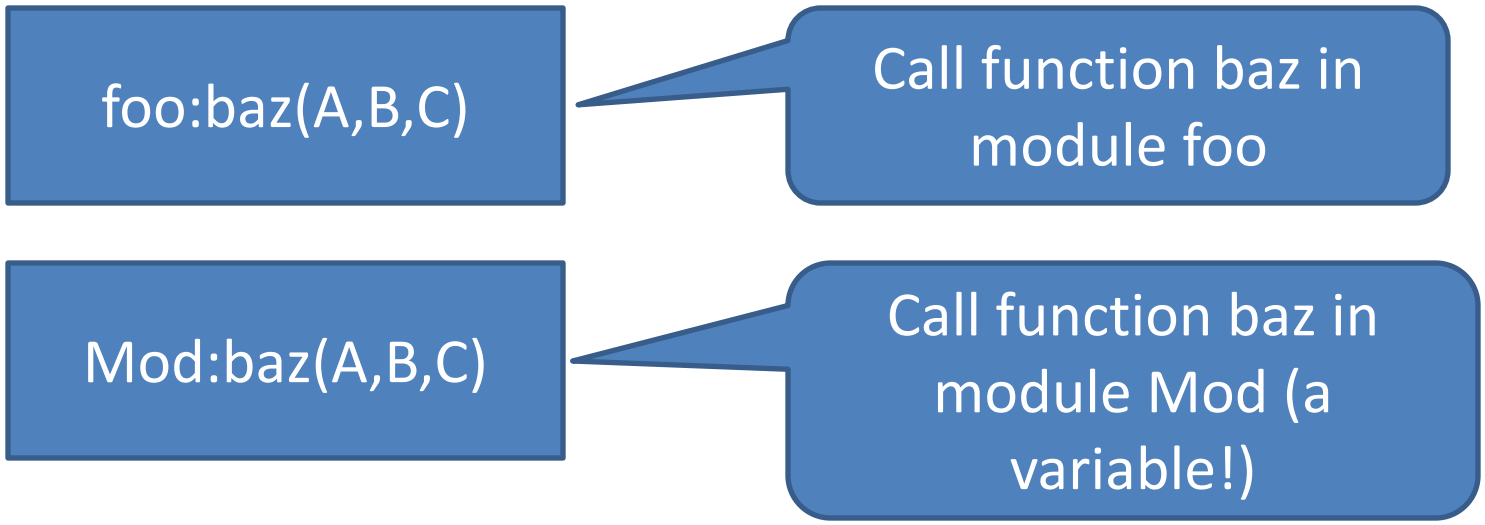
```
server(State) ->
    receive {Client,Msg} -> {Reply,NewState} = handle(Msg,State),
                            reply(Client,Reply),
                            server(NewState)
    end.
```

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:



- 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).
```

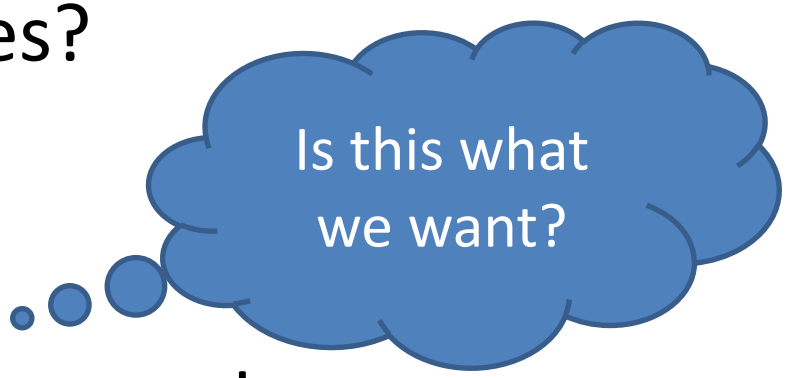
The Bank Account Module

```
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?



