printf debugging, without the printf

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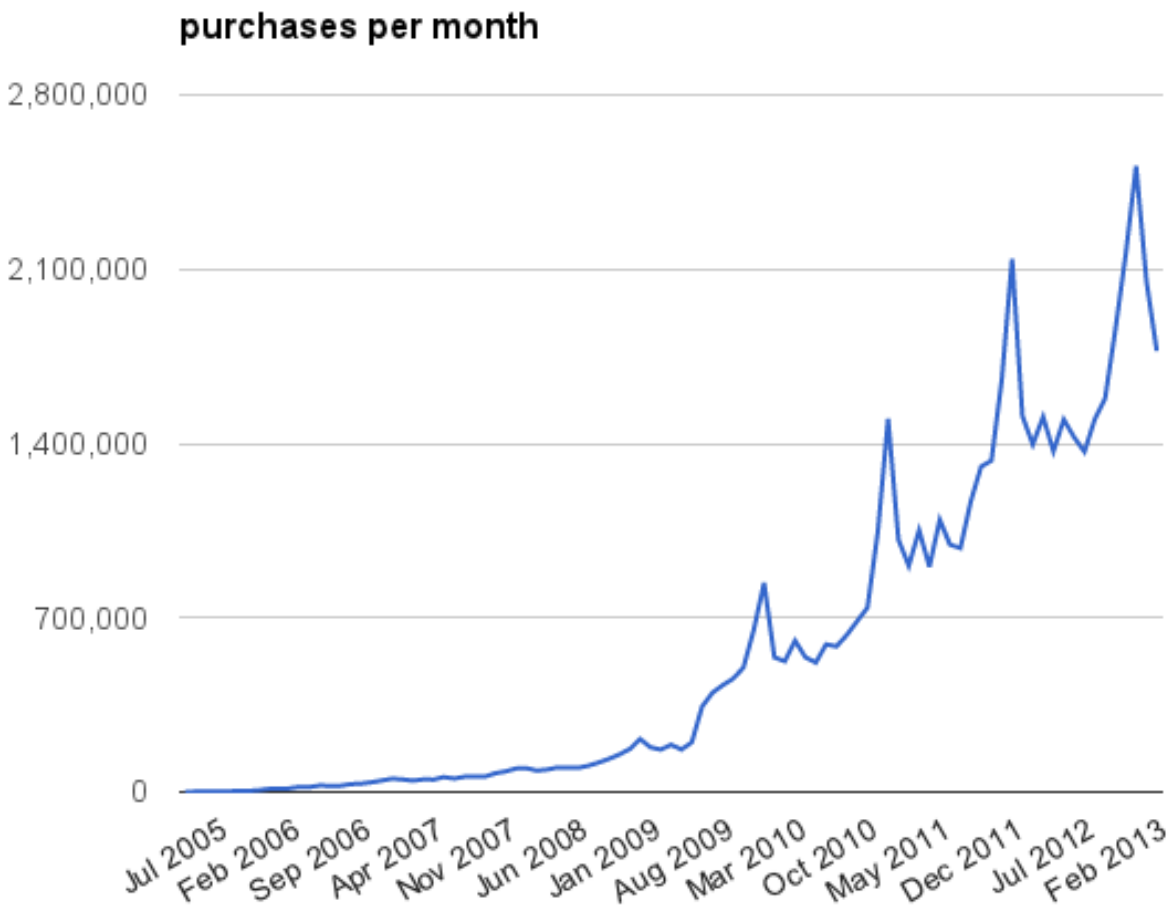
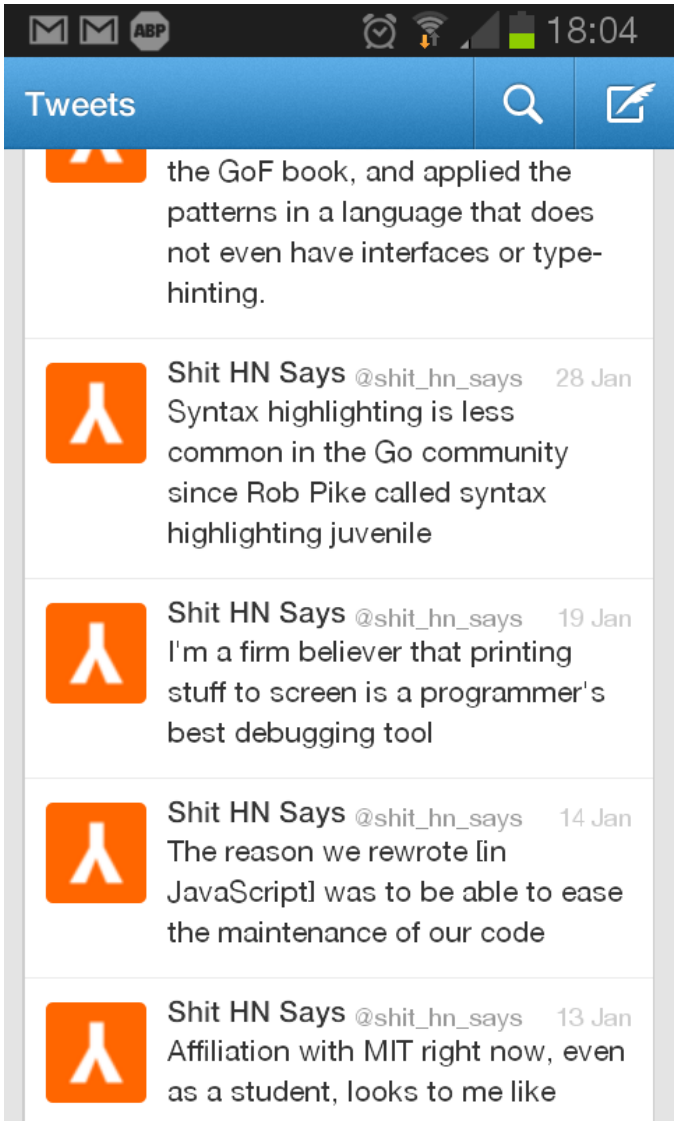
id

