Building highly available systems in Erlang

Joe Armstrong

How can we get

10 nines reliability?

Why Erlang?

Erlang was designed to program fault-tolerant systems

Overview

- Types of HA systems
- Architecture/Algorithms
- HA data
- The six rules for building HA systems
- Quotes on system building
- How the six rules are programmed in Erlang

Types of HA

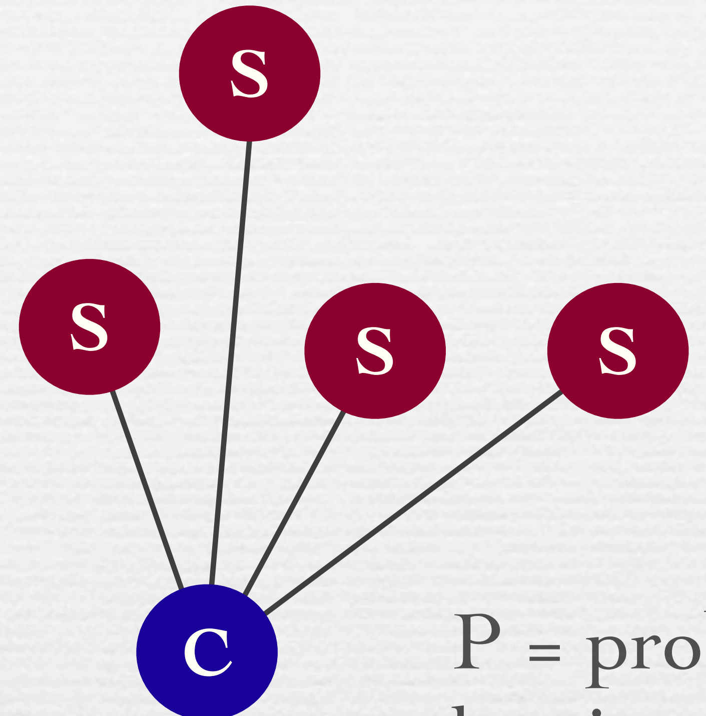
- Washing machine/pacemaker
- Deep-space mission (Voyager 1 & 2)
- Aircraft control systems
- Internet applications *this talk*
- ...

“Internet” HA

- Always on-line
- Soft real-time
- Code upgrade on-the-fly
- Once started never stopped - evolving
- Very scalable (one machine to planet-wise)

Highly available data

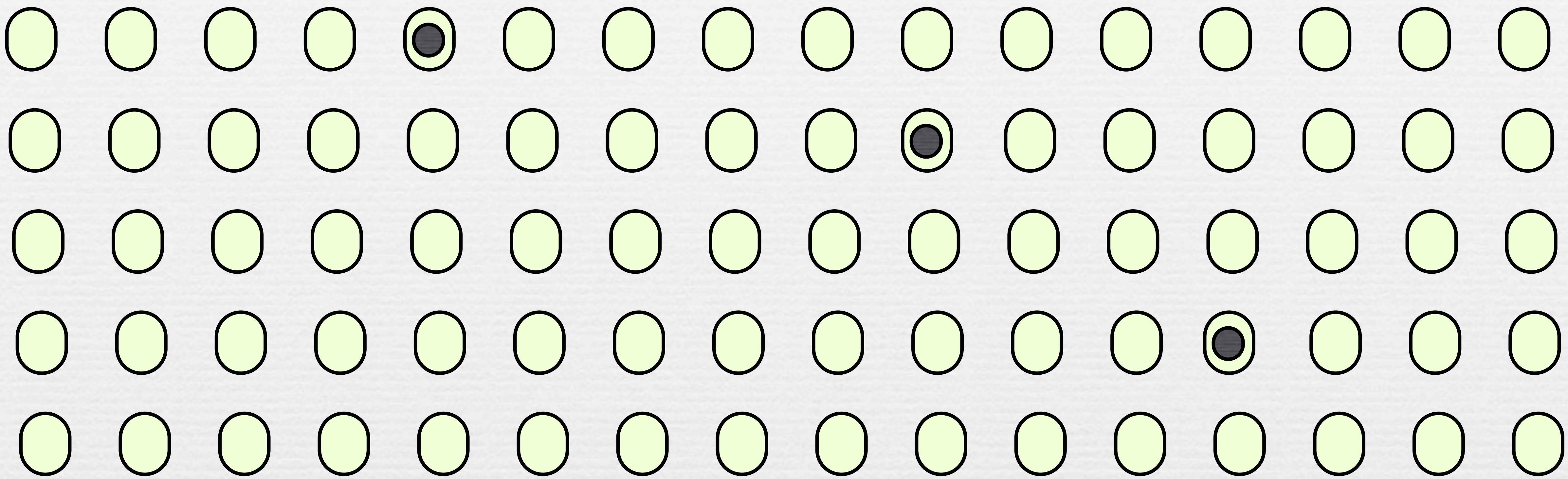
- Data is sacred - but we need multiple copies with independent paths to the data.
- Computation can be performed anywhere
- *Note: in "washing machine" HA - the data and the computation are in the same place.*

