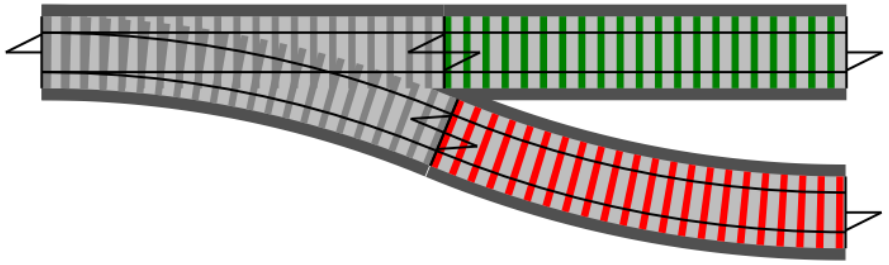
Railway Oriented Programming: Functional error handling



What do railways have to do with programming?

Scott Wlaschin
https://github.com/swlaschin/TechTrain2021

What we will cover today

- Three principles of functional programming
- How to use composition
- Basic error handling in FP
- Building a complete pipeline with errors
- Errors as part of your domain model

Part 1

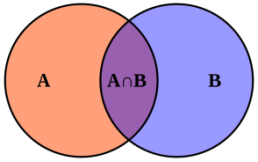
Three core principles of functional programming

Three principles of FP

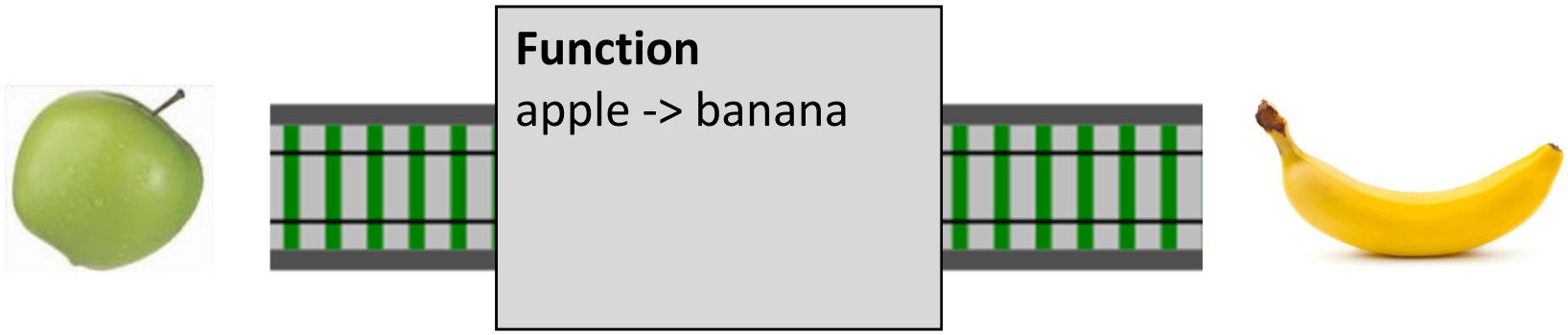
Functions are things

Composition everywhere

Types are not classes



FP principle #1:
Functions are things

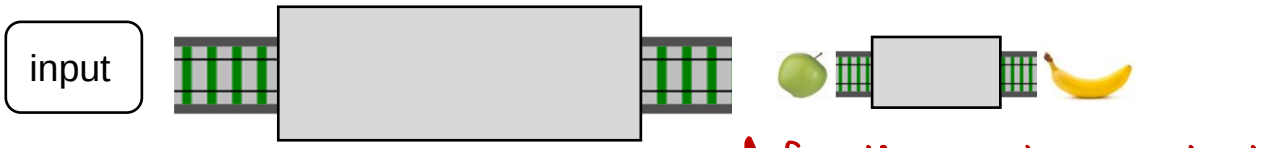


A function is a thing which transforms inputs to outputs

Another word for reusable!

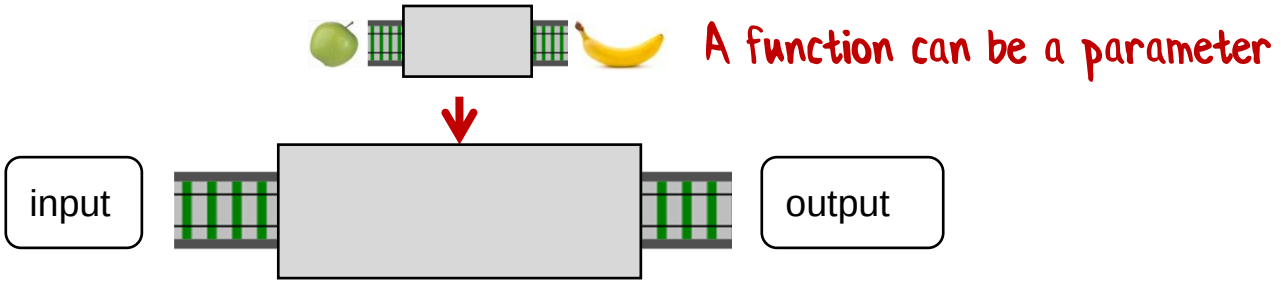
A function is a standalone thing, not attached to a class

It can be used for inputs and outputs of other functions



A function can be an output

A function can be an input

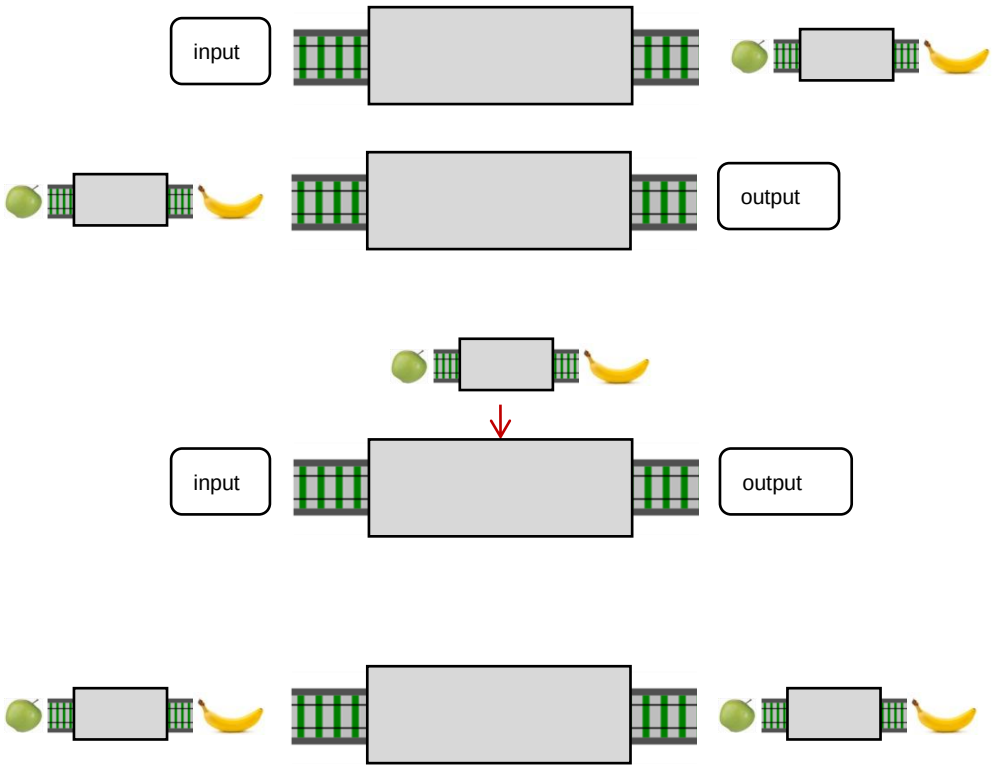


Similar to the "strategy pattern"

A function can be an input

And an output

This is a "Function Transformer".
We will be using these a lot!



You can build very complex systems from this basic foundation!

FP principle #2:
Composition everywhere

What is Composition?

Lego Philosophy

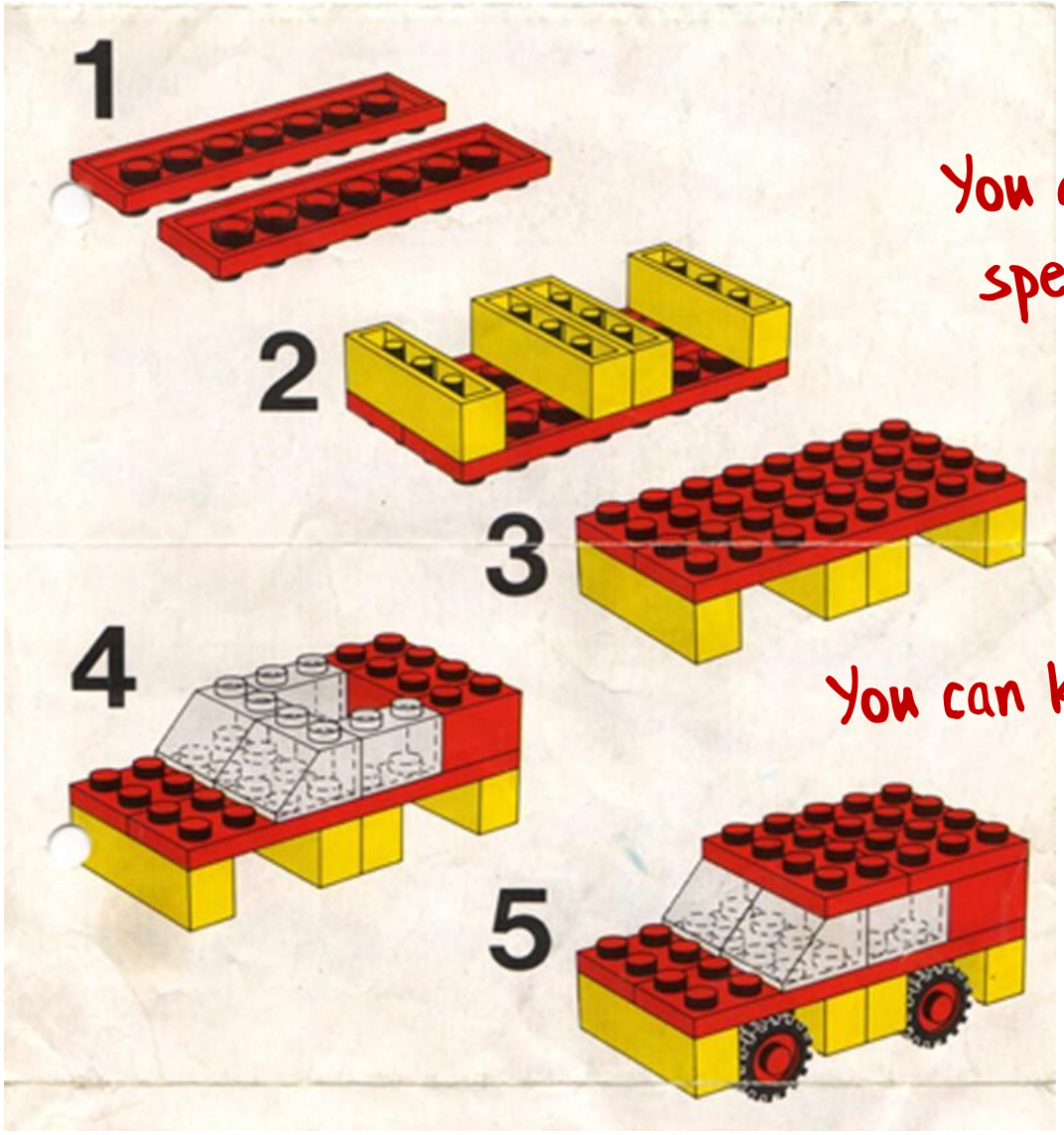
1. All pieces are designed to be connected
2. Connect two pieces together and get another "piece" that can still be connected
3. The pieces are reusable in many contexts

All Lego pieces are designed to be connected

Functional Philosophy

- All functions are designed to be connected

Connect two Lego pieces together and get another "piece" that can still be connected



You don't need to create a special adapter to make connections.

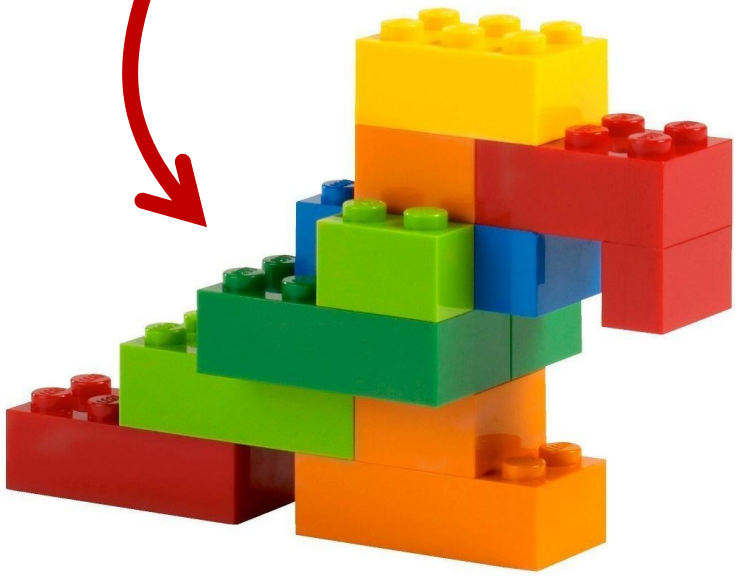
You can keep adding and adding.

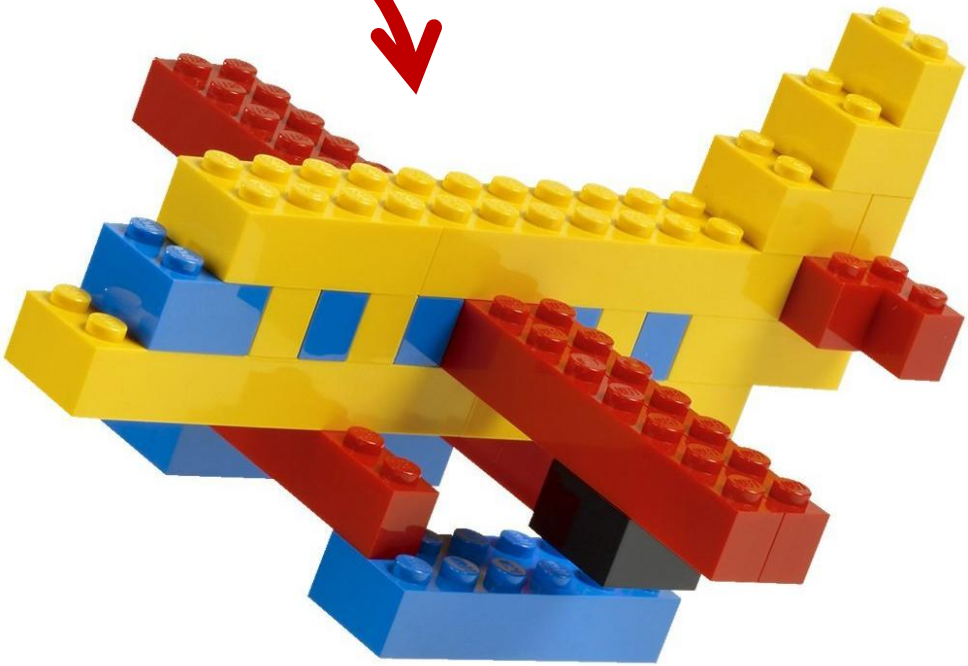
Make big things from small things in the same way

Functional Philosophy

- All functions are designed to be connected
- Connect two functions together and get another function that can still be connected

Lego pieces are reusable in different contexts



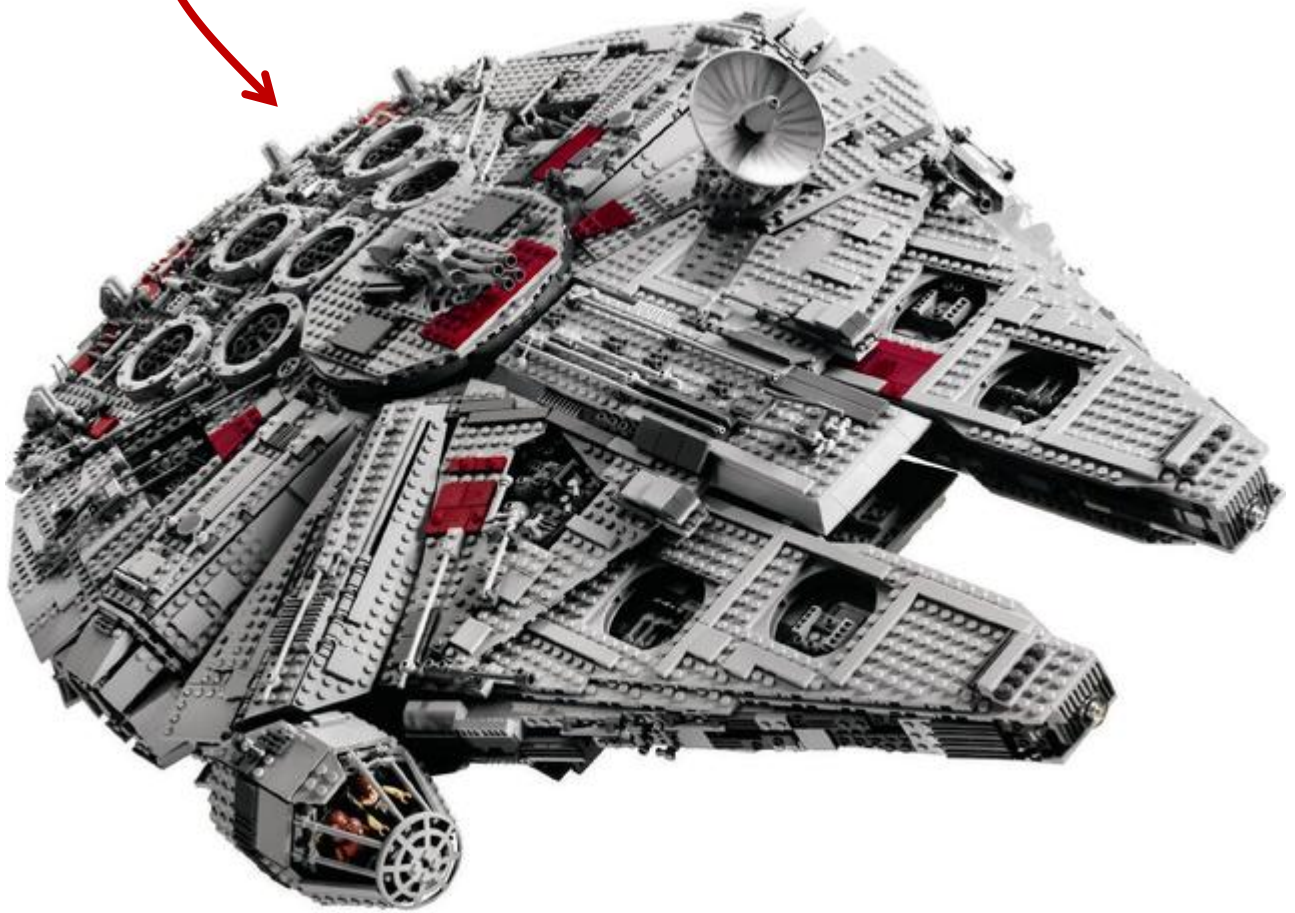


They are self contained.
No strings attached (literally).