- Ph.D. in experimental Nuclear Physics
  - hardware
  - online software
  - offline software
- 10 years @ ericsson
  - building
  - testing
  - troubleshooting
  - supporting (4 years in Budapest)
- 5 years @ klarna
  - developer
  - architect

Klarna™


purchases per month
2,800,000
2,100,000
1,400,000
700,000
0
Jul 2005
Feb 2006
Sep 2006
Apr 2007
Nov 2007
Jun 2008
Jan 2009
Aug 2009
Mar 2010
Oct 2010
May 2011
Dec 2011
Jul 2012
Feb 2013

inspiration



"printing stuff to screen is a programmer's best debugging tool"

sad but true

- code inspection
  - no context
- crash dumps/postmortem,
  - probably wrong context
- logging
  - swamped with trivia, wrong place
- debugger
  - changes timing, non-production only

printf it is

- the good
  - the right context
  - the right place
  - filter out uninteresting stuff
  - minimal impact on timing (not small)
- the bad
  - edit/recompile
  - tricky to undo
  - tricky in production (especially in an embedded system)

the silver bullet

- tracing
  - the right context
  - the right place
  - filter out uninteresting stuff
  - minimal impact on timing (not small)
  - no editing
  - no recompile
  - easy undo

erlang:trace/3

- Tracing is turned on/off by `erlang:trace/3`
- It is turned on per process
- Different trace types
  - message passing (send/receive)
  - garbage collection
  - scheduler
  - call tracing
- Each triggered trace condition generates
  - a message sent to the tracer process
  - writing of a trace event to file

