SIMON THOMPSON

ERLANG: THE POWER OF FUNCTIONAL PROGRAMMING

Erlang is a concurrent, fault-tolerant, robust, distributed programming language …

… that is based on the paradigm of functional programming.

FUNCTIONAL ERLANG

pattern matching

recursion

```
isPath(_Maze,[]) ->
  true;
isPath(Maze,[P]) ->
  inGrid(Maze,P);
isPath(Maze,[P1,P2|Ps]) ->
    inGrid(Maze,P1) andalso
    isEmpty(Maze,P1) andalso
    adjacent(P1,P2) andalso
    isPath(Maze,[P2|Ps]).
```

do-it-yourself data types

```
area({circle,_,R}) ->
  math:pi()*R*R;
area({tri,_,A,B,C}) ->
  S = (A+B+C)/2,
  math:sqrt(S*(S-A)*(S-B)*(S-C)).
```

immutable variables

tail recursion

```
echo(Pid,N) ->
  receive
    Msg -> Pid!Msg
  end,
  echo(Pid,N+1).
```

standard HOFs

```
PossPoints = lists:filter( fun (X) ->
                               not lists:member(X,Avoid) end,adjPoints(Maze,P1)),
lists:concat(lists:map(fun (P)->
    [ [P1|Path] || Path <- allPaths(Maze,P,P2,[P1|Avoid]) ] end, PossPoints))
```

list comprehensions

numbers

atoms

tuples

lists

functions

```
2, 2.3, 123456789023456, …

true, 'not true', symbol, …

{circle,{2.0,3.0},4.3}, …

[2,3,4, … ], [2,3|[4, …]], …

fun(F) ->
    fun(Y) -> F(2*Y) - F(Y) end
end
```

“the influence is clear”

4.13 Influence from functional programming

By now the influence of functional programming on Erlang was clear. What started as the addition of concurrency to a logic language ended with us removing virtually all traces of Prolog from the language and adding many well-known features from functional languages.

Higher-order functions and list comprehensions were added to the language. The only remaining signs of the Prolog heritage lie in the syntax for atoms and variables, the scoping rules for variables and the dynamic type system.

http://webcem01.cem.itesm.mx:8005/erlang/cd/downloads/hopl_erlang.pdf fun

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 plays() :: [play()].

-type strategy() :: fun((plays()) -> play()).
```

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

Random

Echo

No repeats

Statistical

...

```
random(_) ->
    random_play().


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


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

```erlang
interact(Strategy) ->
    interact(Strategy,[]).

% 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.

interact(Strategy,Xs) ->
    Response = Strategy(Xs),
    {ok,[Play|_]} = io:fread('play one of rock, paper, scissors, or stop: ',"~a"),
    case Play of
    stop -> ok;
    _ ->
        Result = result({Play,Response}),
        io:format("Machine has played ~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.

What is a strategy combinator?