Functional Philosophy

- All functions are designed to be connected
- Connect two functions together and get another function that can still be connected
- The functions are reusable in different contexts

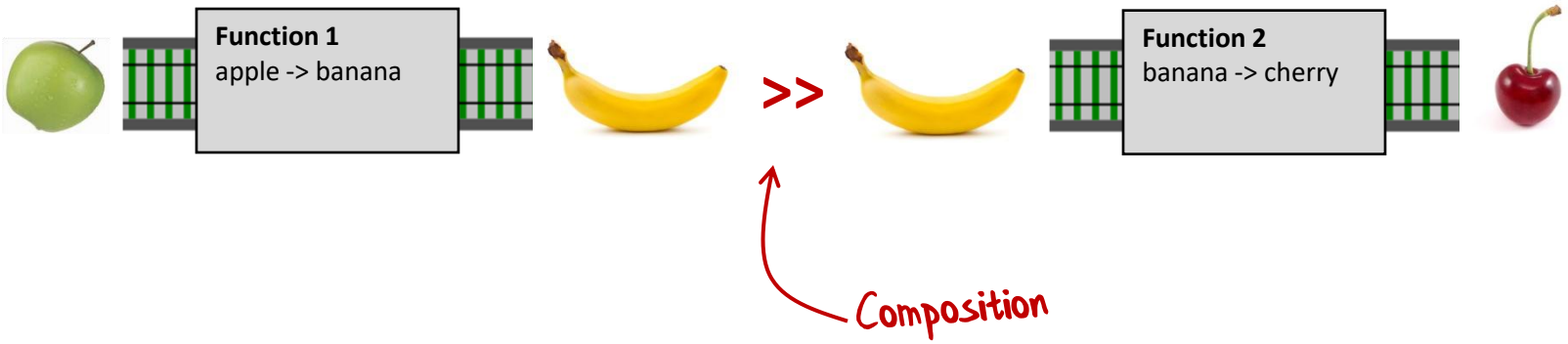
The Power of Composition

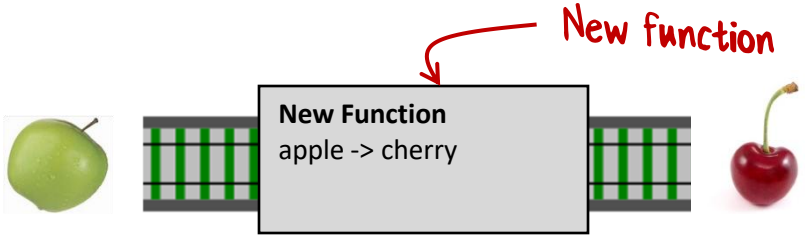


Function Composition


Function 1
apple -> banana
Function 2
banana -> cherry

Function composition





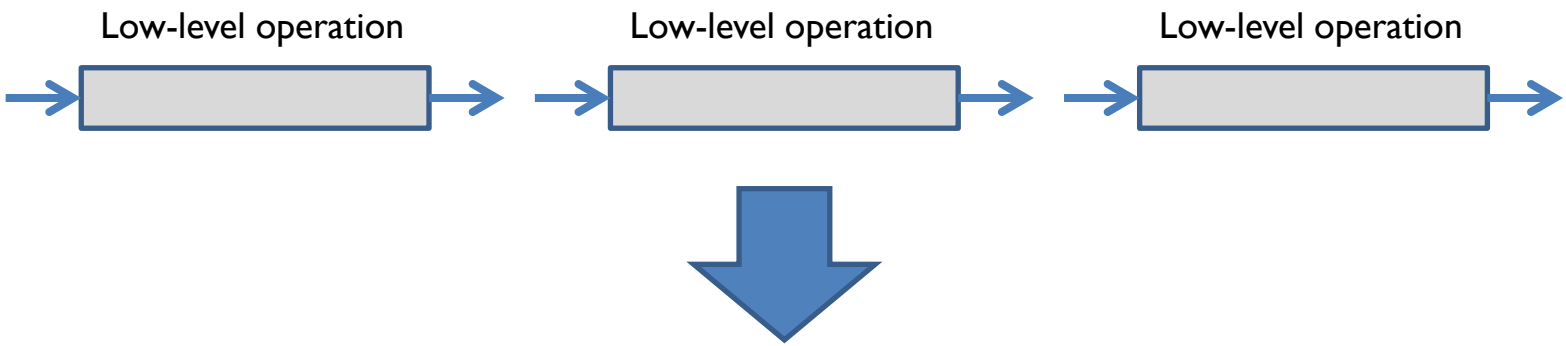
Can't tell it was built from smaller functions!

Where did the banana go?

Building big things from functions

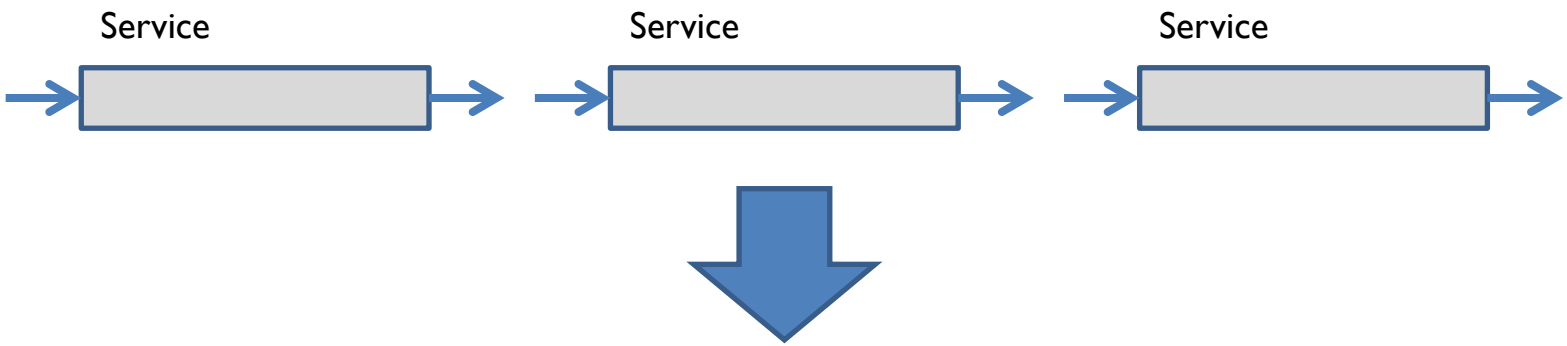
It's compositions all the way up

Low-level operation



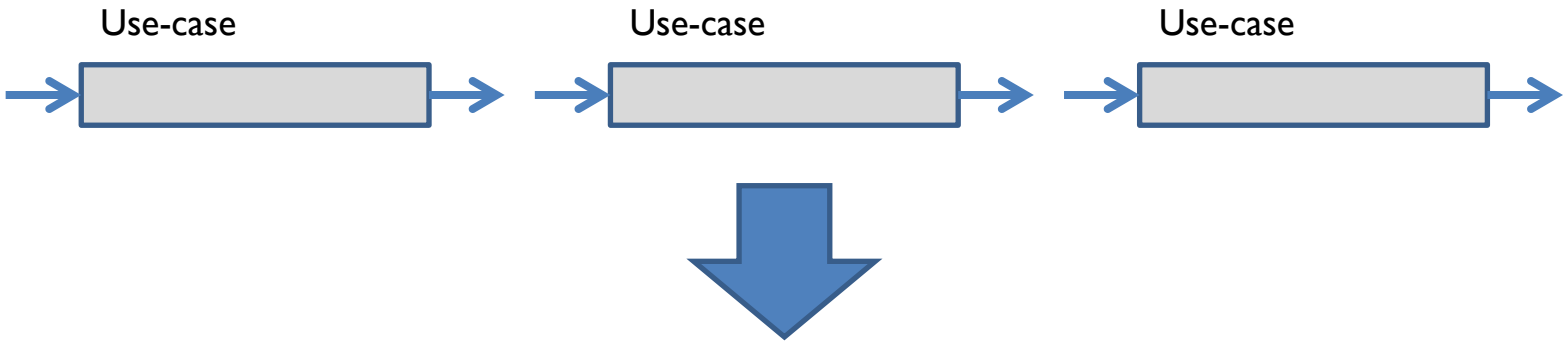
Service

A "Service" is just like a microservice
but without the "micro" in front

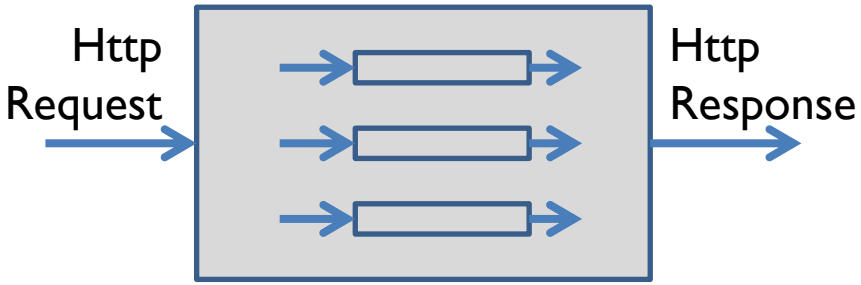

Service
Service
Service

Use-case


ChangeProfile
Request
UpdateProfileData
ChangeProfile
Result

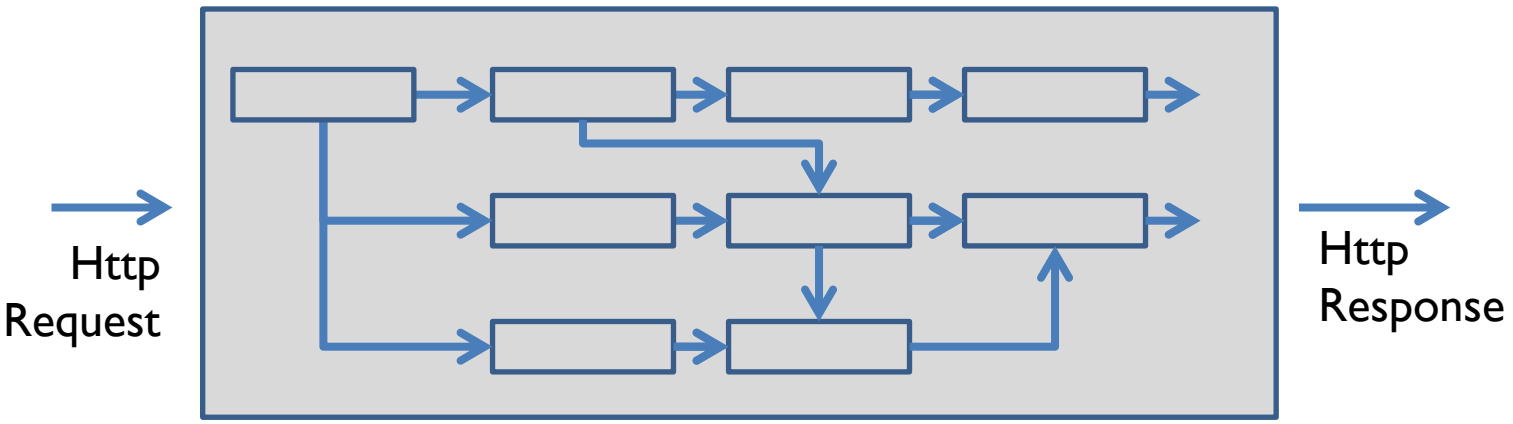


Web application



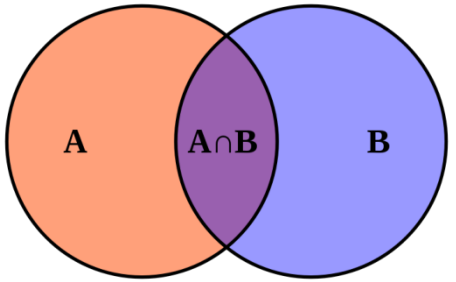
Use a dispatcher (or router, or controller) to pick a workflow to run

The Power of Composition



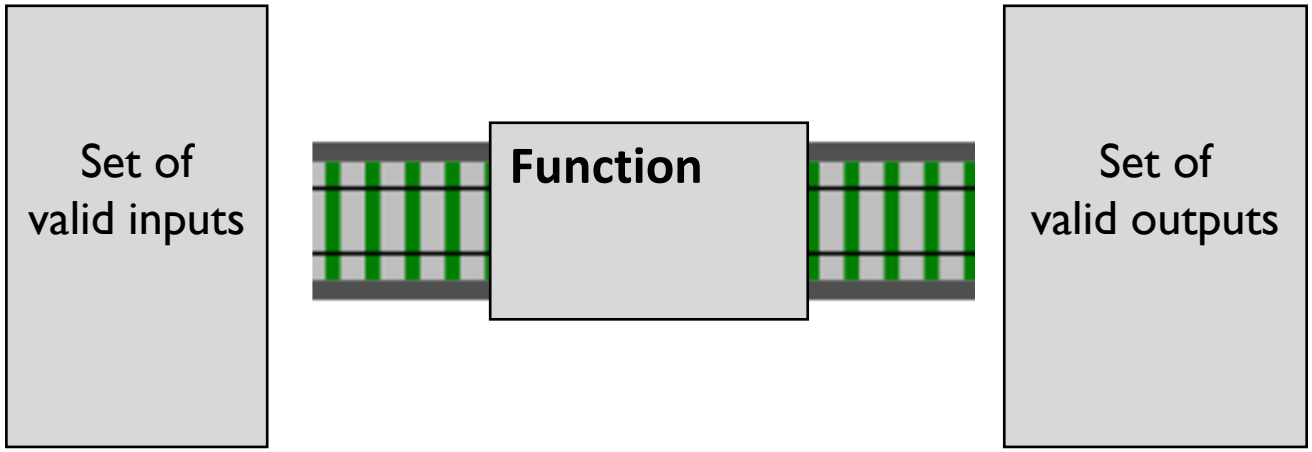
FP principle #3:

Types are not classes

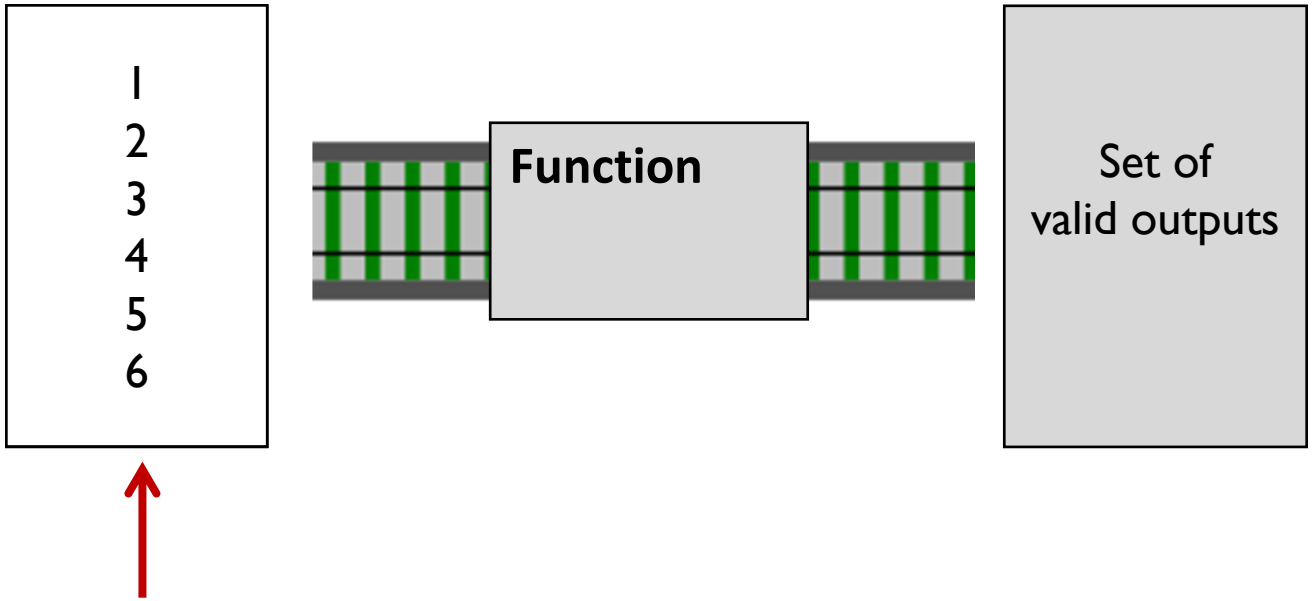


So, what is a type then?

A type is a just a name
for a set of things



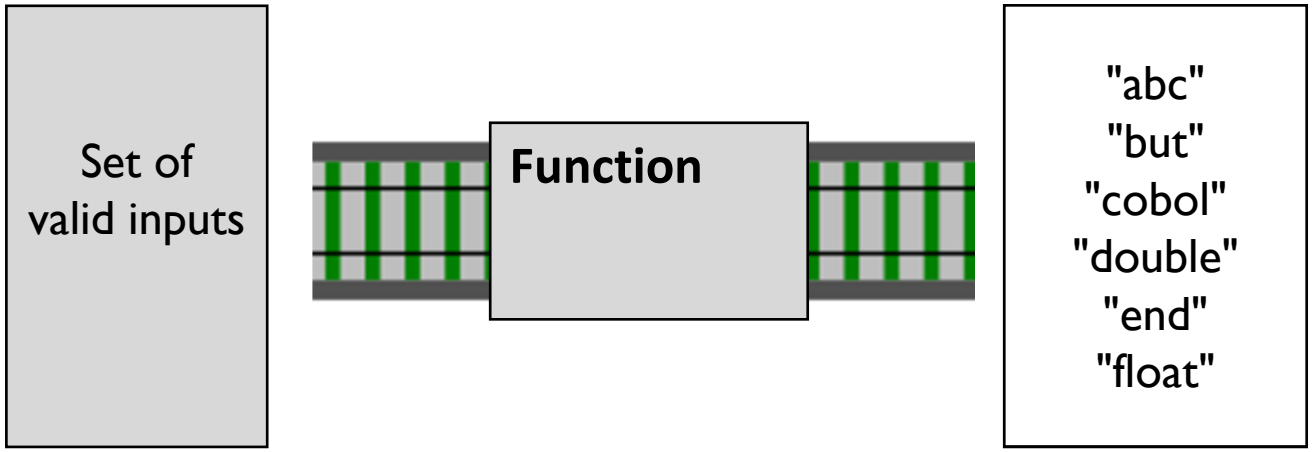
A type is a just a name
for a set of things



This is the set of all integers

type Integer

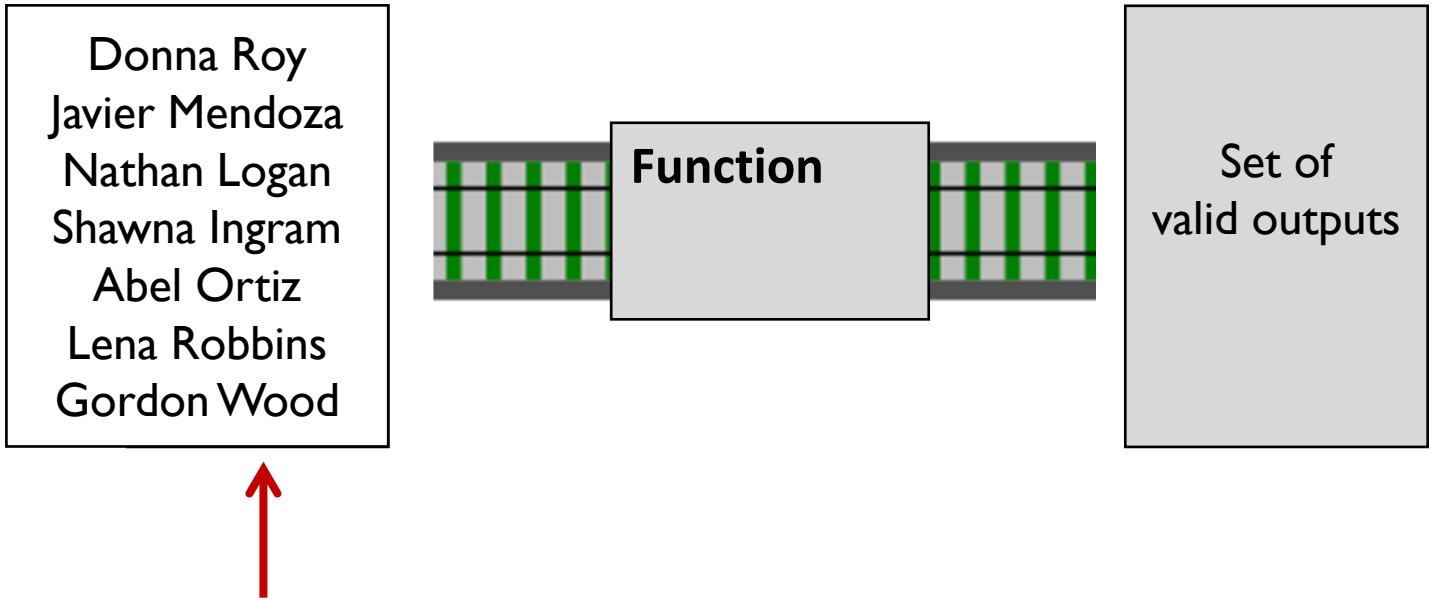
A type is a just a name
for a set of things