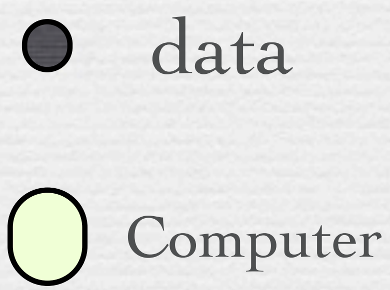


P = probability of loosing data on one machine = 10^{-3}

Probability of loosing data with 4 machines = 10^{-12}

Where is my data?

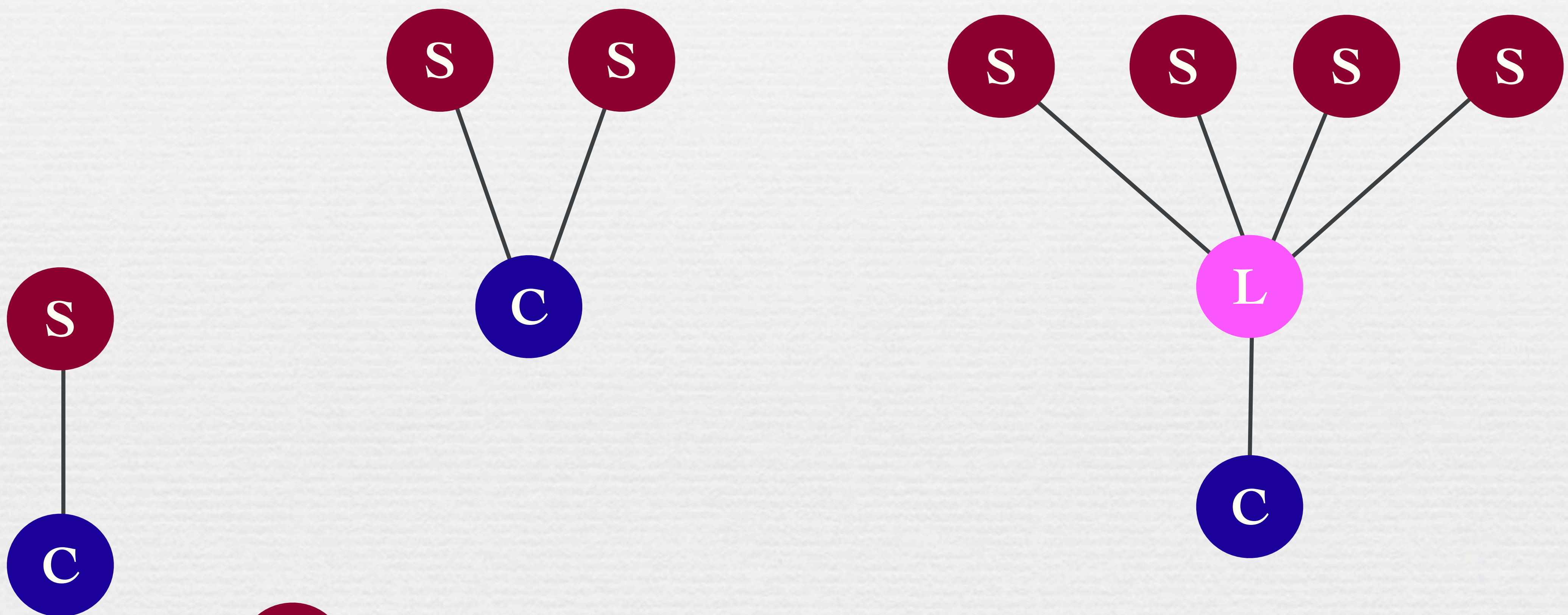




Imagine 10 million computers.
My data is in ten of them.
To find my data I need to know where it is

Key = [5,26,61,...]

