SIMON THOMPSON

# MAKING IT LAZY: NEVER EVALUATE ANYTHING MORE THAN ONCE

fun

https://github.com/simonjohnthompson/streams

# FUNCTIONS AS DATA

"Functions are first-class citizens"

A function actively represents behaviour of some sort, and we deal with it just like any other kind of data.

Original image: https://www.thishopeanchors.com/single-post/2017/04/06/Rock-Paper-Scissors

# What is a strategy?

Random

Echo

No repeats

Statistical

. . .

# What is a strategy?

We choose what to play,
depending on your last
move, or the history of
all your moves.

# What is a strategy?

```
-type play() :: rock | paper | scissors.

-type strategy() :: fun(([play()]) -> play()).
```

We choose what to play,
depending on your last
move, or the history of
all your moves.

Random

Echo

No repeats

Statistical

...

```
echo([]) ->
      random_play();
echo([X|_Xs]) ->
    X.

beat([]) ->
    random_play();
beat([X|_]) ->
    case X of
    rock -> scissors;
    paper -> rock;
    scissors -> paper
    end.
```

```erlang
% The second argument here is the accumulated input from the player
% Note that this function doesn't cheat: the Response is chosen
% before the Play from the player.

-spec interact(strategy(),[play()]) -> ok.

interact(Strategy,Xs) ->
    Response = Strategy(Xs),
    {ok,[Play|_]} = io:fread('play rock, paper, scissors, stop: ',"~a"),
    case Play of
      stop -> ok;
      _ ->
        Result = result({Play,Response}),
        io:format("Machine plays ~p, result is ~p~n",[Response,Result]),
        interact(Strategy,[Play|Xs])
    end.
```

What is a strategy combinator?

Choose randomly between these strategies.

Apply them all and choose most popular result.

Replay each of these strategies on the history so far and apply the one that's been best so far.

Take home

Toy example

Generality: not just a finite set . . .

Up a level: combining strategies

WORLD RPS SOCIETY

Serving the needs of decision makers since 1918

Game Basics | Advanced RPS | World RPS Store | The World RPS Society | Bull Board | Running a Tournament | Blog

# Worldrps.com has a new look

## Say goodbye to the old cluttered look of the World RPS Society site.

The IT Brigade told us it would take them four weeks to re-do the worldrps.com web site. So after consuming four years, 4 palettes of Mellow Yellow, dozens of crates of Pringles, and surviving a few health scares, the team has done it.


http://worldrps.com

# EVALUATION ON DEMAND

# function evaluation in Erlang

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evaluate the arguments

before the body

```
switch(N,Pos,Neg) ->
    case N>0 of
        true -> Pos;
        _    -> Neg
    end.
```

# function evaluation in Erlang

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```
switch(N,Pos,Neg) ->
    case N>0 of
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    end.
```

fully evaluate the argument

```
sum_first_two([A,B|_Rest])
    -> A+B.
```

but if an argument is a
**function** then it's
passed unevaluated.

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```
fun () -> Stuff end
```

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passed unevaluated.

```
fun () -> Stuff end
```

```
fun () -> Stuff end ()
```

DELAY!

# a lazy switch

```
-spec lswitch(number(),fun(() ->T),fun(() ->T)) -> T.


lswitch(N,Pos,Neg) ->
    case N>0 of
        true -> Pos();
        _    -> Neg()
    end.
```

# a lazy switch

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-spec lswitch(number(),fun(() ->T),fun(() ->T)) -> T.


lswitch(N,Pos,Neg) ->
    case N>0 of
        true -> Pos();
        _    -> Neg()
    end.
```

```
lex1() -> lswitch(1,fun() -> 3+4 end,fun () -> 1/0 end).
```

```erlang
-spec lswitch(number(),fun(() ->T),fun(() ->T)) -> T.


lswitch(N,Pos,Neg) ->
    case N>0 of
        true -> Pos();
        _    -> Neg()
    end.
```

```erlang
-define(switch(N,Pos,Neg),
        lswitch(N,fun() -> Pos end,fun() -> Neg end)).
```

```
-spec lswitch(number(),fun(() ->T),fun(() ->T)) -> T.


lswitch(N,Pos,Neg) ->
    case N>0 of
        true -> Pos();
        _    -> Neg()
    end.
```

```
-define(switch(N,Pos,Neg),
        lswitch(N,fun() -> Pos end,fun() -> Neg end)).
```

```
lex2() -> ?switch(1,3+4,1/0).
```

# STREAMS

Original image: http://www.metso.com/services/spare-wear-parts-conveyors/conveyor-belts/

# streams

## build

```
cons(X,Xs) ->
  fun() -> {X,Xs} end.
```

# streams

## build

```
cons(X,Xs) ->
  fun() -> {X,Xs} end.
```

## deconstruct

```
head(L) ->
  case (L()) of
    {H,_} -> H
  end.

tail(L) ->
  case (L()) of
    {_,T} -> T
  end.
```

# streams

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```
-define(cons(X,Xs),
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```
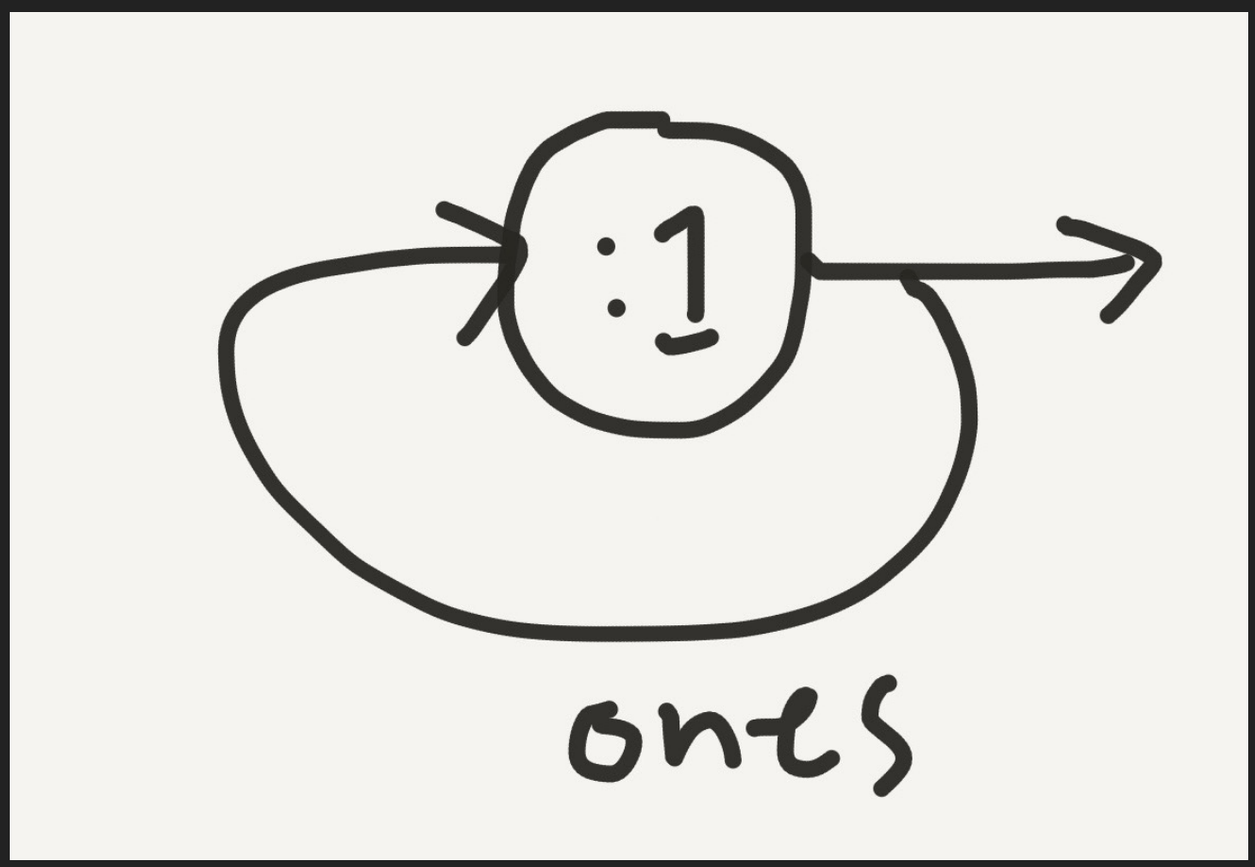