trace BIF in action

```
29> Shell=self().

30> F = fun()->erlang:trace(Shell,true,[running]),
               receive after 3000->
                  Shell!process_info(self(),messages)
               end
        end.
31> spawn(F).

32> flush().
Shell got {messages,[{trace,<0.34.0>,in,{io,
execute_request,2}},
           {trace,<0.34.0>,out,{io,wait_io_mon_reply,2}},
           {trace,<0.34.0>,in,{io,wait_io_mon_reply,2}},
           {trace,<0.34.0>,out,{io,wait_io_mon_reply,2}},
           {trace,<0.34.0>,in,{io,wait_io_mon_reply,2}},
           {trace,<0.34.0>,out,{shell,eval_loop,3}}]}
```

but I wanted printf!

To emulate printf, we need

- a way to insert instrumentation code
- into an arbitrary function
- without recompiling

How hard could it be?

erlang:trace_pattern/3

Loads instrumentation code into a function

The target function is specified as `{M,F,A}`

Wildcards are allowed; `{lists,'_','_'}`

The instrumentation code is a match spec.

match specs

A small, and pretty cryptic, language.

Expressed as an Erlang term.

Each match spec has

- a Head
  - like a function head in Erlang
- a Condition
  - like a guard in Erlang
- a Body
  - like a function body in Erlang

did I say cryptic?

- MatchExpression ::= [MatchFunction, ...]
- MatchFunction ::= { MatchHead, MatchConditions, MatchBody }
- MatchHead ::= MatchVariable | '_' | [MatchHeadPart, ...]
- MatchHeadPart ::= term() | MatchVariable | '_'
- MatchVariable ::= '$<number>'
- MatchConditions ::= [MatchCondition, ...] | []
- MatchCondition ::= { GuardFunction } | { GuardFunction, ConditionExpression, ... }
- BoolFunction ::= is_atom | is_float | is_integer | is_list | is_number | is_pid | is_port |is_reference | is_tuple | is_binary | is_function | is_record | is_seq_trace | 'and' | 'or' |'not' | 'xor' | andalso | orelse
- ConditionExpression ::= ExprMatchVariable | { GuardFunction } | { GuardFunction, ConditionExpression, ... } | TermConstruct
- ExprMatchVariable ::= MatchVariable (bound in the MatchHead) | '$_' | '$$'
- TermConstruct = {{}} | {{ ConditionExpression, ... }} | [] | [ConditionExpression, ...] | NonCompositeTerm | Constant
- NonCompositeTerm ::= term() (not list or tuple)
- Constant ::= {const, term()}
- GuardFunction ::= BoolFunction | abs | element | hd | length | node | round | size | tl | trunc | '+'| '-' | '*' | 'div' | 'rem' | 'band' | 'bor' | 'bxor' | 'bnot' | 'bsl' | 'bsr' | '>' | '>=' | '<' |'=<' | '=:=' | '==' | '=/=' | '/=' | self | get_tcw
- MatchBody ::= [ActionTerm]
- ActionTerm ::= ConditionExpression | ActionCall
- ActionCall ::= {ActionFunction} | {ActionFunction, ActionTerm, ...}
- ActionFunction ::= set_seq_token | get_seq_token | message | return_trace | exception_trace |process_dump | enable_trace | disable_trace | trace | display | caller | set_tcw | silent

example, then

Match a function with two arguments that are equal.
The head of the arguments should be less than 3.

```
[{['$1','$1'],[{'<',{hd,'$1'},3}],[]}]
```

example in action

```
22> Shell = self().

23> MFA = {lists,append,'_'}.

24> MatchSpec = [{['$1','$1'],[{'<',{hd,'$1'},3}],[]}].

25> F = fun()->
          erlang:trace_pattern({'_','_','_'},false,
[local]),
          erlang:trace(Shell,true,[call]),
          erlang:trace_pattern(MFA,MatchSpec,[local]),
          receive after 3000->
            Shell!process_info(self(),messages)
          end
        end.
```

