Error Processing: An Exercise in Functional Design

COS 326
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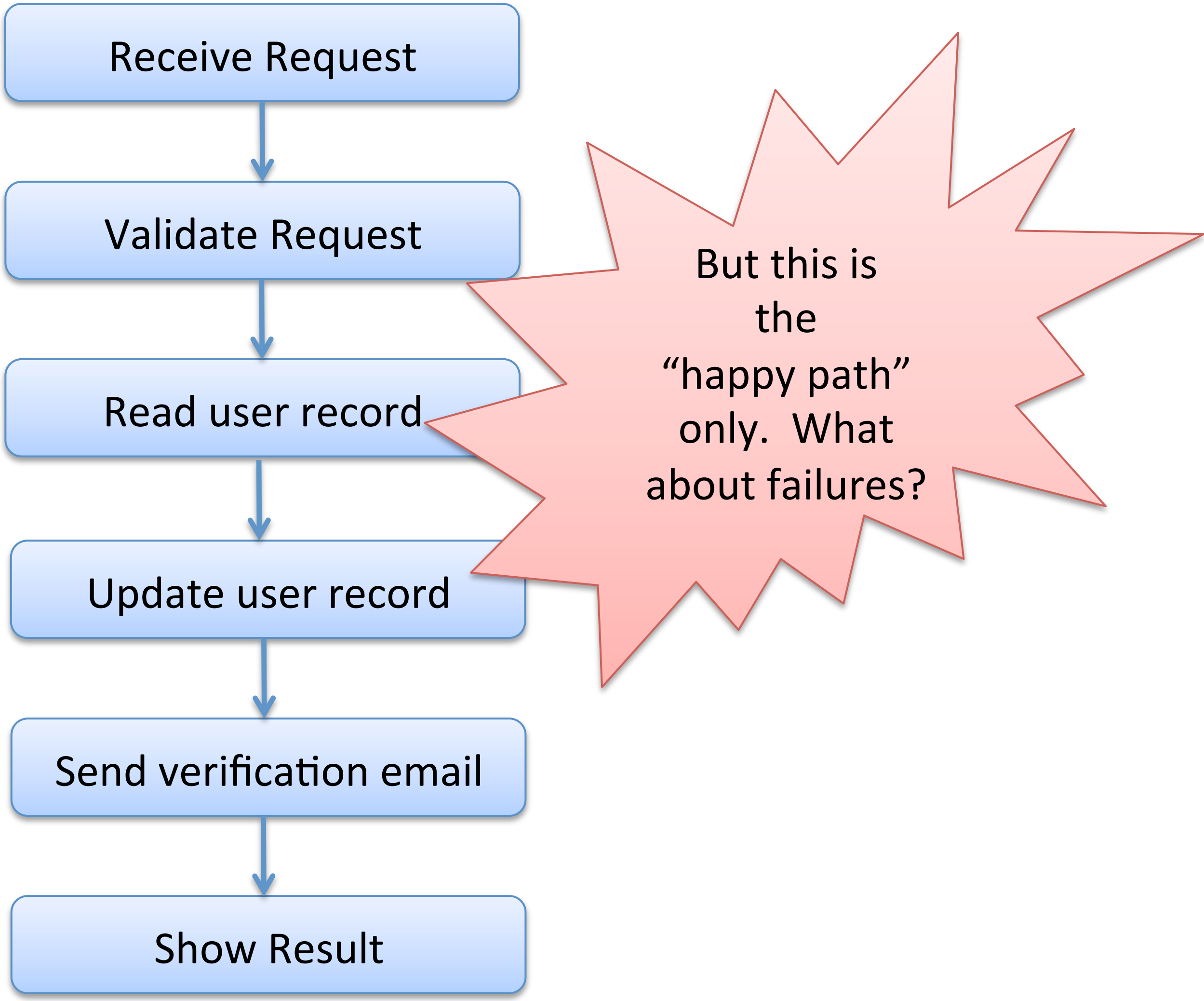
This lecture from a great blog on F#:
http://fsharpforfunandprofit.com/posts/recipe-part1/