This is the set of all strings

type String

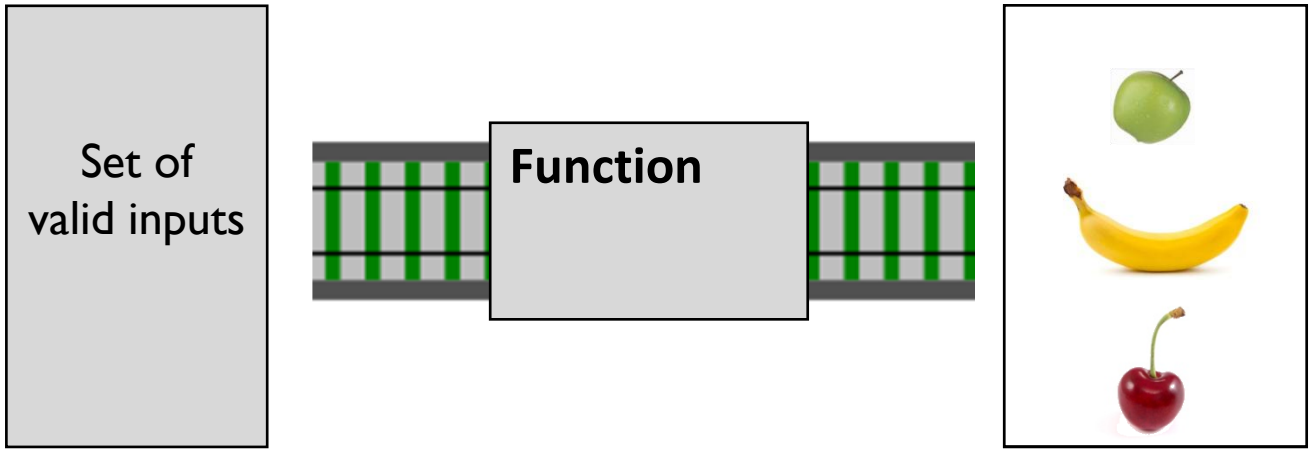
A type is a just a name
for a set of things



This is the set of all people

type Person

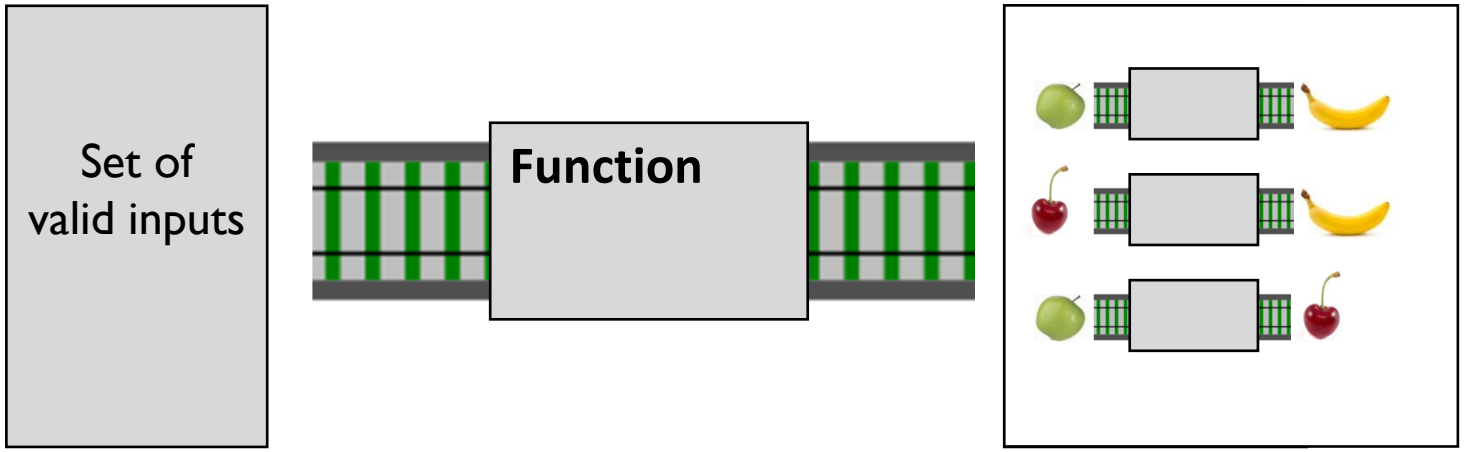
A type is a just a name
for a set of things



This is the set of all fruit

type Fruit

A type is a just a name
for a set of things



This is the set of all functions
with Fruit input and output

type Fruit->Fruit

Composition is type checked!

Different sets

Composition is type checked!

Different sets

Composition everywhere:
Types can be composed too

Composable

~~Algebraic~~ type system

New types are built from smaller types by:

- Composing with "AND"
- Composing with "OR"

Only possible because behavior is separate from data!

Compose with "AND"

FruitSalad = One each of  and  and 

Example: pairs, tuples, records

A record type

```
type FruitSalad = {
    Apple : AppleVariety
    Banana : BananaVariety
    Cherry : CherryVariety
    }
```

Another type, the set of all possible apples

Compose with "OR"

Snack =  or  or 

A choice type

```
type Snack =
    | Apple of AppleVariety
    | Banana of BananaVariety
    | Cherry of CherryVariety
```

Again, the set of all possible apples

A real world example of composing types

Example of some requirements:

We accept three forms of payment:
Cash, PayPal, or Card.

For Cash we don't need any extra information
For PayPal we need an email address
For Cards we need a card type and card number

How would you implement this?

In OO design you would probably implement it as an interface and a set of subclasses, like this:

```
interface IPaymentMethod
{..}

class Cash() : IPaymentMethod
{..}

class PayPal(string emailAddress): IPaymentMethod
{..}

class Card(string cardType, string cardNo) : IPaymentMethod
{..}
```

In FP you would probably implement by composing types, like this:

```
type EmailAddress = string
type CardNumber = string
```

← Primitive types

```
type EmailAddress = ...
type CardNumber = …

type CardType = Visa | Mastercard
type CreditCardInfo = {
   CardType : CardType
   CardNumber : CardNumber
   }
```

Choice type (using OR)

Record type (using AND)

```
type EmailAddress = ...
type CardNumber = ...
type CardType = ...
type CreditCardInfo = ...

type PaymentMethod =
  | Cash
  | PayPal of EmailAddress
  | Card of CreditCardInfo
```

```
type EmailAddress = ...
type CardNumber = ...
type CardType = ...
type CreditCardInfo = ...
type PaymentMethod =
  | Cash
  | PayPal of EmailAddress
  | Card of CreditCardInfo

type PaymentAmount = decimal
type Currency = EUR | USD
```

Another primitive type

Another choice type

```
type EmailAddress = ...
type CardNumber = ...
type CardType = ...
type CreditCardInfo = ...
type PaymentMethod =
  | Cash
  | PayPal of EmailAddress
  | Card of CreditCardInfo
type PaymentAmount = decimal
type Currency = EUR | USD

type Payment = {
  Amount : PaymentAmount
  Currency : Currency
  Method : PaymentMethod  }
```

```
type EmailAddress = ...
type CardNumber = ...
type CardType = ...
type CreditCardInfo = ...
type PaymentMethod =
  | Cash
  | PayPal of EmailAddress
  | Card of CreditCardInfo
type PaymentAmount = decimal
type Currency = EUR | USD

type Payment = {
  Amount : PaymentAmount
  Currency : Currency
  Method : PaymentMethod  }
```

Final type built from many smaller types:

The Power of Composition

FP design principle:

Types are executable documentation

Types are executable documentation

The domain on one screen!

```
type Suit = Club | Diamond | Spade | Heart
type Rank = Two | Three | Four | Five | Six | Seven | Eight
          | Nine | Ten | Jack | Queen | King | Ace
type Card = Suit * Rank

type Hand = Card list
type Deck = Card list

type Player = {Name:string; Hand:Hand}
type Game = {Deck:Deck; Players: Player list}

type Deal = Deck -> (Deck * Card)
type PickupCard = (Hand * Card) -> Hand
```

Types can be nouns

Types can be verbs

Types are executable documentation

```
type CardType = Visa | Mastercard
type CardNumber = CardNumber of string
type CheckNumber = CheckNumber of int

type PaymentMethod =
  | Cash
  | PayPal of EmailAddress
  | Card of CardType * CardNumber
```

The End

This is everything you need to know about functional programming!

Part II

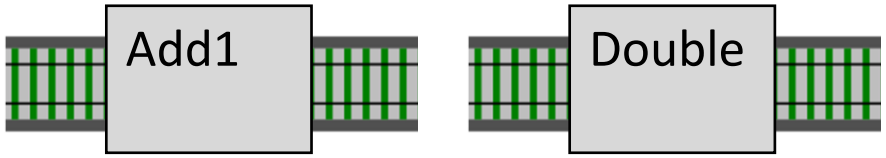
Composition in practice

Composition

```
let add1 x = x + 1
let double x = x + x
let square x = x * x

// in most programming languages,
// composition looks like this...
add1(5)                         // = 6
double(add1(5))                 // = 12
square(double(add1(5)))         // = 144
```

Standard way of nesting function calls can be confusing if too deep

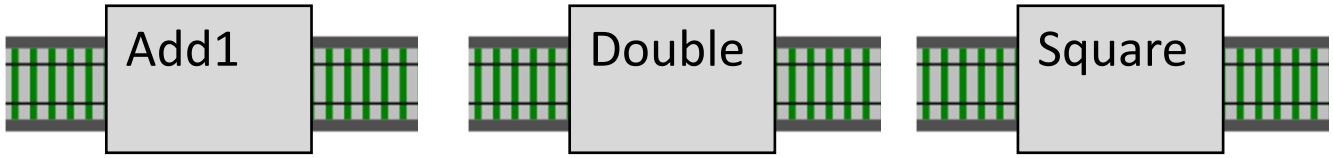
Composition




```
let add1 x = x + 1
let double x = x + x

// in F#, composition looks like this
let add1_double = add1 >> double

let x = add1_double 5    // 12
```

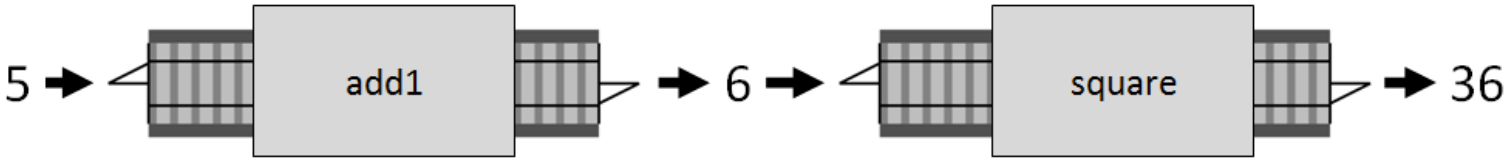
Compositon operator

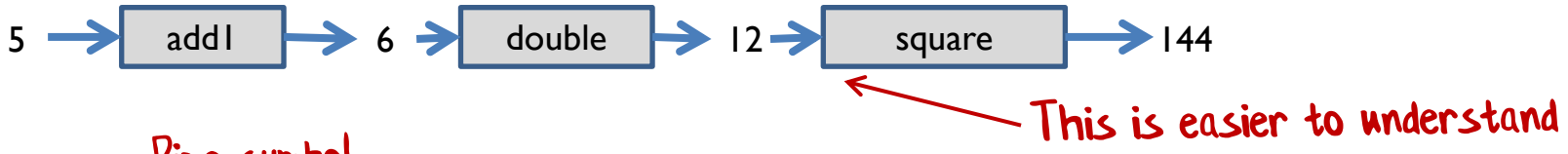
Composition




```
let add1_double_square =
    add1 >> double >> square

let x = add1_double_square 5     // 144
```

Piping





Pipe symbol

```
5 |> add1                          // = 6
5 |> add1 |> double                // = 12
5 |> add1 |> double |> square      // = 144
```

pipe

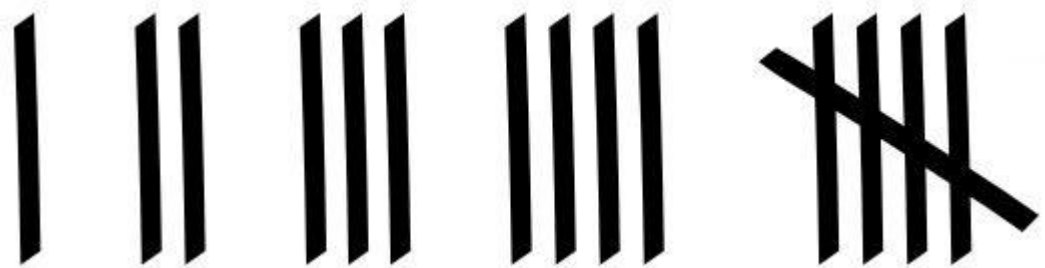
Demo #1:
Piping

Composition in practice:

Roman Numerals Converter

To Roman Numerals

- Task: convert an integer to Roman Numerals
- 5 => "V" 10 => "X" 100 => "C" etc



Roman numbers evolved from this

To Roman Numerals

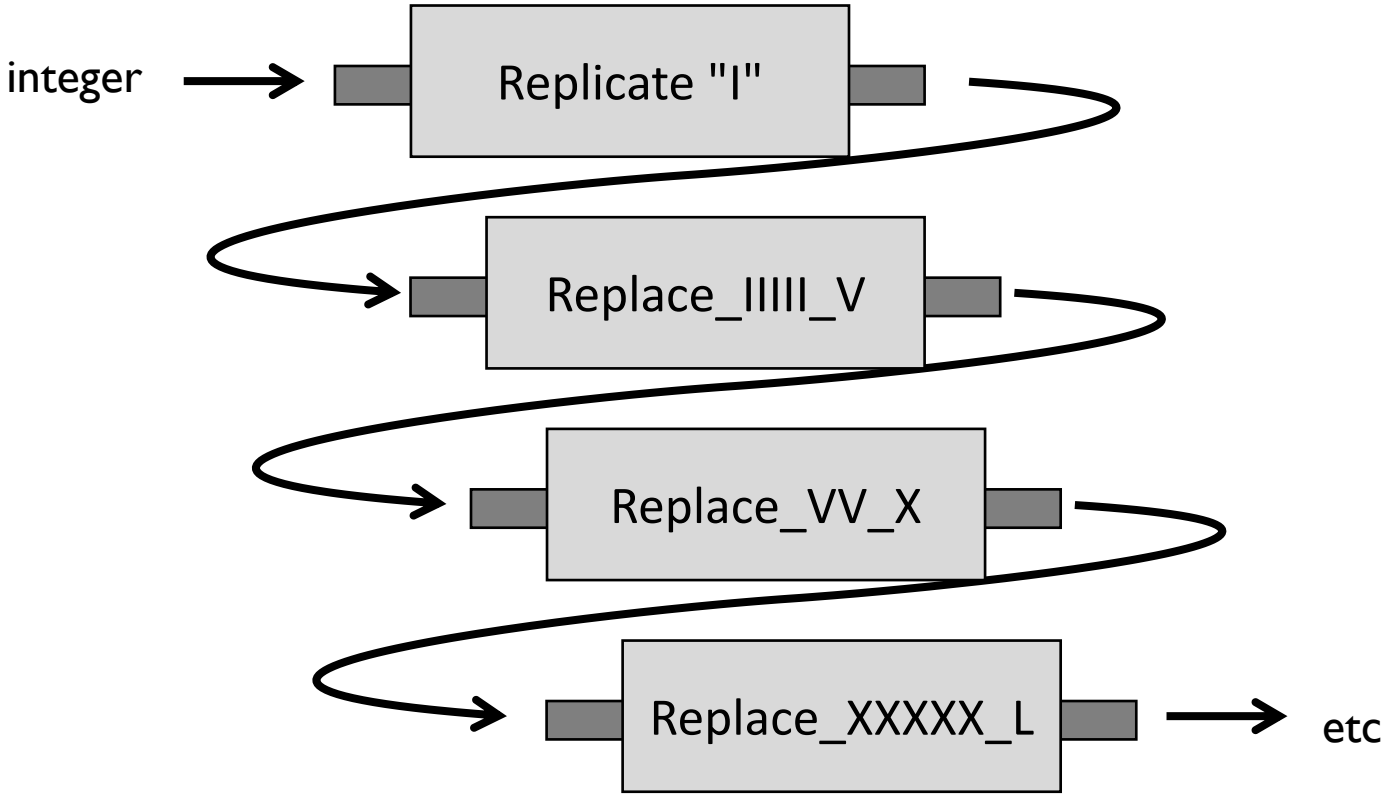
- Use the "tally" approach
  - Start with N copies of "I"
  - Replace five "I"s with a "V"
  - Replace two "V"s with a "X"
  - Replace five "X"s with a "L"
  - Replace two "L"s with a "C"
  - Replace five "C"s with a "D"
  - Replace two "D"s with a "M"

To Roman Numerals

For example, to convert 27

- Start with 27 copies of "I" => "IIIIIIIIIIIIIIIIIIIIIIIII"
- Replace "IIIII" with "V" => "VVVVVII"
- Replace “VV" with "X" => "XXVII"

