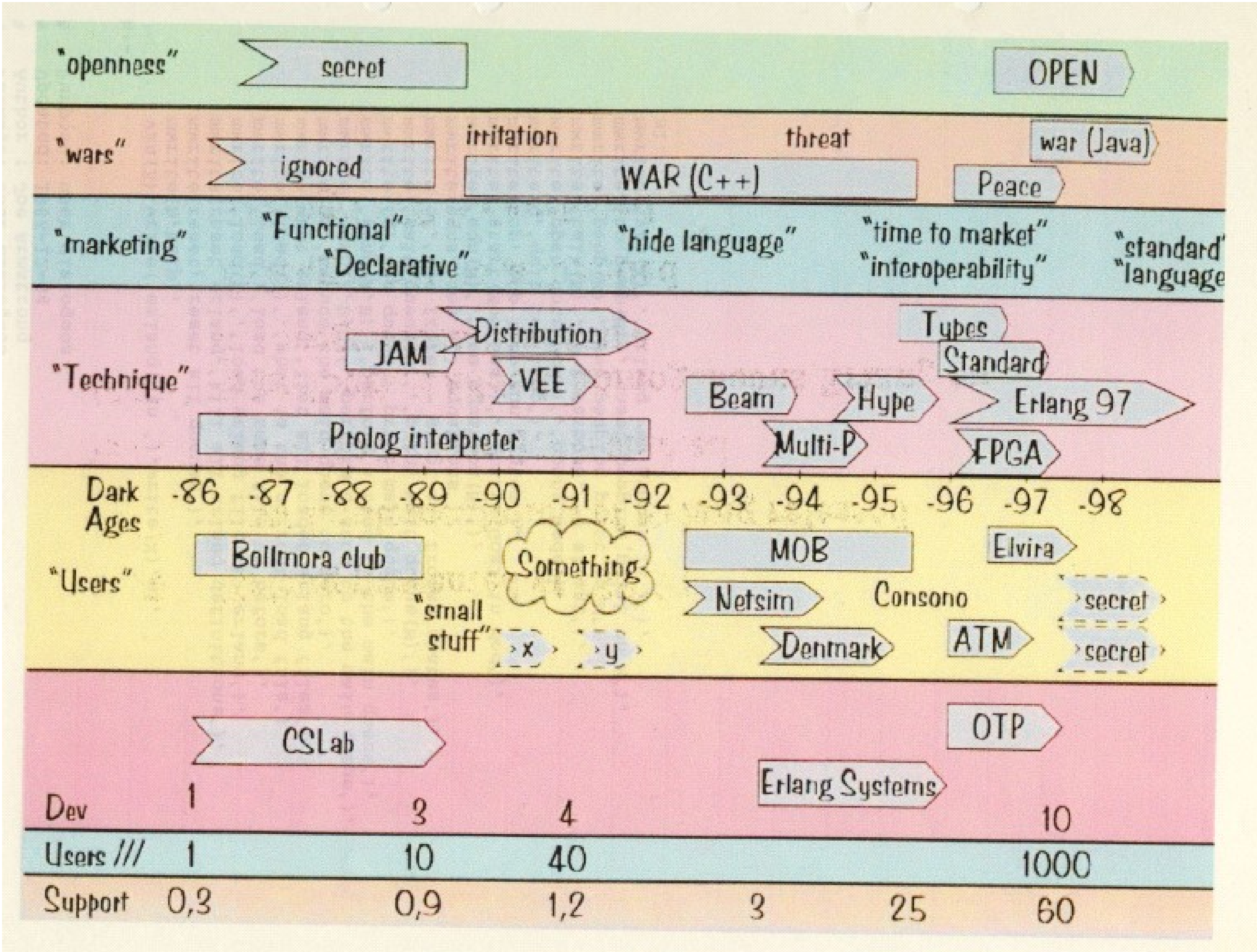
The evolution of the Erlang VM

Joe Armstrong
Robert Virding

1985 - 1998


"openness"
secret
OPEN
"wars"
ignored
irritation
WAR (C++)
threat
war (Java)
Peace
"marketing"
"Functional"
"Declarative"
"hide language"
"time to market"
"interoperability"
"standard"
"language"
"Technique"
JAM
Distribution
VEE
Prolog interpreter
Beam
Multi-P
Hype
Types
Standard
Erlang 97
FPGA
Dark Ages
-86 -87 -88 -89 -90 -91 -92 -93 -94 -95 -96 -97 -98
"Users"
Bollmora club
"small stuff"
x
y
Something
MOB
Netsim
Consono
Denmark
ATM
Elvira
secret
secret
CSLab
Erlang Systems
OTP
Dev 1 3 4 10
Users /// 1 10 40 1000
Support 0,3 0,9 1,2 3 25 60

Pre history

AXE – programmed in PLEX

PLEX
  Programming language for exchanges)
  Proprietary
  blocks (processes) and signals
  in-service code upgrade