```
-spec vote([strategy()]) -> strategy().
```

Apply them all and choose most popular result.

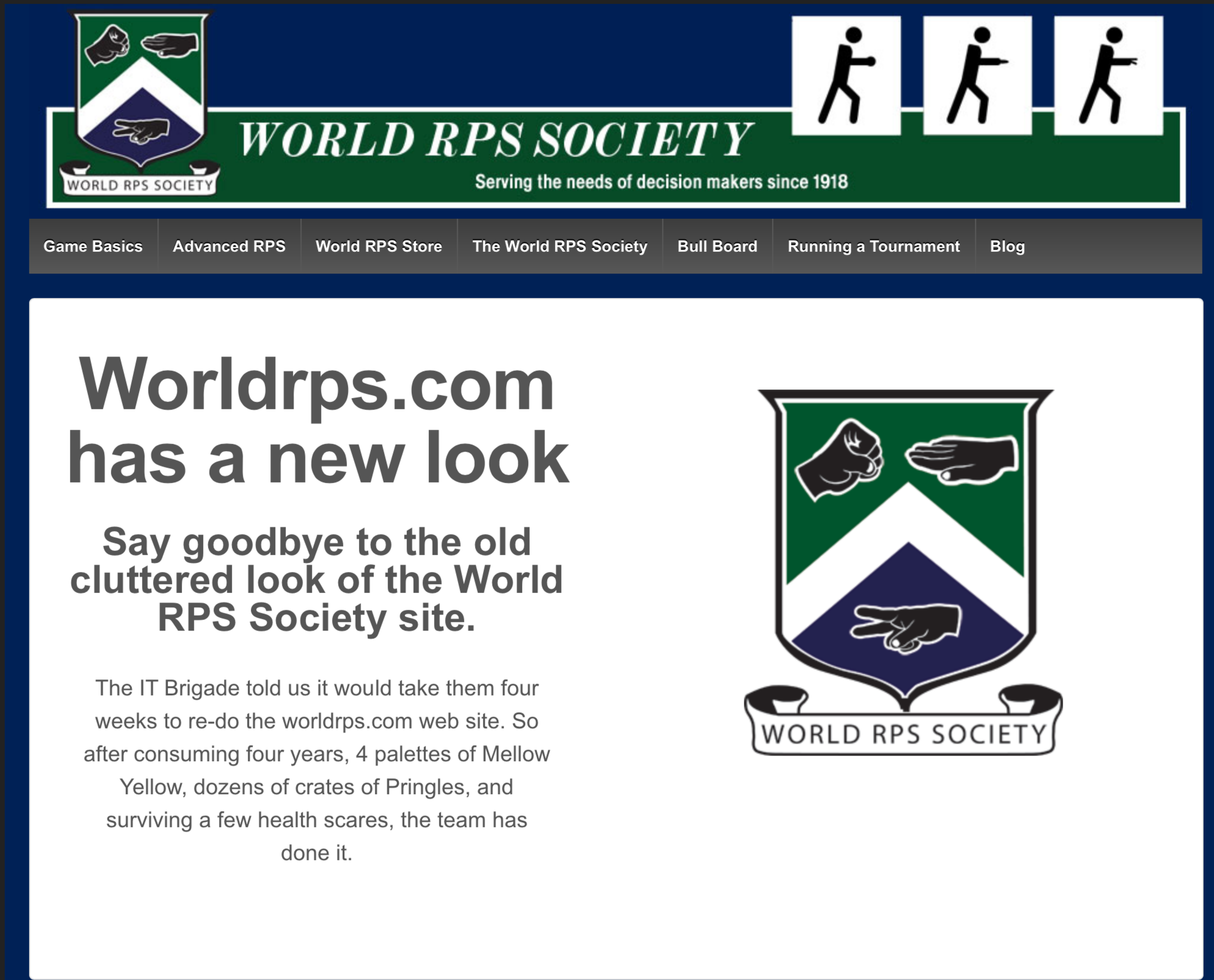
Replay each of these strategies on the history so far and apply the one that's been best so far.

Take home

Toy example

Generality: not just a finite set . . .

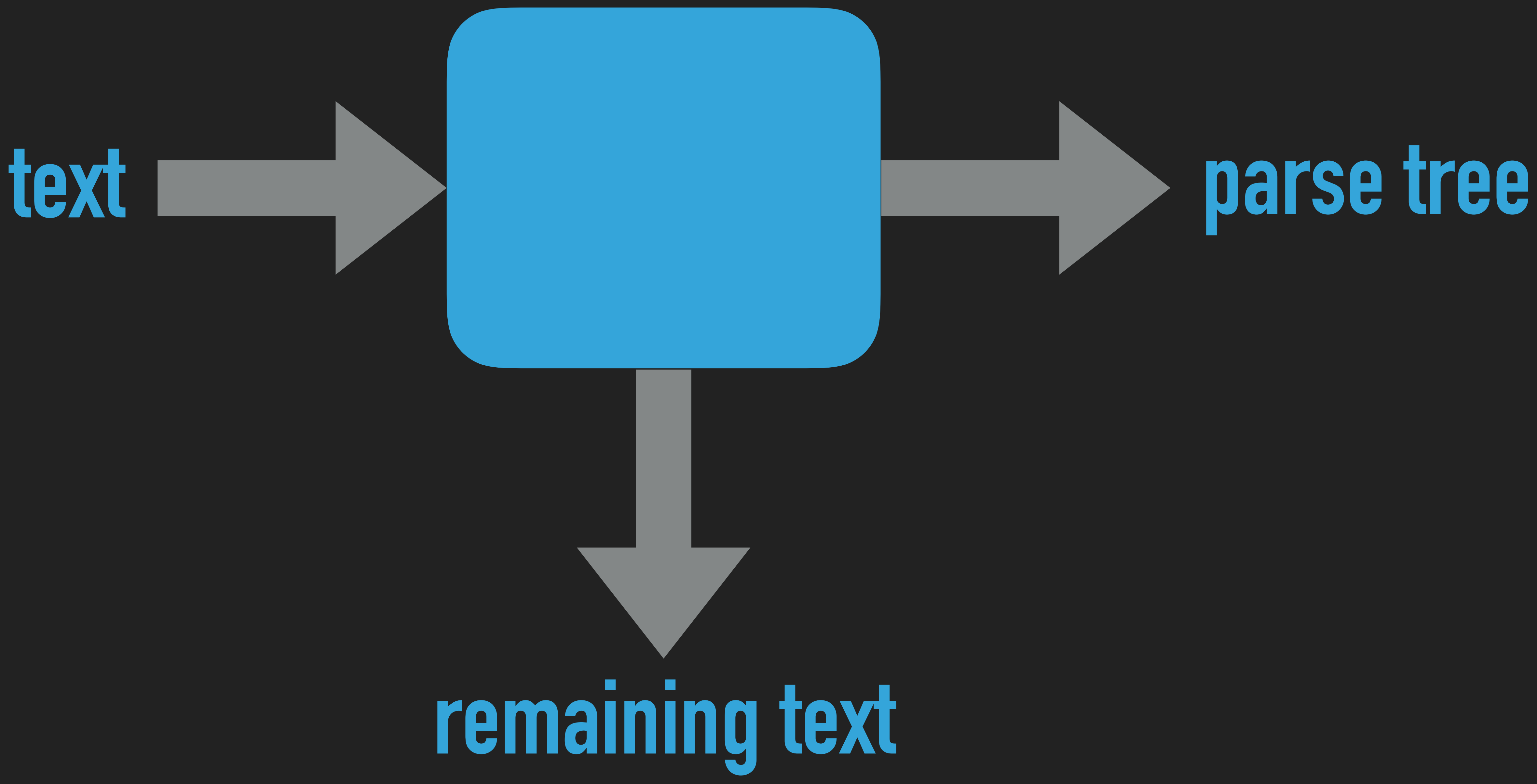
Up a level: combining strategies



http://worldrps.com

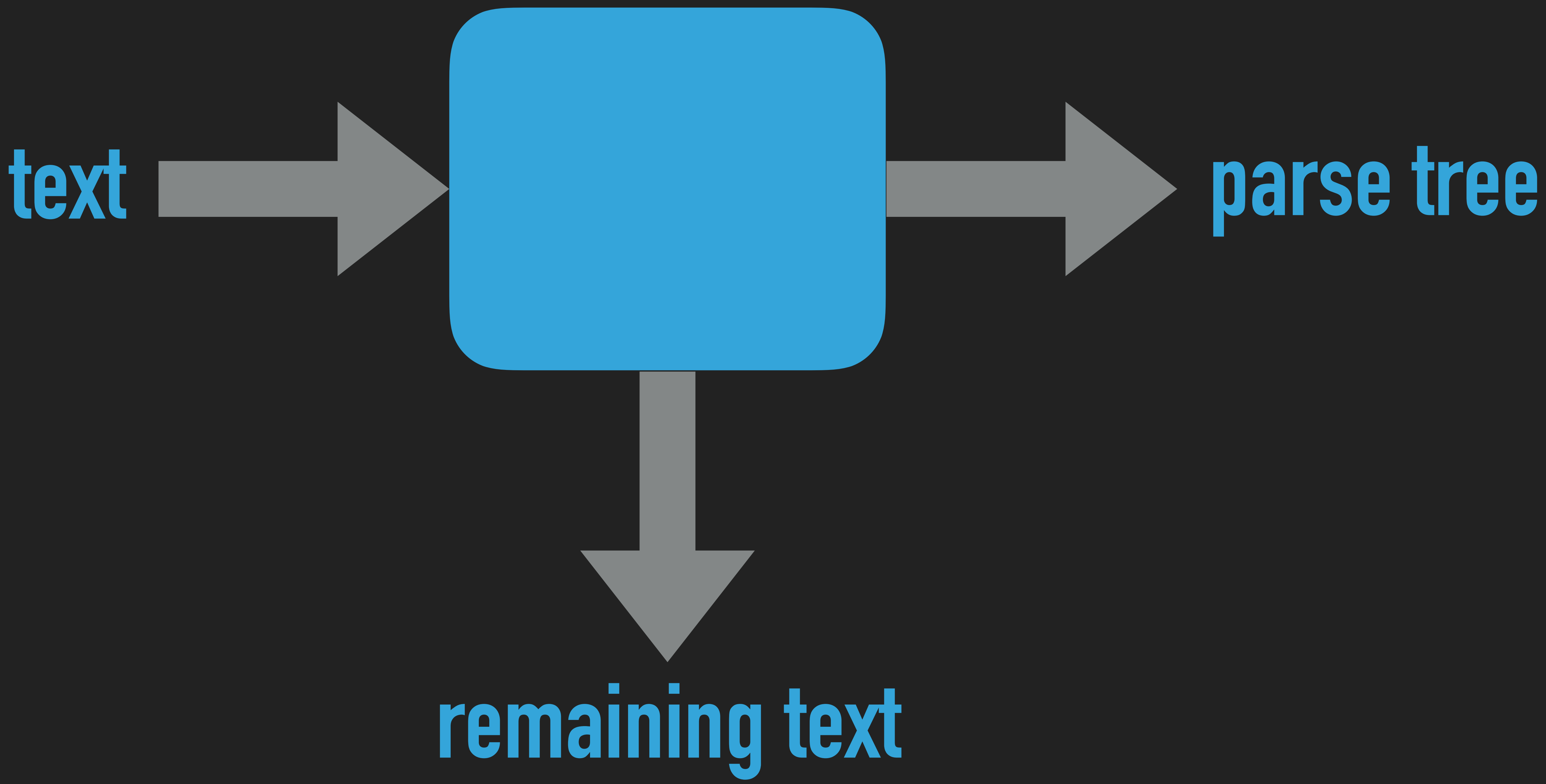
https://github.com/simonjohnthompson/streams

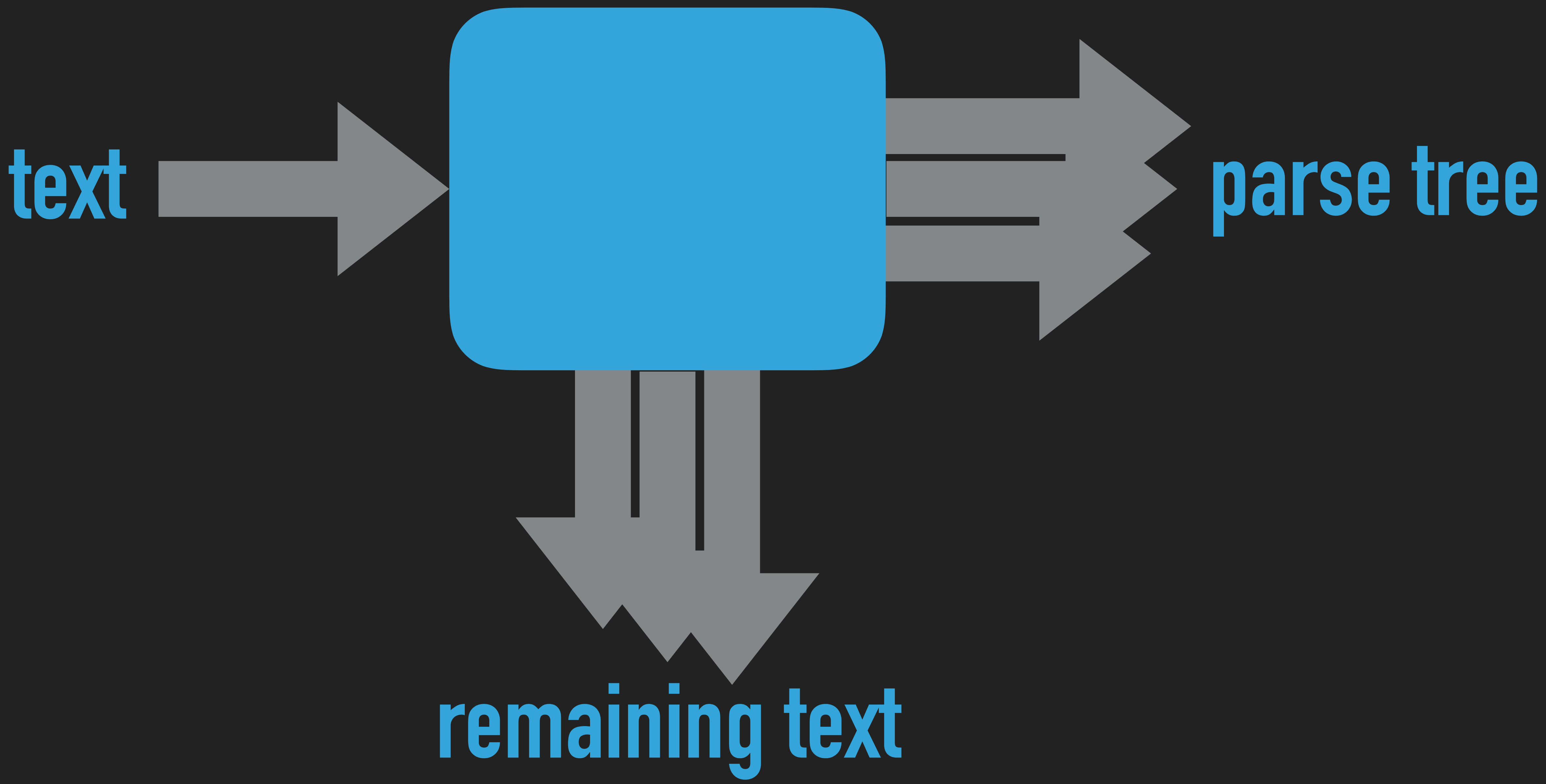
PARSER COMBINATORS


text
parse tree
remaining text