Implementation using piping

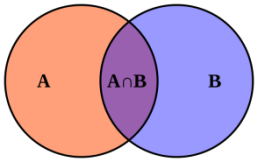


Demo #2:
Roman Numerals

We covered all the core principles of FP

Functions

Types



Composition everywhere

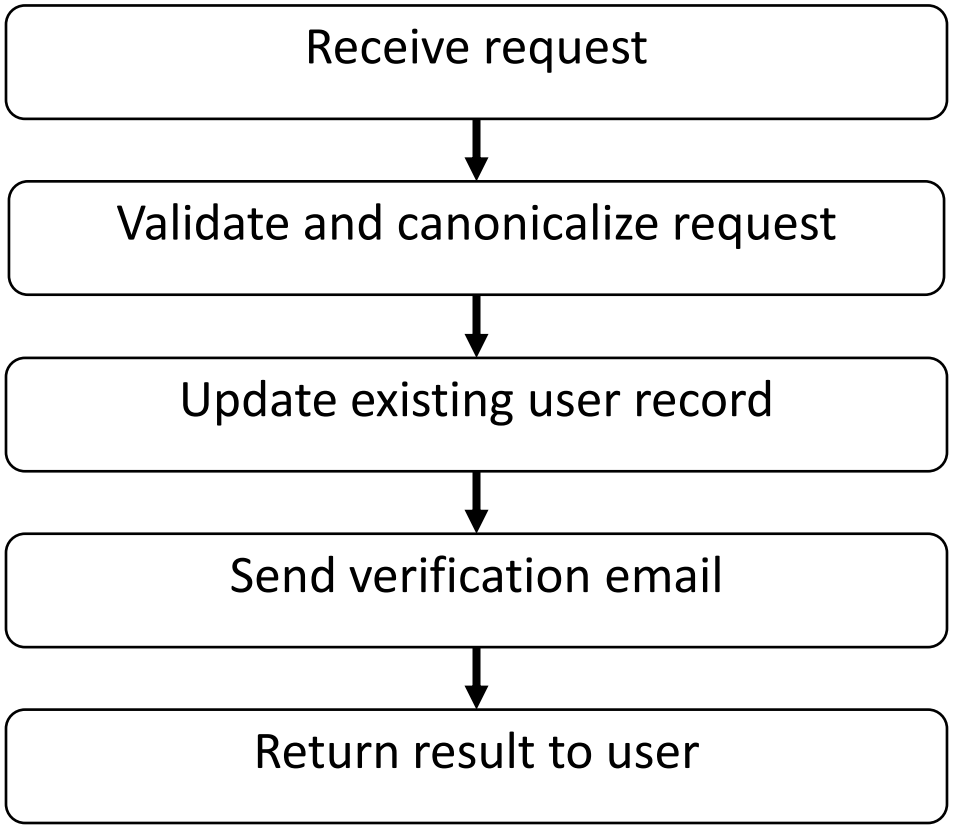
But what if something goes wrong ☹

Part III

Error handling in functional programming

We like to focus on
happy path programming

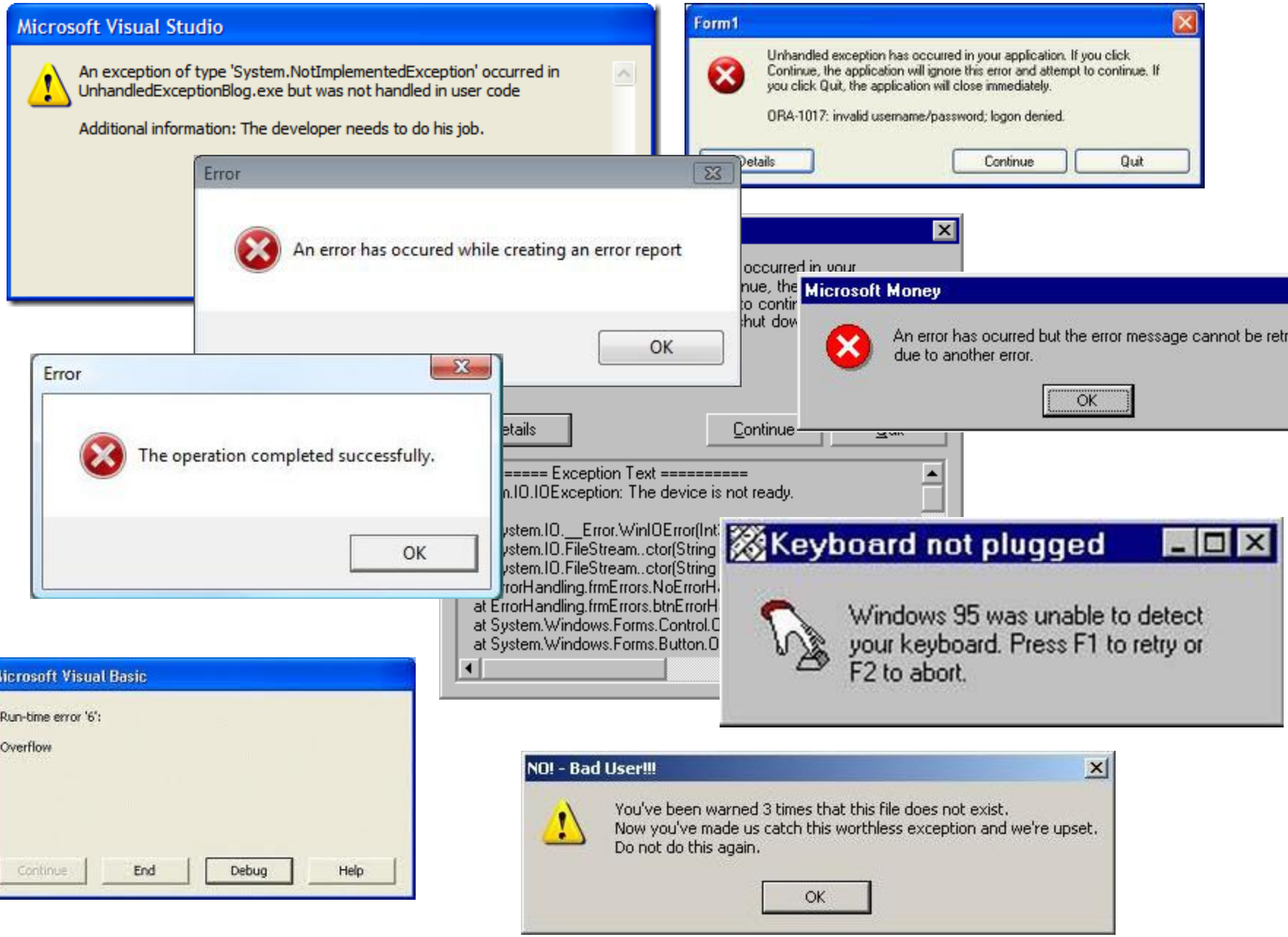
"*As a user I want to update my name and email address*"




```
type Request = {
  userId: int;
  name: string;
  email: string }
```

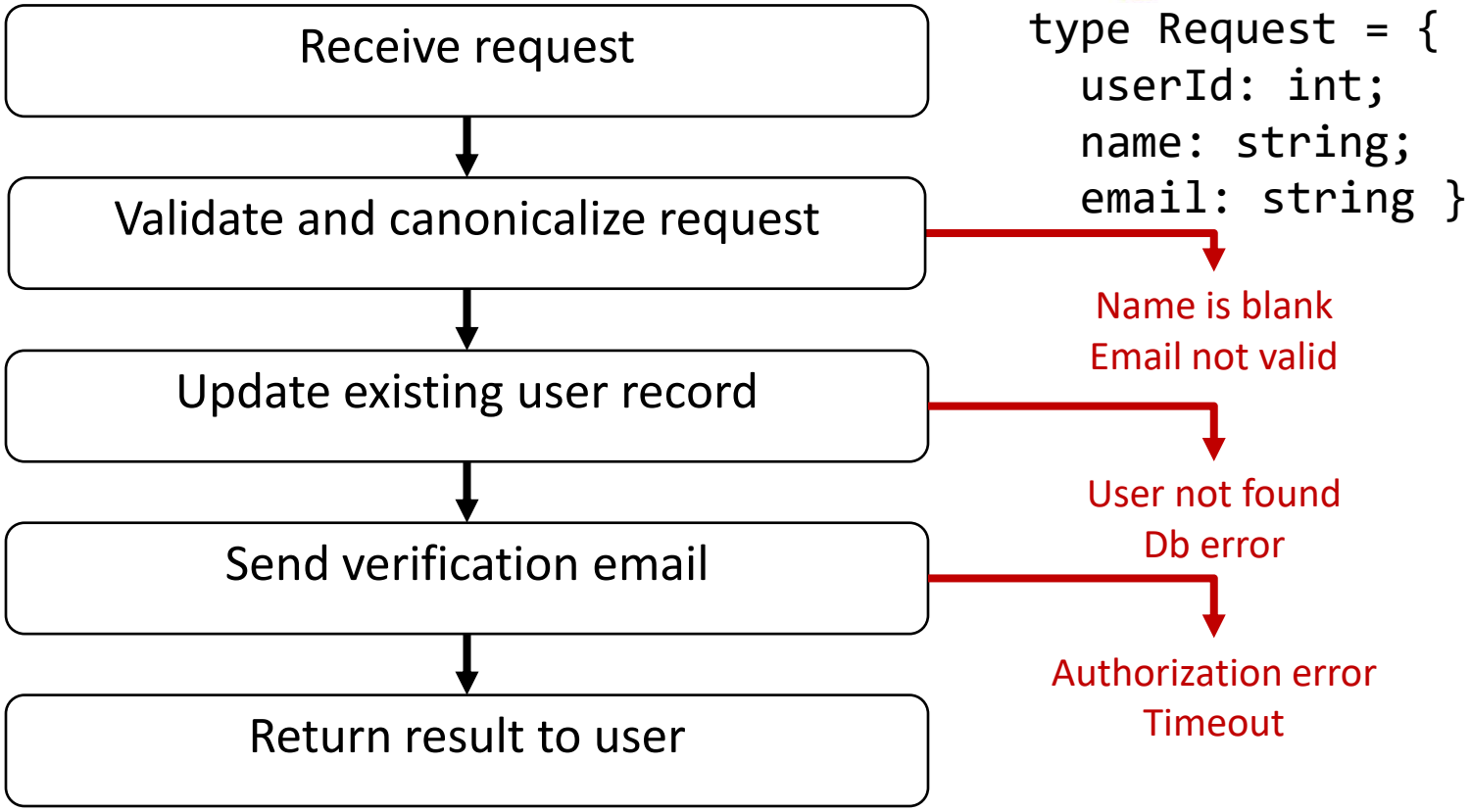
Straying from the happy path...

What do you do when
something goes wrong?


Microsoft Visual Studio
An exception of type 'System.NotImplementedException' occurred in UnhandledExceptionBlog.exe but was not handled in user code
Additional information: The developer needs to do his job.
Form1
Unhandled exception has occurred in your application. If you click Continue, the application will ignore this error and attempt to continue. If you click Quit, the application will close immediately.
ORA-1017: invalid username/password; logon denied.
Details
Continue
Quit
Error
An error has occured while creating an error report
OK
Microsoft Money
An error has ocurred but the error message cannot be retrieved due to another error.
OK
Error
The operation completed successfully.
OK
Continue
===== Exception Text ==========
n.IO.IOException: The device is not ready.
at ErrorHandling.frmErrors.btnErrorH
at System.Windows.Forms.Control.C
at System.Windows.Forms.Button.O
Keyboard not plugged
Windows 95 was unable to detect your keyboard. Press F1 to retry or F2 to abort.
Microsoft Visual Basic
Run-time error '6':
Overflow
Continue
End
Debug
Help
NO! - Bad User!!!
You've been warned 3 times that this file does not exist.
Now you've made us catch this worthless exception and we're upset.
Do not do this again.
OK

"As a user I want to update my name and email address"

- and see sensible error messages when something goes wrong!



```
string UpdateCustomerWithErrorHandling()
{
  var request = receiveRequest();
  validateRequest(request);
  canonicalizeEmail(request);
  db.updateDbFromRequest(request);
  smtpServer.sendEmail(request.Email)

  return "OK";
}
```

```
string UpdateCustomerWithErrorHandling()
{
  var request = receiveRequest();
  var isValidated = validateRequest(request);
  if (!isValidated) {
     return "Request is not valid"
  }
  canonicalizeEmail(request);
  db.updateDbFromRequest(request);
  smtpServer.sendEmail(request.Email)

  return "OK";
}
```

```
string UpdateCustomerWithErrorHandling()
{
  var request = receiveRequest();
  var isValidated = validateRequest(request);
  if (!isValidated) {
     return "Request is not valid"
  }
  canonicalizeEmail(request);
  var result = db.updateDbFromRequest(request);
  if (!result) {
    return "Customer record not found"
  }

  smtpServer.sendEmail(request.Email)

  return "OK";
}
```

```
string UpdateCustomerWithErrorHandling()
{
  var request = receiveRequest();
  var isValidated = validateRequest(request);
  if (!isValidated) {
     return "Request is not valid"
  }
  canonicalizeEmail(request);
  try {
    var result = db.updateDbFromRequest(request);
    if (!result) {
      return "Customer record not found"
    }
  } catch {
    return "DB error: Customer record not updated"
  }

  smtpServer.sendEmail(request.Email)

  return "OK";
}
```

```
string UpdateCustomerWithErrorHandling()
{
  var request = receiveRequest();
  var isValidated = validateRequest(request);
  if (!isValidated) {
     return "Request is not valid"
  }
  canonicalizeEmail(request);
  try {
    var result = db.updateDbFromRequest(request);
    if (!result) {
      return "Customer record not found"
    }
  } catch {
    return "DB error: Customer record not updated"
  }

  if (!smtpServer.sendEmail(request.Email)) {
    log.Error "Customer email not sent"
  }

  return "OK";
}
```

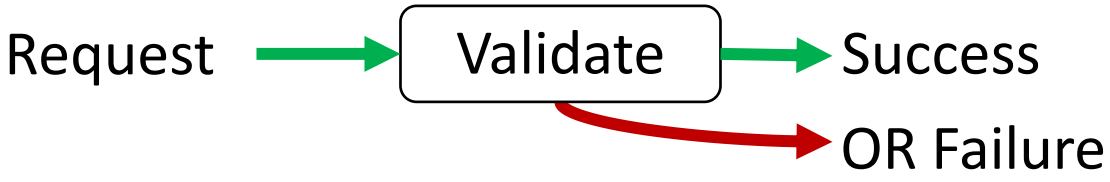
```
string UpdateCustomerWithErrorHandling()
{
  var request = receiveRequest();
  var isValidated = validateRequest(request);
  if (!isValidated) {
     return "Request is not valid"
  }
  canonicalizeEmail(request);
  try {
    var result = db.updateDbFromRequest(request);
    if (!result) {
      return "Customer record not found"
    }
  } catch {
    return "DB error: Customer record not updated"
  }

  if (!smtpServer.sendEmail(request.Email)) {
    log.Error "Customer email not sent"
  }

  return "OK";
}
```

Q: What is the functional equivalent of this code?

Can we preserve the elegance of the original functional version?

6 clean lines -> 18 ugly lines. 200% extra!
Sadly this is typical of error handling code.

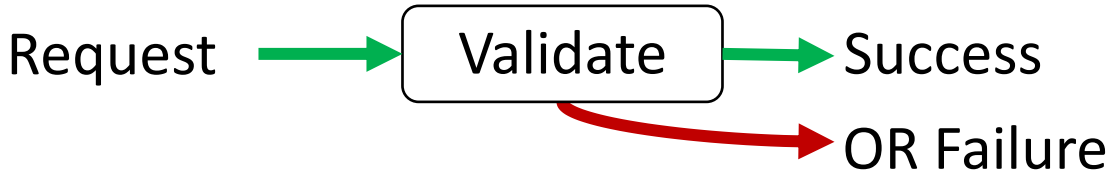
Using a *Result* type for error handling




```
type Result =
    | Ok of SuccessValue
    | Error of ErrorValue
```

Define a choice type details of the error

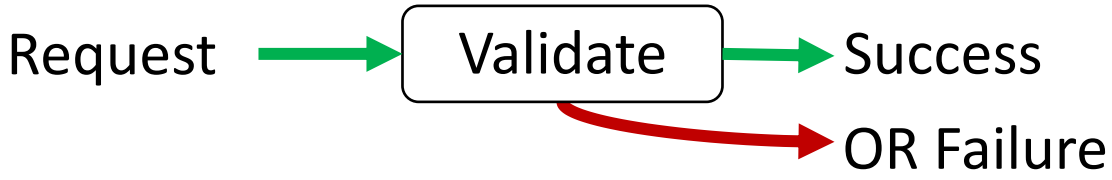
But this is not generic, so...




```
type Result<'SuccessType,'ErrorType> =
    | Ok of 'SuccessType
    | Error of 'ErrorType
```

A generic, reusable Result type

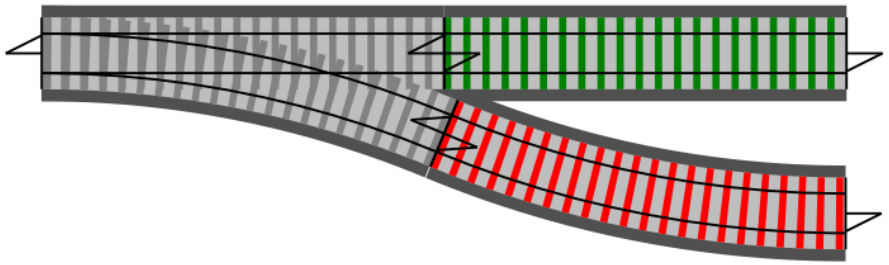
This type is built-in to F#, but if not, you could always define it yourself.




```
let validateInput input =
    if input.name = "" then
        Error "Name must not be blank"
    else if input.email = "" then
        Error "Email must not be blank"
    else
        Ok input  // happy path
```

We have data for both success and failure paths

Input ->

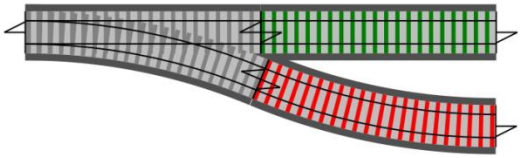


Success!

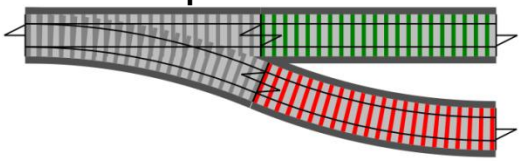
Failure

We design all functions to return choices like this...

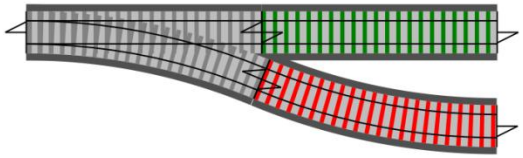
Validate



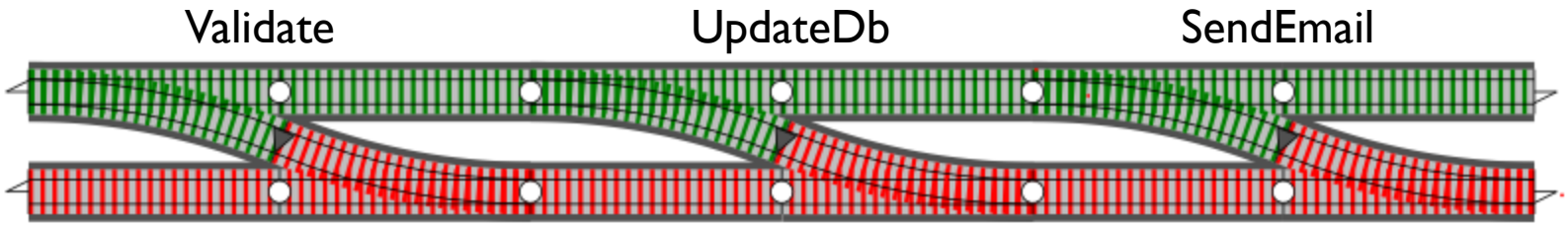
UpdateDb



SendEmail



...and then compose them together into a pipeline



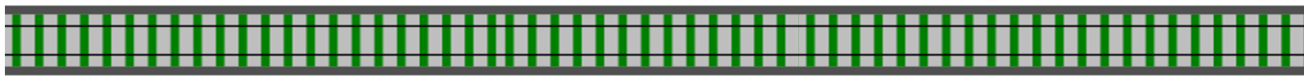
This is the "two track" model –
the basis for the "Railway Oriented Programming"
approach to error handling.