The Task

- Imagine you are designing a front end for a database that takes update requests.
  - A user submits some data (userid, name, email)
  - Check for validity of name, email
  - Update user record in database
  - If email has changed, send verification email
  - Display end result to user

In Pictures



Receive Request

Validate Request

Read user record

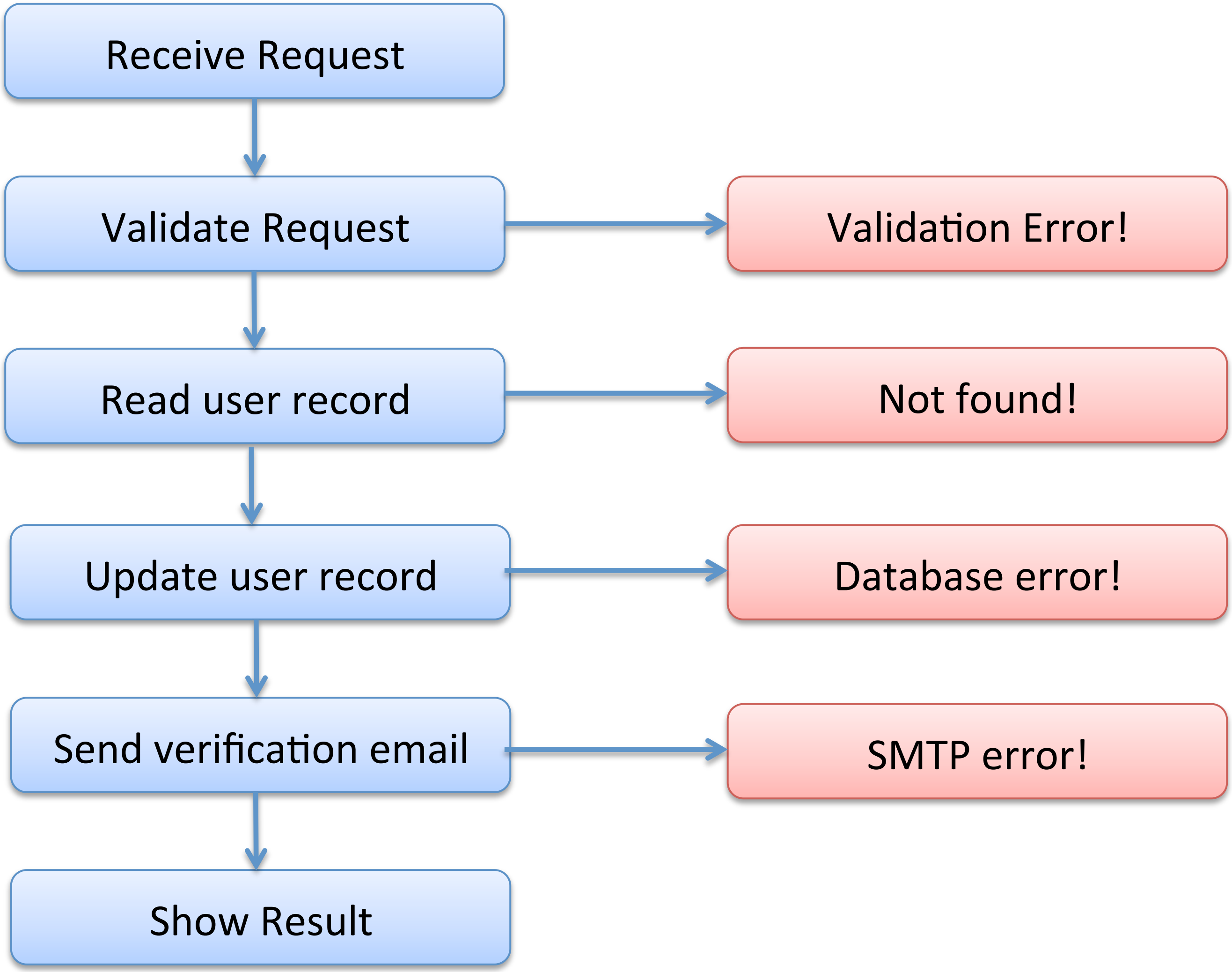
Update user record

Send verification email

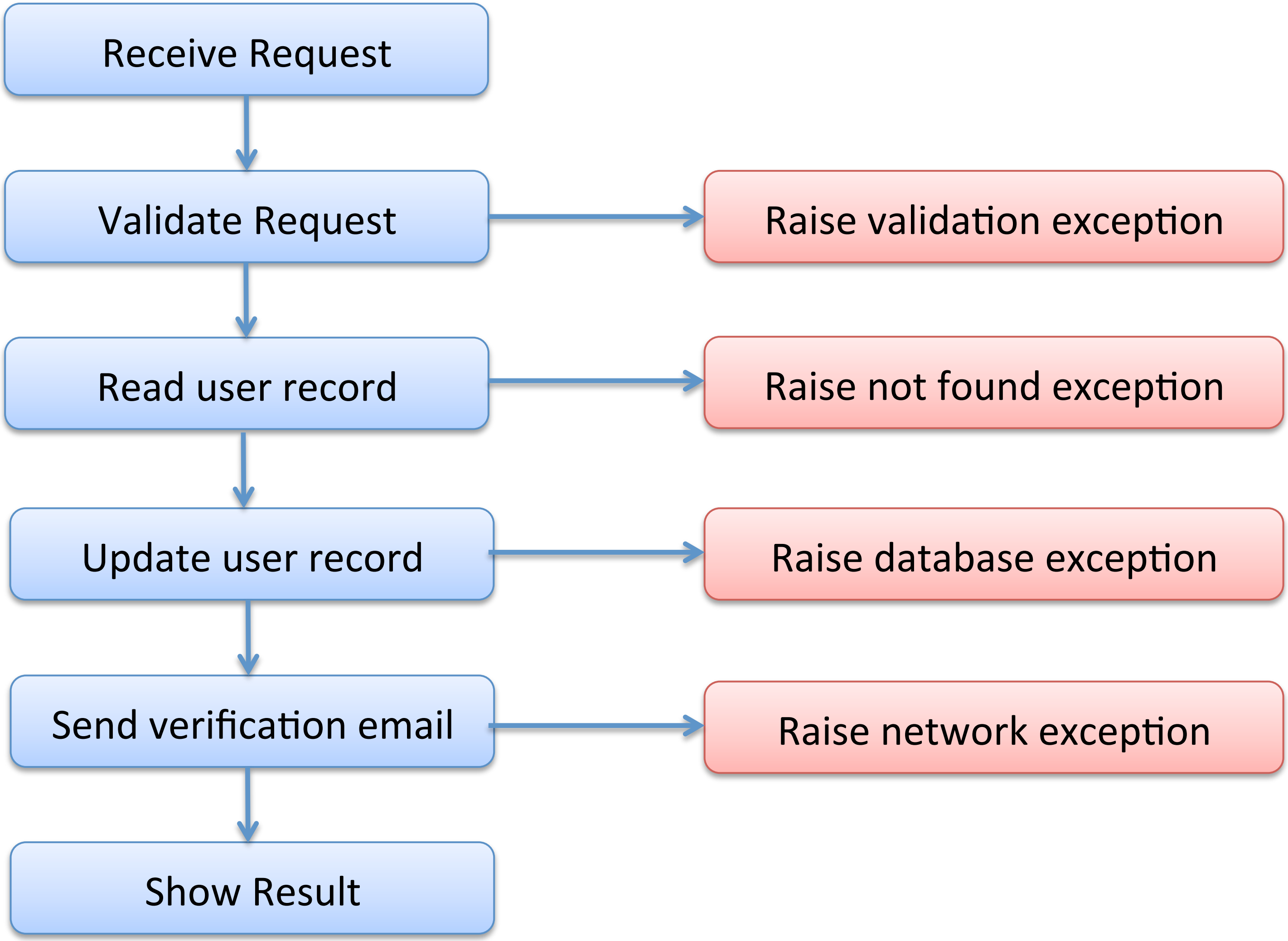
Show Result

But this is the "happy path" only. What about failures?