```
ones() ->
  ?cons(1,ones()).
```

1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, . . .

```
ones() ->
  ?cons(1,ones()).
```



```
ns(N) ->
  ?cons(N,ns(N+1)).
```

42, 43, 44, 45, 46, 47, 48, 49, 50, . . .

2, 3, 5, 7, 11,

13, 17, 19,

23, 29, 31,

37, 41, 43,

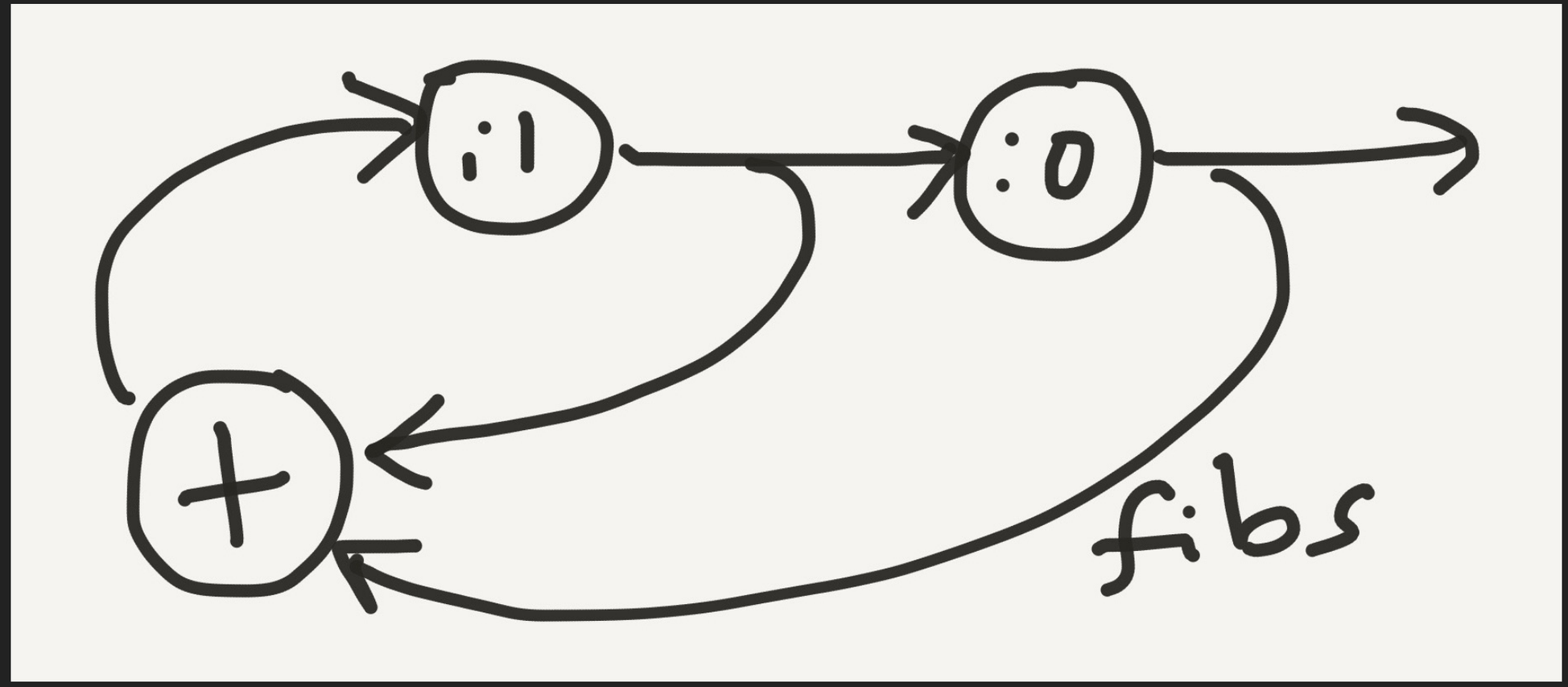
47, ...

```
primes() -> sieve(ns(2)).

sieve(Ns) ->
  H = head(Ns),
  ?cons(H,sieve(cut(H,tail(Ns)))).

cut(N,Ns) ->
  H = head(Ns),
  case H rem N of
    0 ->          cut(N,tail(Ns));
    _ -> ?cons(H,cut(N,tail(Ns)))
  end.
```

```
fibs() ->
  ?cons(0,
    ?cons(1,
      addZip(fibs(),tail(fibs())))).

addZip(Xs,Ys) ->
   ?cons(head(Xs)+head(Ys), addZip(tail(Xs),tail(Ys))).
```

0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, . . .