Eri Pascal

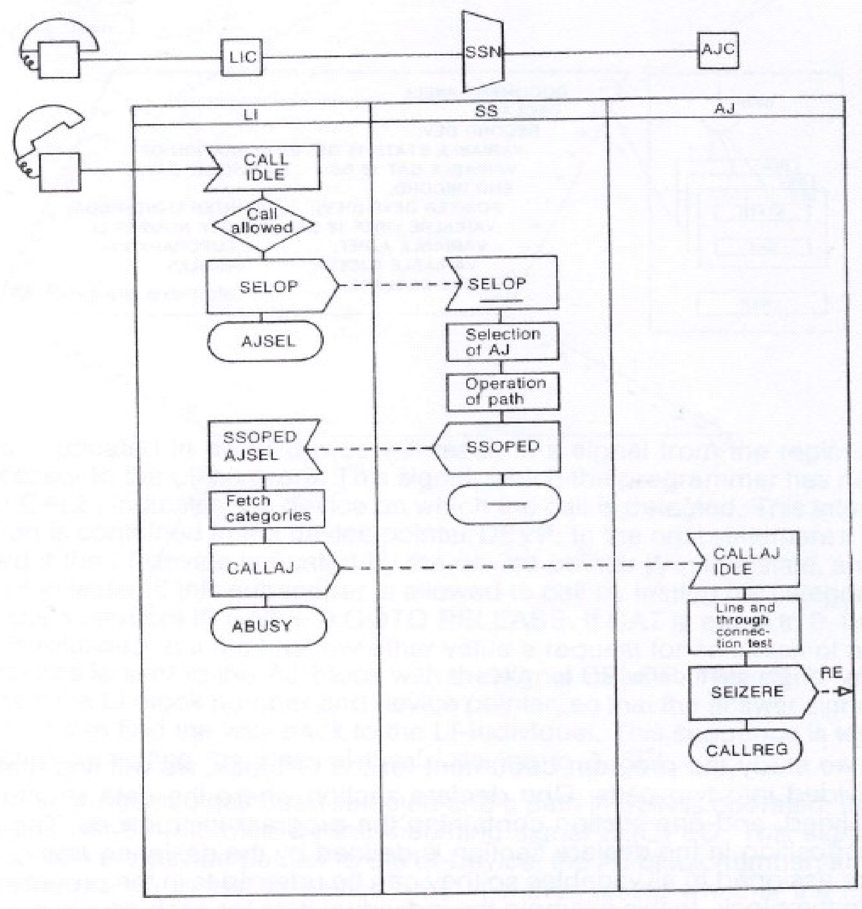
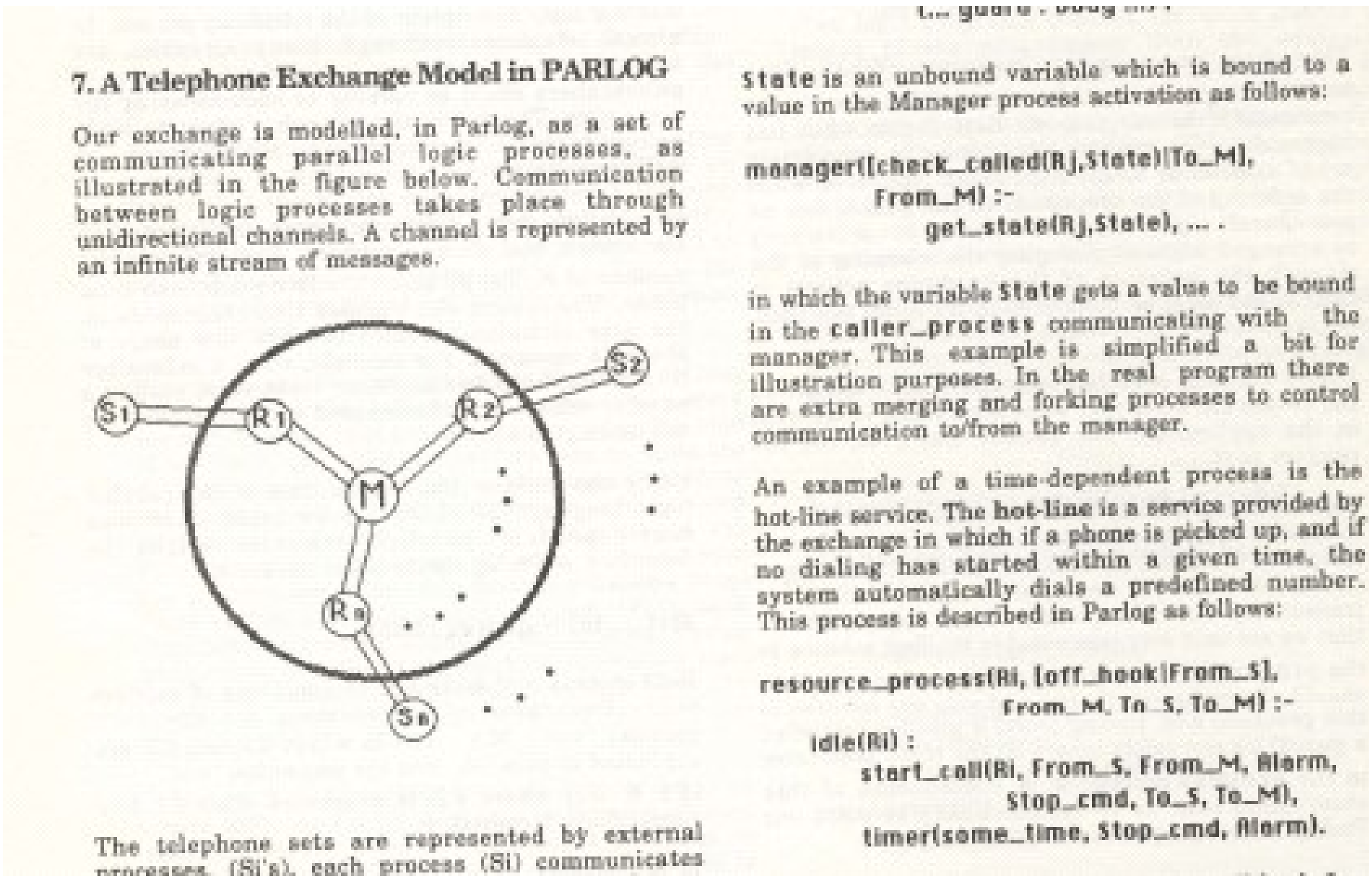


Fig. 11 AXE programming by PLEX

Phoning philosphers



t... guard : body ... .

7. A Telephone Exchange Model in PARLOG

Our exchange is modelled, in Parlog, as a set of communicating parallel logic processes, as illustrated in the figure below. Communication between logic processes takes place through unidirectional channels. A channel is represented by an infinite stream of messages.

The telephone sets are represented by external processes (Si's), each process (Si) communicates

State is an unbound variable which is bound to a value in the Manager process activation as follows:

```
manager([check_called(Rj,State)|To_M],
        From_M) :-
            get_state(Rj,State), ... .
```

in which the variable State gets a value to be bound in the caller_process communicating with the manager. This example is simplified a bit for illustration purposes. In the real program there are extra merging and forking processes to control communication to/from the manager.