Architectures/algorithms



S Server

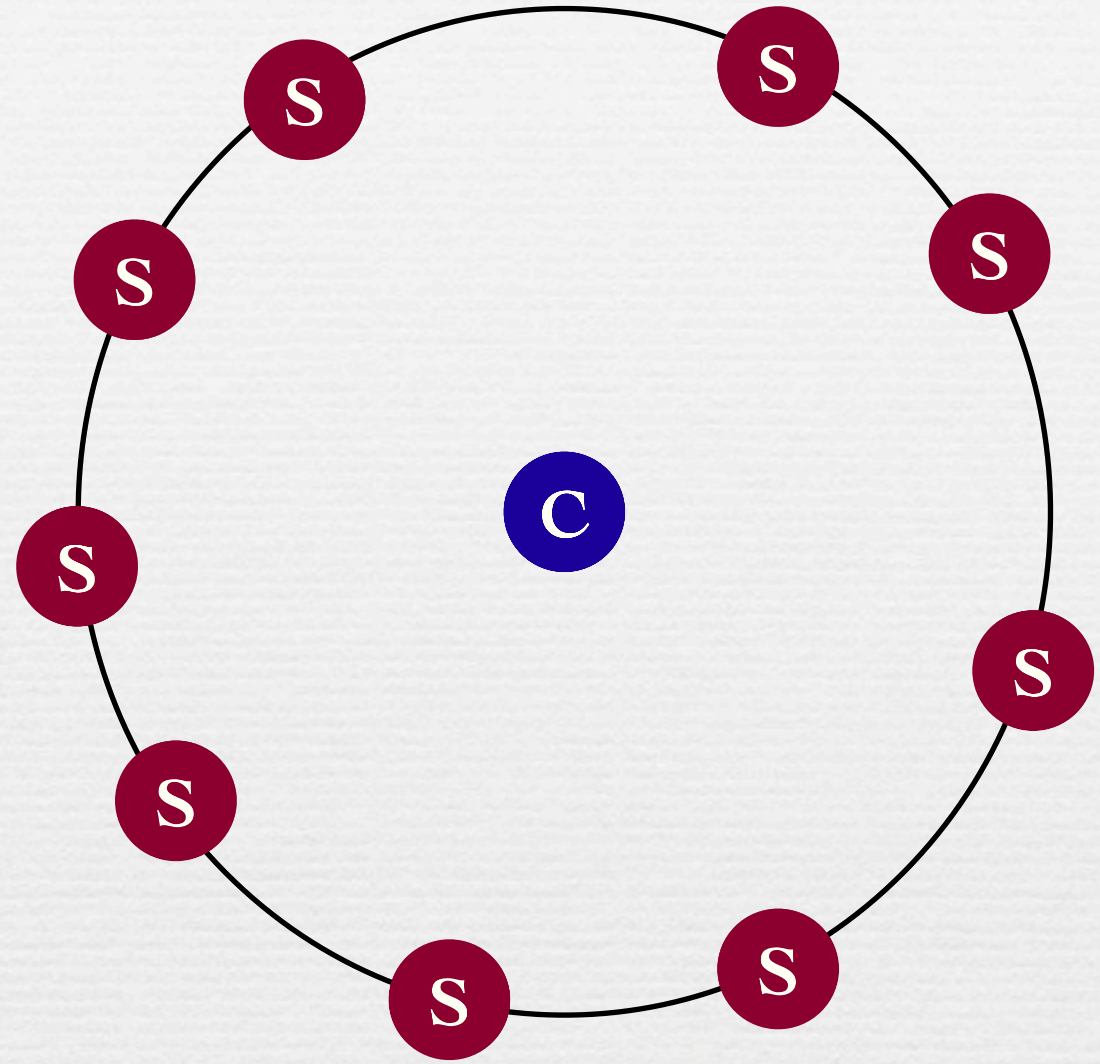
C Client

L Load balancer

"traditional" architectures

Chord

```
S1 IP = 235.23.34.12
S2 IP = 223.23.141.53
S2 IP = 122.67.12.23
..
md5(ip(s1)) = C82D4DB065065DBDCADFBC5A727208E
md5(ip(s2)) = 099340C20A42E004716233AB216761C3
md5(ip(s3)) = A0E607462A563C4D8CCDB8194E3DEC8B

Sorted
099340C20A42E004716233AB216761C3 => s2
A0E607462A563C4D8CCDB8194E3DEC8B => s3
C82D4DB065065DBDCADFBC5A727208E => s1
...

lookup Key = "mail-23412"
md5(“mail-23412”) =>
  B91AF709D7C1E6988FCEE7ADF7094A26

So the Value is on machine s3 (first machine
with Md5 lower than md5 of key)

Replica
md5(md5(“mail-23412”)) =>
   D604E7A54DC18FD7AC70D12468C34B63

So the replica is on machine s1
```