In Pictures


Receive Request
Validate Request
Validation Error!
Read user record
Not found!
Update user record
Database error!
Send verification email
SMTP error!
Show Result

One solution



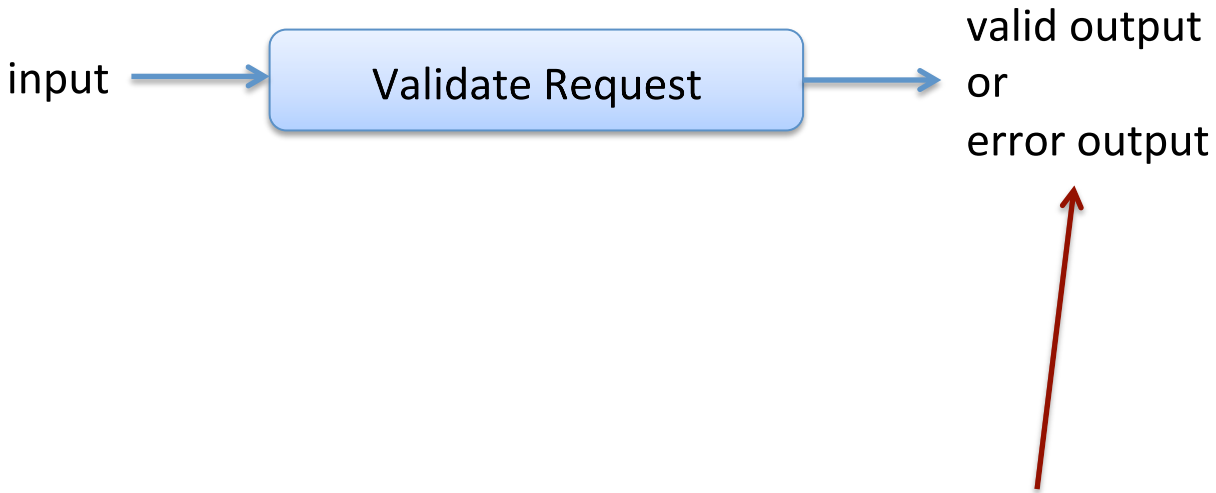
The trouble with exceptions

People forget to catch them!

- applications fail
- sadness ensues
- See *A type-based analysis of uncaught exceptions* by Pessaux and Leroy.
  - Uncaught exceptions: a big problem in OCaml (and Java!)
  - (not a big problem in C. Why not? ☹)

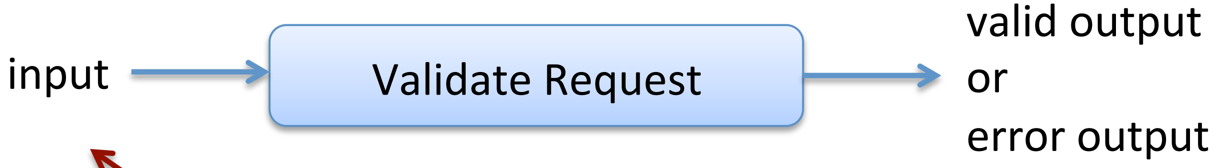
In a more functional approach, the full behavior of a program is determined exclusively *by the value it returns*, not by its “effect”

Functional Error Processing



Explicitly return “good” result or error. If we use OCaml data types to represent the two possibilities we will force the client code to process the error (or get a warning from the OCaml type checker).