- 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
  - …

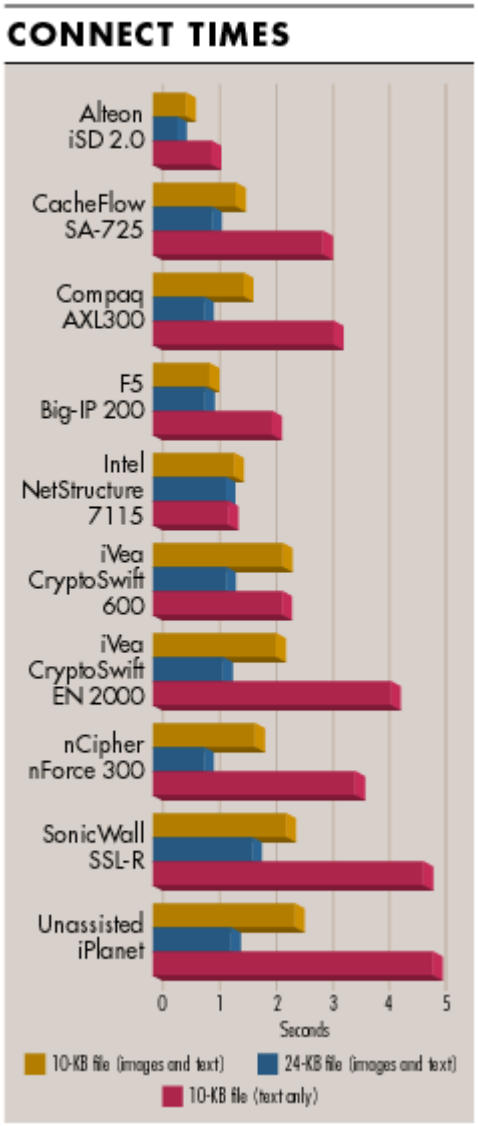
Erlang's Secret

- 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

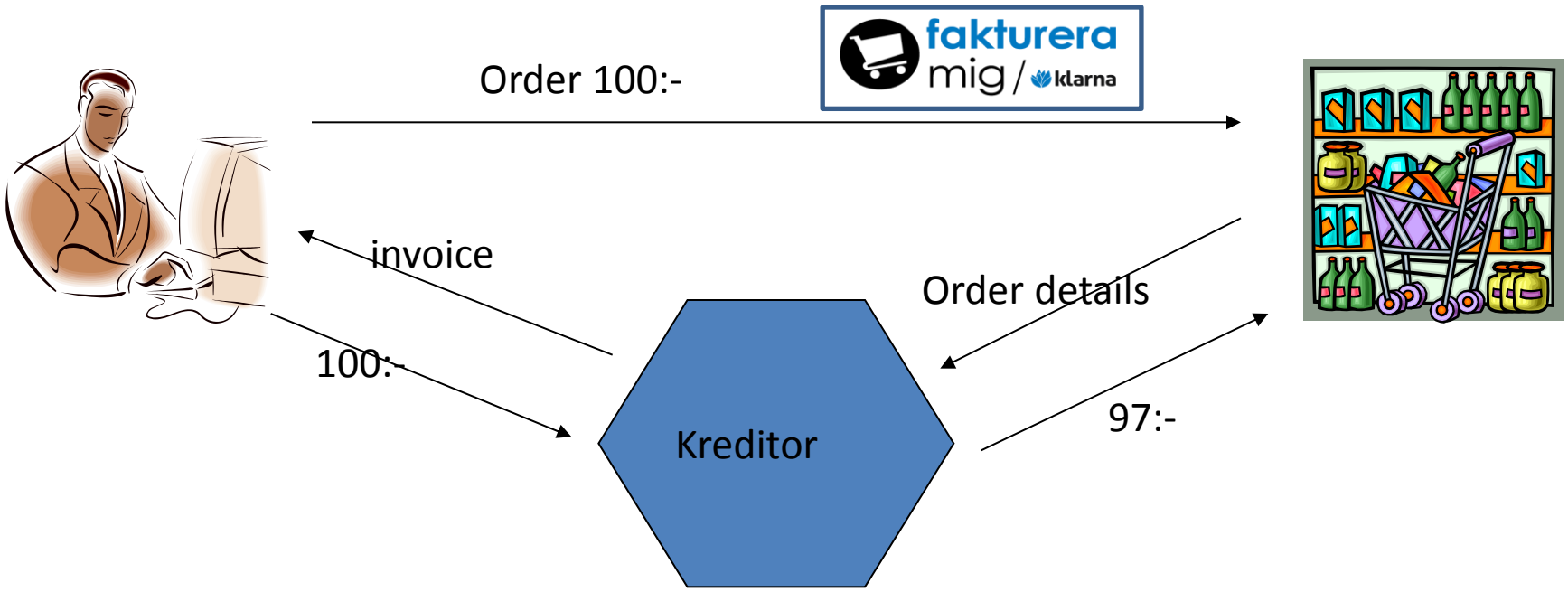
$140 million in <18 months

SSL Accelerator



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

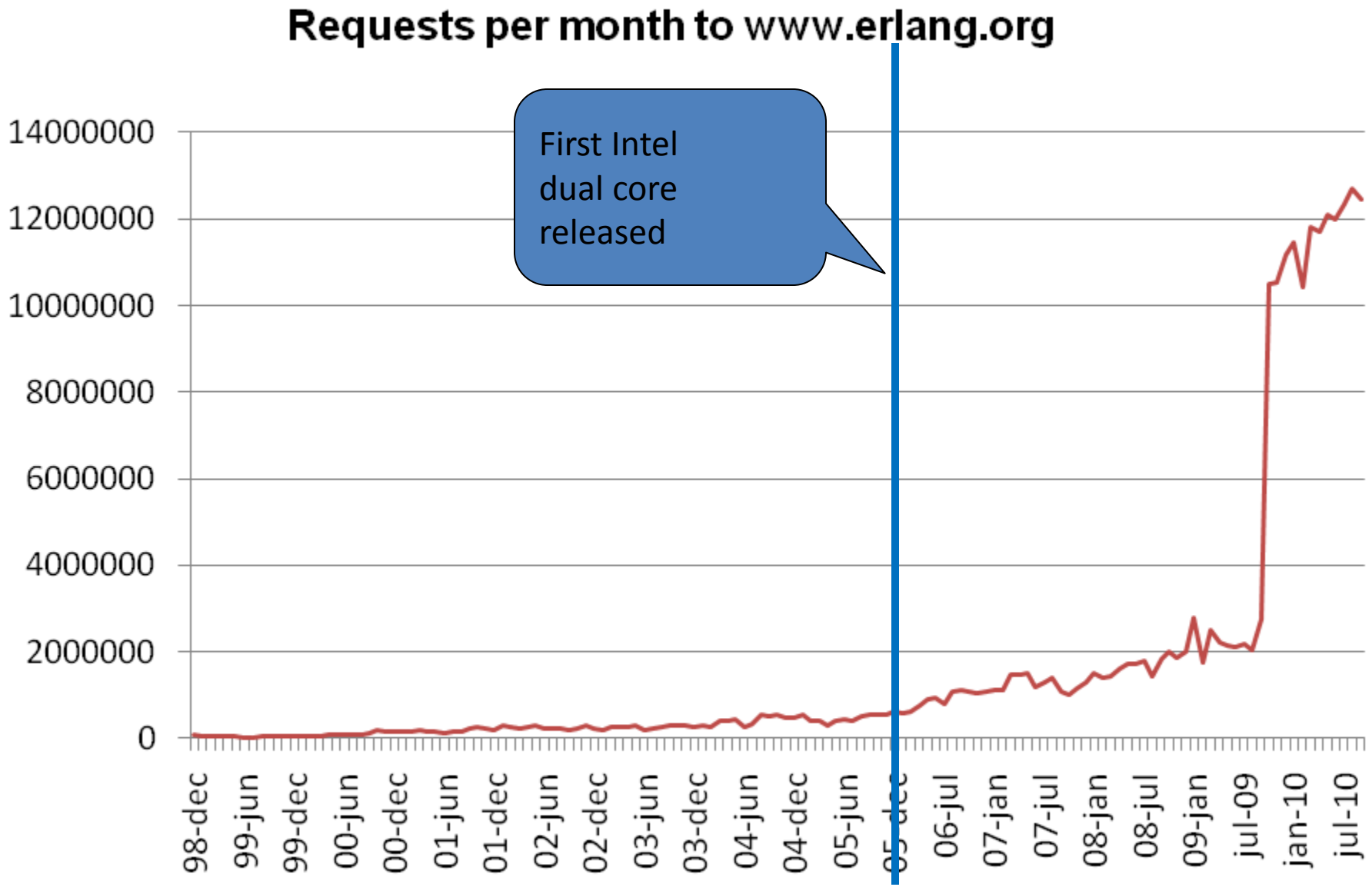
2004 Start-up: Kreditor



- New features every few weeks—never down
- ”Company of the year” in 2007
- Growth : >13,000% (to over 700 people!)
- Market leader in Scandinavia

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, CouchDB, Hibari…)
  - Many many start-ups
- ”Erlang style concurrency” widely copied
  - Akka in Scala (powers Twitter), Cloud Haskell…


Requests per month to www.erlang.org
First Intel dual core released
14000000
12000000
10000000
8000000
6000000
4000000
2000000
0
98-dec
99-jun
99-dec
00-jun
00-dec
01-jun
01-dec
02-jun
02-dec
03-jun
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04-jun
04-dec
05-jun
06-jul
07-jan
07-jul
08-jan
08-jul
09-jan
jul-09
jan-10
jul-10

Erlang Events

- Erlang User Conference, Stockholm
- Erlang Factory (multiple tracks)
  - London
  - San Francisco
- Erlang Factory Lite
  - Brisbane, Paris, Munich, Edinburgh, Amsterdam
  - Brussels, Krakow, Zurich, St.Andrews…
- ErlangCamp
  - Chicago, Spain…

Coming up on Thursday…

MAP/REDUCE