Functional flow without error handling

Before error handling

```
let updateCustomer =
  receiveRequest()
  |> validateRequest
  |> canonicalizeEmail
  |> updateDbFromRequest
  |> sendEmail
  |> returnMessage
```

One track

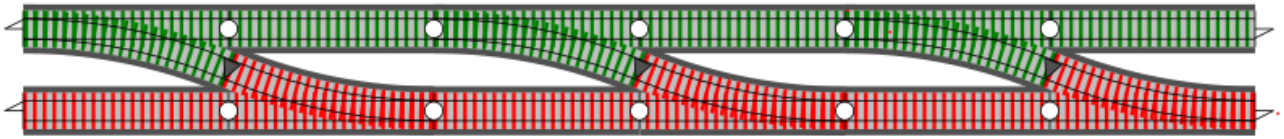


Functional flow with error handling

After

```
let updateCustomerWithErrorHandling =
  receiveRequest()
  |> validateRequest
  |> canonicalizeEmail
  |> updateDbFromRequest
  |> sendEmail
  |> returnMessage
```

Two track

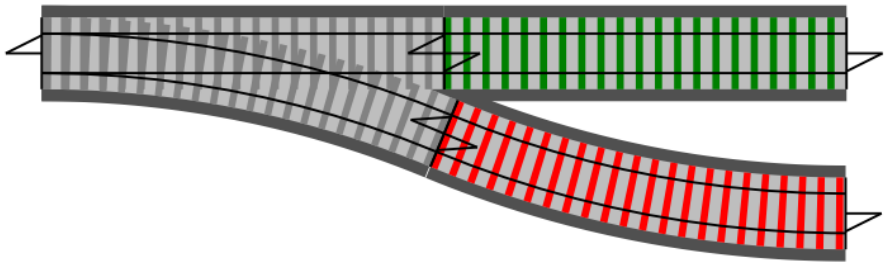


I will show you this code soon!

How to compose railway functions

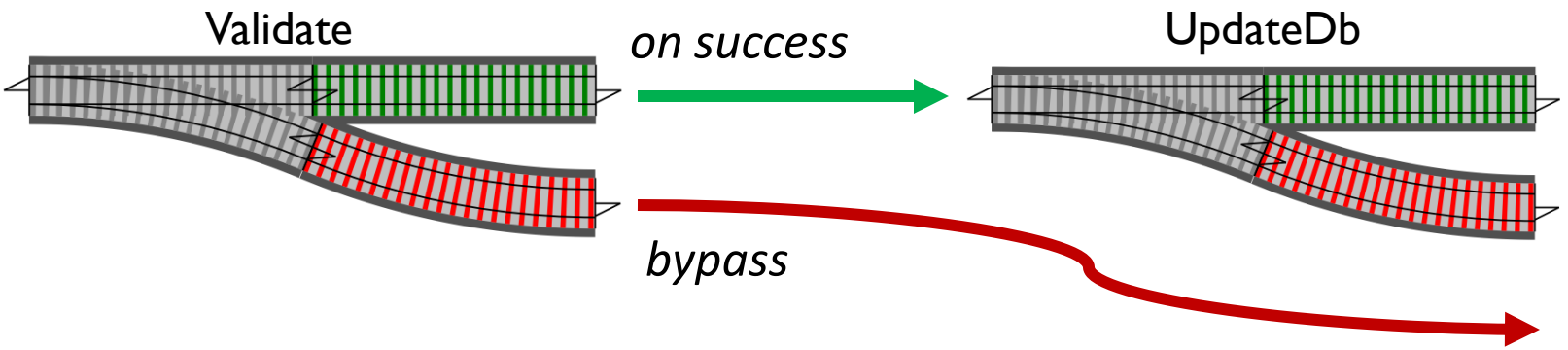
a.k.a. "Railway Oriented Programming"

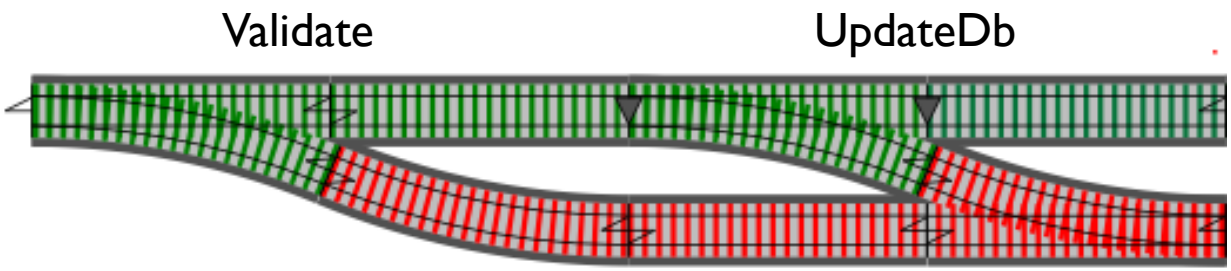
Input ->



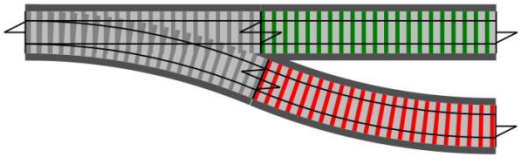
Success!

Failure

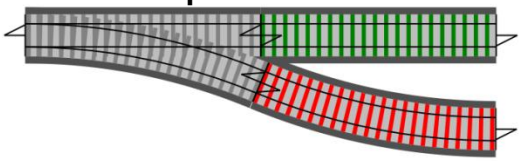

Validate
on success
UpdateDb
bypass


Validate
UpdateDb

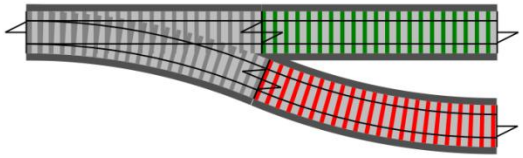
Validate

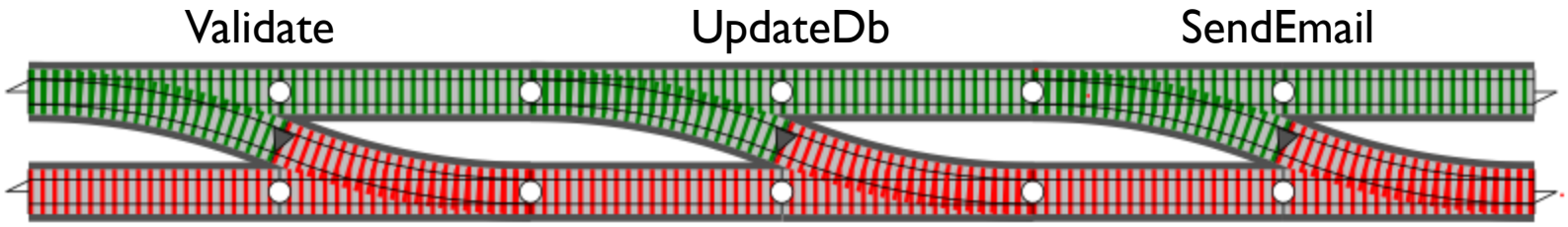


UpdateDb



SendEmail

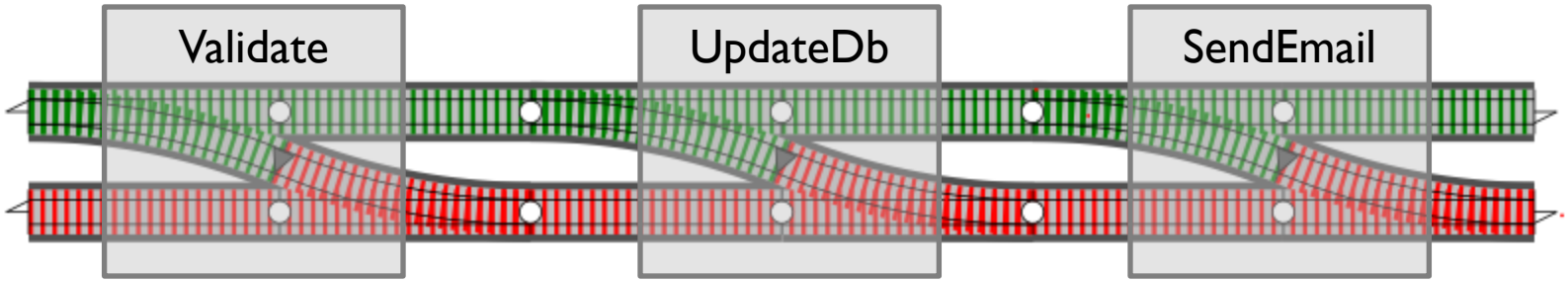




Composition is obvious in theory!

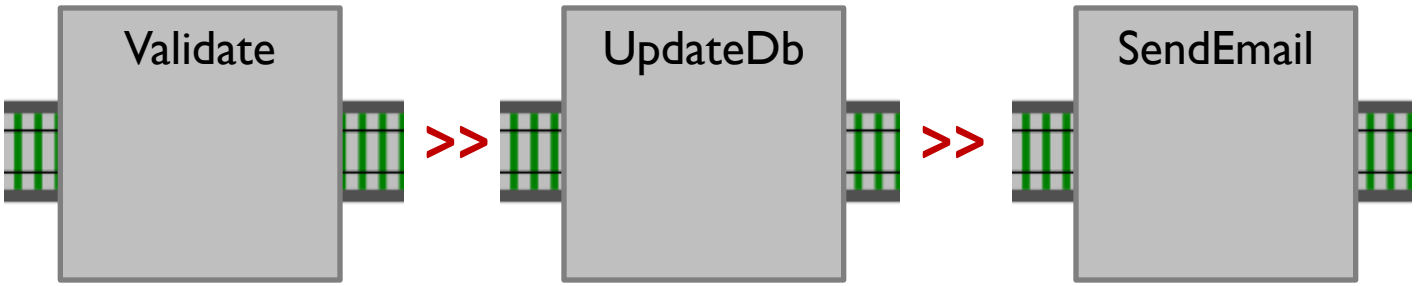
But how do you do it in practice?

How to compose
these functions?

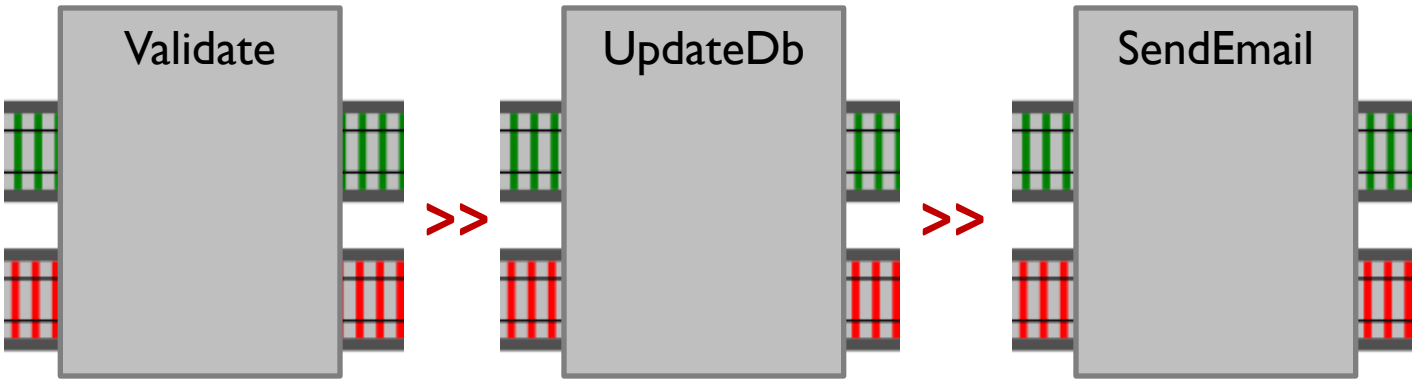


Here we have a series of black box functions
that are straddling a two-track railway.

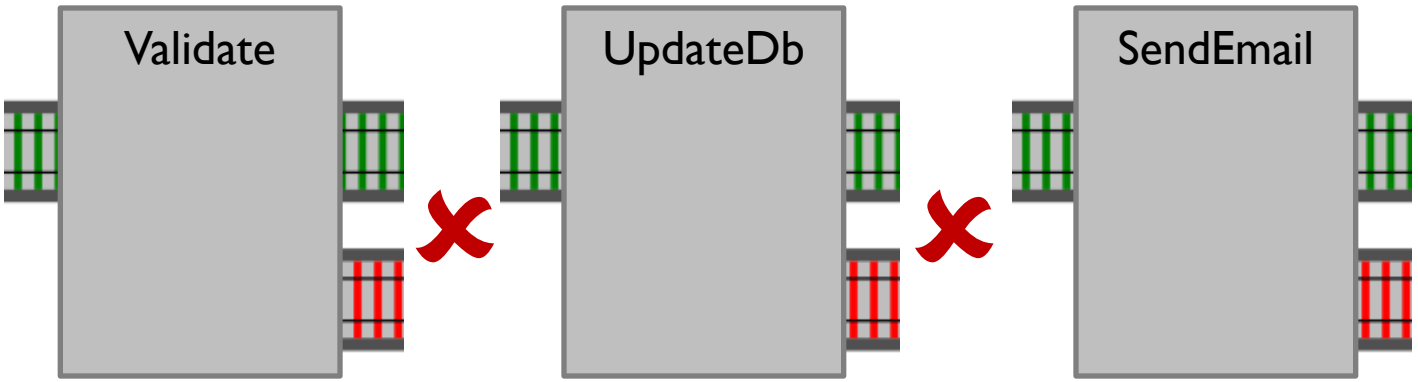
Inside each box there is a switch function.



Composing one-track functions is fine...

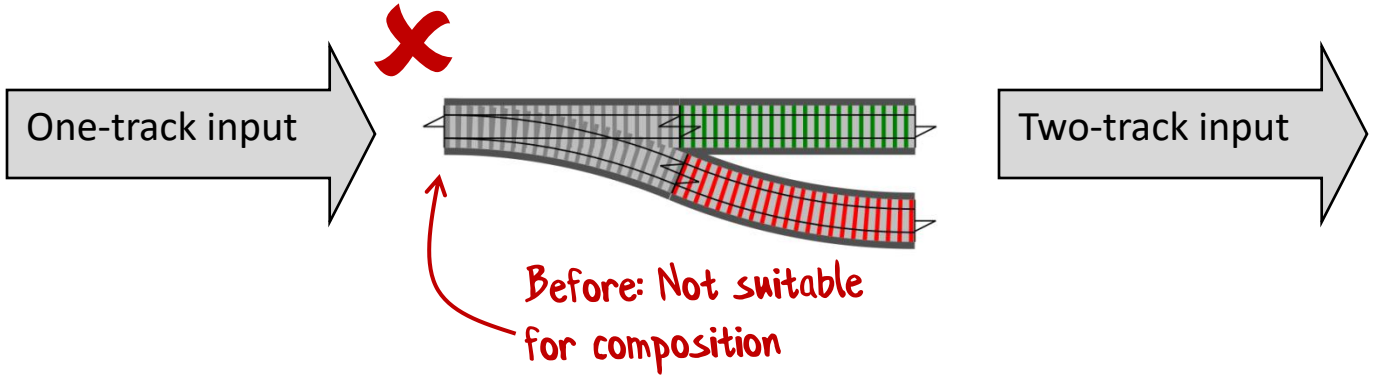


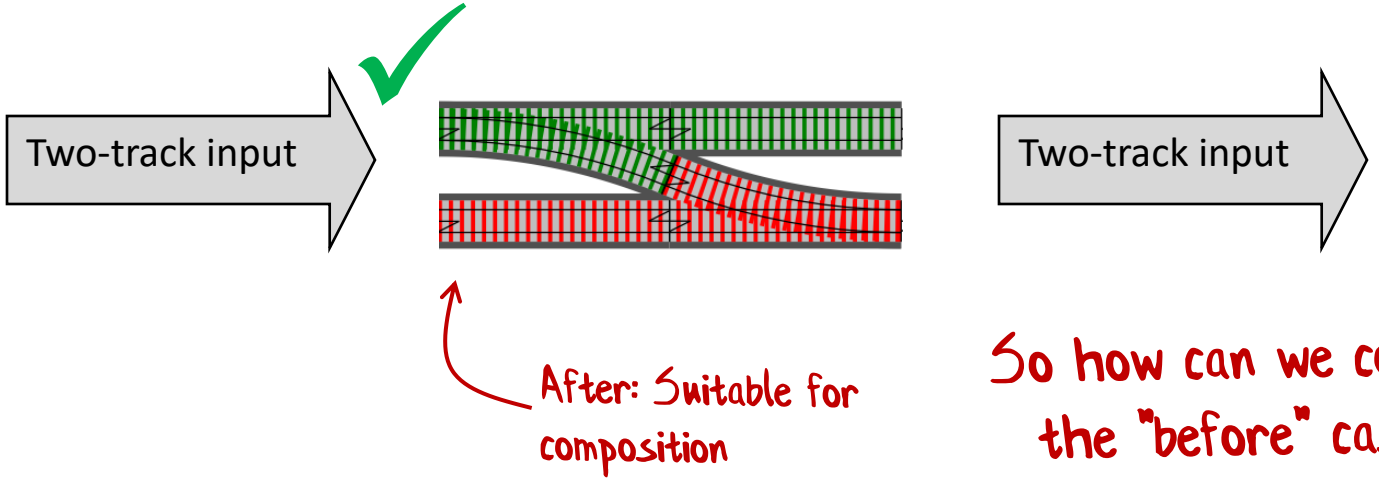
... and composing two-track functions is fine...



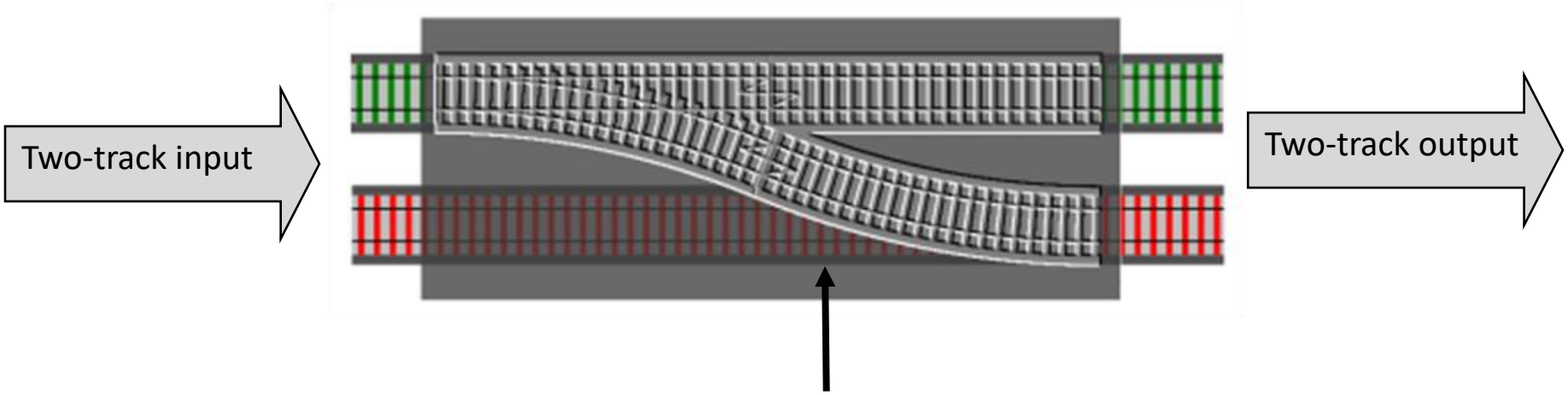
... but composing switches is not allowed!

How to combine the mismatched functions?