Main idea

Hash keys & IP addresses into the same namespace

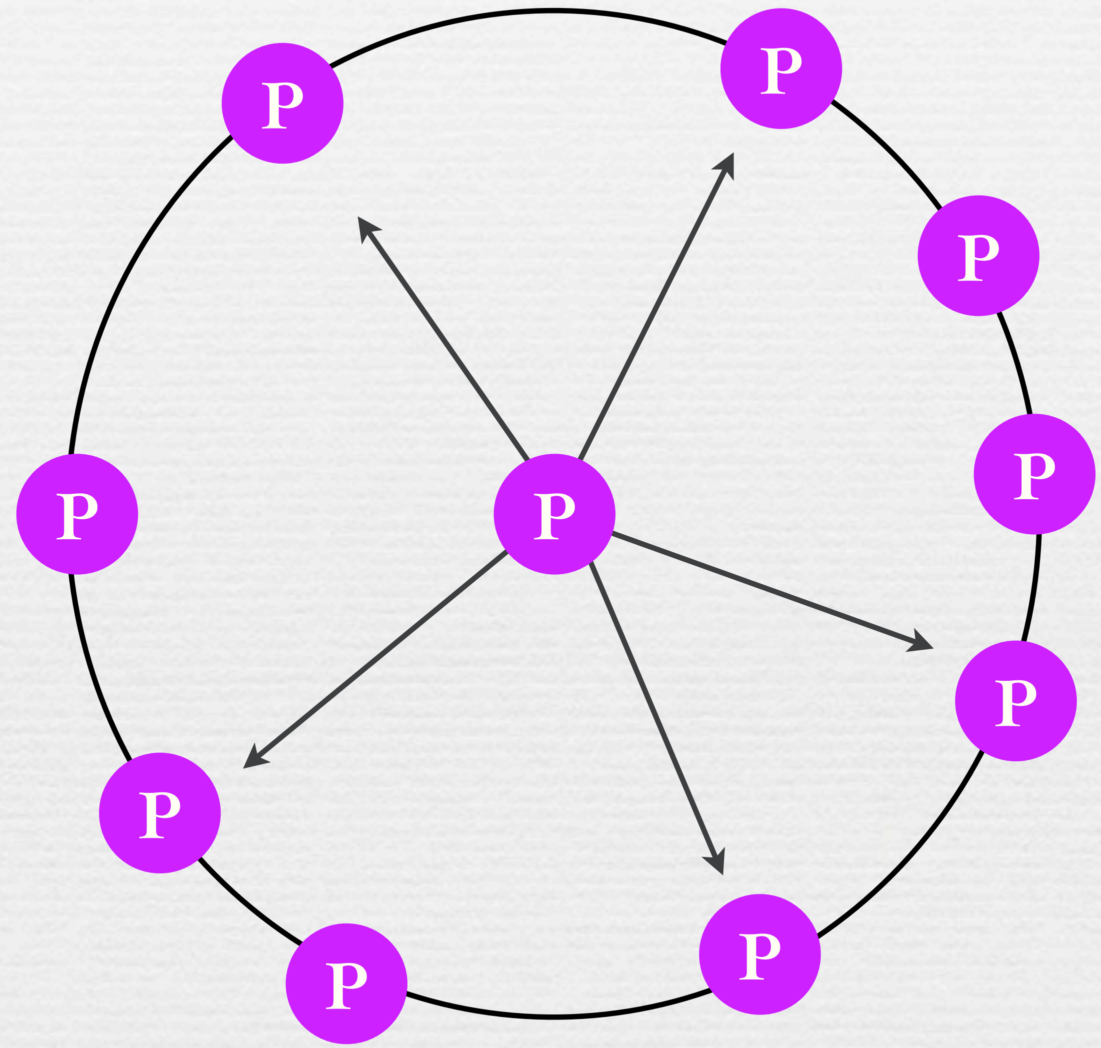
Failure probabilities

- Assume we keep 9 replicas (odd number)
- We want to retrieve 5 copies (more than half)
- works with 1 .. 4 machine failing - but if 5 fail we're screwed
- If probability of 1 failure 10^{-2} the probability of 5 failing *at the same time* $=10^{-10}$

Collect five copies in parallel

P Peer

So making 5 replicas takes the same time as two



“P2P is the new client-server”

The problem of
reliable storage
of data
has been solved

How do we write the code?

SIX RULES

ONE

ISOLATION

Isolation

- **Things must be isolated**
- 10 nines = 99.99999999% availability
- P(fail) = 10^{-10}
- If P(fail | one computer) = 10^{-3} then
  P(fail | four computers) = 10^{-12}

TWO

CONCURRENCY

Concurrency

- World is concurrent
- Many problems are **Embarrassingly Parallel**
- Need at least TWO computers to make a non-stop system (or a few hundred)
- TWO *or more* computers = **concurrent and distributed**

THREE

MUST DETECT FAILURES

Failure detection

- If you can't detect a failure you can't fix it
- Must work across machine boundaries
  the entire machine might fail
- Implies distributed error handling,
  no shared state,
  asynchronous messaging

FOUR

FAULT IDENTIFICATION

Fault Identification

- Fault detection is not enough - you must no **why** the failure occurred
- Implies that you have sufficient information for post hock debugging

FIVE

LIVE
CODE
UPGRADE

Live code upgrade

- Must upgrade software while it is running
- Want zero down time
- Once a system is started we never stop it

SIX

STABLE STORAGE

Stable storage

- **Must store stuff forever**
- No backup necessary - storage just works
- Implies multiple copies, distribution, ...