An example of a time-dependent process is the hot-line service. The hot-line is a service provided by the exchange in which if a phone is picked up, and if no dialing has started within a given time, the system automatically dials a predefined number. This process is described in Parlog as follows:

```
resource_process(Ri, [off_hook|From_S],
                 From_M, To_S, To_M) :-
    idle(Ri) :
        start_call(Ri, From_S, From_M, Alarm,
                   Stop_cmd, To_S, To_M),
        timer(some_time, Stop_cmd, Alarm).
```

Conclusion – Concurrent Logic programming with channel communication

Armstrong, Elshiewy, Virding (1986)

The Telephony Algebra - (1985)

idle(N) means the subscriber N is idle
on(N) means subscribed N in on hook
...

+t(A, dial_tone) means add a dial tone to A

process(A, f) :- on(A), idle(A), +t(A,dial-tone),
+d(A, []), -idle(A), +of(A)

Using this notation, POTS could be described using fifteen rules. There was just one major problem: the notation only described how one telephone call should proceed. How could we do this for thousands of simultaneous calls?

The reduction machine - (1985)

A -> B,C,D.
B -> x,D.
D -> y.
C -> z.

We can interrupt this at any time

A
B,C,D
x,D,C,D
D,C,D
y,C,D
C,D
z,D
D
y
{}

A,B,C, D = nonterminals
x,y,z = terminals

To reduce X,...Y...
If X is a nonterminal replace it by it's definition
If X is a terminal execute it and then do ...Y...

Aside - term rewriting is tail recursive

A -> x,y,A

A
x,y,A
y,A
A
x,y,A
y,A
A
...

```
loop(X) ->
    ...
    loop(X).
```

factorial

```
rule(fac, 0)  -> [pop,{push,1}];
rule(fac, _)  -> [dup,{push,1},minus,{call,fac},times].

run() -> reduce0([{call,fac}], [3]).

reduce0(Code, Stack) ->
   io:format("Stack:~p Code:~p~n",[Stack,Code]),
   reduce(Code, Stack).

reduce([],[X])                    -> X;
reduce([{push,N}|Code], T)    -> reduce0(Code, [N|T]);
reduce([pop|Code], T)          -> reduce0(Code, tl(T));
reduce([dup|Code], [H|T])      -> reduce0(Code, [H,H|T]);
reduce([minus|Code], [A,B|T]) -> reduce0(Code, [B-A|T]);
reduce([times|Code], [A,B|T]) -> reduce0(Code, [A*B|T]);
reduce([{call,Func}|Code], [H|_]=Stack) ->
   reduce0(rule(Func, H) ++ Code, Stack).
```

factorial

```
> fac:run().
Stack:[3] Code:[{call,fac}]
Stack:[3] Code:[dup,{push,1},minus,{call,fac},times]
Stack:[3,3] Code:[{push,1},minus,{call,fac},times]
Stack:[1,3,3] Code:[minus,{call,fac},times]
Stack:[2,3] Code:[{call,fac},times]
Stack:[2,3] Code:[dup,{push,1},minus,{call,fac},times,times]
Stack:[2,2,3] Code:[{push,1},minus,{call,fac},times,times]
Stack:[1,2,2,3] Code:[minus,{call,fac},times,times]
Stack:[1,2,3] Code:[{call,fac},times,times]
Stack:[1,2,3] Code:[dup,{push,1},minus,{call,fac},times,times,times]
Stack:[1,1,2,3] Code:[{push,1},minus,{call,fac},times,times,times]
Stack:[1,1,1,2,3] Code:[minus,{call,fac},times,times,times]
Stack:[0,1,2,3] Code:[{call,fac},times,times,times]
Stack:[0,1,2,3] Code:[pop,{push,1},times,times,times]
Stack:[1,2,3] Code:[{push,1},times,times,times]
Stack:[1,1,2,3] Code:[times,times,times]
Stack:[1,2,3] Code:[times,times]
Stack:[2,3] Code:[times]
Stack:[6] Code:[]
```

787 Kreds/sec

1985 - 1989

Timeline

- Programming POTS/LOTS/DOTS (1885)
- A Smalltalk model of POTS
- A telephony algebra (math)
- A Prolog interpretor for the telephony algebra
- Added processes to prolog
- Prolog is too powerful (backtracking)
- Deterministic prolog with processes
- "Erlang" !!! (1986)
- ...
- Compiled to JAM code (1989)
- ...

erlang vsn 1.05

h	help
(*) **reset**	reset all queues
reset_erlang	kill all erlang definitions
load(F)	load erlang file <F>.erlang
load	load the same file as before
load(?)	what is the current load file
what_erlang	list all loaded erlang files
go	reduce the main queue to zero
send(A,B,C)	perform a send to the main queue
send(A,B)	perform a send to the main queue
cq	see queue - print main queue
wait_queue(N)	print wait_queue(N)
cf	see frozen - print all frozen states
eqns	see all equations
eqn(N)	see equation(N)
start(Mod,Goal)	starts Goal in Mod
top	top loop run system
q	quit top loop
open_dots(Node)	opens Node
talk(N)	N=1 verbose, =0 silent
peep(M)	set peeping point on M
no_peep(M)	unset peeping point on M
vsn(X)	erlang vsn number is X

The manual

1986 (or 85)

Running a program

```
joe> cat  test.erlang                    listing of program
module(test).
1: start --> write('hello'),nl,go.
2: go --> start_proc(foo1,test,test),start_proc(foo2,test,test).
3: test --> wait.
4: wait,[X,1].
5: wait,[X,Y] --> write(received(Y)),nl,wait.
joe> erlang                              start erlang
erlang vsn 1.05
type h for help

yes
| ?- load(test).                         load  the program in test.erlang
translating the file:test.erlang
Module:test
12345                                    equantion numbers are displayed
compiling the file:test.obj
[/u/joe/logic/quintus/erlang/dots/test.obj compiled (1.950 sec 480 bytes)]
loading completed ...
```