```
fibs() ->
  ?cons(0,
    ?cons(1,
      addZip(fibs(),tail(fibs())))).

addZip(Xs,Ys) ->
   ?cons(head(Xs)+head(Ys), addZip(tail(Xs),tail(Ys))).
```



demo

# Take home

"infinite" streams

apparently circular

repeated re-computation

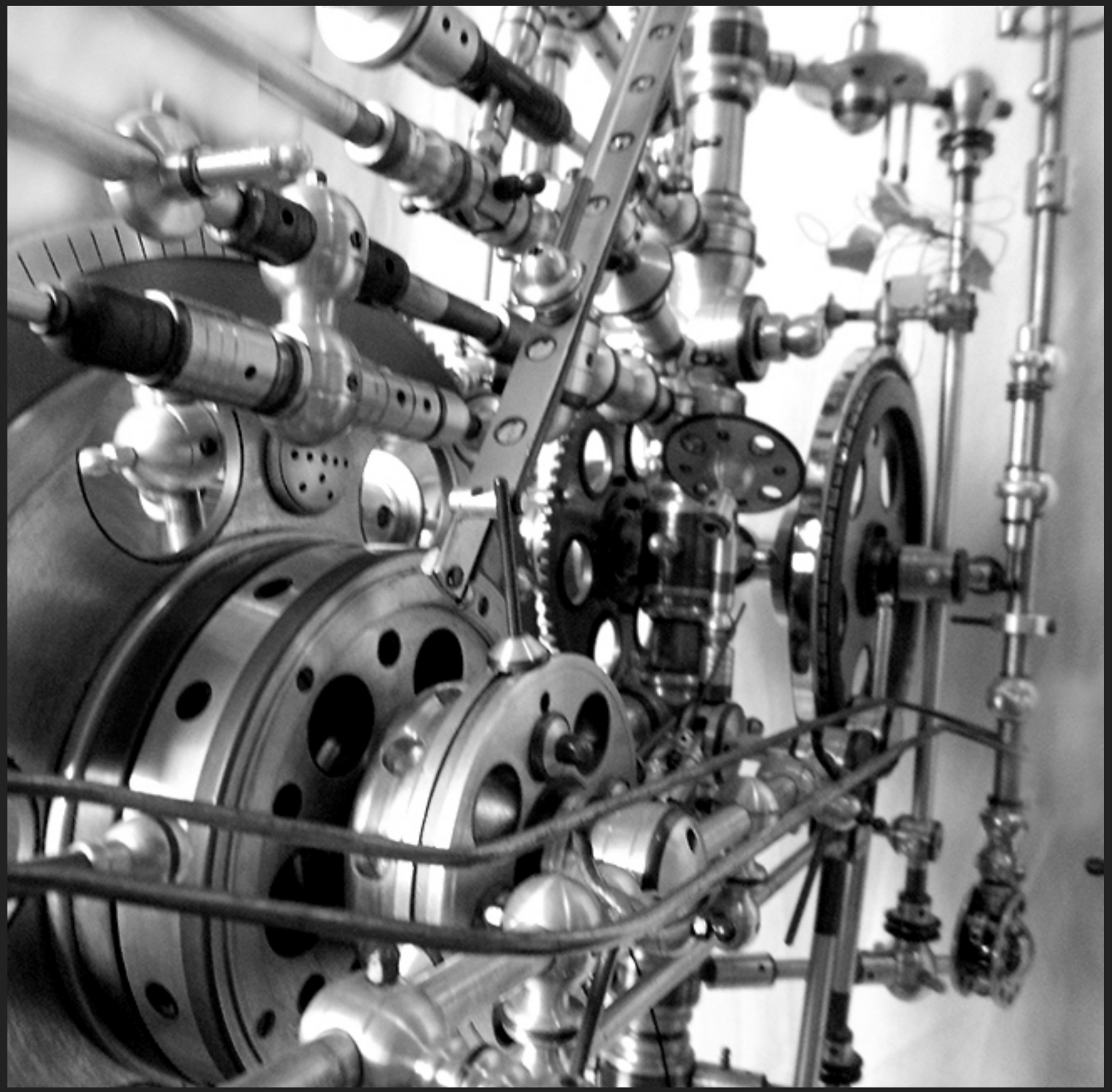
# LAZY EVALUATION

ensure that each argument is
evaluated at most once

ensure that each argument is evaluated at most once

we must ensure that results are memoised in some way

but isn't that a job for the compiler?



# key idea

we explicitly manage how
results are stored once evaluated

use an ETS table to keep track
of evaluated results, or . . .

. . . model the store functionally,
thread it through the calculations

# MEMOISATION

# use ETS for general memoisation

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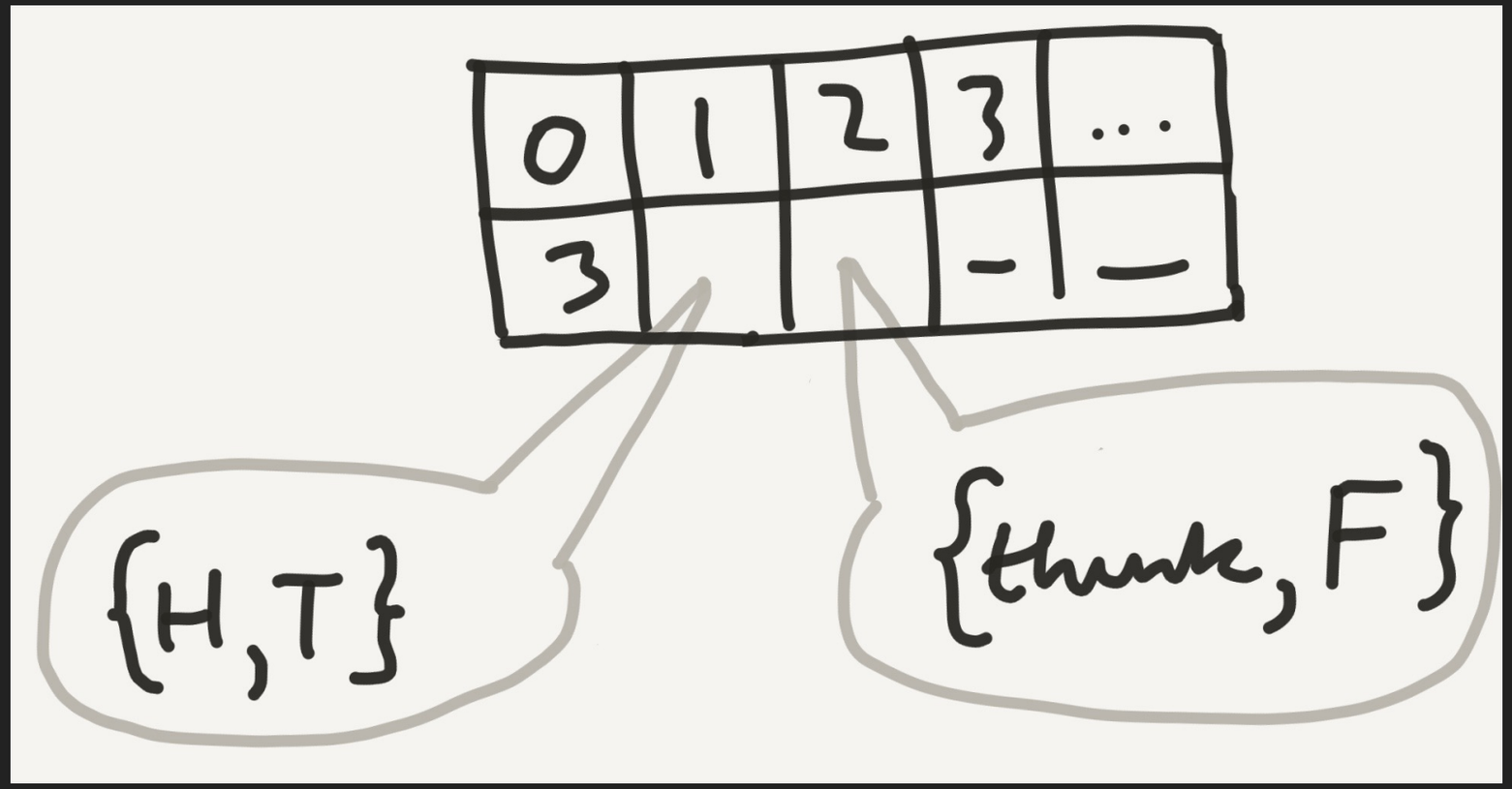
```
fib(0) -> 0;
fib(1) -> 1;
fib(N) -> fib(N-1) + fib(N-2).
```