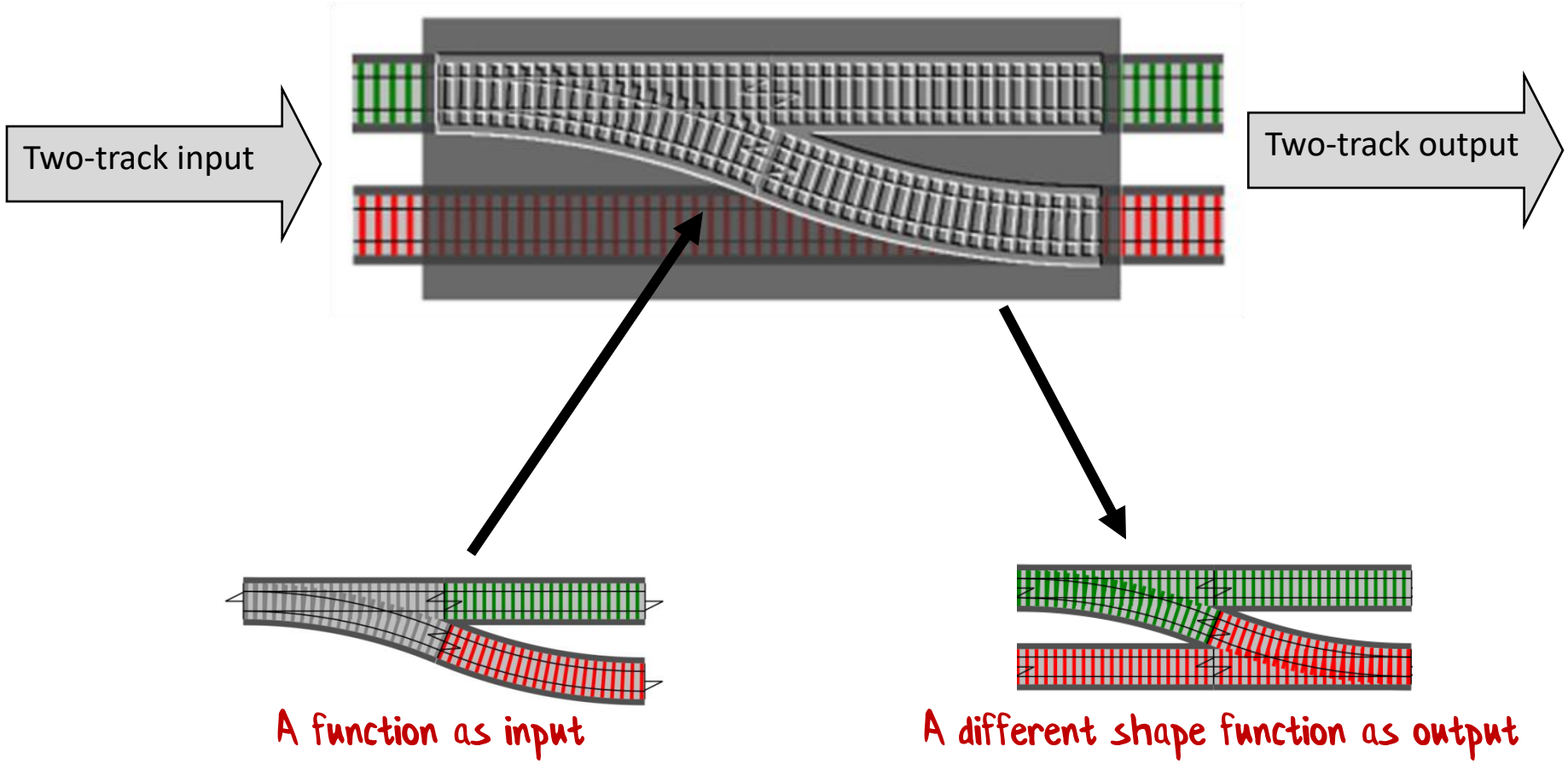


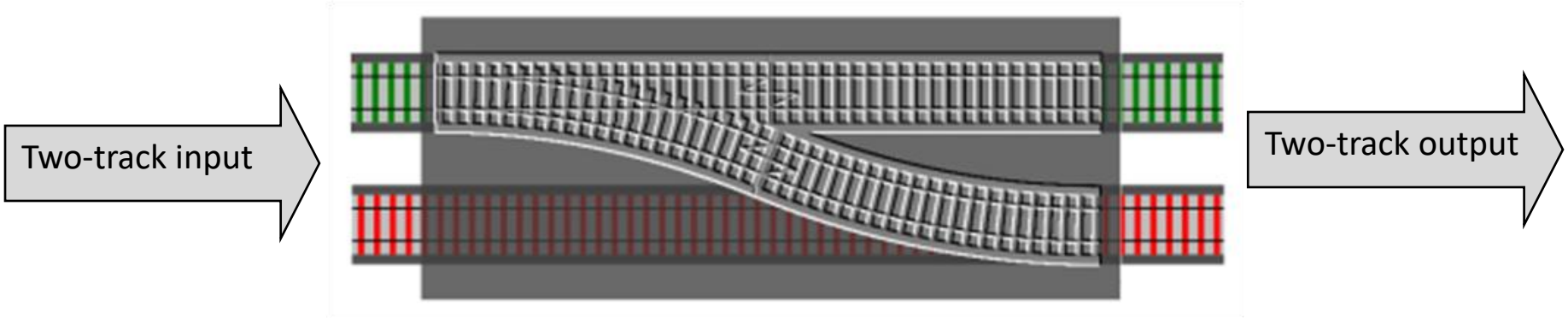


So how can we convert from the "before" case to the "after" case?


Two-track input
Two-track output
Slot for switch function

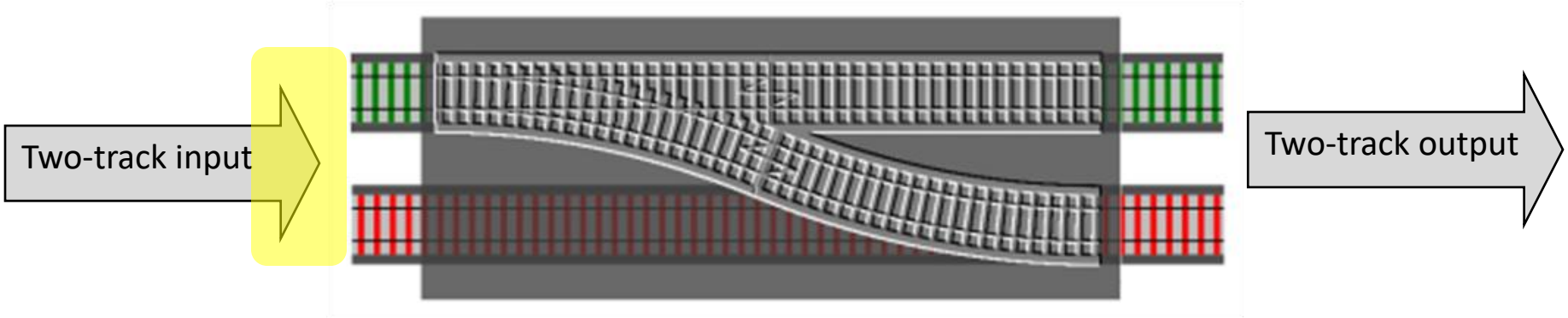
This adapter block is
a "function transformer"





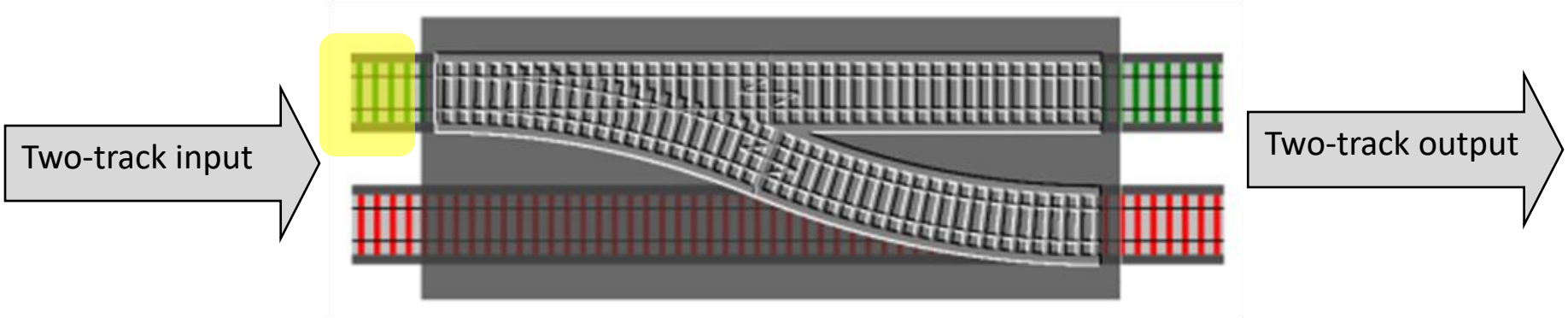

```
let bind nextFunction result =
    match result with
    | Ok s -> nextFunction s
    | Error e -> Error e
```

"bind" is the common name for this kind of function.
Also called "flatMap" or "andThen" or ">>=".
In LINQ it's "SelectMany"



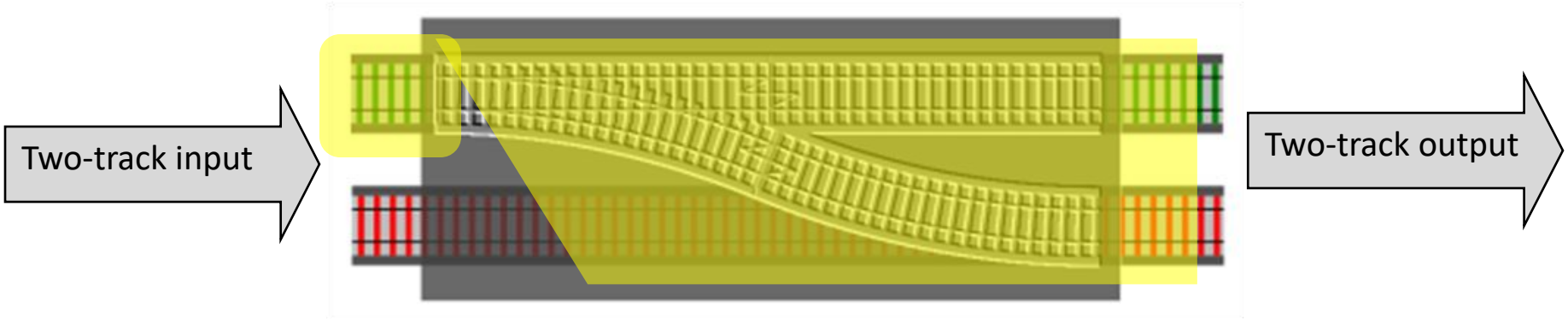

```
let bind nextFunction result =
    match result with
    | Ok s -> nextFunction s
    | Error e -> Error e
```

The input is a two-track value

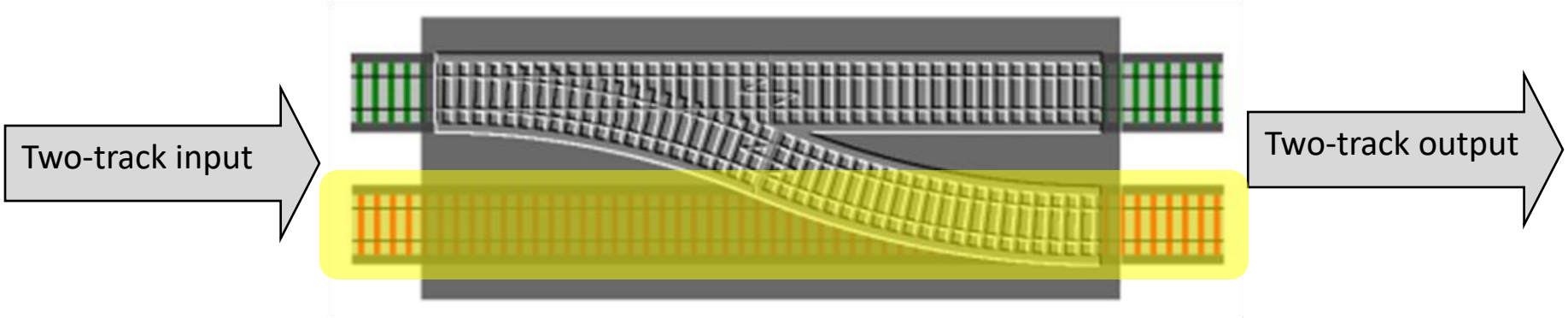



```
let bind nextFunction result =
    match result with
    | Ok s -> nextFunction s
    | Error e -> Error e
```

a) Handle the Ok track



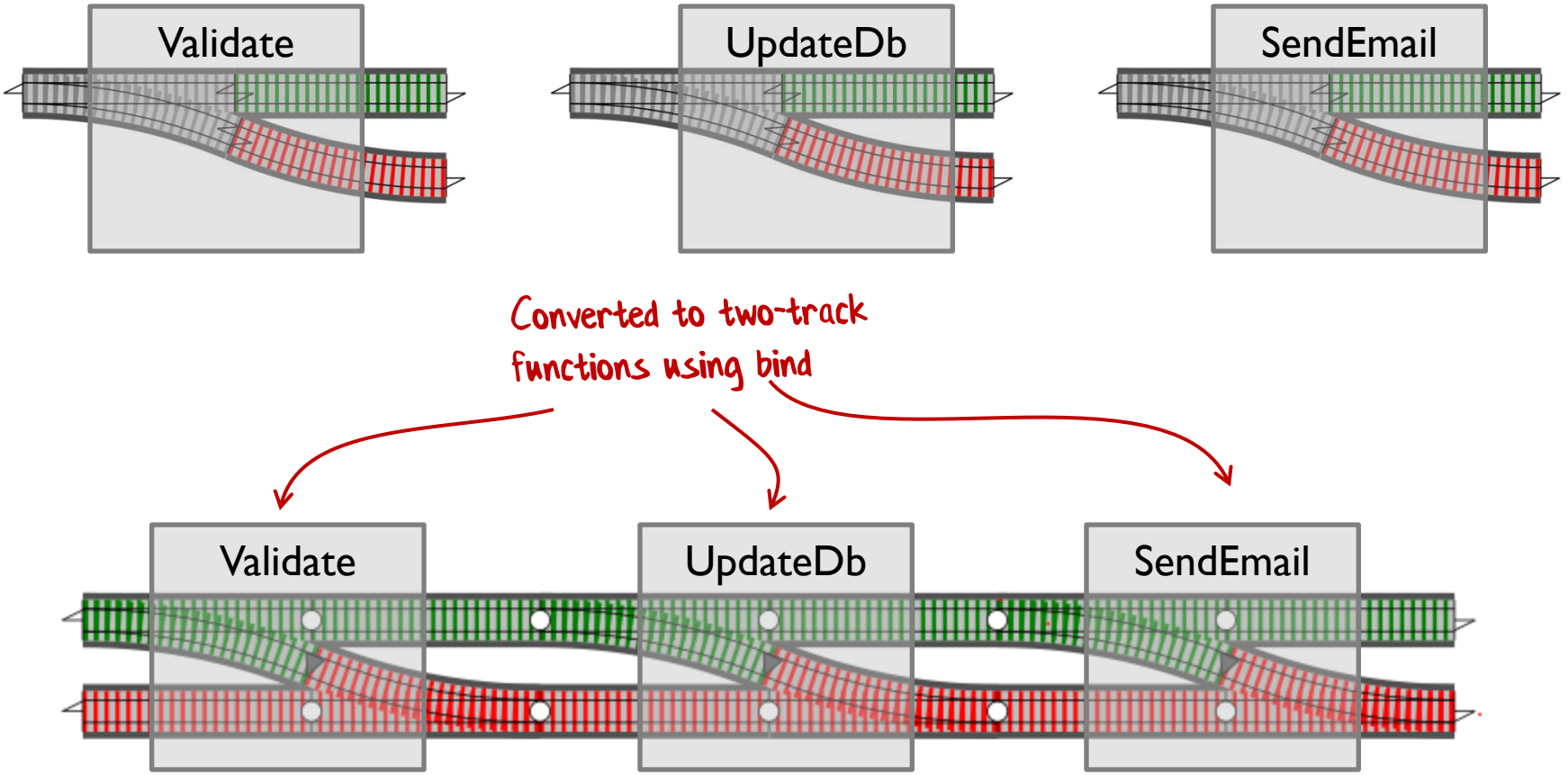

```
let bind nextFunction result =
    match result with
    | Ok s -> nextFunction s
    | Error e -> Error e
```




```
let bind nextFunction result =
    match result with
    | Ok s -> nextFunction s
    | Error e -> Error e
```

b) Handle the Error track

Composing switches - review



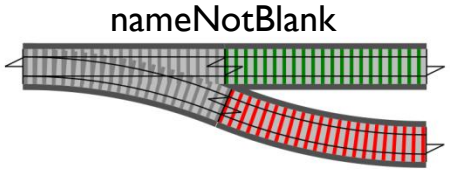
Bind example

Validating input

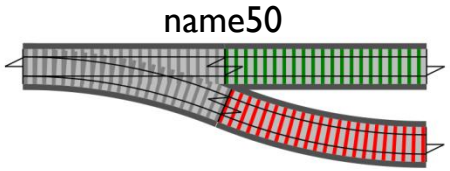
```
type Request = {
    Name : string
    Email : string
}
```

Is this data valid?