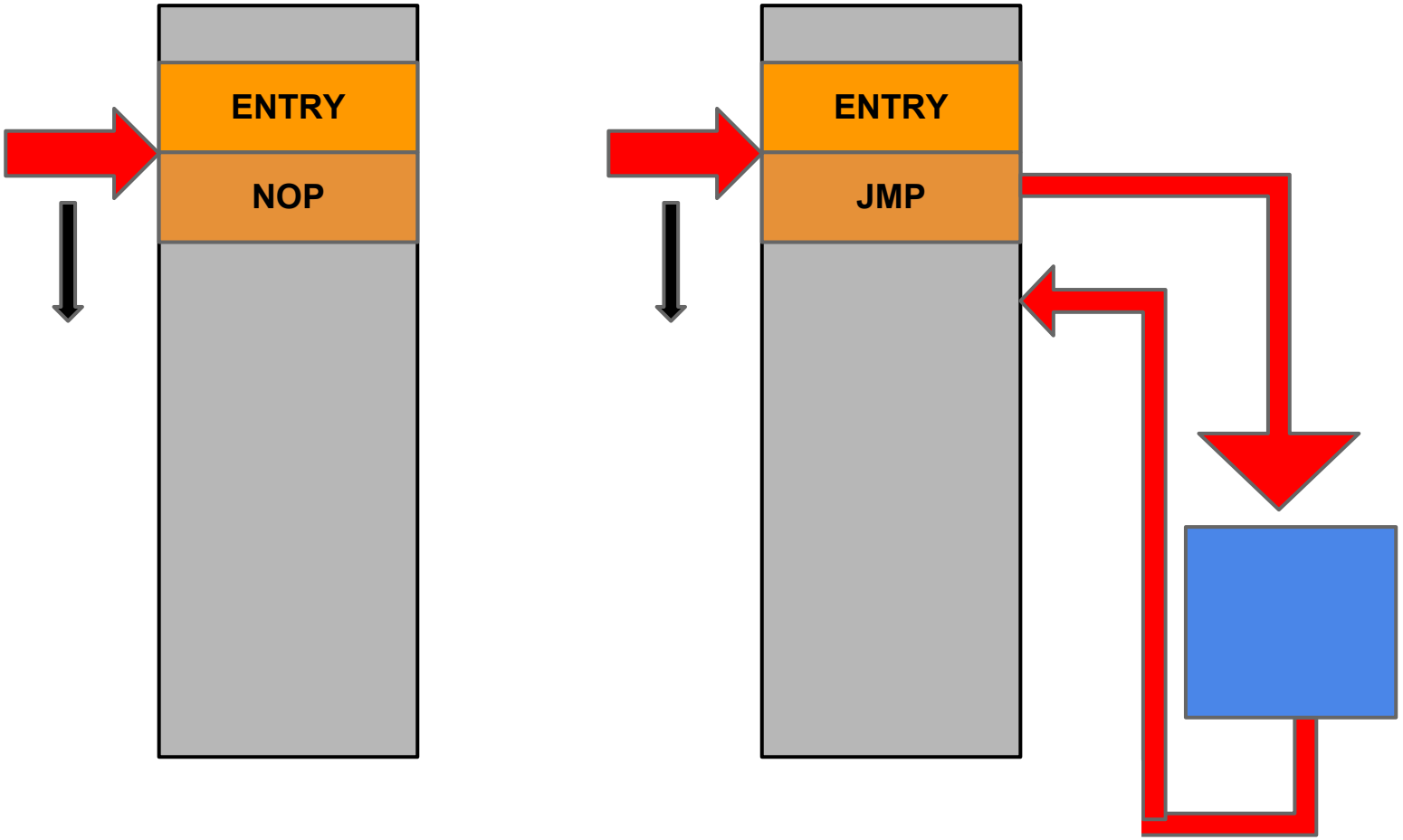
example works!

```
26> spawn(F).
27> lists:append([5],[5]).
28> lists:append([2],[2]).
29> flush().
Shell got {messages,[{trace,<0.34.0>,call,{lists,append,
[[2],[2]]}}]}
```

how does it work?