```
fib(0) -> 0;
fib(1) -> 1;
fib(N) -> fib(N-1) + fib(N-2).
```

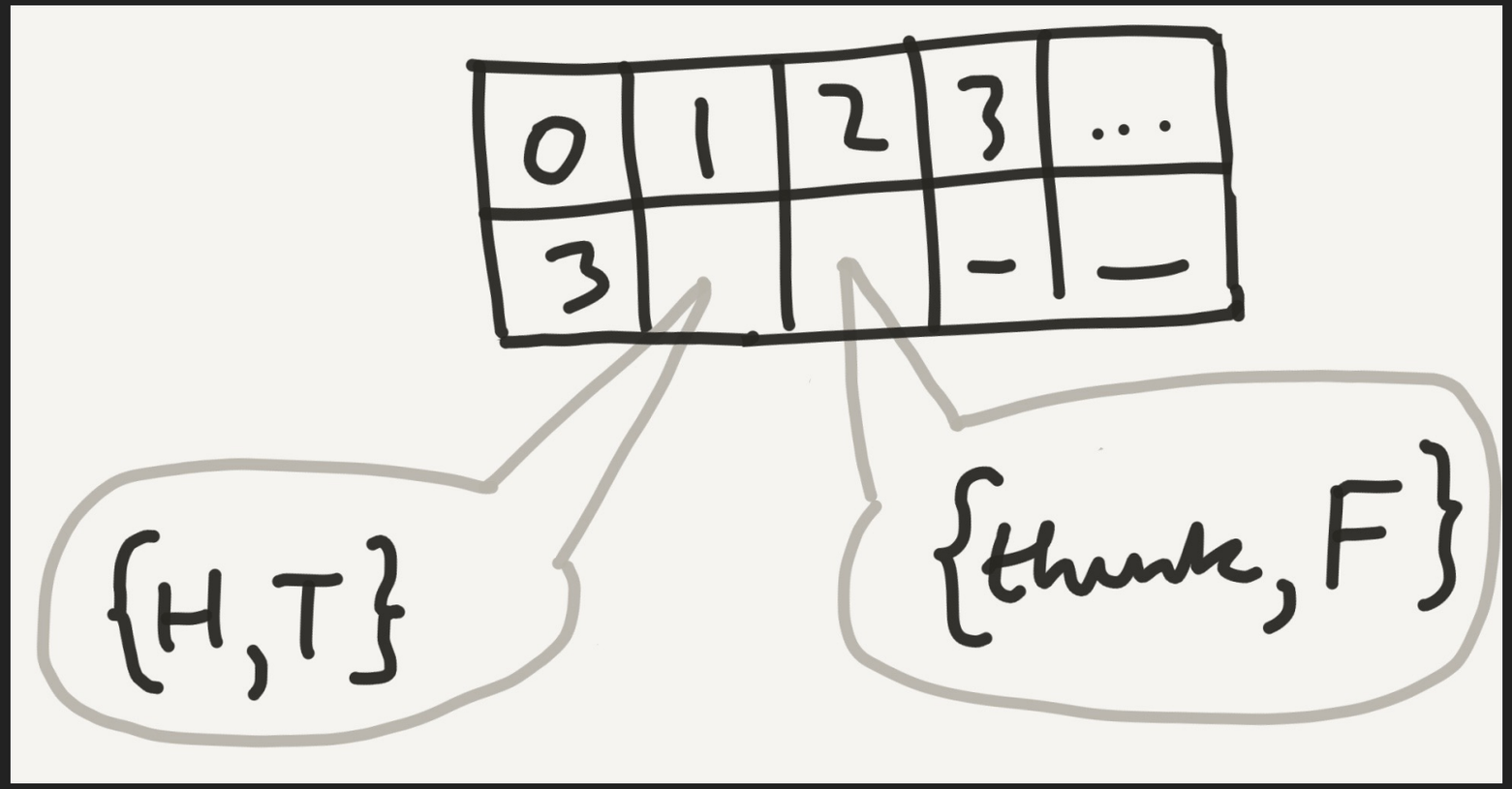
```
fibM(0) -> 0;
fibM(1) -> 1;
fibM(N) ->
    case ets:lookup(tab,N) of
        [] -> V = fibM(N-1) + fibM(N-2),
              ets:insert(tab,{N,V}),
              V;
        [{N,V}] -> V
    end.
```

# USING ETS TABLES

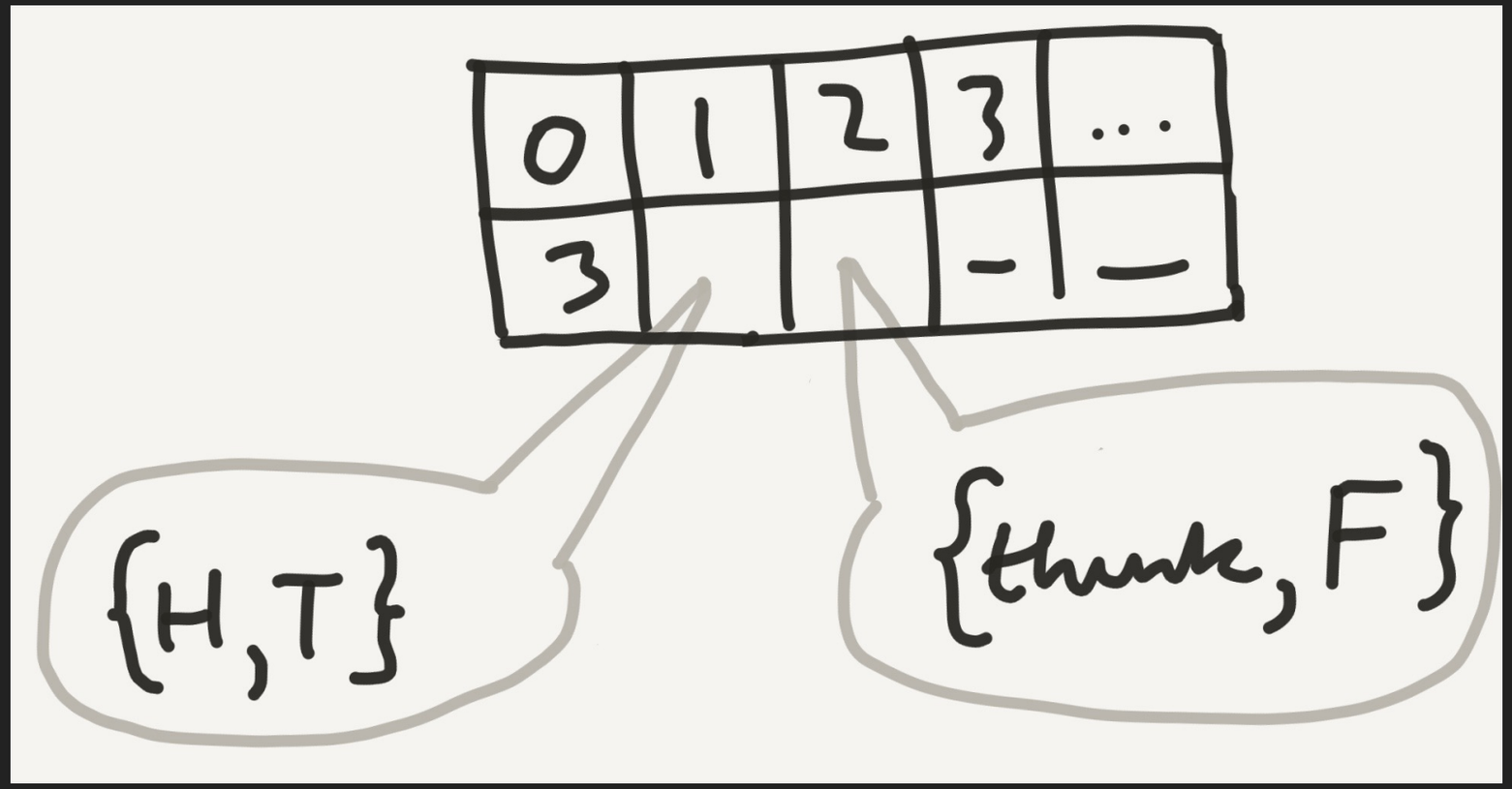