```
-type parser() :: fun((string()) -> {ast(),string()}).

-spec sequence(parser(),parser()) -> parser().
```

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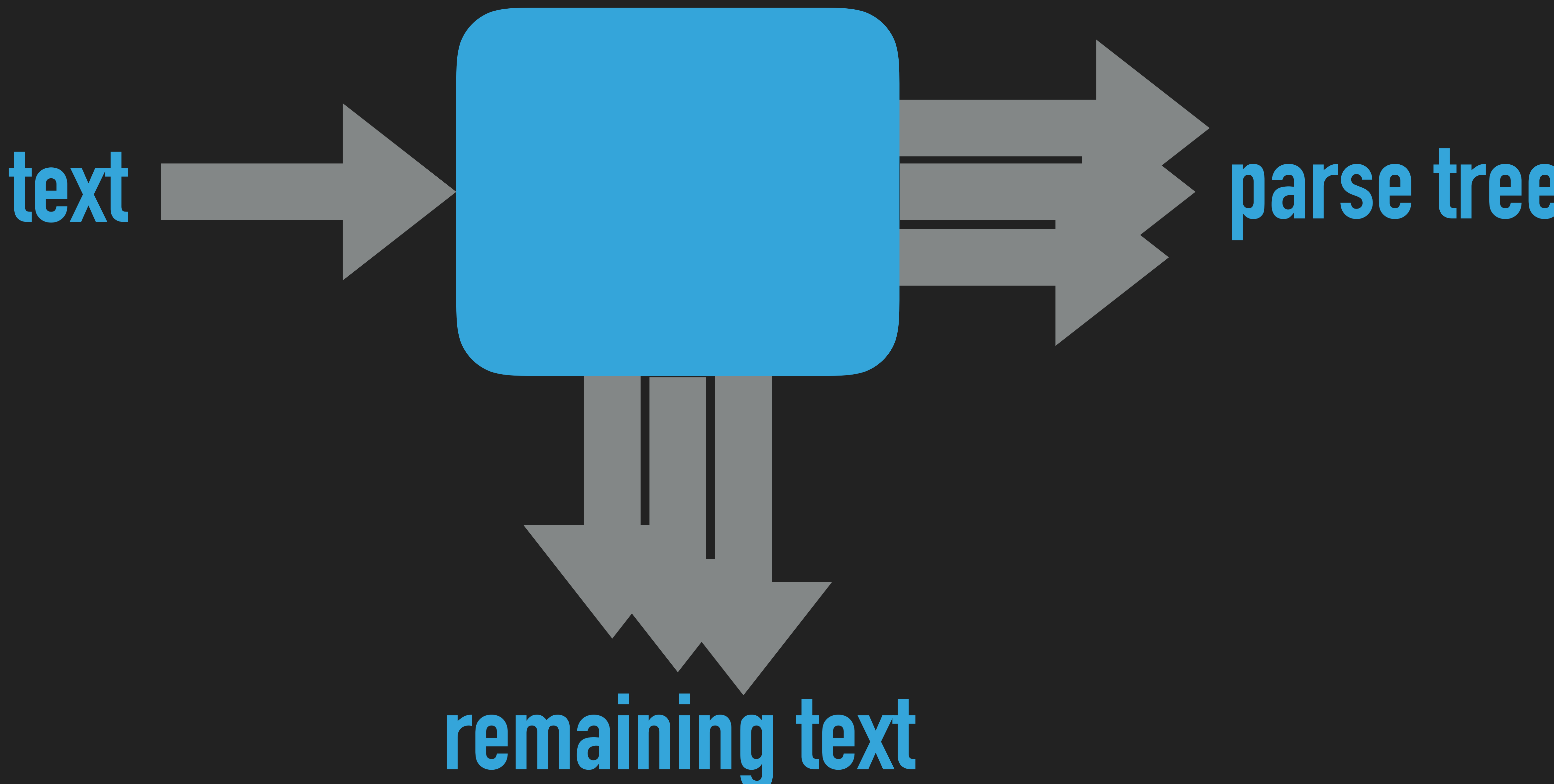


Take home

Real example

Haskell, Scala, OCaml, Elixir, . . .

Hints at a design pattern

but . . .

If all we want is **one** parse,

then we should only

evaluate the list of

possible results

on demand

EVALUATION ON DEMAND

function evaluation in Erlang

function evaluation in Erlang

evaluate the arguments before the body

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

function evaluation in Erlang

evaluate the arguments before the body

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

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

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

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

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

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

STREAMS

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

streams

build

deconstruct

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

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

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

streams

build

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

deconstruct

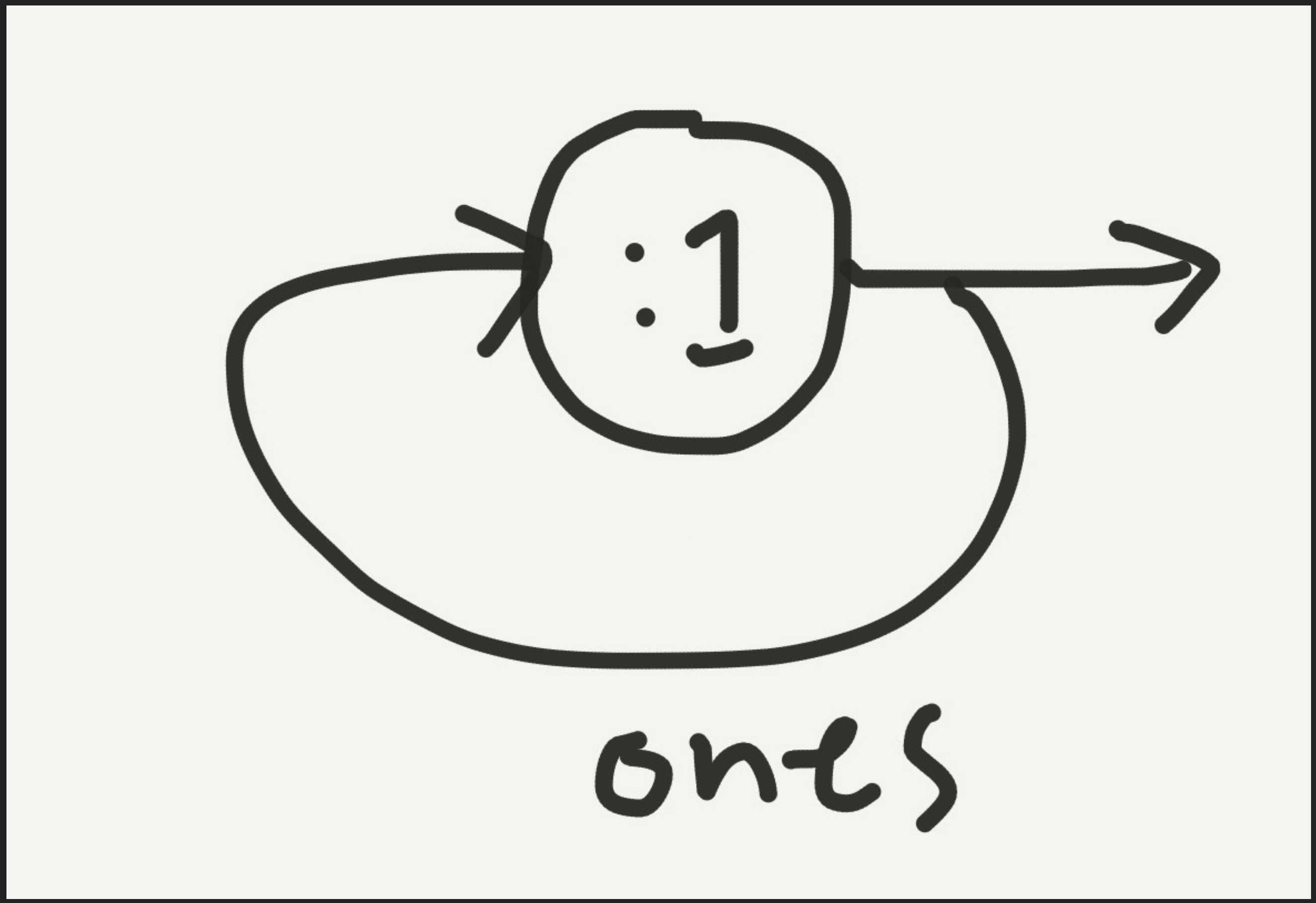
```
head(L) ->
  case (L()) of
    {H,_} -> H
  end.