- Must keep crash reports

QUOTES

Those who cannot learn from history are doomed to repeat it.

George Santayana

GRAY

As with hardware, the key to software fault-tolerance is to hierarchically decompose large systems into modules, each module being a unit of service and a unit of failure. A failure of a module does not propagate beyond the module.

...

The process achieves fault containment by sharing no state with other processes; **its only contact with other processes is via messages** carried by a kernel message system

- Jim Gray
- Why do computers stop and what can be done about it
- Technical Report, 85.7 - Tandem Computers,1985

GRAY

- Fault containment through fail-fast software modules.
- Process-pairs to tolerant hardware and transient software faults.
- Transaction mechanisms to provide data and message integrity.
- Transaction mechanisms combined with process-pairs to ease exception handling and tolerate software fault
- **Software modularity through processes and messages.**

Fail fast

The process approach to fault isolation advocates that the process software be fail-fast, it should either function correctly or it should detect the fault, signal failure and stop operating.

Processes are made fail-fast by defensive programming. They check all their inputs, intermediate results and data structures as a matter of course. If any error is detected, they signal a failure and stop. In the terminology of [Christian], fail-fast software has small fault detection latency.

Gray
Why ...

Fail early

A fault in a software system can cause one or more errors. The latency time which is the interval between the existence of the fault and the occurrence of the error can be very high, which complicates the backwards analysis of an error ...