store either the head and tail,
or a “thunk” to be evaluated



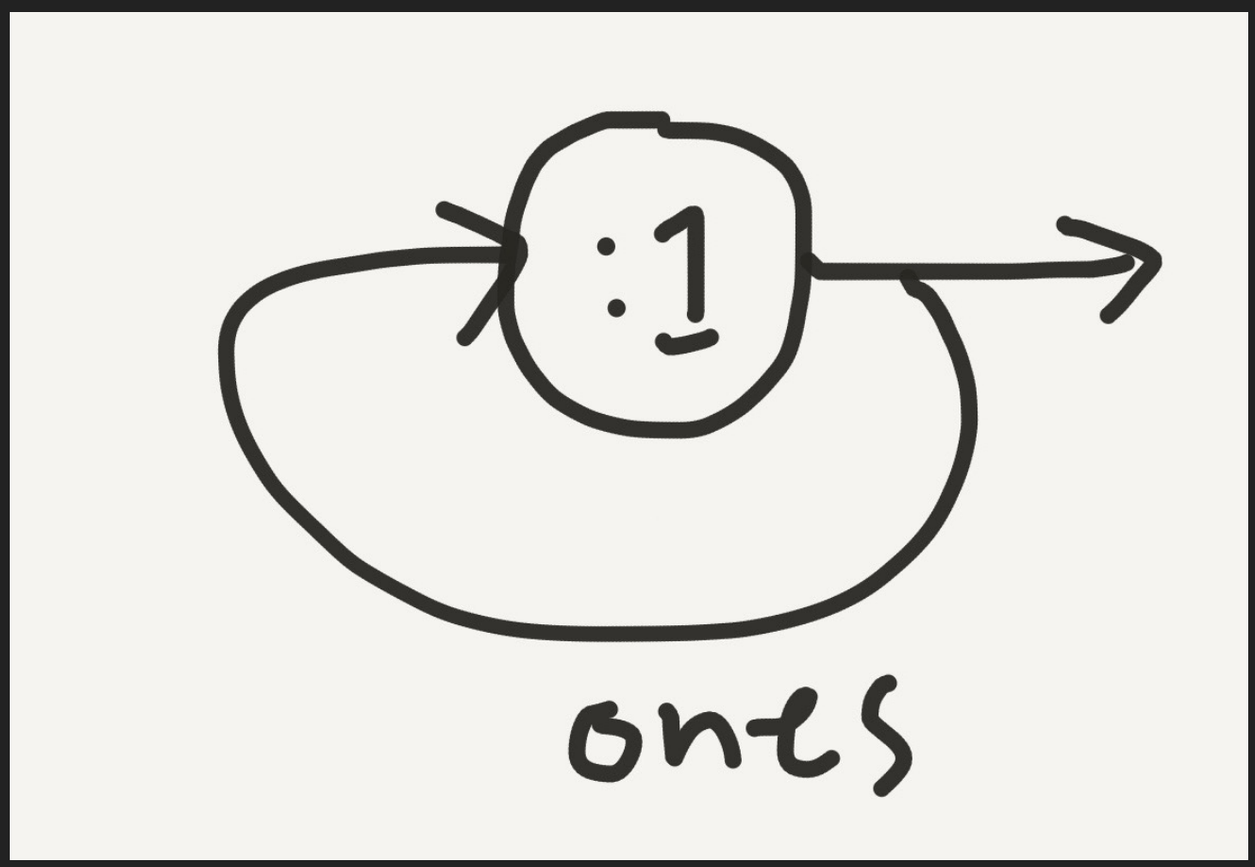
```erlang
-define(cons(X,Xs), begin ets:insert(tab,{0,next_ref()+1}) ,
                          ets:insert(tab, {next_ref(),
                                           {thunk, fun () -> {X,Xs} end}}),