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

```
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.
```

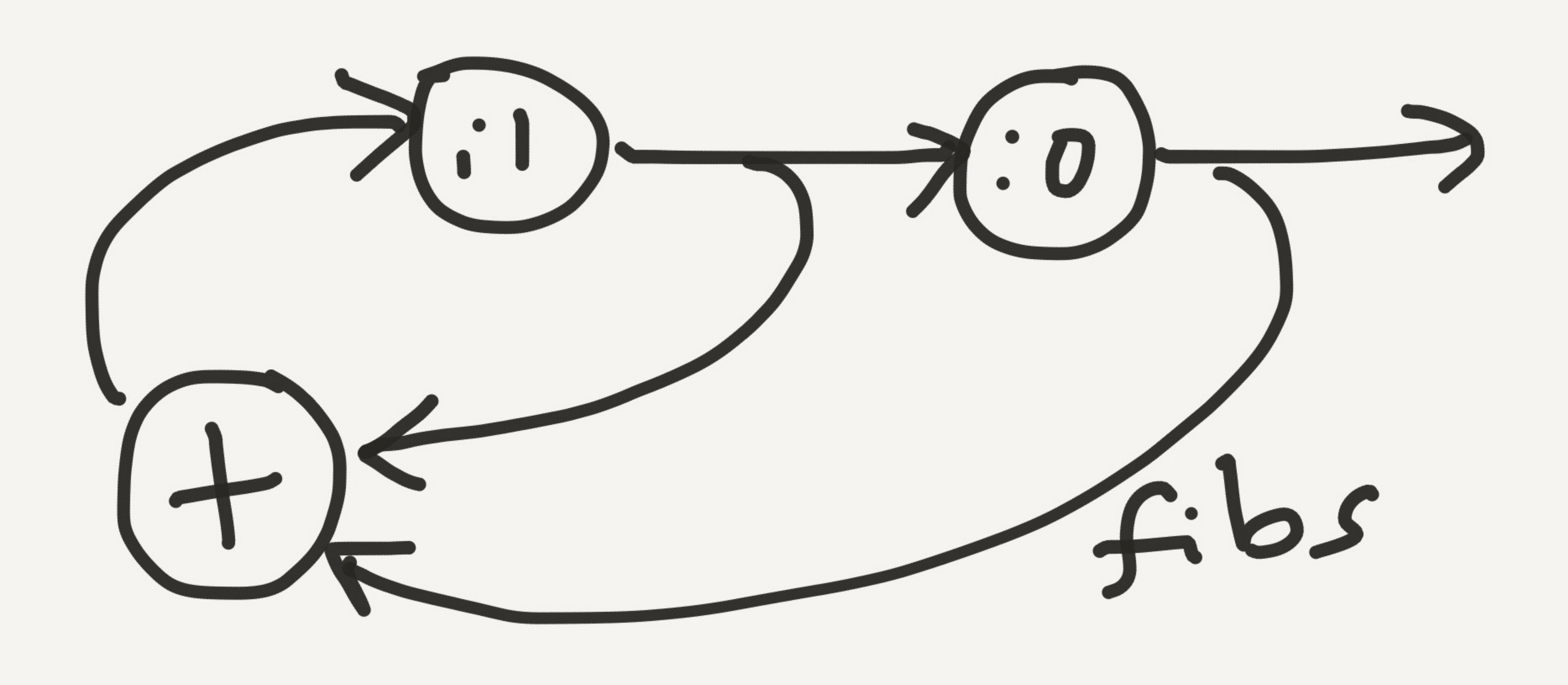
```
fibs() ->
  ?cons(0,
    ?cons(1,
      addZip(fibs(),tail(fibs())))).

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

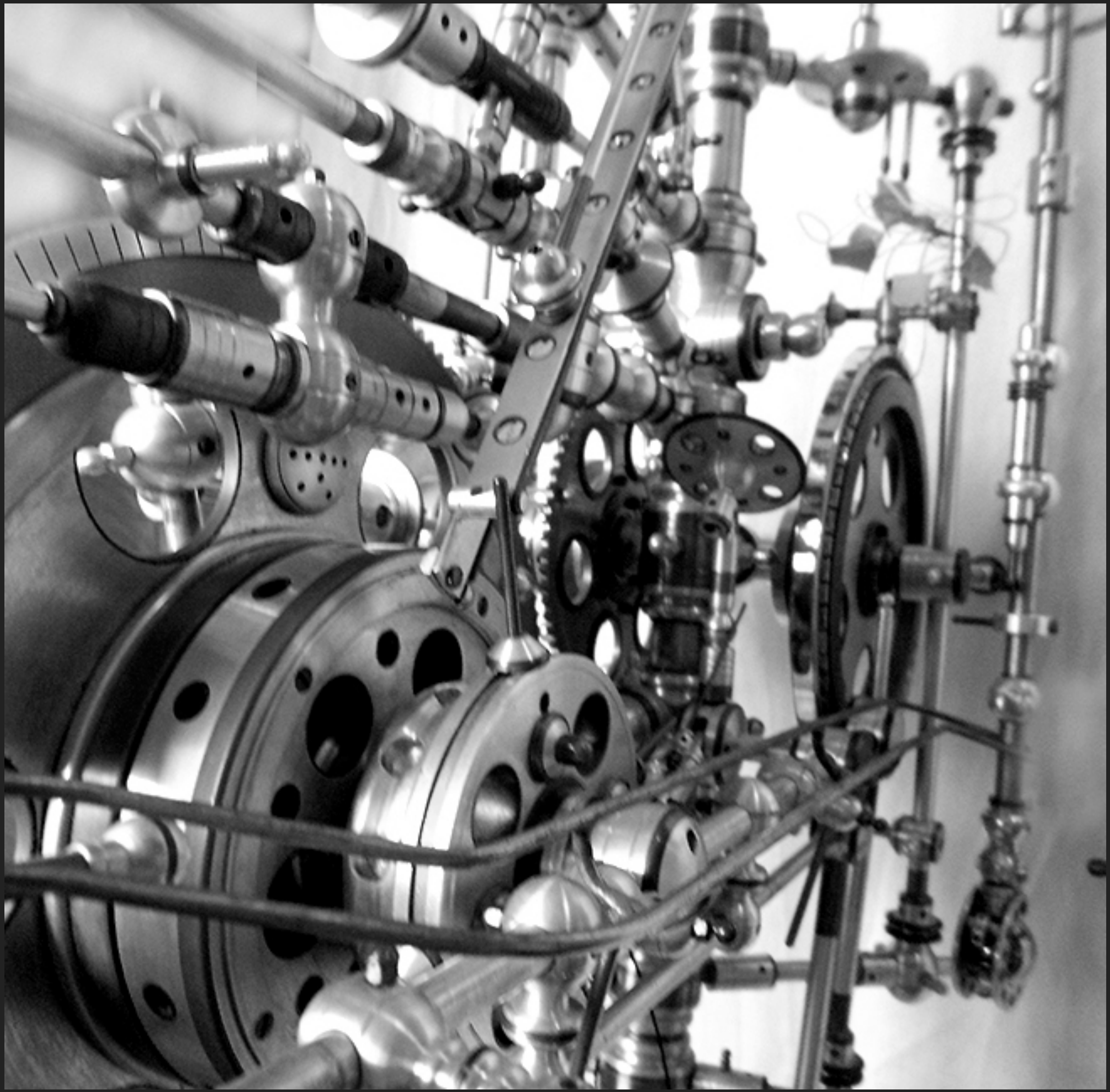
LAZY EVALUATION

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

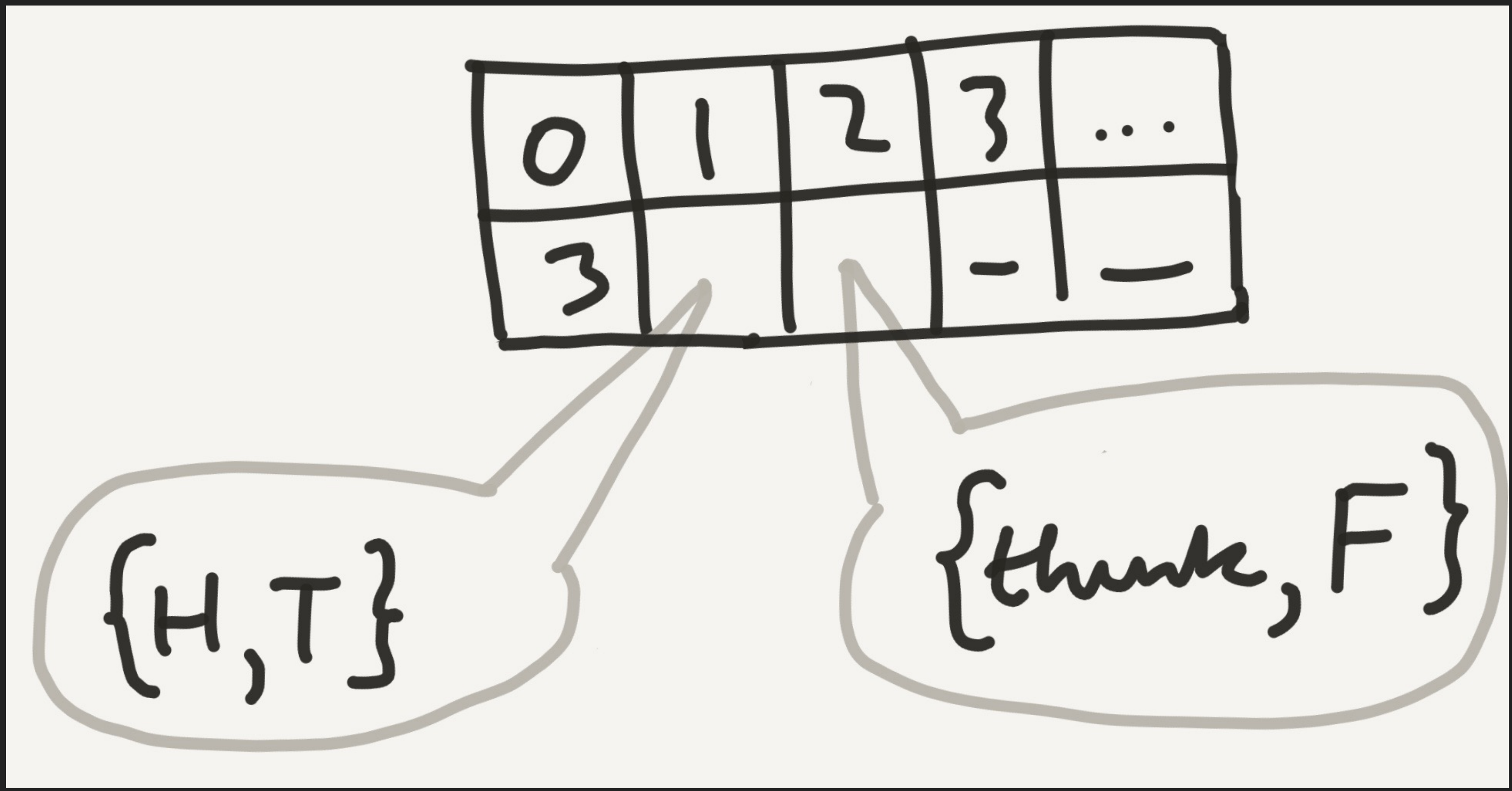
use an ETS table to keep track