When beam code is loaded into the emulator, the loader inserts a NOP right after each function entry point.
When call tracing is turned on, a JMP is inserted in place of the NOP of the function(s) specified in the trace pattern.
At the JMP target the VM runs the MFA of the called function against the match spec, possibly binding match spec variables.
If they match, the match spec Body is executed.

eh, what?



a war story

- Embedded system running OTP R5.
- Live in Denmark.
- There was no way to log into the CPU.
- There was no way to load new code.
- There was no usable debugging tool.
- You could physically connect a terminal.

The node got overloaded after 90 days.
A tech travelled there to reboot every 89 days.

...tracing...

- Wrote a one-liner...
- ...that ran a one-minute trace, wrote to a file.
- Sent it to the Danish tech by mail...
- ...who ran it by pasting it into a shell...
- ...before and after the reboot...
- ...and emailed the files to me (base-64 encoded)

...saves the day!

Wrote a comparison profiler.
Compare the average execution time for each function, before and after the reboot.

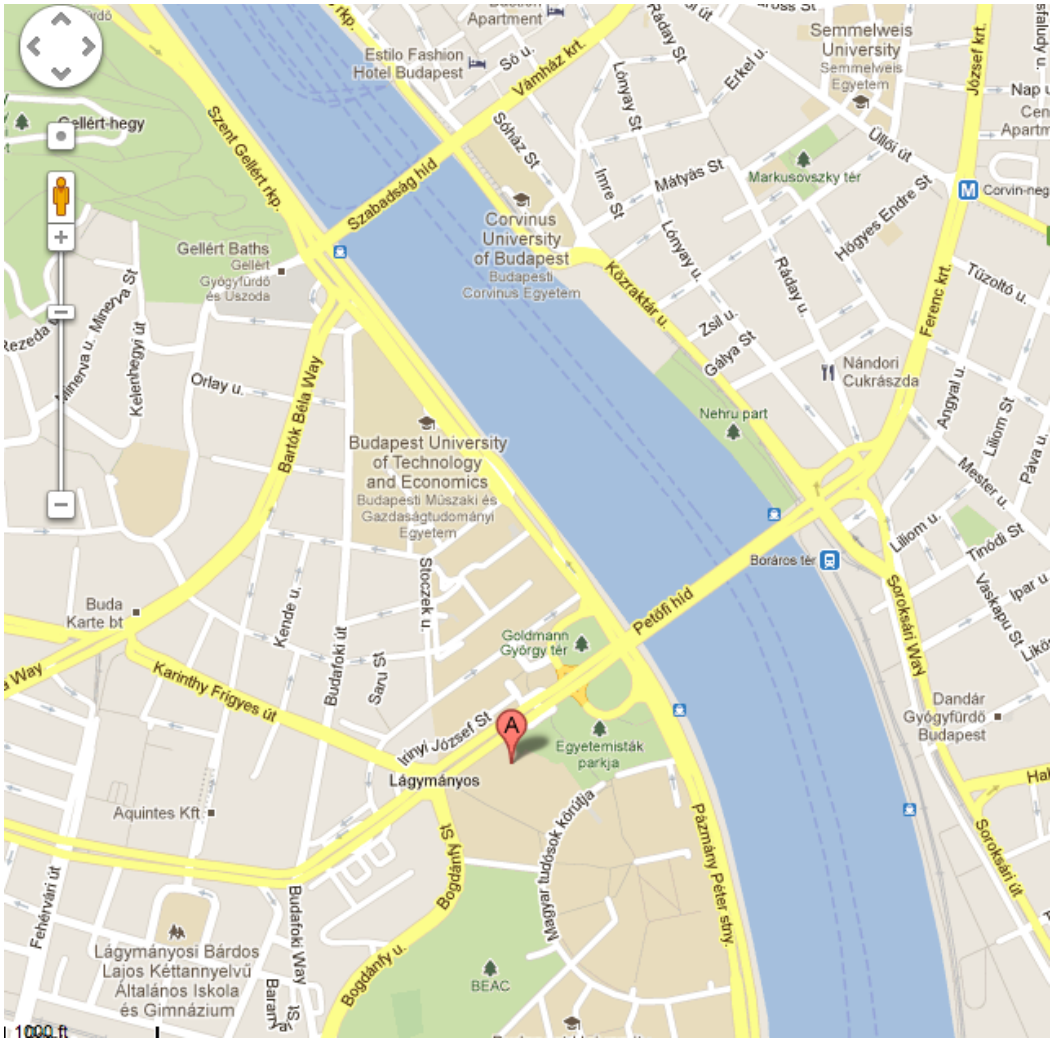
`ets:lookup/2`
was 100 times slower before the reboot.