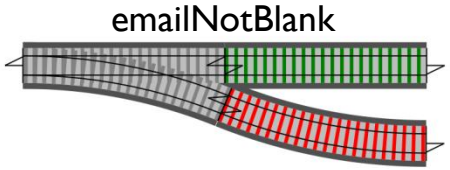
```
let checkNameNotBlank input =
  if input.Name = "" then
     Error "Name must not be blank"
  else
     Ok input
```

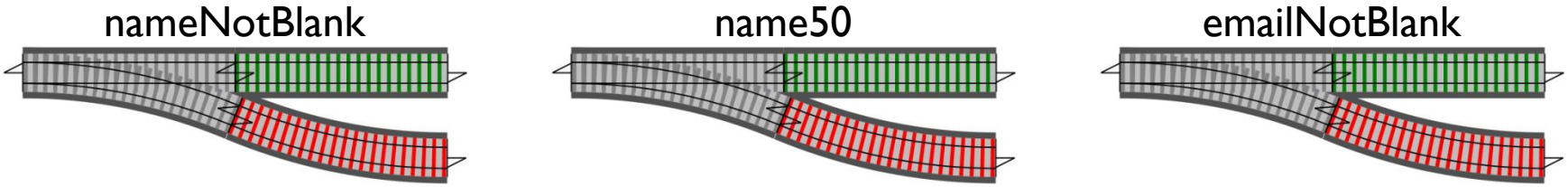



```
let checkName50 input =
  if input.Name.Length > 50 then
     Error "Name must not be longer than 50 chars"
  else
     Ok input
```

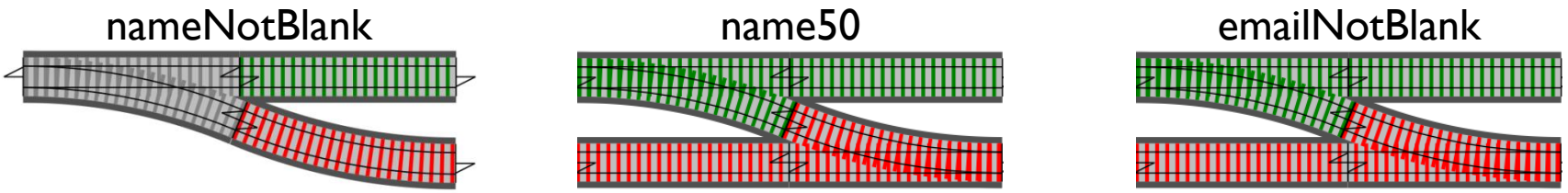



```
let checkEmailNotBlank input =
  if input.Email = "" then
     Error "Email must not be blank"
  else
     Ok input
```






```
checkNameNotBlank (composed with)
            checkName50 (composed with)
                                checkEmailNotBlank
```

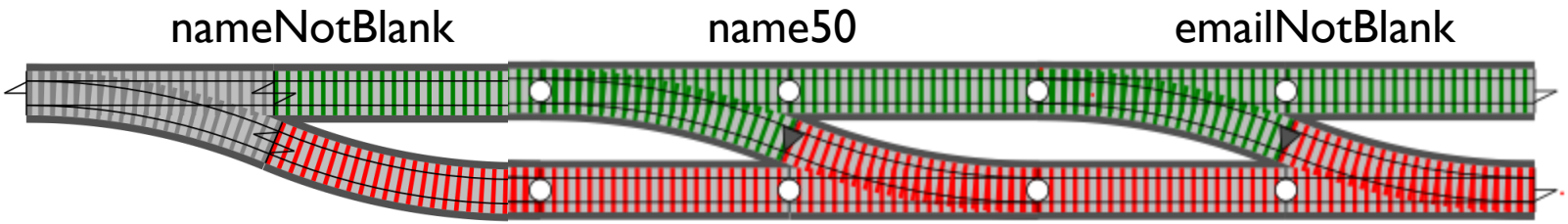



```
checkNameNotBlank
```

```
bind checkName50
```

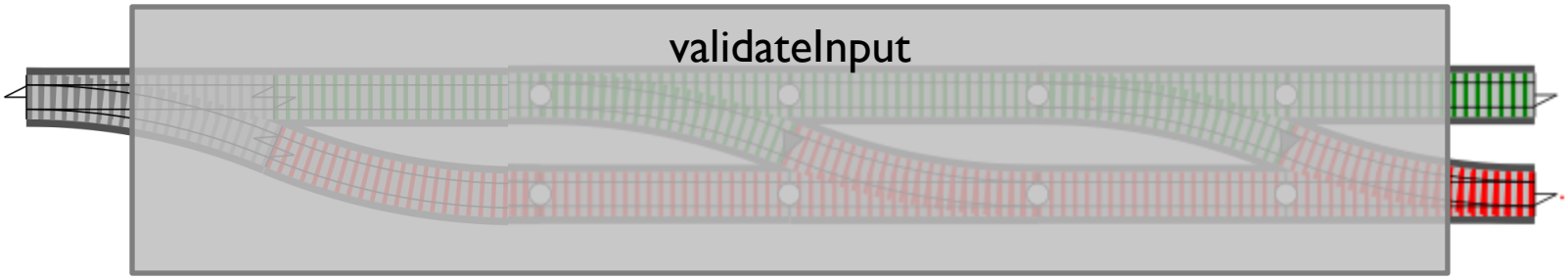
```
bind checkEmailNotBlank
```

use "bind" to
convert to 2-track




```
request
|> checkNameNotBlank
|> Result.bind checkName50
|> Result.bind checkEmailNotBlank
```

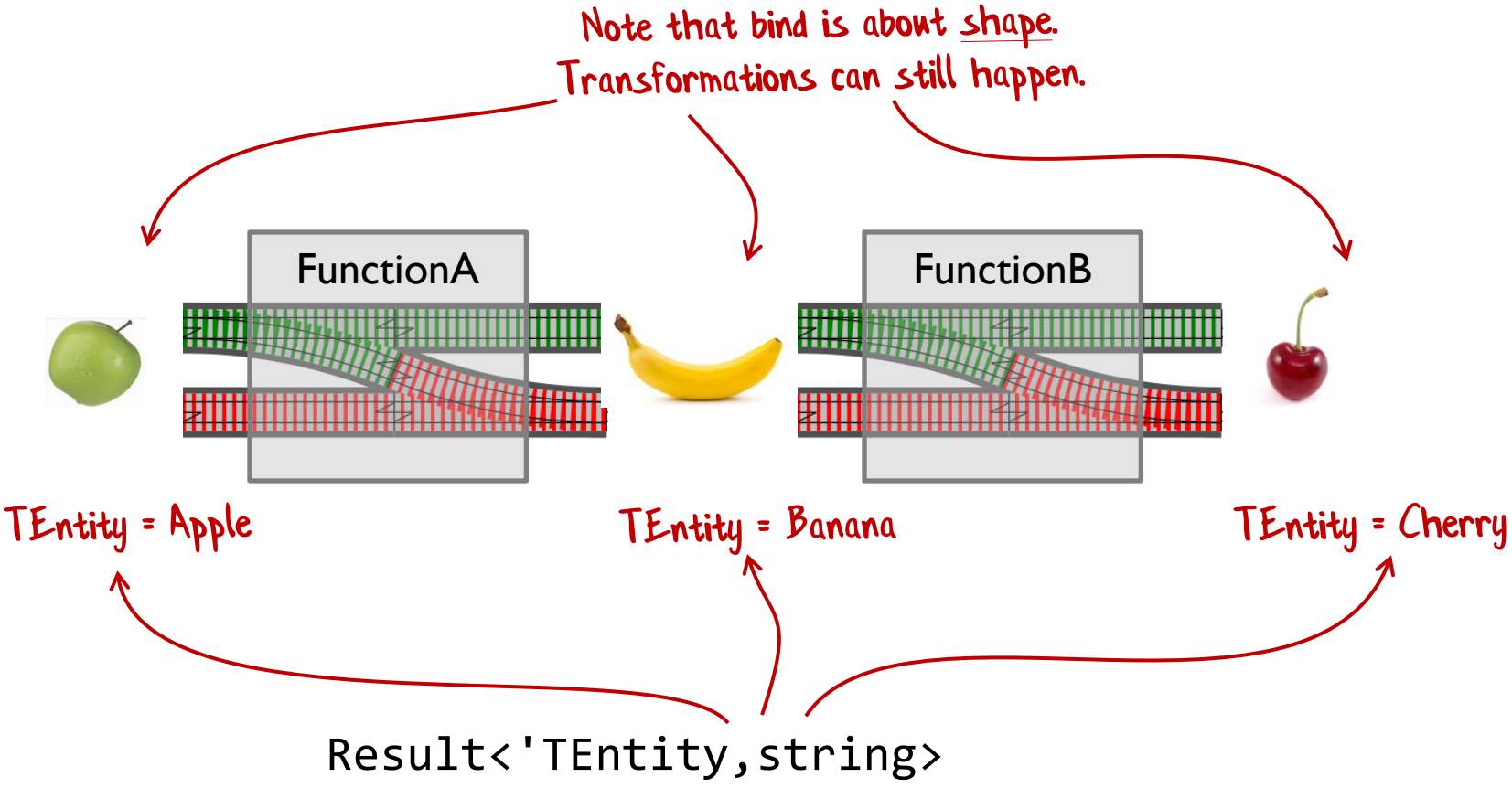
then compose together



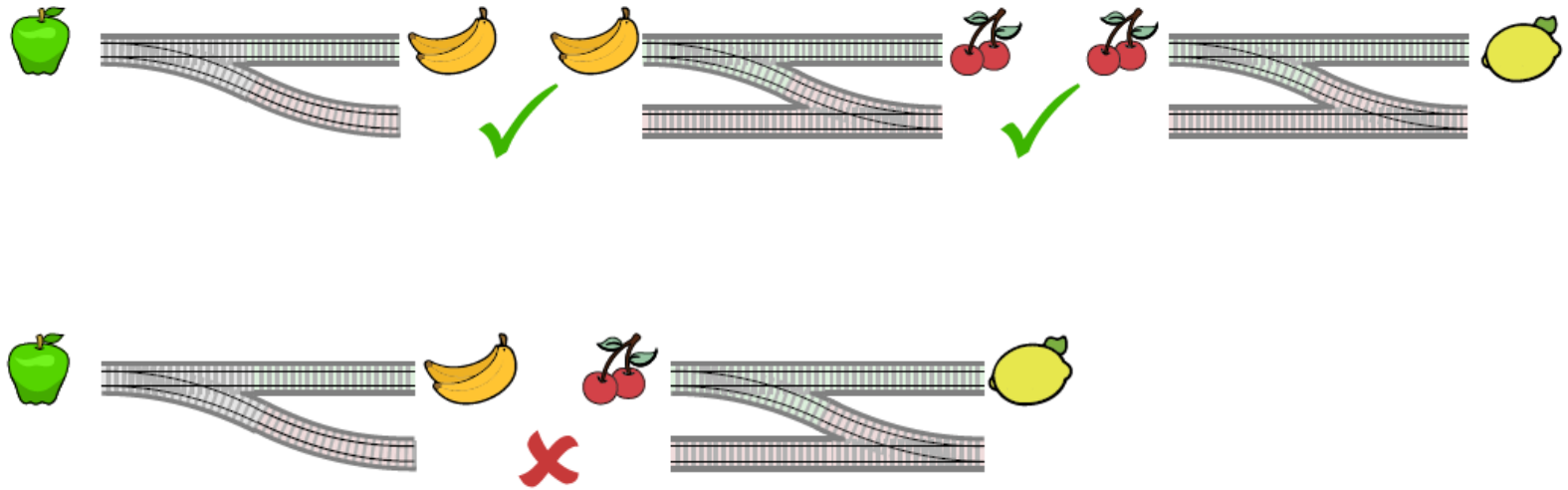
Define a function

```
let validateInput input =
  input
  |> checkNameNotBlank
  |> Result.bind checkName50
  |> Result.bind checkEmailNotBlank
```

Overall result is a new two-track function


Note that bind is about shape.
Transformations can still happen.
FunctionA
FunctionB
TEntity = Apple
TEntity = Banana
TEntity = Cherry
Result<'TEntity,string>

Type checking still applies



Demo #3:

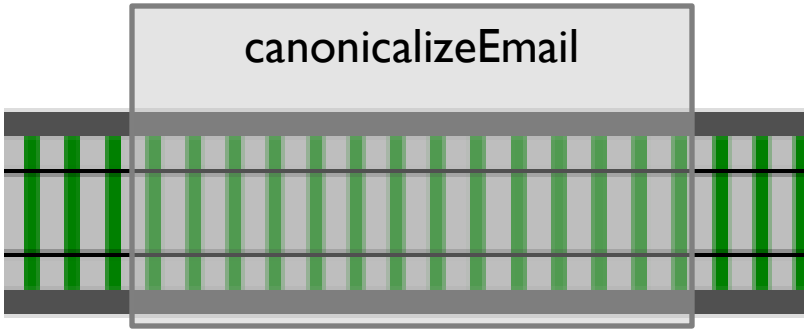
Bind example

Part IV:

Handling different "shapes" of track

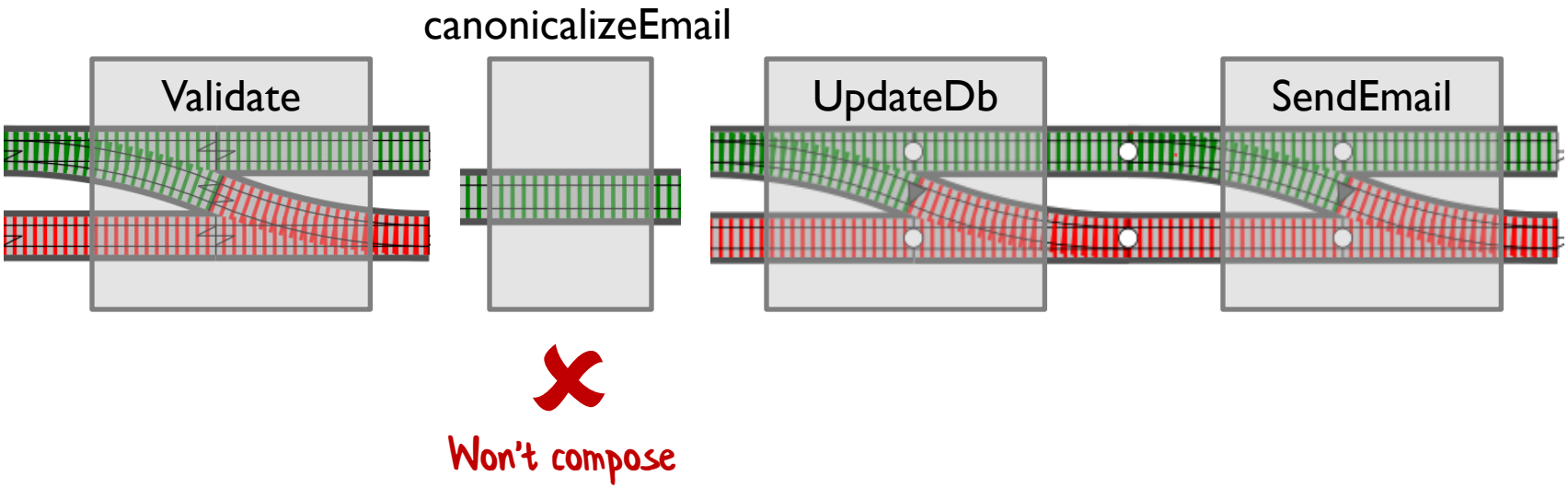
Not everything looks like that!

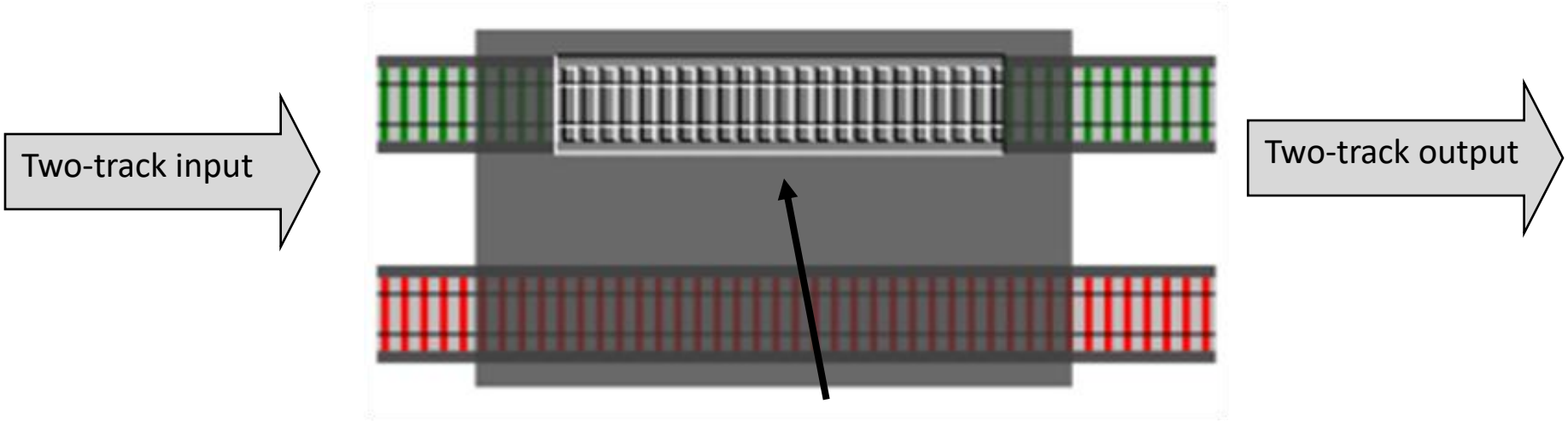
Working with "one-track" functions



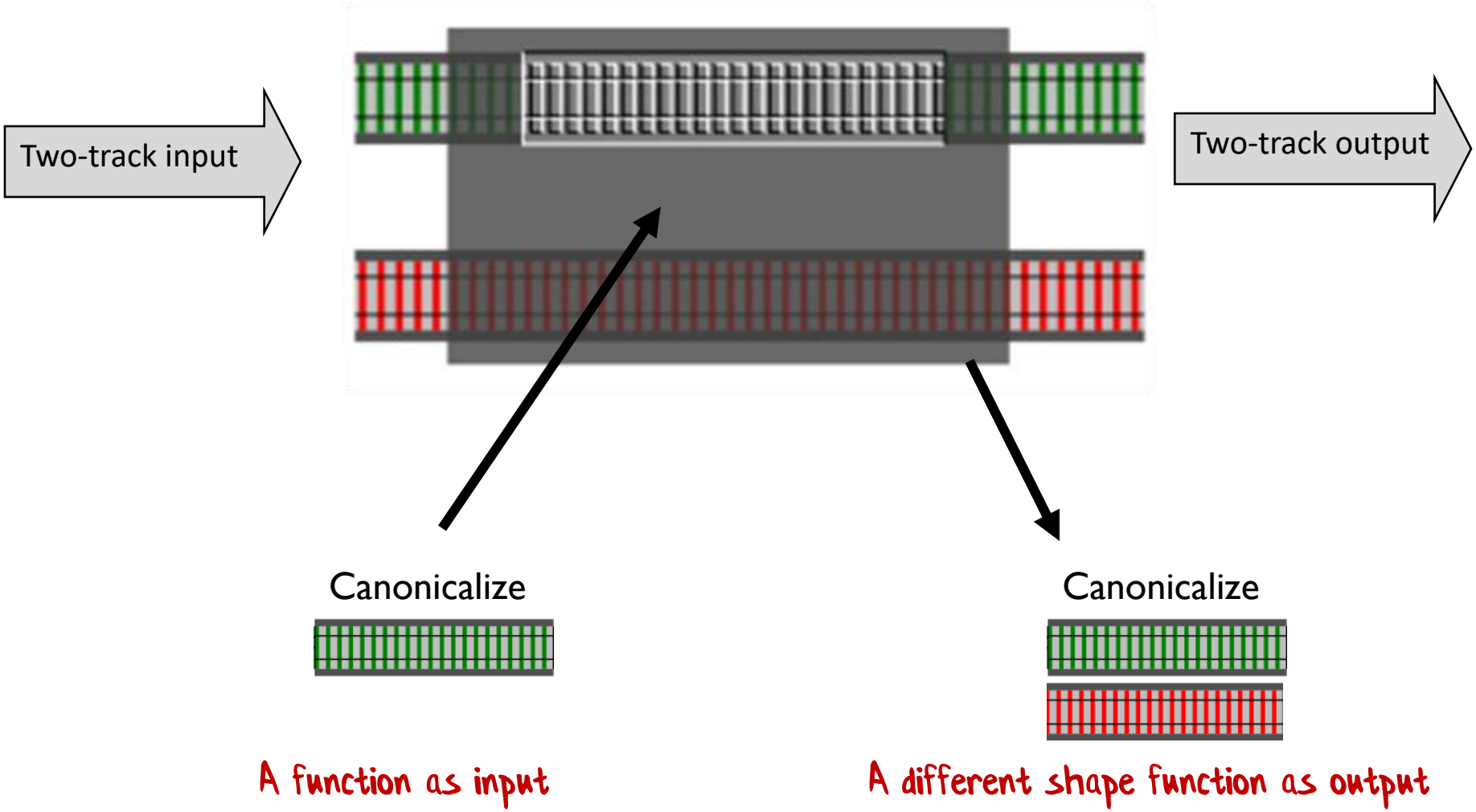

```
// trim spaces and lowercase
let canonicalizeEmail input =
   { input with email = input.email.Trim().ToLower() }
```

A simple function that doesn't generate errors — a "one-track" function.