of evaluated results, or . . .

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

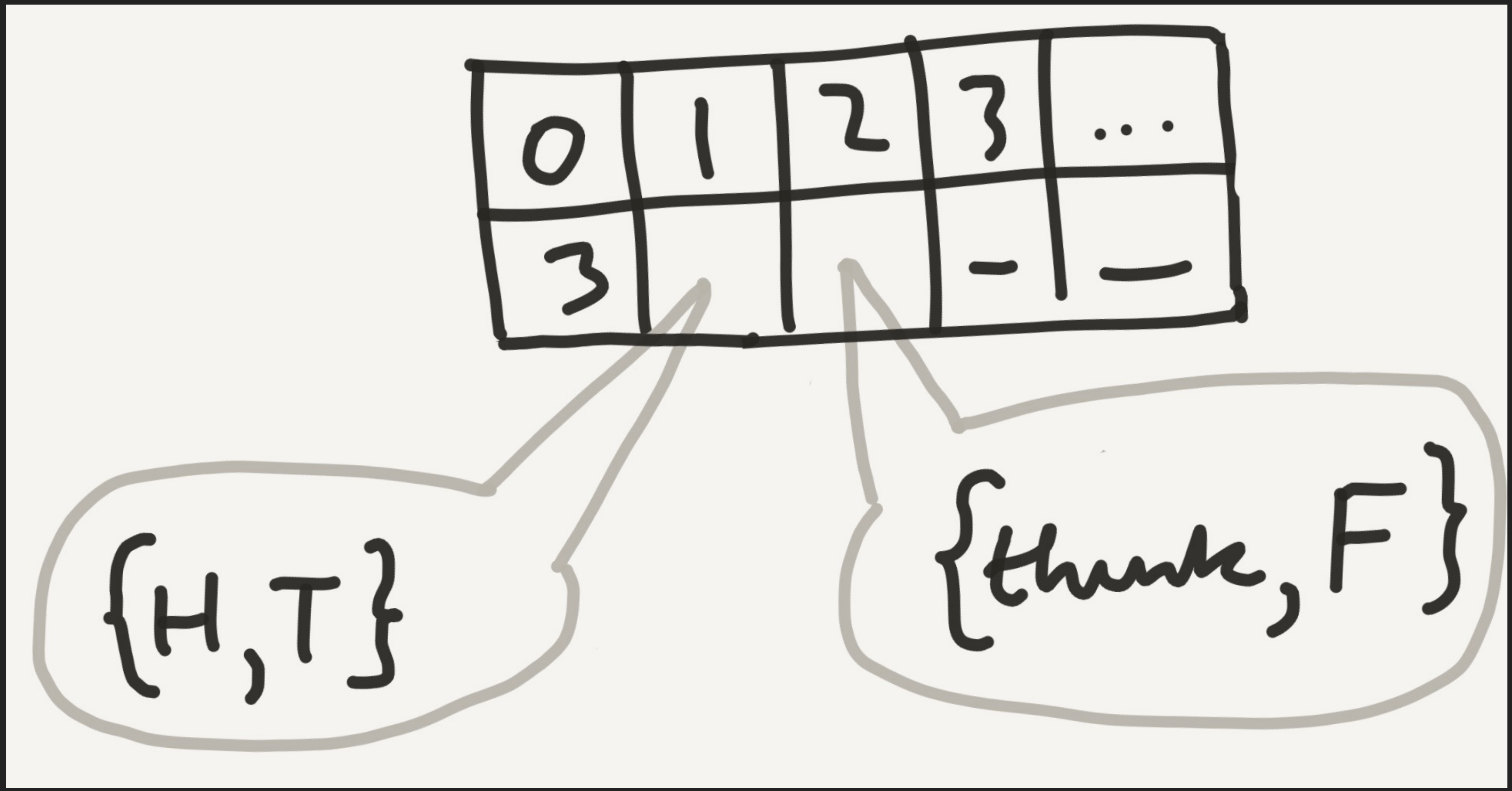
USING ETS TABLES

store either the head and tail,

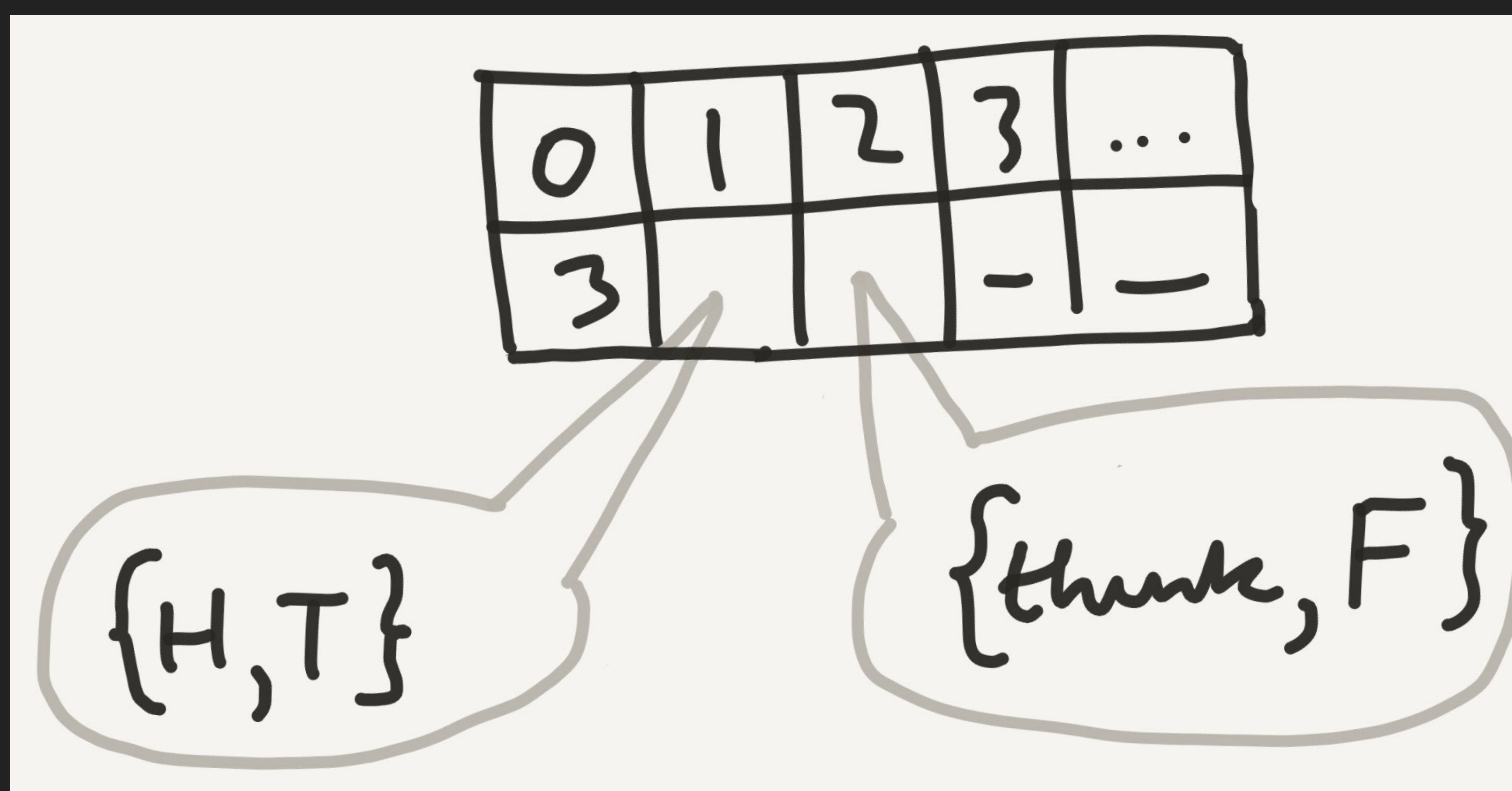
or a "thunk" to be evaluated



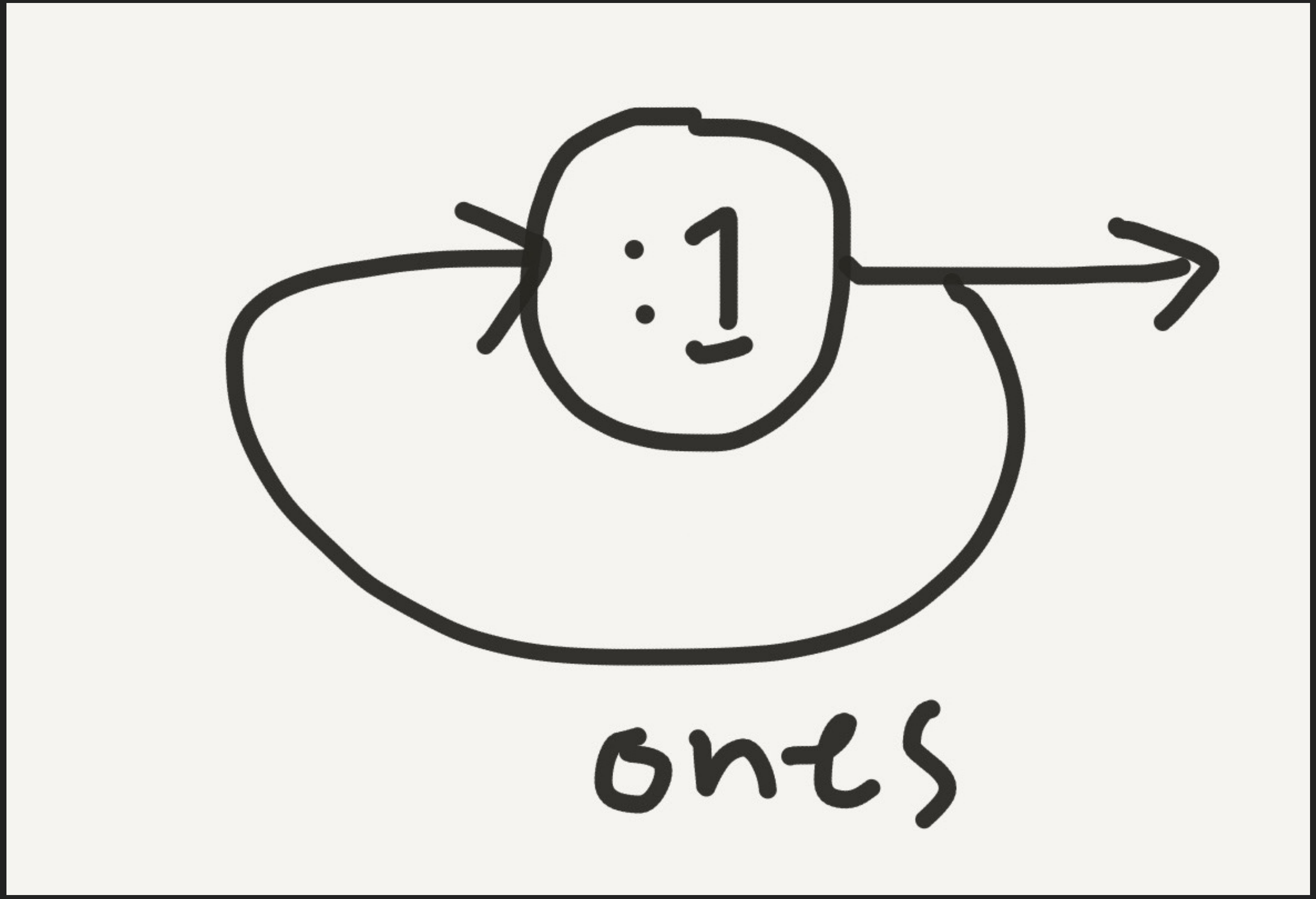
```erlang
-define(cons(X,Xs), begin ets:insert(tab,{0,next_ref()+1}) ,
                          ets:insert(tab, {next_ref(), {thunk, fun () -> {X,Xs} end}}),