For an effective error handling we must detect errors and failures as early as possible

Renzel -
Error Handling for Business Information Systems,
Software Design and Management, GmbH & Co. KG, München, 2003

KAY

Folks --

Just a gentle reminder that I took some pains at the last OOPSLA to try to remind everyone that **Smalltalk** is not only NOT its syntax or the class library, **it is not even about classes**. I'm sorry that I long ago coined the term "objects" for this topic because it gets many people to focus on the lesser idea.

The big idea is "messaging" -- that is what the kernel of Smalltalk/ Squeak is all about (and it's something that was never quite completed in our Xerox PARC phase)....

http://lists.squeakfoundation.org/pipermail/squeak-dev/1998-October/017019.html

SCHNEIDER

Halt on failure in the event of an error a processor should halt instead of performing a possibly erroneous operation.

Failure status property when a processor fails, other processors in the system must be informed. The reason for failure must be communicated.

Stable Storage Property The storage of a processor should be partitioned into stable storage (which survives a processor crash) and volatile storage which is lost if a processor crashes.

Schneider
ACM Computing Surveys 22(4):229-319, 1990

ARMSTRONG

- Processes are the units of error encapsulation. Errors occurring in a process will not affect other processes in the system. We call this property *strong isolation*.
- Processes do what they are supposed to do or fail as soon as possible.
- Failure and the reason for failure can be detected by remote processes.
- **Processes share no state, but communicate by message passing.**

Armstrong
Making reliable systems in the presence of software errors
PhD Thesis, KTH, 2003

Programming

How do we program our six rules?

- Use a library?
- Use a programming language designed for this

Erlang was
designed
to program
fault-tolerant
systems

How we implement the six rules in Erlang

Rule 1 = Isolation

- Erlang processes are isolated
- One process cannot damage another
- One Erlang node can have millions of processes
- Process have no shared memory
- Process are very lightweight

Rule 2 = Concurrency

- Erlang processes are concurrent
- All processes run in parallel (in theory)
- On a multi-core the processes spread over the cores

```
Pid = spawn(fun() -> ... end)

Pid ! Message

receive
   Pattern1 -> Actions1;
   Pattern2 -> Actions2;
   Pattern3 -> Actions3;
   ...
end
```

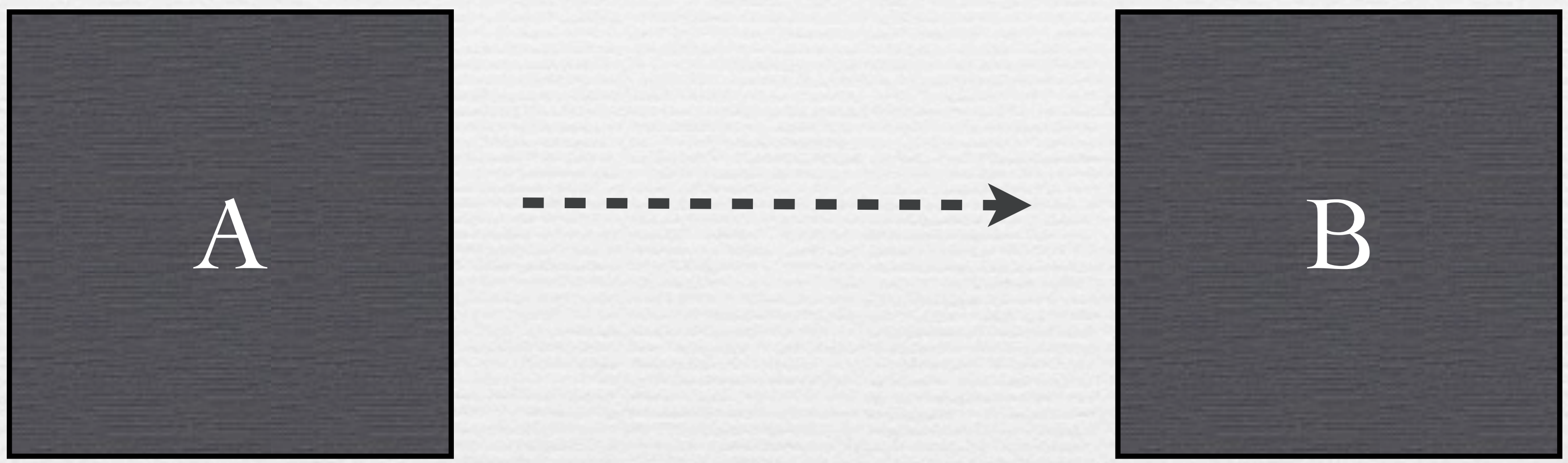
Rule 3 = Failure detection

- Erlang processes can detect failures

```
Pid = spawn_link(fun() -> ... end),
process_flag(trap_exit, true)

receive
   {'EXIT', Pid, Why} ->
        ...
end
```