The Prolog interpreter (1986)

```
%   Package: make erlang
%   Author : Joseph Armstrong
%   Updated: 1986-12-18
%   Purpose: compiles and loads the erlang system


% this line MUST come first
:- ensure_loaded('/u/joe/logic/quintus/lib/set_library.pl').

%   vsn 1.03 lost in the mists of time
%   vsn 1.04 added modules and peeping (removed tracing)
%   vsn 1.05 mean version - fails in top loop to conserve space

%   vsn 1.06
%       added process constants
%               added commands
%               start_proc(Id,Module,Goal,Process_constants)
%                       is similar to start_proc/3 with added
%                       Process_constans
%                       Process_constants are a list of pairs of the form
%                               [(Key,Val),(Key1,Val1),...]
%               pconst(Key,Val)
%                       looks up the value of the process constant
%                       with key Key - Binds result to Value or makes
%                       error messages
%       added table driven number analyser
%               anal(Seq,Res)
%                       given a dialled sequence Seq binds Res
%                       to one of [invalid,get_more_digits,matched(Reason)]

vsn(1.06).


:- ensure_loaded(library(prims)).
:- ensure_loaded(library(findall)).

:- ensure_loaded('erlang1.04').
:- ensure_loaded(run).
:- ensure_loaded(queue).
:- ensure_loaded(reduce).
:- ensure_loaded(resume).
:- ensure_loaded(timeout).
```

version 1.06

dated

1986-12-18

1.03 "lost in the mists of time"

1988 – Interpreted Erlang

- 4 days for a complete re-write
- 245 reductions/sec
- semantics of language worked out
- Robert Virding joins the "team"

88/12/16
12:44:20

erlang.pl

```
/*
 * $HOME/erlang.pro
 *
 *            Copyright (c) 1988 Ericsson Telecom
 *
 * Author: Joe Armstrong
 * Creation Date: 1988-03-24
 * Purpose:
 *      main reduction engine
 *
 * Revision History:
 *      88-03-24        Started work on multi processor version
 *                      of erlang
 *      88-03-28        First version completed (Without timeouts)
 *      88-03-29        Correct small errors
 *      88-03-29        Changed 'receive' to make it return the pair
 *                      msg(From,Mess)
 *      88-03-29        Generate error message when out of goals
 *                      i.e. program doesn't end with terminate
 *      88-03-29        added trace(on), trace(off) facilities
 *      88-03-29        Removed Var := {....} , this can be achieved
 *                      with {..}
 *      88-05-27        Changed name of file to erlang.pro
 *                      First major revision started - main changes
 *                      Complete change from process to channel
 *                      based communication
 *                      here we (virtually) throw away all the
 *                      old stuff and make a bloody great data base
 *      88-05-31        The above statements were incorrect much better
 *                      to go back to the PROPER way of doing things
 *                      long live difference lists
 *      88-06-02        Reds on run([et5]) = 245
 *                      changing the representation to separate the
 *                      environment and the process - should improve things
 *                      It did .... reds = 283 - and the program is nicer!
 *      88-06-08        All pipe stuff working (pipes.pro)
 *                      added code so that undefined functions can return
 *                      values
```

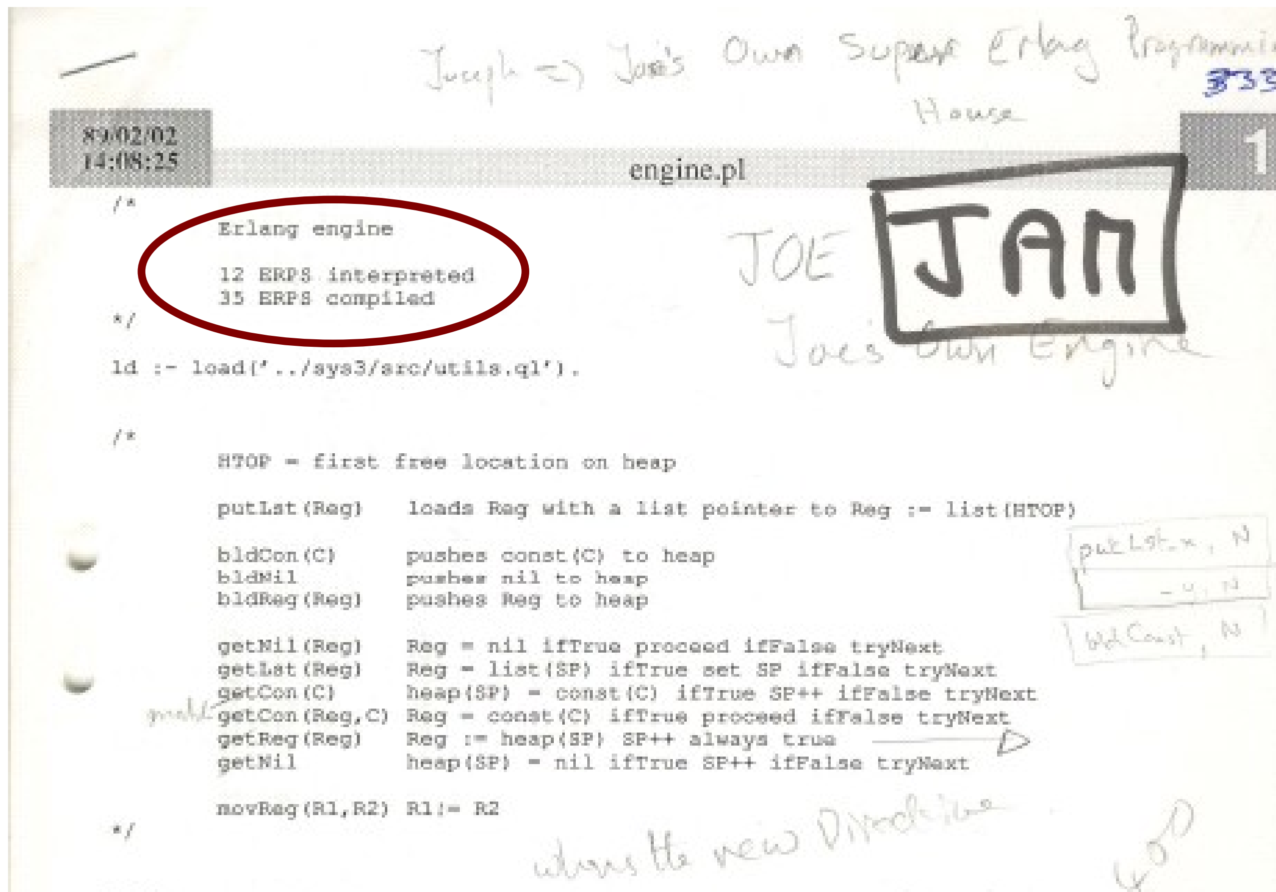
1989 – The need for speed

ACS- Dunder
- “we like the language but it's too slow” - must be 40 times faster

Mike Williams writes the emulator (in C)