                          % io:format("done cons insert~n"),
                          {ref,next_ref()} end).
```



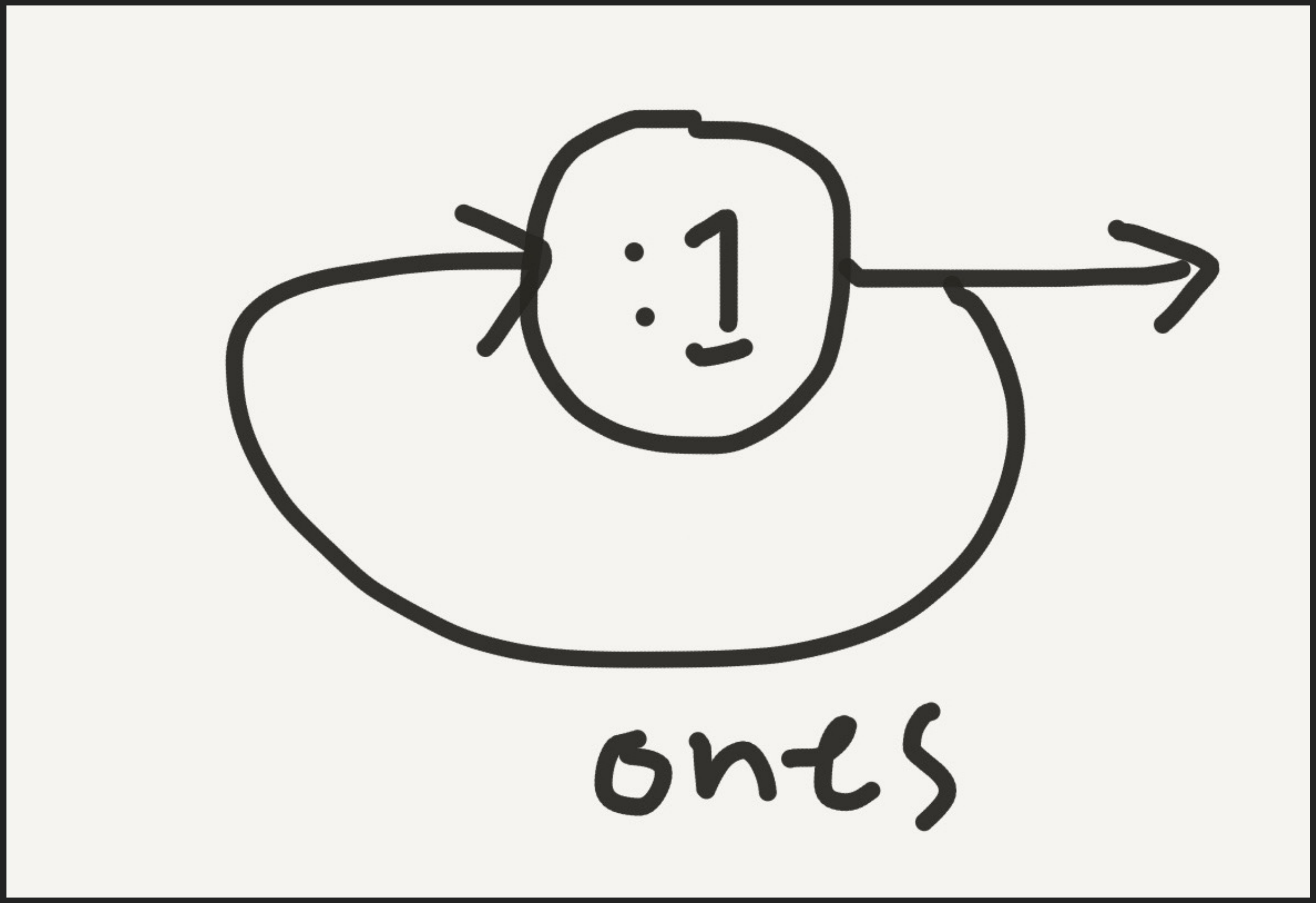
```
head({ref,Ref}) ->
  case ets:lookup(tab,Ref) of
    [{Ref,{thunk,F}}] -> Val = F(),
                         ets:insert(tab,{Ref,Val}),
                         {H,_} = Val,
                          H;
    [{Ref,{H,_}}] -> H
  end.
```



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

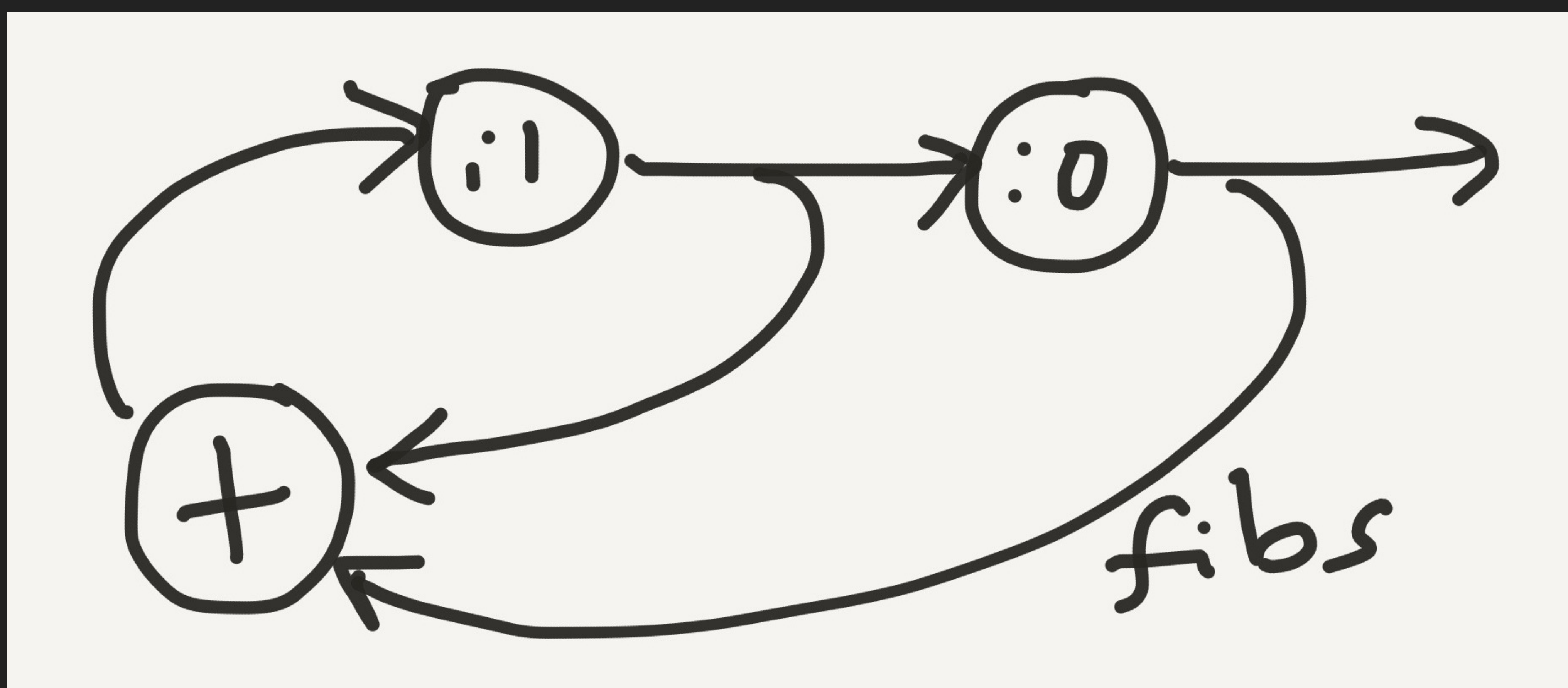