                          % io:format("done cons insert~n"),
                          {ref,next_ref()} end).
```



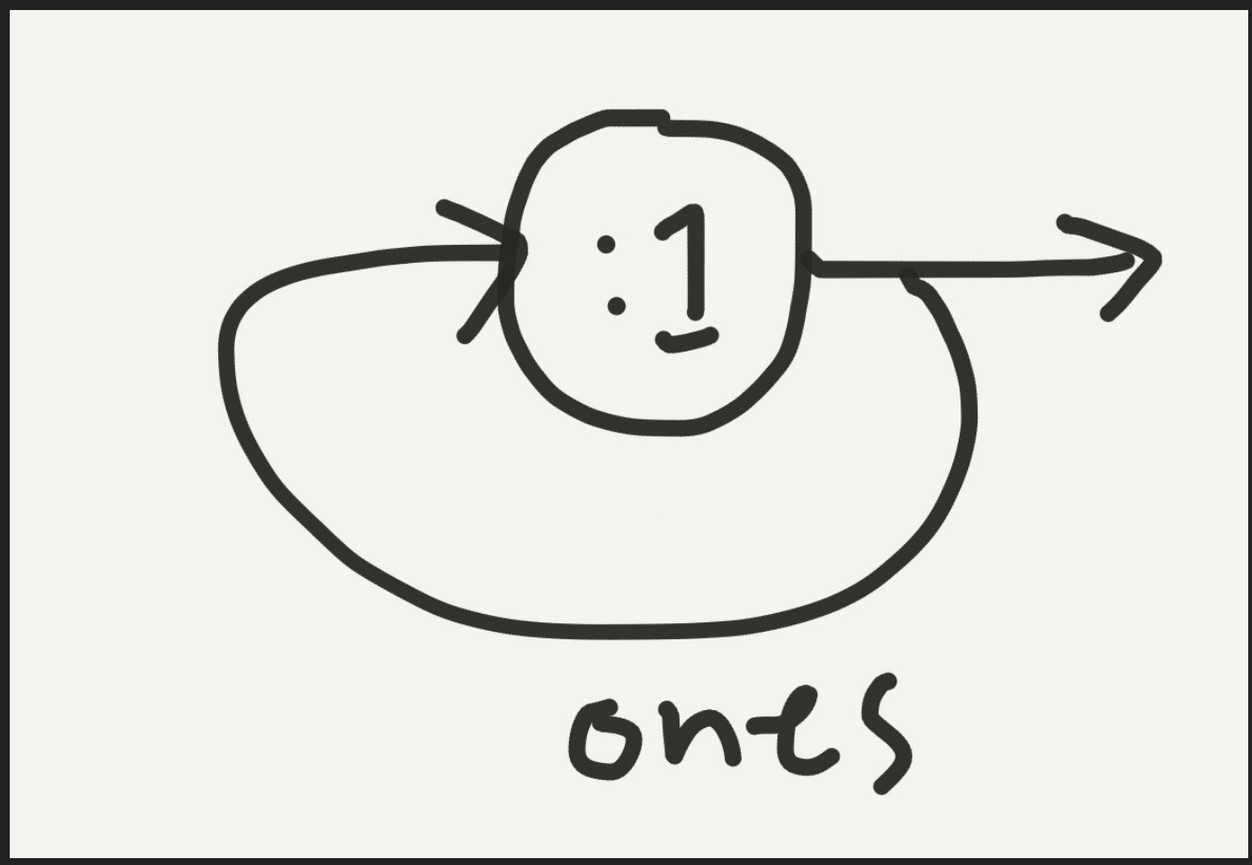
```erlang
head({ref,Ref}) ->
 case ets:lookup(tab,Ref) of
    [{Ref,{thunk,F}}] -> Val = F(),
                         ets:insert(tab,{Ref,Val}),
                         {H,_} = Val,
                          H;