Joe Armstrong writes the compiler

Robert Virding writes the libraries


```
89/02/02
14:08:25                     engine.pl                        1

/*
        Erlang engine

        12 ERPS interpreted
        35 ERPS compiled
*/

ld :- load('../sys3/src/utils.ql').

/*
        HTOP = first free location on heap

        putLst(Reg)    loads Reg with a list pointer to Reg := list(HTOP)

        bldCon(C)      pushes const(C) to heap
        bldNil         pushes nil to heap
        bldReg(Reg)    pushes Reg to heap

        getNil(Reg)    Reg = nil ifTrue proceed ifFalse tryNext
        getLst(Reg)    Reg = list(SP) ifTrue set SP ifFalse tryNext
        getCon(C)      heap(SP) = const(C) ifTrue SP++ ifFalse tryNext
        getCon(Reg,C)  Reg = const(C) ifTrue proceed ifFalse tryNext
        getReg(Reg)    Reg := heap(SP) SP++ always true
        getNil         heap(SP) = nil ifTrue SP++ ifFalse tryNext

        movReg(R1,R2)  R1:= R2
*/
```

How does the JAM work?

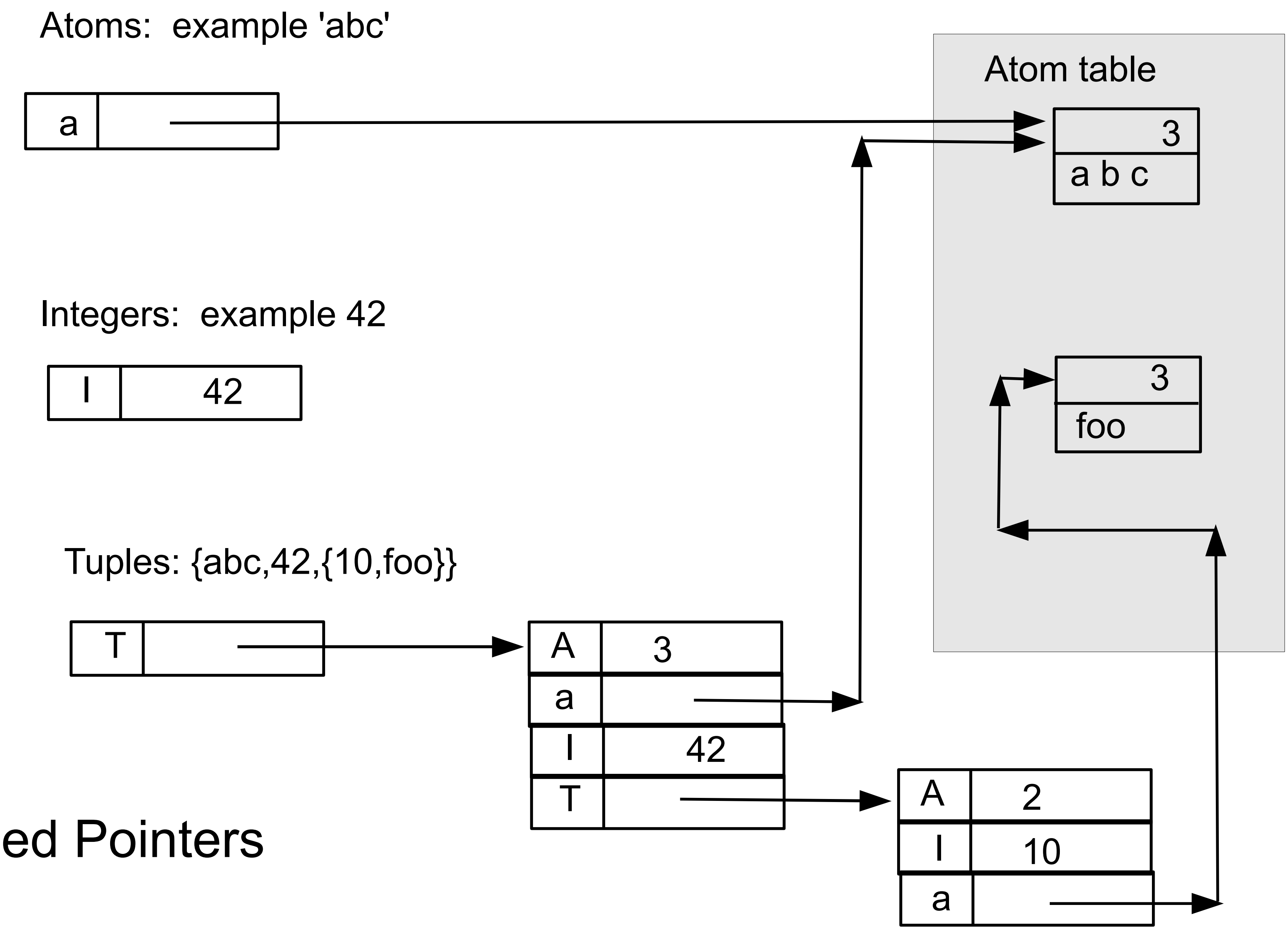
- JAM has thee global data areas

  code space + atom table + scheduler queue

- Each process has a stack and a heap
- Erlang data structures are represented as tagged pointers on the stack and heap