- Can link to a remote process

Fix the error somewhere else



A is a black box.
It might be an entire machine
If an entire machine crashes
another machine must fix the problem

Rule 4 - fault identification

- Erlang error signals contain error descriptors

```
Pid = spawn_link(fun() -> ... end),
process_flag(trap_exit, true)

receive
   {'EXIT', Pid, Why} ->
        error_log:log_error({erlang:now(),Pid,Why})
        ...
end
```

Rule 5 - live code upgrade

- Erlang can be modified as it runs

```
-module(foo).

...

f1(X) ->
   foo:bar(X),     %% Call the latest version of foo:bar
   bar(X).         %% Call this version of bar

bar(X) ->
   ...
```

- Applications can be upgraded as they run (this is a large part of OTP)

Rule 6 - Stable storage

- Use mnesia - highly customizable - can store data on disk + RAM, can RAM replicate etc.
- Use third-party storage - Riak, CouchDB etc

Fault tolerance implies scalability

- To make things fault-tolerant we have to make sure they are made from isolated components
- If the components are isolated they can be run in parallel
- Things that are isolated and can be run in parallel are scalable

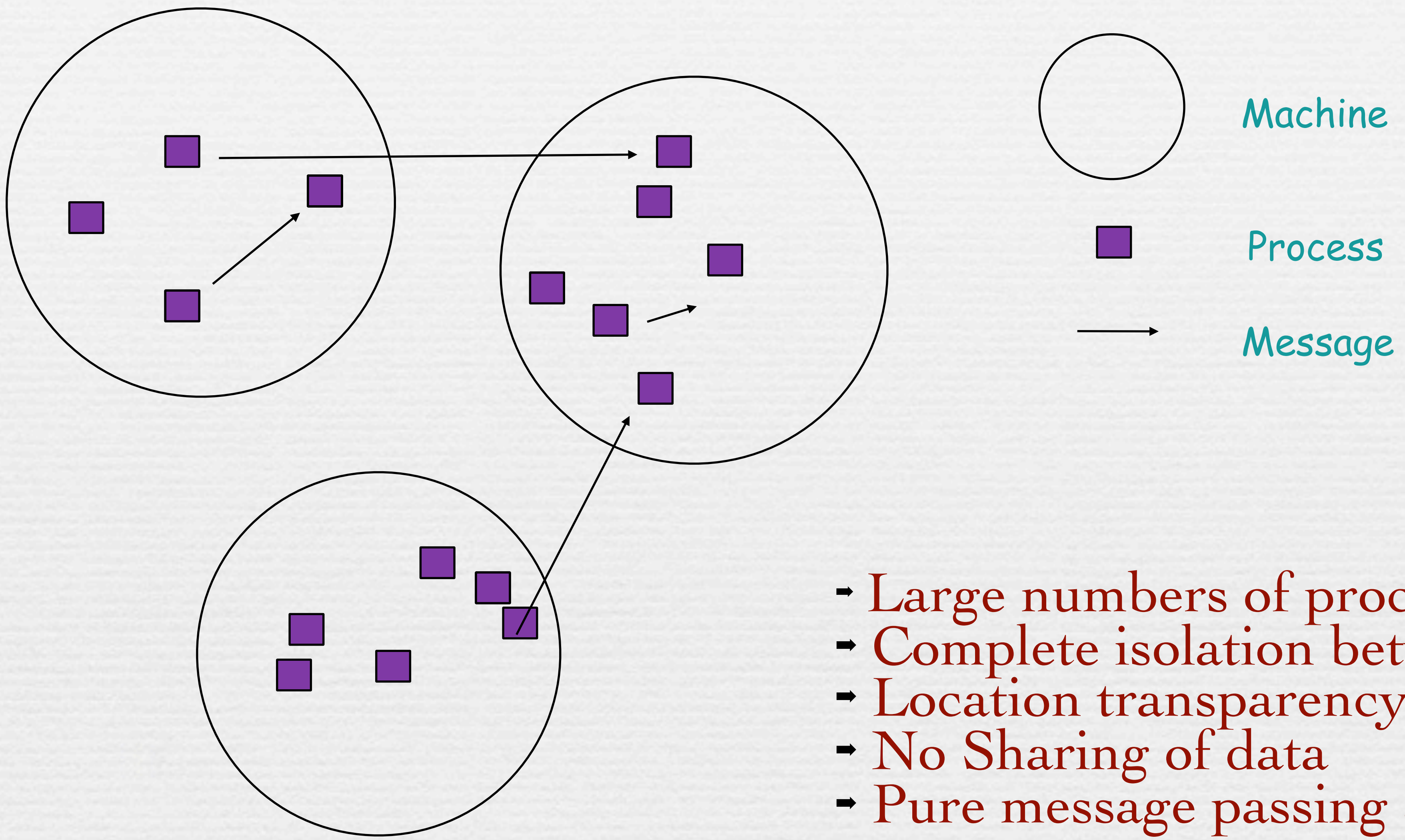
Erlang

- Very light-weight processes
- Very fast message passing
- Total separation between processes
- Automatic marshalling/demarshalling
- Fast sequential code
- Strict functional code
- Dynamic typing
- Transparent distribution
- Compose sequential AND concurrent code

Properties

- No sharing
- Hot code replacement
- Pure message passing
- No locks
- Lots of computers (= fault tolerant scalable ...)
- Functional programming (controlled side effects)

What is COP?



- Large numbers of processes
- Complete isolation between processes
- Location transparency
- No Sharing of data
- Pure message passing systems

No Mutable State

- Mutable state needs locks
- No mutable state = no locks = programmers bliss

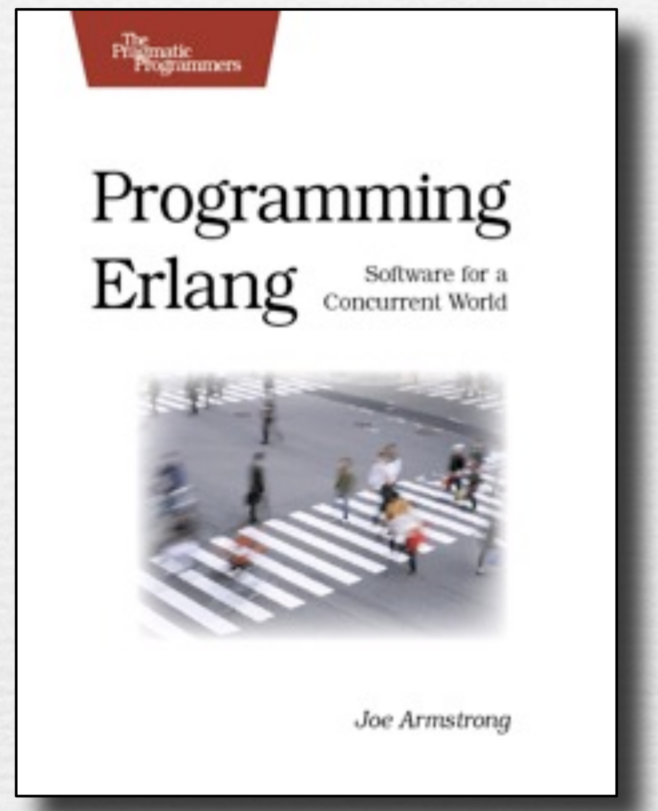
Projects

- CouchDB
- Amazon SimpleDB
- Mochiweb (facebook chat)
- Scalaris
- Nitrogren
- Ejabberd (xmpp)
- Rabbit MQ (amqp)
- Riak

Companies

- Ericsson
- Amazon
- Tail-f
- Klarna
- Facebook
- ...

Books



http://www.sics.se/~joe/thesis/armstrong_thesis_2003.pdf

QUESTIONS