the answer

The hash function was broken for bignums.

another war story

budai hídfő


Gellért-hegy
Szent Gellért rkp.
Szabadság híd
Gellért Baths
Gellért Gyógyfürdő és Uszoda
Minerva u.
Kelenhegyi út
Orlay u.
Bartók Béla Way
Budapest University of Technology and Economics
Budapesti Műszaki és Gazdaságtudományi Egyetem
Corvinus University of Budapest
Budapesti Corvinus Egyetem
Közraktár u.
Nehru part
Nándori Cukrászda
Markusovszky tér
Semmelweis University
Semmelweis Egyetem
Estilo Fashion Hotel Budapest
Vámház krt.
Sóház St
Lónyay St
Mátyás St
Imre St
Ráday St
Erkel u.
Üllői út
Hőgyes Endre St
Ferenc krt.
József krt.
Tűzoltó u.
Angyal u.
Liliom St
Mester u.
Páva u.
Liliom u.
Tinódi St
Vaskapu St
Soroksári Way
Soroksári út
Dandár Gyógyfürdő Budapest
Boráros tér
Petőfi híd
Goldmann György tér
Egyetemisták parkja
Irinyi József St.
Lágymányos
Karinthy Frigyes út
Buda Karte bt
Kende u.
Budafoki út
Saru St
Stoczek u.
Aquintes Kft
Fehérvári út
Budafoki Way
Lágymányosi Bárdos Lajos Kéttannyelvű Általános Iskola és Gimnázium
Bogdánfy u.
Bogdány St
Magyar tudósok körútja
Pázmány Péter stny.
BEAC
1000 ft

the situation

- live network in Germany
- switch in Frankfurt was misbehaving
- millions of connected Germans
- ~10,000 ongoing calls
- no appropriate debugging support
- shell access