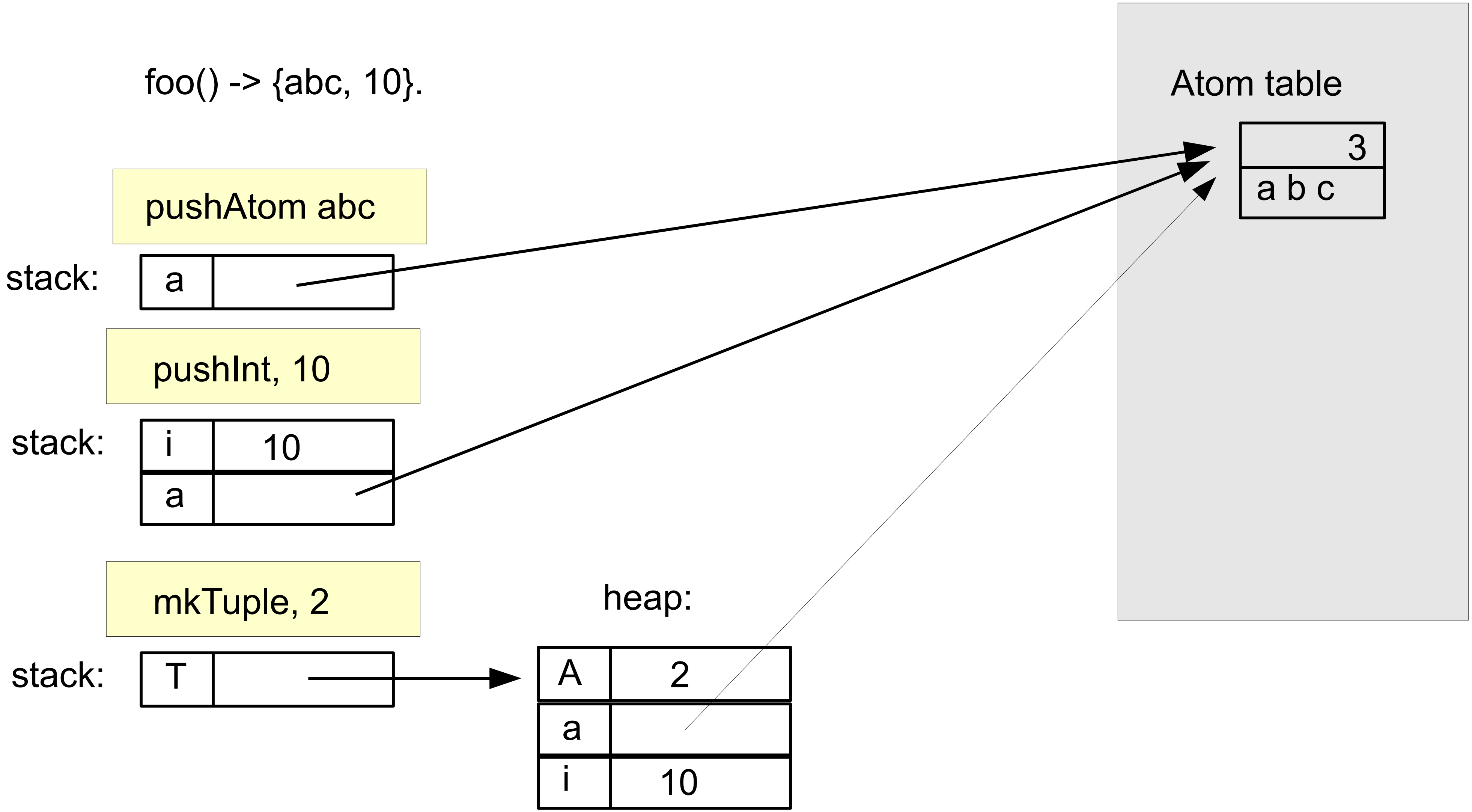
JAM

- Compile code into sequences of instructions that manipulate data structures stored on the stack and heap (Joe)
- Write code loader, scheduler and garbage collector (Mike)
- Write libraries (Robert)



Tagged Pointers

foo() -> {abc, 10}.



pushAtom abc
stack:
a
pushInt, 10
stack:
i
10
a
mkTuple, 2
stack:
T
heap:
A
2
a
i
10
Atom table
3
a b c

Compiling foo() -> {abc,10}

```
{enter, foo,2}
{pushAtom, “abc”}
{pushInt, 10},
{mkTuple, 2},
ret
```

Byte code

16,10,20,2

pc = program counter
stop = stack top
htop = heap top

```
switch(*pc++){
    case 16: // push short int
          *stop++ = mkint(*pc++);
          break;
    case 20: // mktuple
          arity = *pc++;
          *htop++ = mkarity(arity);
          while(arity>0){
                *htop++ = *stop--;
                arity--;
           };
          break;
```

Part of the byte code interpreter

An early JAM compiler (1989)

```
sys_sys.erl              18 dummy
sys_parse.erl           783 erlang parser
sys_ari_parser.erl      147 parse arithmetic expressions
sys_build.erl           272 build function call arguments
sys_match.erl           253 match function head arguments
sys_compile.erl         708 compiler main program
sys_lists.erl            85 list handling
sys_dictionary.erl       82 dictionary handler
sys_utils.erl            71 utilities
sys_asm.erl             419 assembler
sys_tokenise.erl        413 tokeniser
sys_parser_tools.erl     96 parser utilities
sys_load.erl            326 loader
sys_opcodes.erl         128 opcode definitions
sys_pp.erl              418 pretty printer
sys_scan.erl            252 scanner
sys_boot.erl             59 bootstrap
sys_kernel.erl            9 kernel calls
18 files               4544
```

```
fac(0) -> 1;
fac(N) -> N * fac(N-1)

{info, fac, 1}
 {try_me_else, label1}
       {arg, 0}
       {getInt, 0}
       {pushInt, 1}
       ret
 label1: try_me_else_fail
       {arg, 0}
       dup
       {pushInt, 1}
       minus
       {callLocal, fac, 1}
       times
       ret
```

Like the WAM with added primitives for spawning processes and message passing

factorial

```
rule(fac, 0)  ->
   [pop,{push,1}];
rule(fac, _)  ->
   [dup,{push,1},
    Minus,
    {call,fac},
    times].
```

```
fac(0) -> 1;
fac(N) -> N * fac(N-1)

{info, fac, 1}
 {try_me_else, label1}
        {arg, 0}
        {getInt, 0}
        {pushInt, 1}
        ret
 label1: try_me_else_fail
        {arg, 0}
        dup
        {pushInt, 1}
        minus
        {callLocal, fac, 1}
        times
        ret
```

Jam improvements

- Uncessary stack -> heap movements
- Better with a register machine
- Convert to register machine by emulating top N stack locations with registers
- And a lot more ...