```
onesC() ->
  This = next_ref()+1,
  ?cons(1,{ref,This}).
```

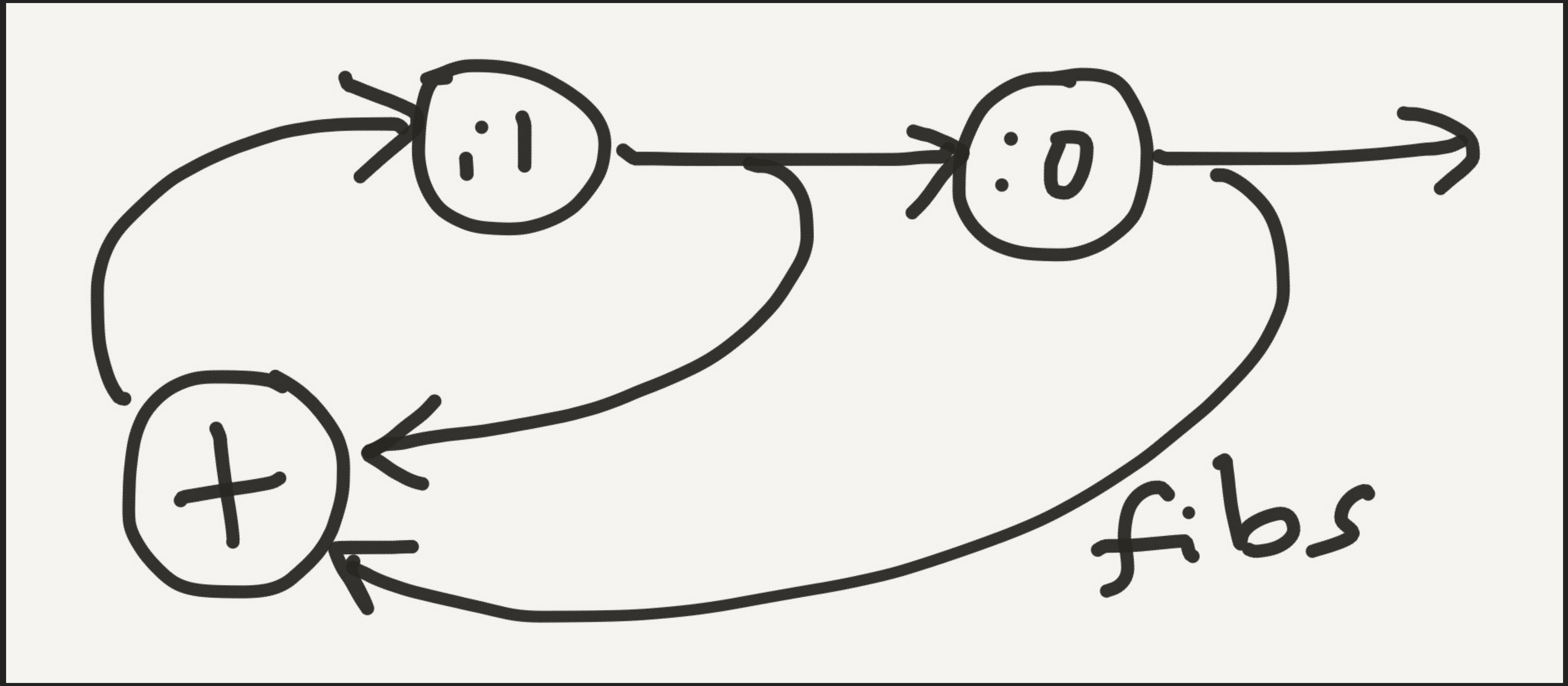