the oneliner

```
Pi = fun(P) when pid(P) -> case process_info(P, registered_name) of[] -> case process_info(P, initial_call) of {_,
{proc_lib,init_p,5}}-> proc_lib:translate_initial_call(P); {_,MFA} -> MFA; undefined ->unknown end; {_,Nam} -> Nam;
undefined -> unknown end; (P) whenport(P) -> {name,N} = erlang:port_info(P,name), [Hd|_] =string:tokens(N," "), Tl
=lists:reverse(hd(string:tokens(lists:reverse(Hd),"/"))),list_to_atom(Tl); (R) when atom(R) -> R; ({R,Node}) when
atom(R),Node == node() -> R; ({R, Node}) when atom(R), atom(Node) -> {R,Node} end, Ts = fun(Nw) -> {_,{H,M,S}}
=calendar:now_to_local_time(Nw), {H,M,S,element(3,Nw)} end, Munge =fun(I) -> case string:str(I, "Return addr") of 0 -
> casestring:str(I, "cp = ") of 0 -> []; _ -> [_, C|_] =string:tokens(I,"()+"), list_to_atom(C) end; _ -> case
string:str(I,"erminate process normal") of 0 -> [_, C|_] =string:tokens(I,"()+"), list_to_atom(C); _ -> [] end end
end, Stack= fun(Bin) -> L = string:tokens( binary_to_list( Bin),"\n"),{stack,lists:flatten(lists:map(Munge,L))} end,
Prc = fun(all) ->all; (Pd) when pid(Pd) -> Pd; ({pid,P1,P2}) when integer(P1),integer(P2) -> c:pid(0,P1,P2); (Reg)
when atom(Reg) -> case whereis(Reg) of undefined -> exit({rdbg, no_such_process, Reg}); Pid when pid(Pid) -> Pid end
end, MsF = fun(stack, [{Head,Cond,Body}])-> [{Head,Cond,[{message,{process_dump}}|Body]}]; (return,[{Head,Cond,
Body}]) -> [{Head,Cond, [{return_trace}|Body]}]; (Head,[{_,Cond,Body}]) when tuple(Head)-> [{Head,Cond,Body}]; (X,_)
->exit({rdbg,bad_match_spec,X}) end, Ms = fun(Mss) -> lists:foldl(MsF,[{'_',[],[]}], Mss) end, ChkTP = fun({M,F})
when atom(M), atom(F),M/='_', F/='_' -> {{M,F,'_'},[],[global]}; ({M,F,MS}) when atom(M),atom(F), M/='_', F/='_' ->
{{M,F,'_'},Ms(MS),[global]};({M,F,MS,local}) when atom(M), atom(F), M/='_', F/='_' ->{{M,F,'_'},Ms(MS), [local]};
({M,F,MS,global}) when atom(M), atom(F),M/='_', F/='_' -> {{M,F,'_'},Ms(MS),[global]}; (X) ->exit({rdbg,
unrec_trace_pattern,X}) end, ChkTPs = fun(TPs) when list(TPs) -> lists:map(ChkTP,TPs); (TP) -> [ChkTP(TP)] end,
SetTPs =fun({MFA,MS,Fs}) -> erlang:trace_pattern(MFA,MS,Fs) end, DoInitFun =fun(Time) -> erlang:register(rdbg,
self()),erlang:start_timer(Time,self(), {die}),erlang:trace_pattern({'_','_','_'}, false,[local]),erlang:
trace_pattern({'_','_','_'},false,[global]) end, InitFun =fun(Time,all,send) -> exit({rdbg, too_many_processes});
(Time,all,'receive') -> exit({rdbg,too_many_processes}); (Time,P,send) -> DoInitFun(Time), erlang:trace(Prc(P),true,
[send,timestamp]); (Time,P,'receive') ->DoInitFun(Time), erlang:trace(Prc(P),true, ['receive', timestamp]);(Time,P,
TPs) -> CTPs = ChkTPs(TPs), DoInitFun(Time),erlang:trace(Prc(P),true, [call,timestamp]), lists:foreach(SetTPs,CTPs)
end, LoopFun = fun(G,N,Out) when N < 1 -> erlang:trace(all, false,[call,send,'receive']), erlang:trace_pattern
({'_','_','_'},false,[local]), erlang:trace_pattern( {'_','_','_'},f alse,[global]), io:fwrite("**rdbg, ~w msgs
**~n", [length(Out)]), io:fwrite("~p~n", [lists:reverse(Out)]), io:fwrite("~p~n", process_info(self(),
message_queue_len)]); (G,Cnt,Out) -> case process_info(self(),message_queue_len) of {_,N} when N > 100 -exit({rdbg,
msg_queue, N}); _ -> ok end, receive {timeout,_,{die}} ->G(G,0,Out); {trace_ts,Pid,send,Msg,To,TS} ->G(G,Cnt-1,
[{send,Ts(TS), Pi(To),Msg}|Out]); {trace_ts,Pid,'receive',Msg,TS} ->G(G,Cnt-1,[{'receive',Ts(TS),Msg}|Out]);
{trace_ts,Pid,return_from, MFA,V,TS} ->G(G,Cnt-1,[{return,MFA,V}|Out]); {trace_ts,Pid,call,MFA,B,TS} whenbinary(B) ->
G(G,Cnt-1,[{Pi(Pid),Ts(TS), {Stack(B),MFA}}|Out]);{trace_ts,Pid,call,MFA,TS} -> G(G,Cnt-1,[{Pi(Pid),Ts(TS),MFA}|Out])
end end, Rdbg = fun(Time,Msgs,Proc, Trc) when integer(Time),integer(Msgs) -> Start = fun() ->InitFun(Time,Proc,Trc),
LoopFun(LoopFun,Msgs,[]) end, erlang:spawn_link(Start) end.
```