    [{Ref,{H,_}}]     ->  H
  end.
```



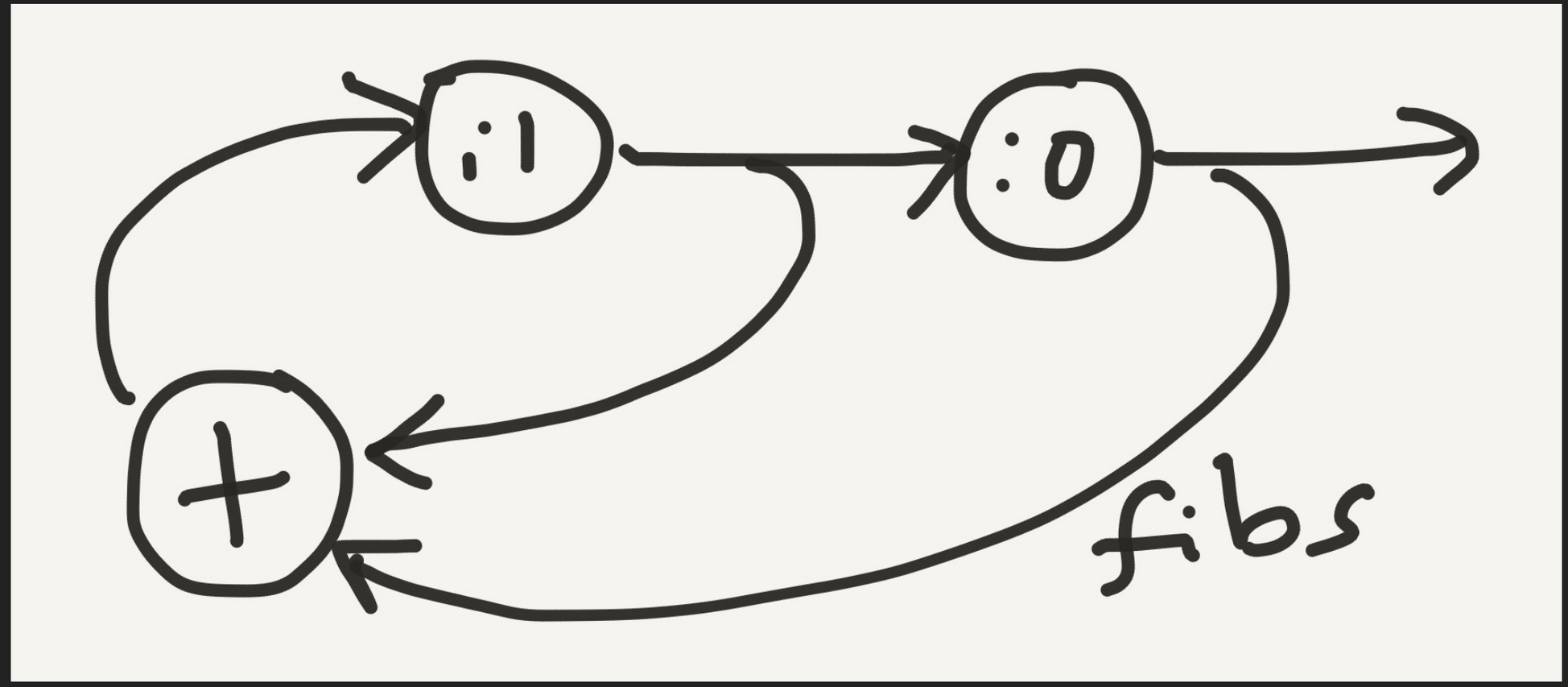
```
ones() ->
  ?cons(1,ones()).
```



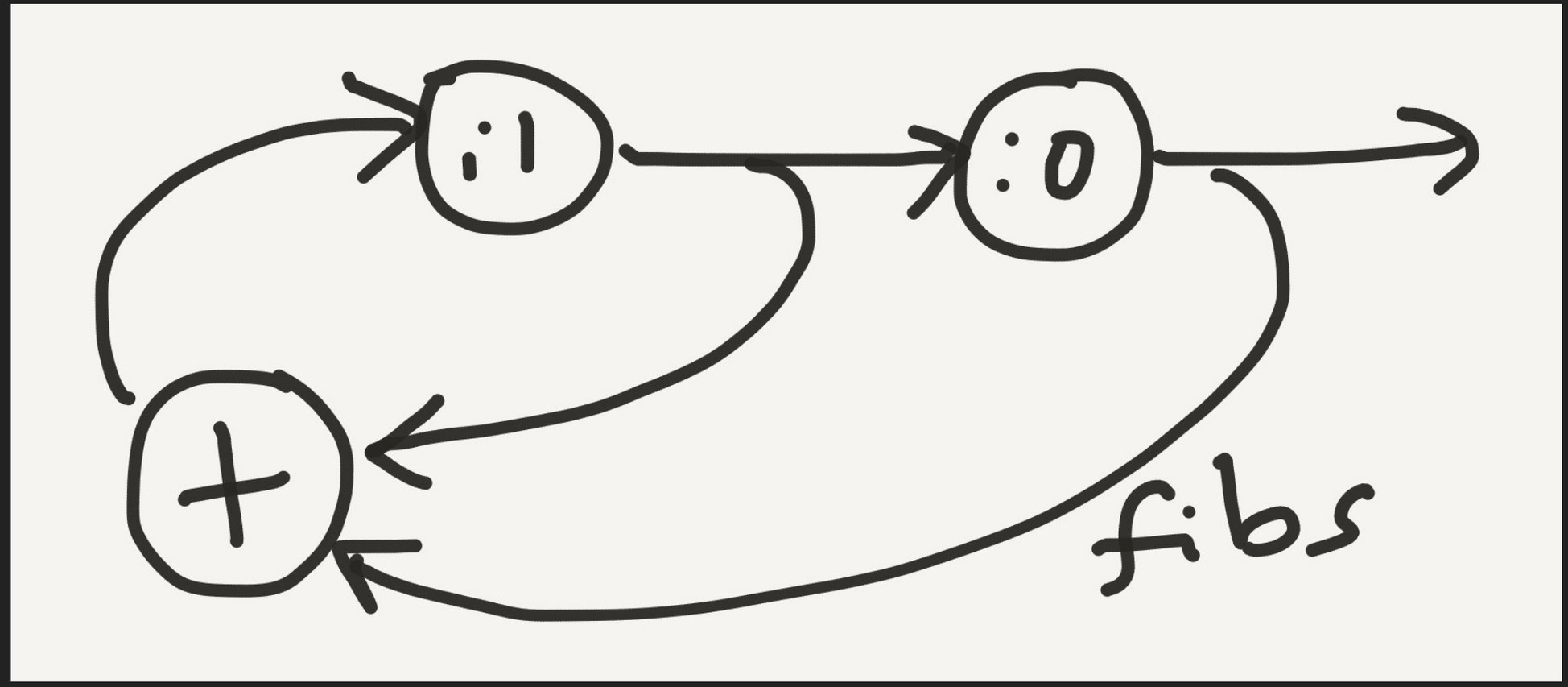
```erlang
onesC() ->
  This = next_ref()+1,
  ?cons(1,{ref,This}).
```



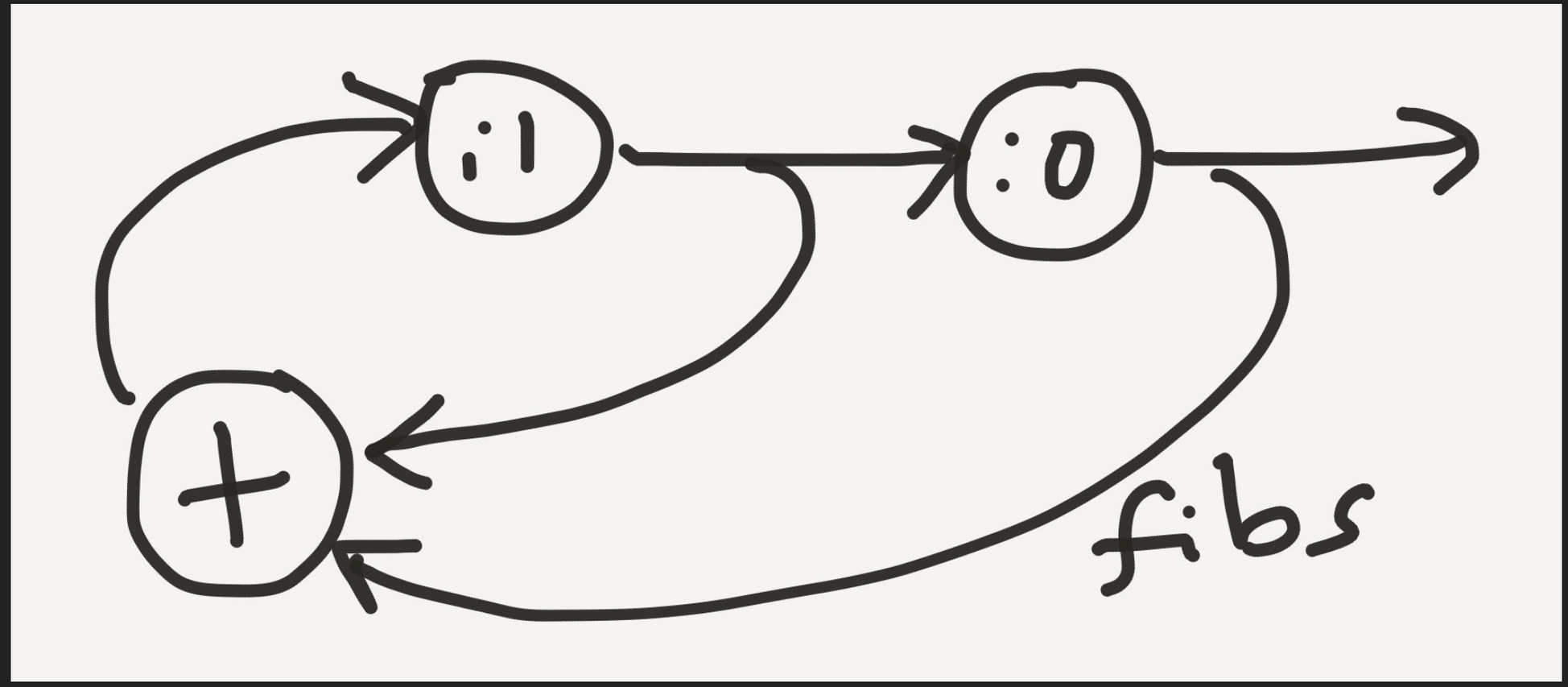
```
fibs() ->
  ?cons(0,
    ?cons(1,
      addZip(fibs(),tail(fibs())))).