```
fibs() ->
  ?cons(0,
    ?cons(1,
      addZip(fibs(),tail(fibs())))).

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



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



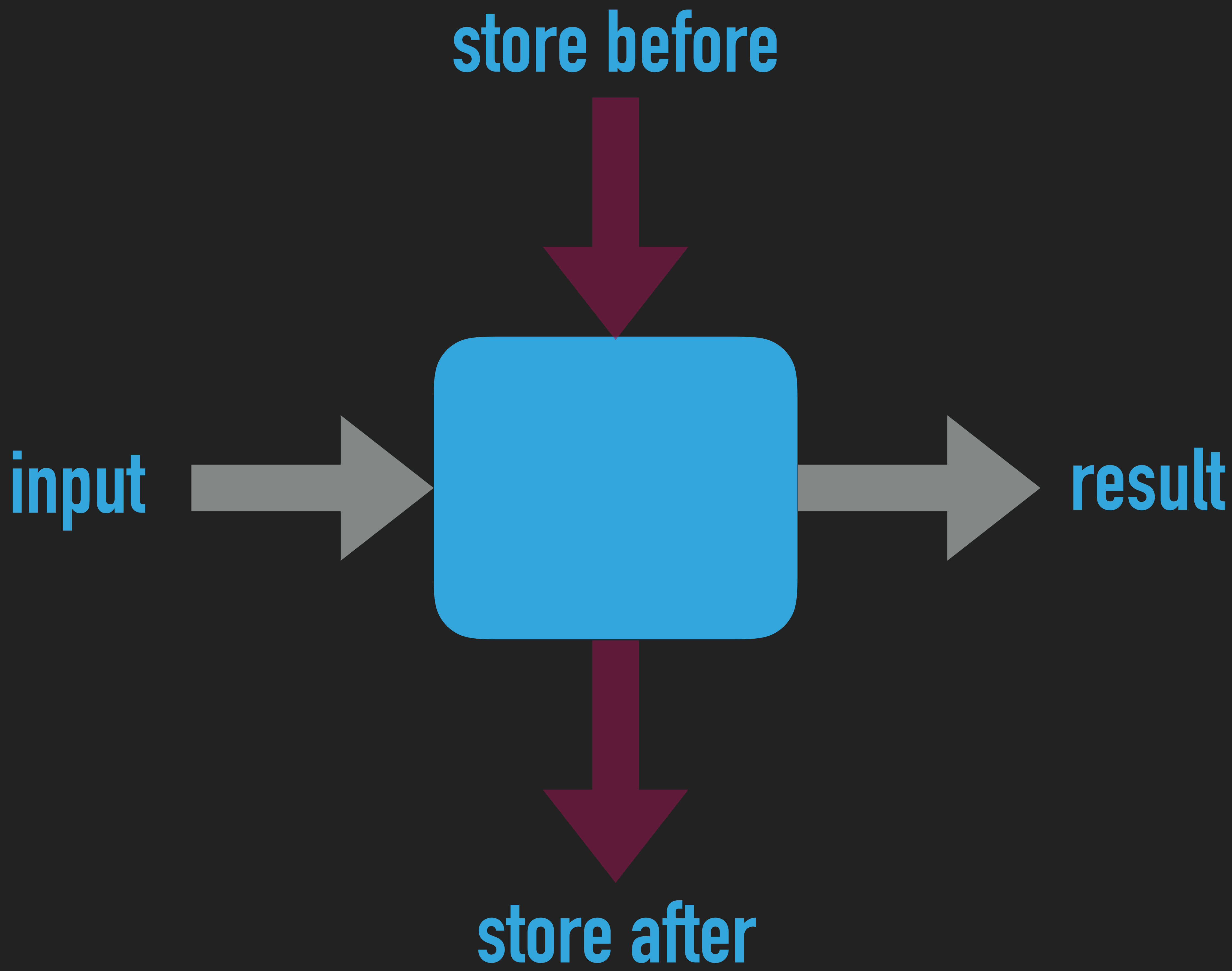
Explicitly managed refs

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

```
ps(Xs,N,Tab) ->
  io:format("~w~n",[head(Xs,Tab)]),
  {T,Tab1} = tail(Xs,Tab),
  ps(T,N-1,Tab1).
```

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.

MEMOISATION

use ETS for general memoisation

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

use ETS for general memoisation

```
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.
```

vectors

```
-type vector(T) :: {integer(),list(T)}.

-define(mkV(Xs),{length(Xs),Xs}).

-define(length(V),element(1,V)).
```

vectors

```
-type vector(T) :: {integer(),list(T)}.

-define(mkV(Xs),{length(Xs),Xs}).

-define(length(V),element(1,V)).

-spec joinV(T,vector(T)) -> vector(T).

joinV(Sep,{M,Xs}) -> {2*M-1,lists:join(Sep,Xs)}.

-define(join(Sep,V),element(2,joinV(Sep,V))).
```

TO CONCLUDE

functions are flexible and powerful modelling tool

strategies

parsers

simulation

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

functions are flexible and powerful modelling tool

strategies

parsers

simulation

https://github.com/simonjohnthompson/streams and I didn’t say anything directly about dependent types ;-(