Alternate implementations

VEE (Virding's Erlang Engine)

- Experiment with different memory model
  - Single shared heap with real-time garbage collector (reference counting)
- Blindingly fast message passing

BUT

- No overall speed gain and more complex internals

Alternate implementations

Strand88 machine

- An experiment using another HLL as "assembler"
- Strand88 a concurrent logic language – every reduction a process and messages as cheap as lists
- Problem was to restrict parallelism

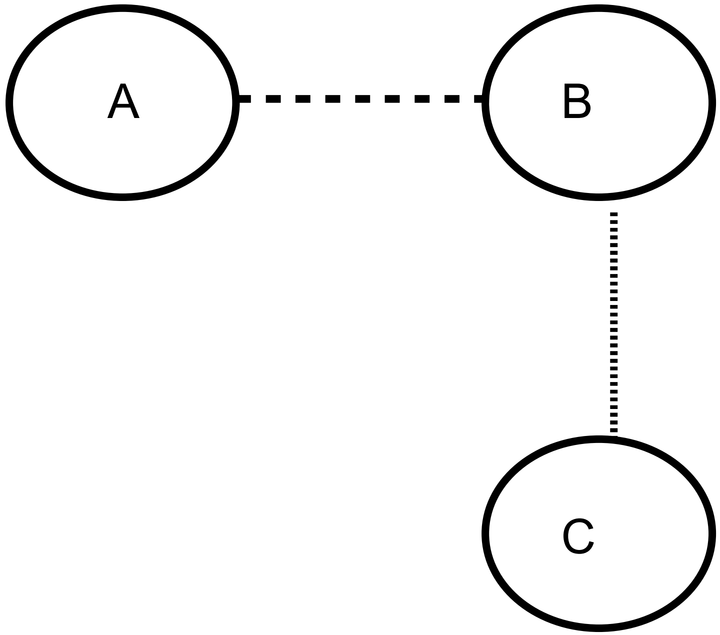
BUT

- Strand's concurrency model was not good fit for Erlang
- Worked but not as well as the JAM

Speedups

- Prolog Erlang Interpretor (1988) – 245 reds/sec
- Prolog JAM emulator – 35 reds/sec
- C Erlang JAM emulator (1989) – 30K reds/sec
- C Erlang BEAM emulator (2010) – 9 Mega reds/sec
- Erlang JAM emulator (2010) – 787K reds/sec
- Speedup 787K/35 = 22400 in 21 years
- K^21 = 22400 so K = 1.61 (61% / year) Smartness
- or K^21 = 767K/30K = 1.16 (16% / year) Mores law

Links



A is linked to B
B is linked to C

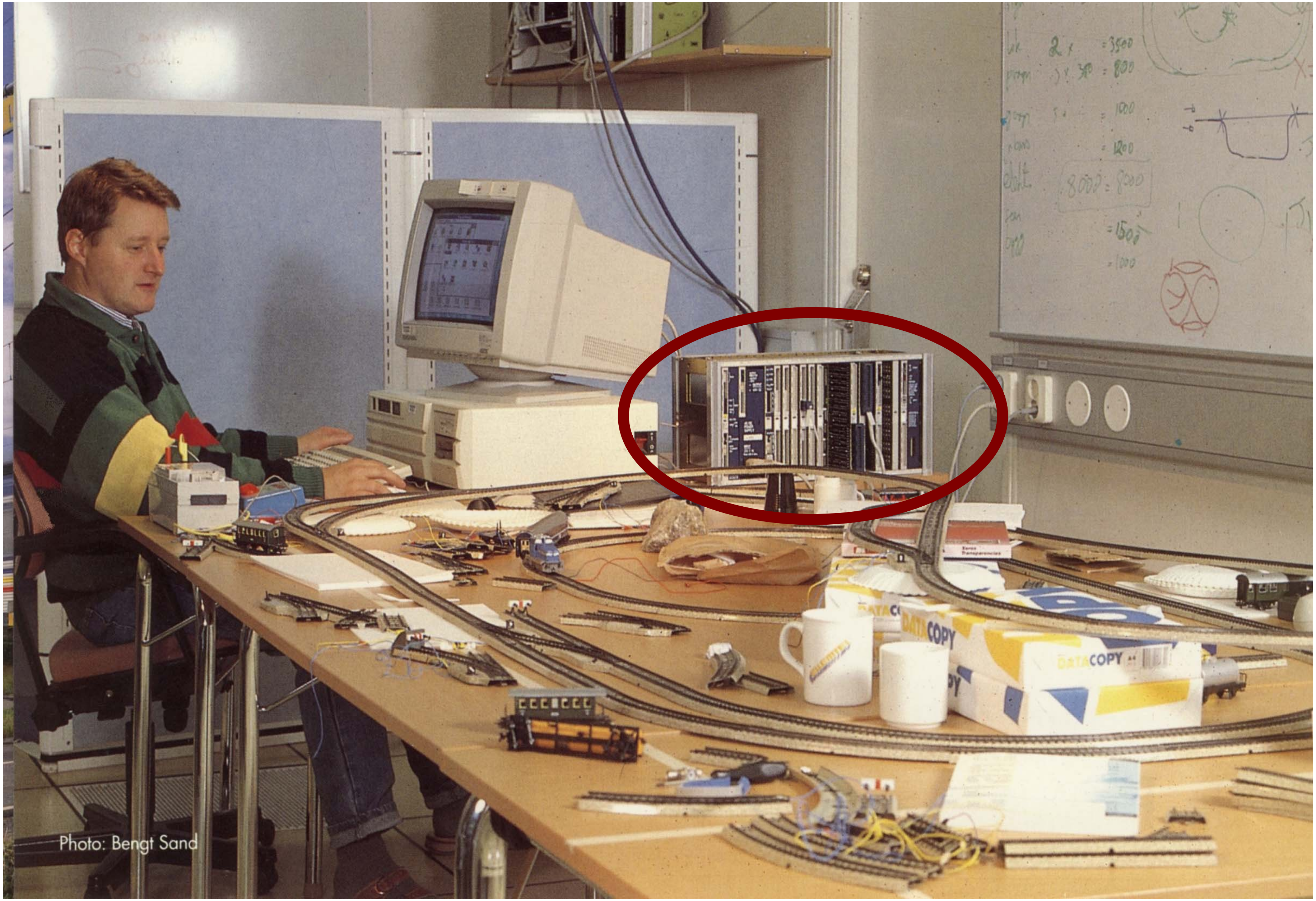
If any process crashes an EXIT message is sent to the linked processes