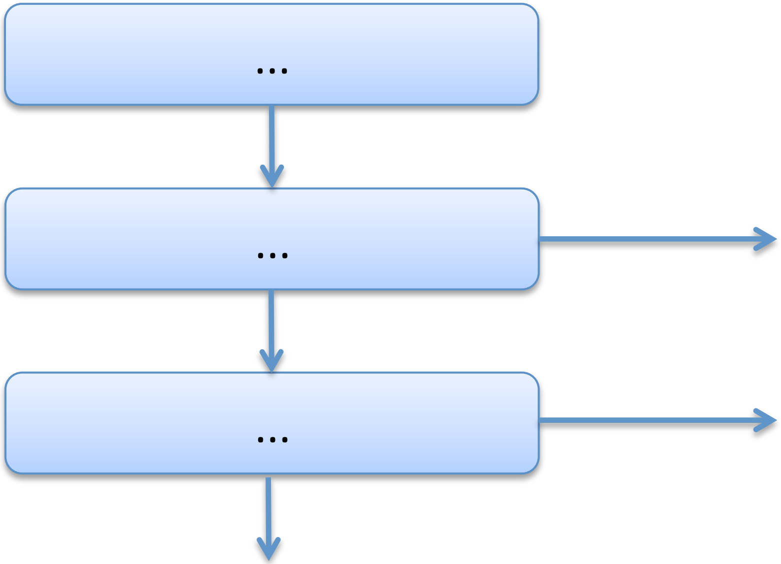
Functional Error Processing



input

Validate Request

valid output
or
error output



...

...

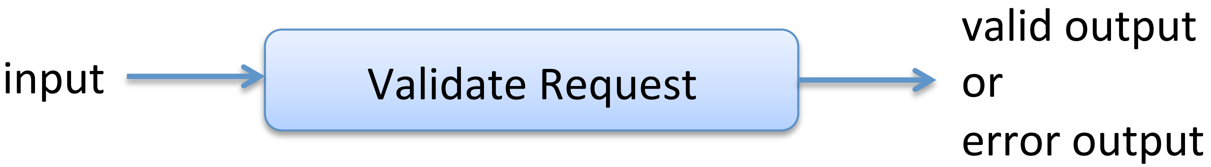
...

Notice input and output aren't the same type. On the surface, this makes it look awkward to compose a series of such steps, but:

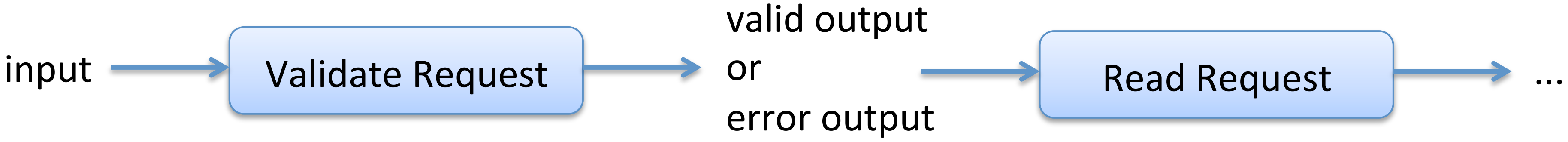
Good abstractions are compositional ones.

Let's design a generic library for error processing that is *highly reuseable* and *compositional*.

Functional Error Processing



The Challenge: Composition



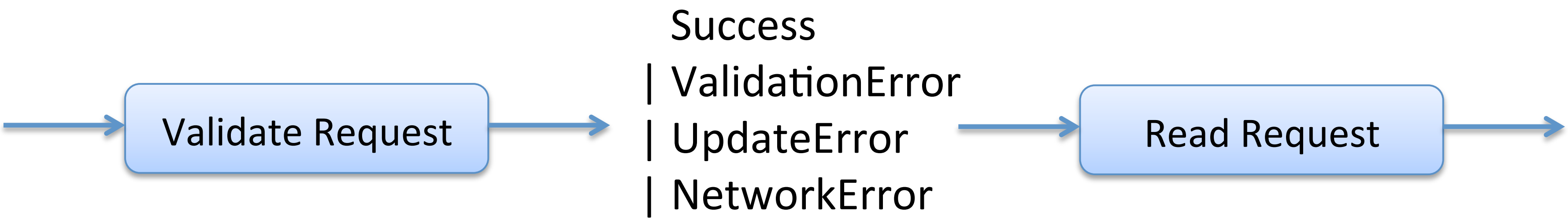
One Possibility

Define a datatype to represent all outputs:

```
type result =
  Success | ValidationError | UpdateError | NetworkError
```

But:

- not very reuseable (very specific set of errors)
- adding a new error is irritating
- every function in the chain must process all possible errors as inputs:



Validate Request

Success
| ValidationError
| UpdateError
| NetworkError

Read Request

A better idea:
Generic errors & error-processing library

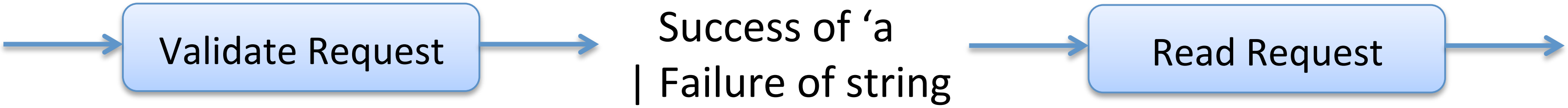
A generic result type:

```
type (‘a, ‘b) result =
      Success of  ‘a
    | Failure of ‘b
```

Specialized to string errors:

```
type ‘a eresult = (‘a, string) result
```

A processing pipeline:



Validate Request

Success of ‘a
| Failure of string

Read Request

An Example Pipeline Function

```
type request = {name:string; email:string}

let validate input =
  if input.name = “” then
     Failure “name must not be blank”
  else if input.email = “” then
     Failure “email must not be blank”
  else
     Success input
```

```
// result is a Success of ‘a or Failure of string
type ‘a eresult = (‘a, string) result
```

```
validate : request -> request eresult
```

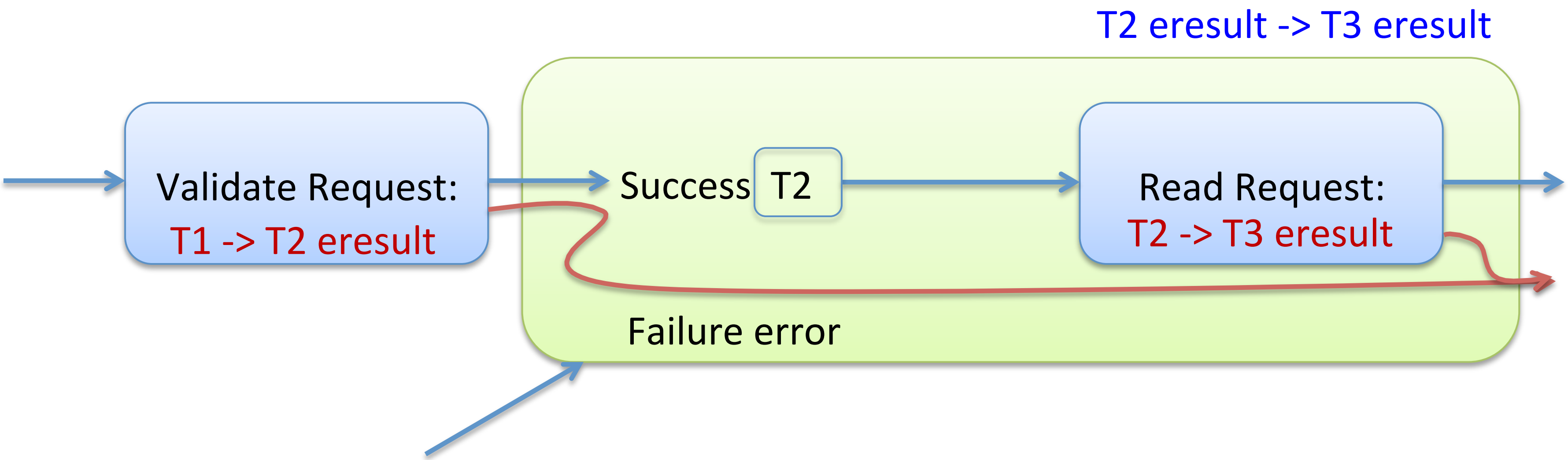
Note: we really don’t want to have match on a possibly erroneous input every single time, so we assume a good input (a request) gets passed in, a possibly erroneous result (a request eresult) returned

In general:

```
T1 -> T2 eresult
```

is the type of a possibly-erroneous function that takes a T1 and may return a good result of type T2 or fail.