addZip(Xs,Ys) ->
   ?cons(head(Xs)+head(Ys), addZip(tail(Xs),tail(Ys))).
```



```
fibs() ->
  ?cons(0,
    ?cons(1,
      addZip(fibs(),tail(fibs()))))
```



```
fibsCVar() ->
  This = next_ref()+1,
  ?cons(0,
    ?cons(1,
      addZip({ref,This},tail({ref,This})))).
```



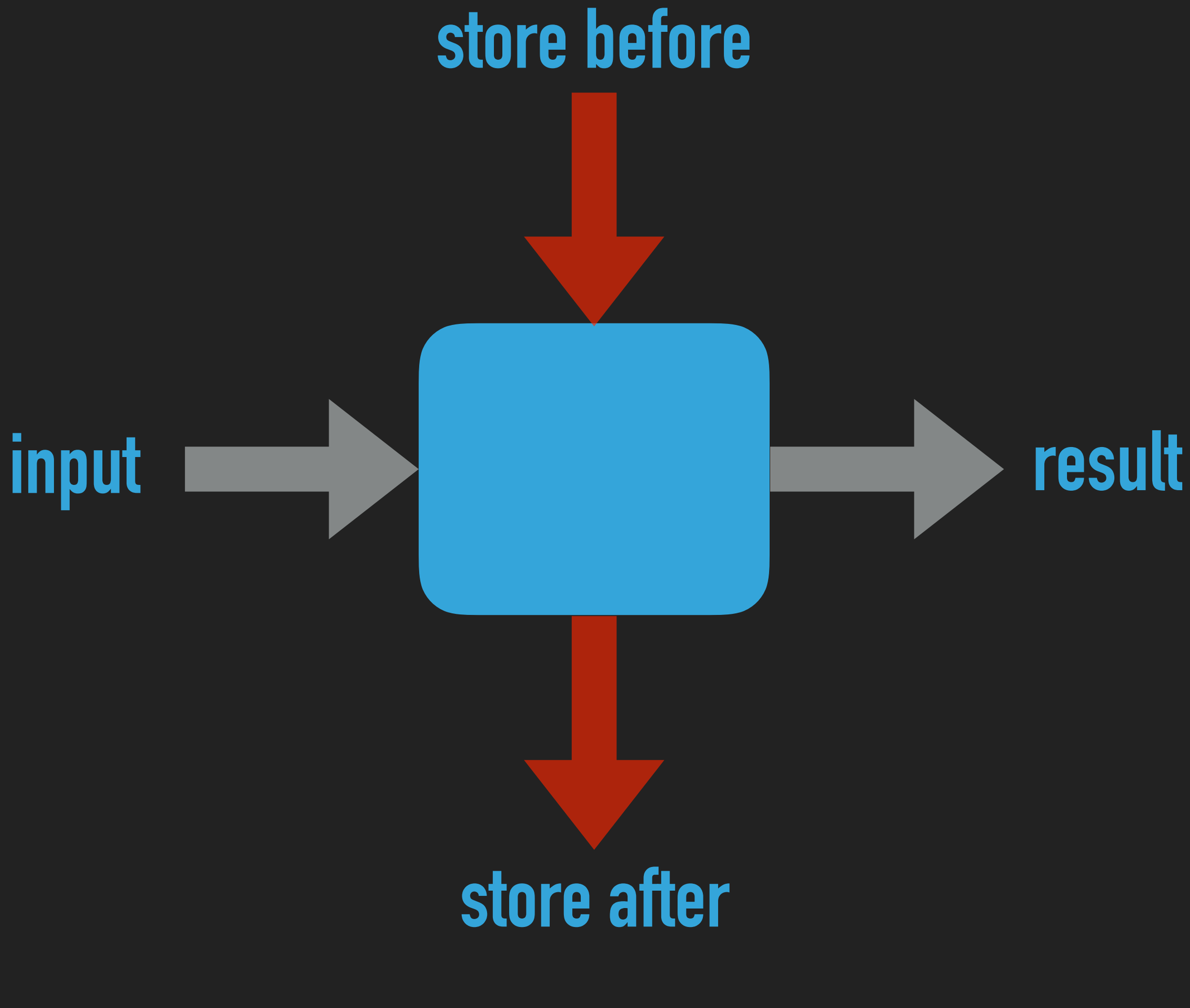
Explicitly managed refs

Simulates full lazy implementation

Uses impure features . . .

. . . but a smooth transition

# AN EXPLICIT STORE


store before
input
result
store after

# Printing out the first N values

```
ss(_Xs,0,_T) ->
  io:format("~n");

ss(Xs,N,Sto) ->
  io:format("~w, ",[head(Xs,Sto)]),
  {T,Sto1} = tail(Xs,Sto),
  ss(T,N-1,Sto1).
```

Node to {Head, {thunk, Tail}}

Thunk takes state as argument . . .

. . . so that the suspended computation can be evaluated in the context of the current state.

# Construct a list

```
-define(cons(X,F,Sto),
        begin {{ref,next_ref(Sto)},
               Sto#{next_ref(Sto) => {X, {thunk, F}},
                    0 => next_ref(Sto)+1}}
        end).
```

```
tail({ref,Ref},Sto) ->
  case maps:get(Ref,Sto) of
    {ref,R}     ->
                  Hd = head({ref,R}, Sto),
                  {Tl,Sto1} = tail({ref,R},Sto),
                  Sto2 = Sto1#{Ref => {Hd,Tl}},
                  {Tl,Sto2};
    {Hd,{thunk,F}} ->
                  {Tl,StoC} = F(Sto),
                  Sto1 = StoC#{Ref => {Hd,Tl}},
                  {Tl,Sto1};
    {_,T} ->
                  {T,Sto}
  end.
```

# Fibonacci numbers

```
fibsC(Sto) ->
  This = next_ref(Sto),
  ?cons(0, fun(T) ->
             ?cons(1, fun(S) ->
                        begin
                        {Tl,S1} = tail({ref,This},S),
                        addZip({ref,This},Tl,S1)
                        end
                      end,
                   T)
           end,
        Sto).
```

# TO CONCLUDE

functions are flexible and
powerful modelling tool

strategies

simulations

suspensions

pure modelling of effects
is not straightforward

monads, monad transformers,
effects, . . . provide some
useful patterns

reify?

can model DSLs of strategies,
parsers, and write interpreters
for these DSLs into the
functions we've seen here

data and types

all the data we used here was

well understood 30 years ago

it is just that the types have changed

https://github.com/simonjohnthompson/streams

fun