the outcome

I killed the switch.
Many angry Germans.
Luckily, they couldn't phone and complain.

Turned out to be a hardware error.

the other outcome

tracing is insanely powerful...

...but using it is way too complicated.

what about dbg then?

`dbg` is an OTP layer on top of the trace BIFs.

It's still way too complicated.

And unsafe.

redbug

```
redbug:start(Trc,Opts).
```

```
Trc: list('send'|'receive'|string(RTP))
```

where RTP is like

```
"lists:append(X,X)when hd(X)<3"
```

instead of the MFA,match spec

```
{lists,append,'_'},
[{['$1','$1'],[{'<',{hd,'$1'},3}],[]}]
```

redbug - guards

```
10> redbug:start("lists:append(X,X)when hd(X)<3").
{30,1}
11> lists:append([3],[4]).
[3,4]
12> lists:append([3],[3]).
[3,3]
13> lists:append([2],[2]).
[2,2]
00:41:31 <{erlang,apply,2}> {lists,append,[[2],[2]]}
redbug done, timeout - 1
```

redbug - stack

```
14> redbug:start("lists:append(X,X)when hd(X)<3->stack").
{30,1}
15> lists:append([2],[2]).
[2,2]
00:44:58 <{erlang,apply,2}> {lists,append,[[2],[2]]}
  shell:eval_loop/3
  shell:eval_exprs/7
  shell:exprs/7
```

redbug - return

```
16> redbug:start("lists:append(X,X)when hd(X)<3->return").
{30,1}
17> lists:append([2],[2]).
[2,2]

00:46:03 <{erlang,apply,2}> {lists,append,[[2],[2]]}

00:46:03 <{erlang,apply,2}> {lists,append,2} -> [2,2]
```

redbug trace patterns

```
RTP:  restricted trace pattern

  the RTP has the form: "<mfa> when <guards> -> <actions>"
  where <mfa> can be;
  "mod", "mod:fun", "mod:fun/3" or "mod:fun('_',atom,X)"
  <guard> is something like;
  "X==1" or "is_atom(A)"
  and <action> is;
  "return" and/or "stack" (separated by ";")
```

redbug opts I

```
Opts: list({Opt,Val})

  general opts:
time          (15000)    stop trace after this many ms
msgs          (10)       stop trace after this many msgs
proc          (all)      (list of) Erlang process(es)
                         all|pid()|atom(RegName)|{pid,I2,I3}
target        (node())   node to trace on
```

redbug opts II

```
Opts: list({Opt,Val})

  print-related opts
arity        (false)    print arity instead of arg list
max_queue    (5000)    fail if internal queue gets this long
max_msg_size (50000)      fail if seeing a msg this big
buffered     (no)         buffer messages till end of trace
print_form   ("~s~n")     print msgs using this format
print_file  (standard_io) print to this file
print_re     ("")         print only strings that match this
```

redbug opts III

```
Opts: list({Opt,Val})

  trc file related opts
file          (none)         use a trc file based on this name
file_size     (1)            size of each trc file
file_count    (8)            number of trc files
```

in conclusion

- Reliability is easier in Erlang than C++
- but it is not automatic - not a silver bullet
- to get high reliability you need testing
- ... and debugging
- debuggability is a core strength of Erlang
- ... especially the call tracing