Composition



Goal: Create a bypass combinator to convert an ‘a -> ‘b eresult function into a function with type ‘a eresult -> ‘b eresult

```
let bind f =
   fun result ->
      match result with
            Success v -> f v
          | Failure s -> result
```

bind : (‘a -> ‘b eresult) -> (‘a eresult -> ‘b eresult)

Using the bypass combinator

```
let validate1 input =
  if input.name = “” then
    Failure “no name”
  else
    Success input

let validate2 input =
  if String.length (input.name) > 50 then
    Failure “name too long”
  else
    Success input
```

```
validate1 :  request -> request eresult
validate2 :  request -> request eresult
```

Using the bypass combinator

```
validate1 :  request -> request eresult
validate2 :  request -> request eresult
```

```
let validate1’ = bind validate1

let validate2’ = bind validate2
```

```
validate1’ :  request eresult -> request eresult
validate2’ :  request eresult -> request eresult
```

```
(* reverse function composition *)
let (>>) f g x = g (f x)

let validator =
          validate1’
    >> validate 2’
    >> validate 3’
```

```
(>>) :  (‘a -> ‘b) -> (‘b -> ‘c) -> (‘a -> ‘c)
```

```
validator :  request eresult -> request eresult
```

An Alternative

```
let (>=>) f1 f2 =
  fun x ->
       match f1 x with
          Success s -> f2 s
       | Failure f -> Failure f
```

```
>=> : (‘a -> ‘b eresult) -> (‘b -> ‘c eresult) -> (‘a -> ‘c eresult)
```

similar to ordinary function composition, but for eresults

```
let validator =
         validate_name1
  >=> validate_name2
  >=> validate_email
```

```
validator :  request -> request eresult
```

An Error-Processing Library

Generic Stuff

```
(|>) : ‘a -> (‘a -> ‘b) -> ‘b                  (* generic pipe *)

(>>) : (‘a -> ‘b) -> (‘b -> ‘c) -> (‘a -> ‘c)  (* generic function composition *)
```

Error-Specific Stuff

```
type (‘a, ‘b) result = Success of ‘a | Failure of ‘b

type ‘a eresult = (‘a, string) result

return : ‘a -> ‘a eresult                      (* successful with ‘a *)

fail : string -> ‘a eresult                    (* automatic failure *)

bind :   (‘a -> ‘b eresult) -> (‘a eresult -> ‘b eresult)

map : (‘a -> ‘b) -> (‘a eresult -> ‘b eresult)      (* convert an error-free function *)

(>>=) :  ‘a eresult –> (‘a -> ‘b eresult) -> ‘b eresult

(>=>) : (‘a -> ‘b eresult) -> (‘b -> ‘c eresult) -> (‘a -> ‘c eresult)
```

An Error-Processing Library

Generic Stuff

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(>>) : (‘a -> ‘b) -> (‘b -> ‘c) -> (‘a -> ‘c)    (* generic function composition *)
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Error-Specific Stuff

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(>>=) :  ‘a eresult –> (‘a -> ‘b eresult) -> ‘b eresult

(>=>) : (‘a -> ‘b eresult) -> (‘b -> ‘c eresult) -> (‘a -> ‘c eresult)
```

A coincidence?

error computations: map : (‘a -> ‘b) -> ‘a eresult -> ‘b eresult

list computations: map : (‘a -> ‘b) -> ‘a list -> ‘b list

error computations: bind : (‘a -> ‘b eresult) -> (‘a eresult -> ‘b eresult)

list computations: bind : (‘a -> ‘b list) -> (‘a list -> ‘b list)

error computations: return : ‘a -> ‘a eresult

list computations: return : ‘a -> ‘a list

Monads

- A *monad* is a triple of (*set of values*, *bind*, *return*) that satisfies certain equational laws:

```
(return a >>= f)  ==  f a
```

```
m >>= return  ==  m
```

```
m >>= (fun x -> k x >>= h)  ==  m >>= k >>= h
```

- In this lecture, we saw how a monad library helped us handle one kind of effect: an exception
- Monads are a general mechanism for handling effects
- Haskell has a built-in syntax for monads and has structured their libraries so that a function with type a -> b has no *effect*. Only functions with type a -> M b for certain monads M have effects.

Summary

SCORE: OCAML 4, JAVA 0

Functi

bind er > (‘a ere lt -> ‘b eresult)

>>= : a eresult –> (‘a -> ‘b eresult) -> ‘b eresult

>=> : (‘a -> ‘b eresult) -> (‘b -> ‘c eresult) -> (‘a -> ‘c eresult)