This idea comes from the "C wire" in early telephones (ground the C wire to cancel the call)

Encourages "let it crash" programming

By 1990 things
were going
so well
that we
could
...

Buy a train set



We added new stuff

- Distribution
- OTP structure
- BEAM
- HIPE
- Type tools
- Philosophy
- Bit syntax
- Compiling pattern matching
- OTP tools
- Documented way of doing things

TEAM

Turbo Erlang Abstract Machine

By Bogumil Hausman

- Make a new efficient implementation of Erlang

TEAM

- New machine design
  - Register machine
- Generate native code by smart use of GNU CC
- Same basic structures and memory design as JAM

```
append([H|T],X) -> [H|append(T,X)];
append([],X) -> X.
```

```
append_2:
    Clause;
    TestNonEmptyList(x(0),next);
    Allocate(1);

    GetList2(x(0),y(0),x(0));
    Call(append_2,2);


    TestHeap(2);
    PutList2(x(0),y(0),x(0));
    Deallocate(1);
    Return;
    ClauseEnd;

    Clause;
    TestNil(x(0),next);
    Move(x(1),x(0));
    Return;
    ClauseEnd;

    ErrorAction(FunctionClause);
```

TEAM

- Significantly faster than the JAM

BUT

- Module compilation was slow
- Code explosion, resultant code size was too big for customers

SO

- Hybrid machine with both native code and emulator

TEAM --> BEAM

Bogdan's Erlang Abstract Machine

And lots of improvements have been made and lots of good stuff added!

Better GC (generational), SMP, NIFs, etc. etc.

Bit syntax

- Pattern matching over bits

```
unpack(<<Red:5,Green:6,Blue:5>>) ->
    ...
```

Due to Klacke
(Claes Vikström)

```
-define(IP_VERSION, 4).
-define(IP_MIN_HDR_LEN, 5).

DgramSize = size(Dgram),
case Dgram of
    <<?IP_VERSION:4, HLen:4, SrvcType:8, TotLen:16,
      ID:16, Flgs:3, FragOff:13,
      TTL:8, Proto:8, HdrChkSum:16,
      SrcIP:32,
      DestIP:32, RestDgram/binary>> when HLen>=5,
4*HLen=<DgramSize ->
        OptsLen = 4*(HLen - ?IP_MIN_HDR_LEN),
        <<Opts:OptsLen/binary,Data/binary>> = RestDgram,
    ...
end.
```

(unpack Ipv4 datagram)

Compiling pattern matching

- Erlang semantics say match clauses sequentially

BUT

- Don't have to if you are smart!
- Can group patterns and save testing

The Implementation of Functional Languages

Simon Peyton Jones

(old, from 1987, but still full of goodies)

Compiling pattern matching

```
scan1([$\s|Cs], St, Line, Col, Toks) when St#erl_scan.ws ->
scan1([$\s|Cs], St, Line, Col, Toks) ->
scan1([$\n|Cs], St, Line, Col, Toks) when St#erl_scan.ws ->
scan1([$\n|Cs], St, Line, Col, Toks) ->
scan1([C|Cs], St, Line, Col, Toks) when C >= $A, C =< $Z ->
scan1([C|Cs], St, Line, Col, Toks) when C >= $a, C =< $z ->
%% Optimization: some very common punctuation characters:
scan1([$,|Cs], St, Line, Col, Toks) ->
scan1([$(|Cs], St, Line, Col, Toks) ->
```

Compiling pattern matching

```
expr({var,Line,V}, Vt, St) ->
expr({char,_Line,_C}, _Vt, St) -> {[],St};
expr({integer,_Line,_I}, _Vt, St) -> {[],St};
expr({float,_Line,_F}, _Vt, St) -> {[],St};
expr({atom,Line,A}, _Vt, St) ->
expr({string,_Line,_S}, _Vt, St) -> {[],St};
expr({nil,_Line}, _Vt, St) -> {[],St};
expr({cons,_Line,H,T}, Vt, St) ->
expr({lc,_Line,E,Qs}, Vt0, St0) ->
expr({bc,_Line,E,Qs}, Vt0, St0) ->
expr({tuple,_Line,Es}, Vt, St) ->
expr({record_index,Line,Name,Field}, _Vt, St) ->
expr({bin,_Line,Fs}, Vt, St) ->
expr({block,_Line,Es}, Vt, St) ->
expr({'if',Line,Cs}, Vt, St) ->
expr({'case',Line,E,Cs}, Vt, St0) ->
```

The Erlang VM as an assembler

- Efene
  - Mariano Guerra
- Reia
  - Tony Arcieri
  - http://wiki.reia-lang.org/wiki/Reia_Programming_Language
- LFE (Lisp Flavoured Erlang)
  - http://github.com/rvirding/lfe

The End