canonicalizeEmail
Validate
UpdateDb
SendEmail
Won't compose

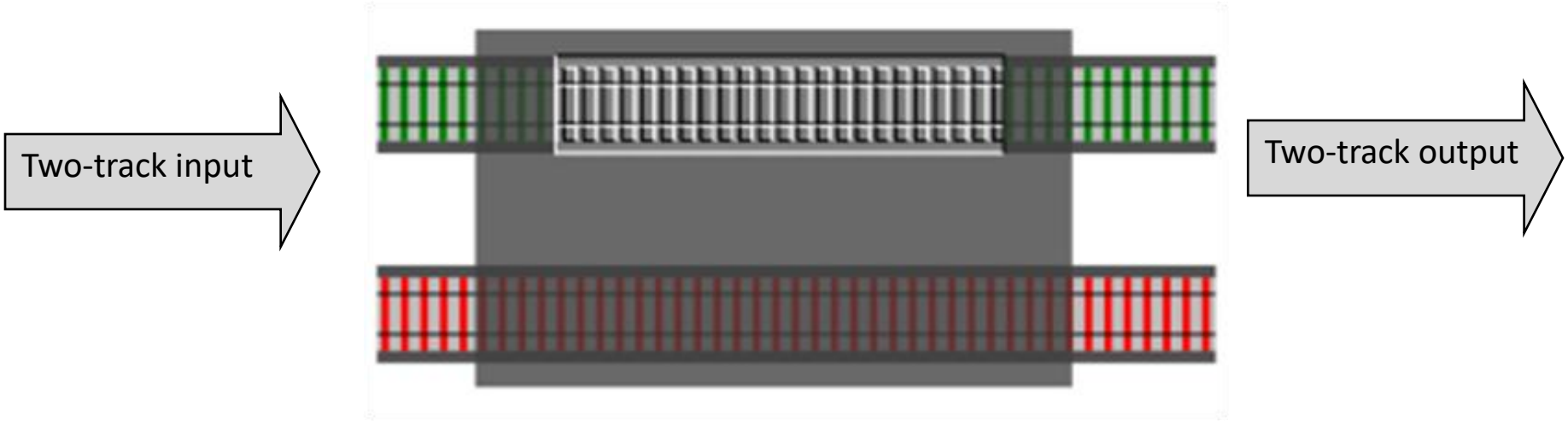

Two-track input
Two-track output
Slot for one-track function

This adapter block is
another "function transformer"



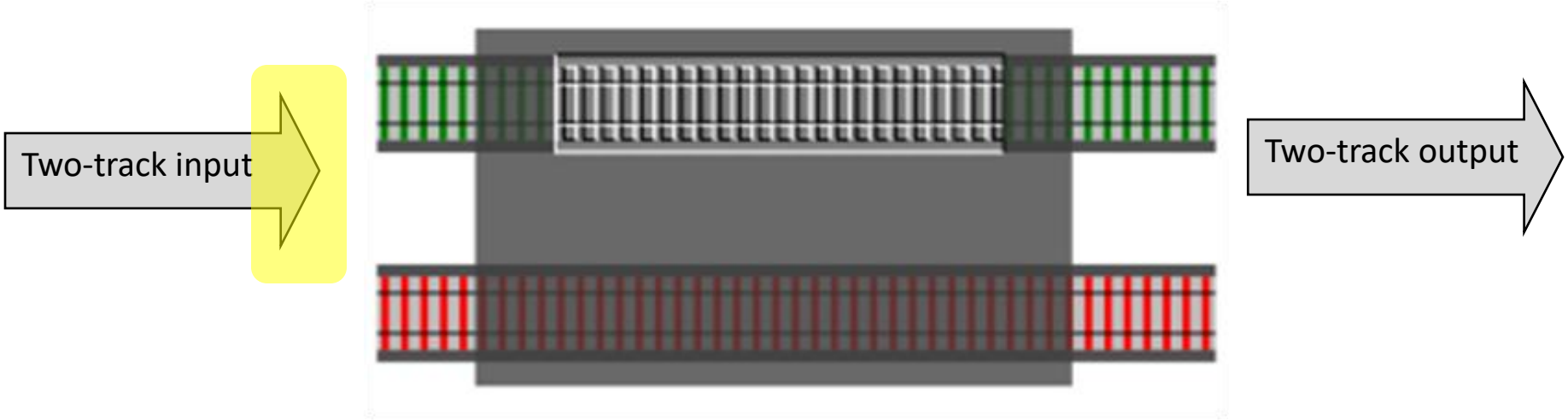
A function as input

A different shape function as output

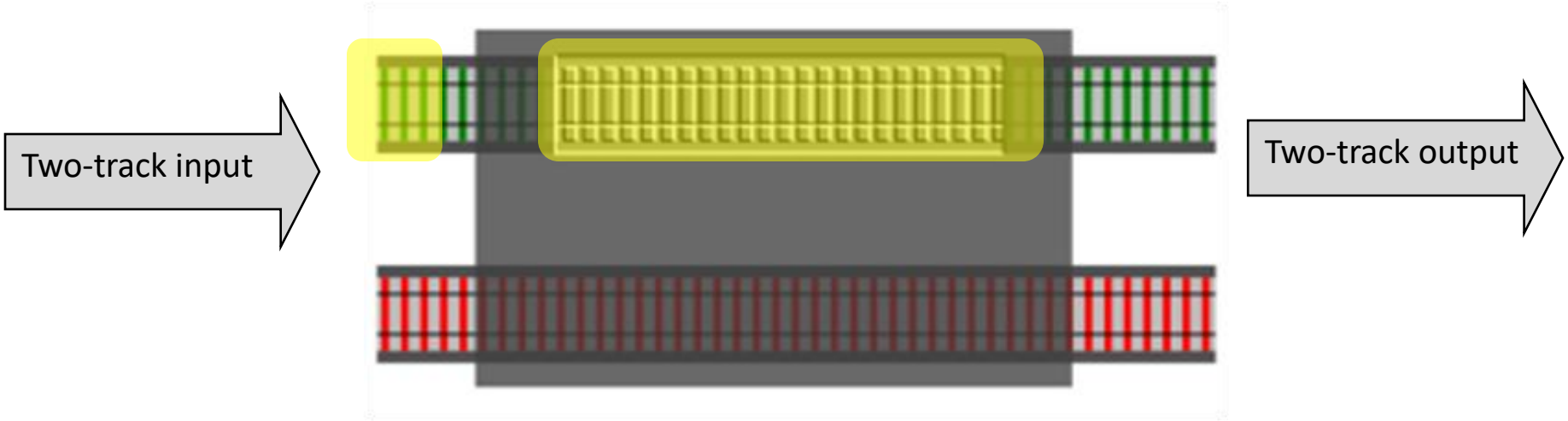



```
let map singleTrackFunction twoTrackInput =
  match twoTrackInput with
    | Ok s -> Ok (singleTrackFunction s)
    | Error f -> Error f
```

"map" is the common name for this kind of function.
In LINQ it's "Select"

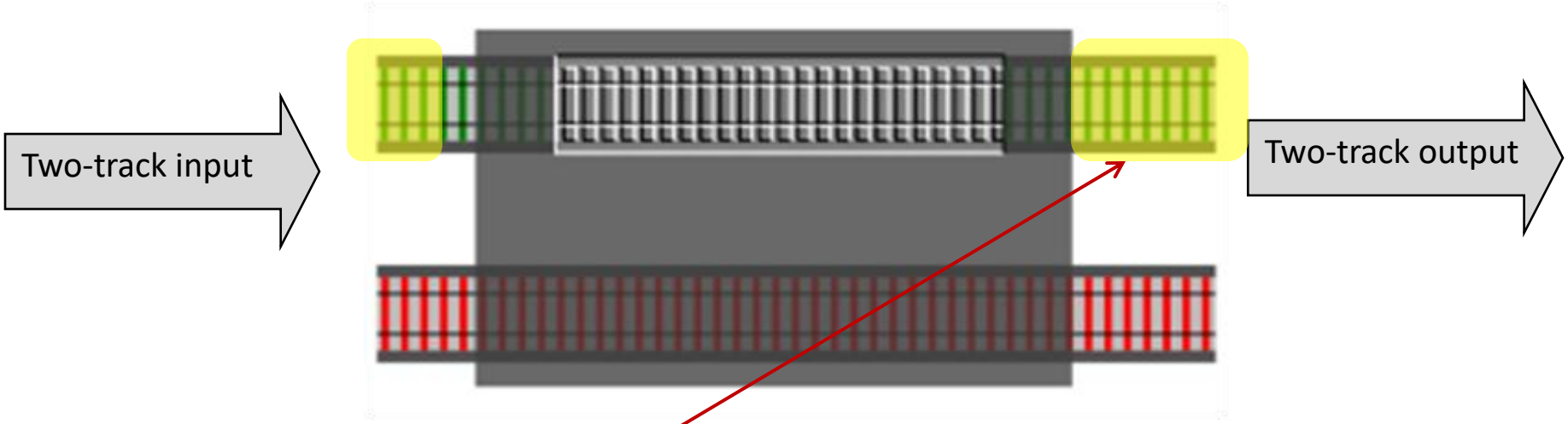



```
let map singleTrackFunction twoTrackInput =
  match twoTrackInput with
  | Ok s -> Ok (singleTrackFunction s)
  | Error f -> Error f
```



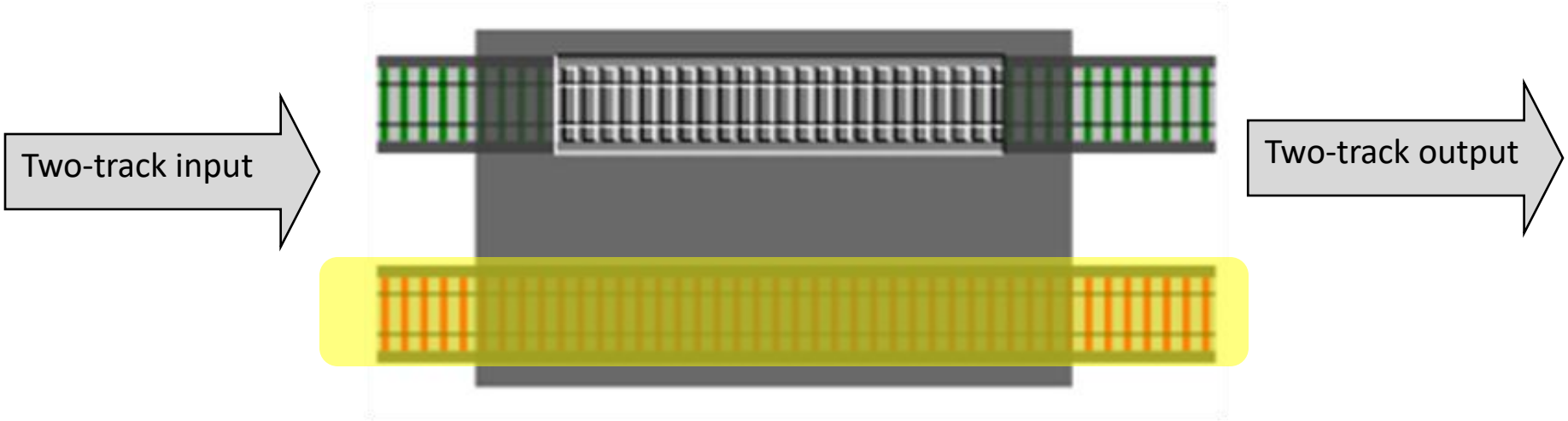

```
let map singleTrackFunction twoTrackInput =
  match twoTrackInput with
  | Ok s -> Ok (singleTrackFunction s)
  | Error f -> Error f
```

a) Handle the Ok track




```
let map singleTrackFunction twoTrackInput =
  match twoTrackInput with
  | Ok s -> Ok (singleTrackFunction s)
  | Error f -> Error f
```

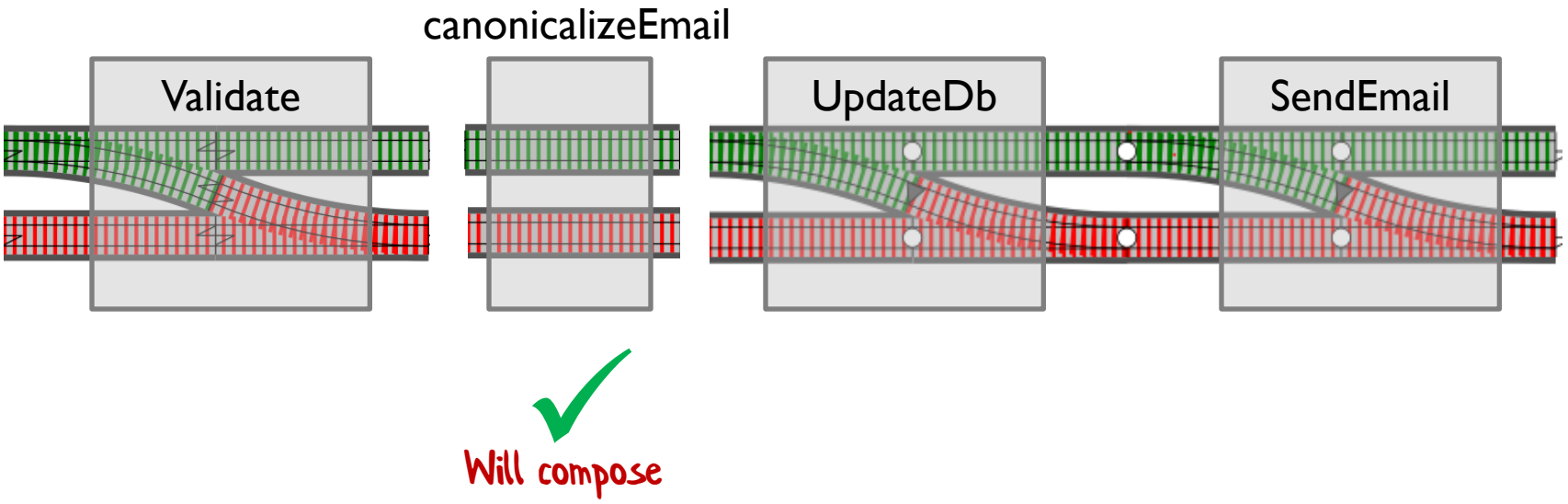
a) Handle the Ok track



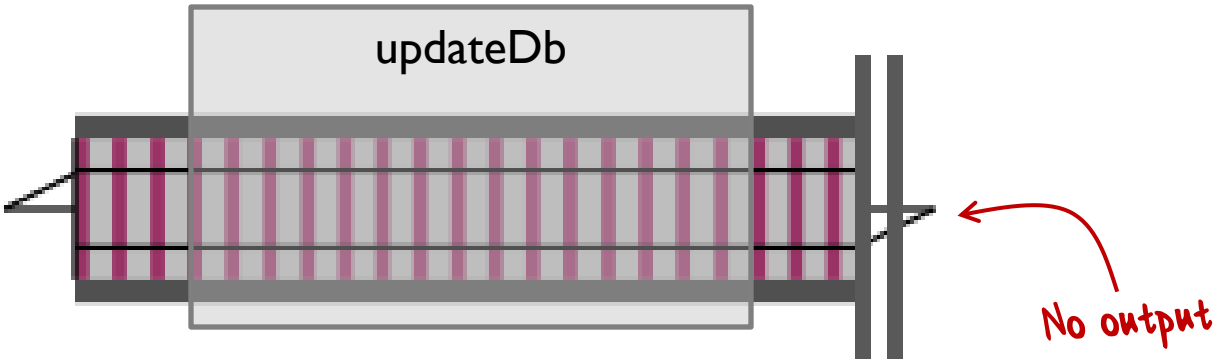

```
let map singleTrackFunction twoTrackInput =
  match twoTrackInput with
  | Ok s -> Ok (singleTrackFunction s)
  | Error f -> Error f
```

b) Handle the Error track

Converting one-track functions

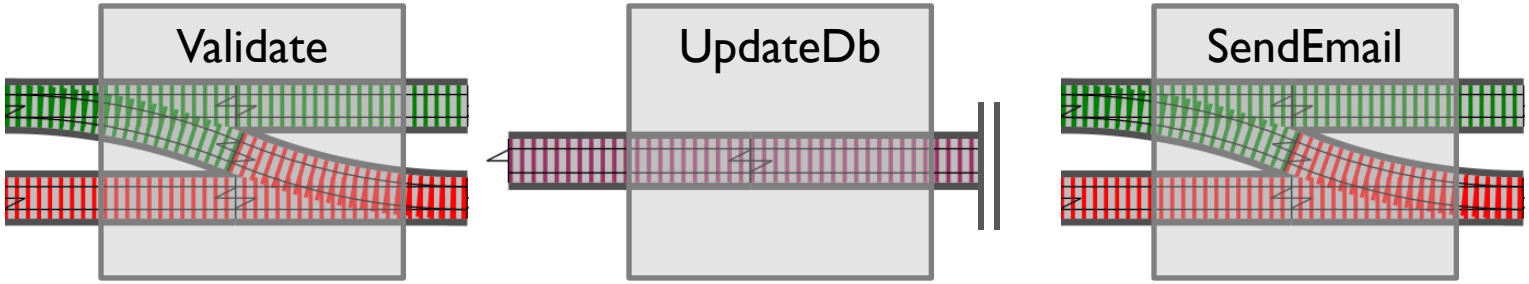


Working with "dead-end" functions

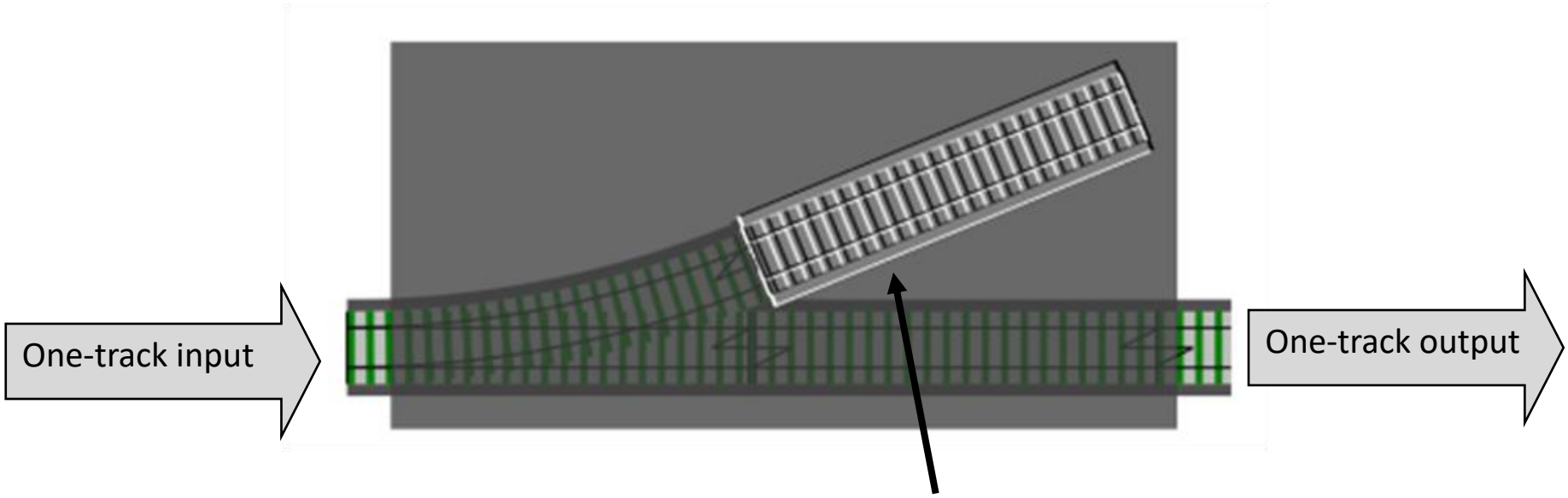



```
let updateDb request =
    // do something
    // return nothing at all
```

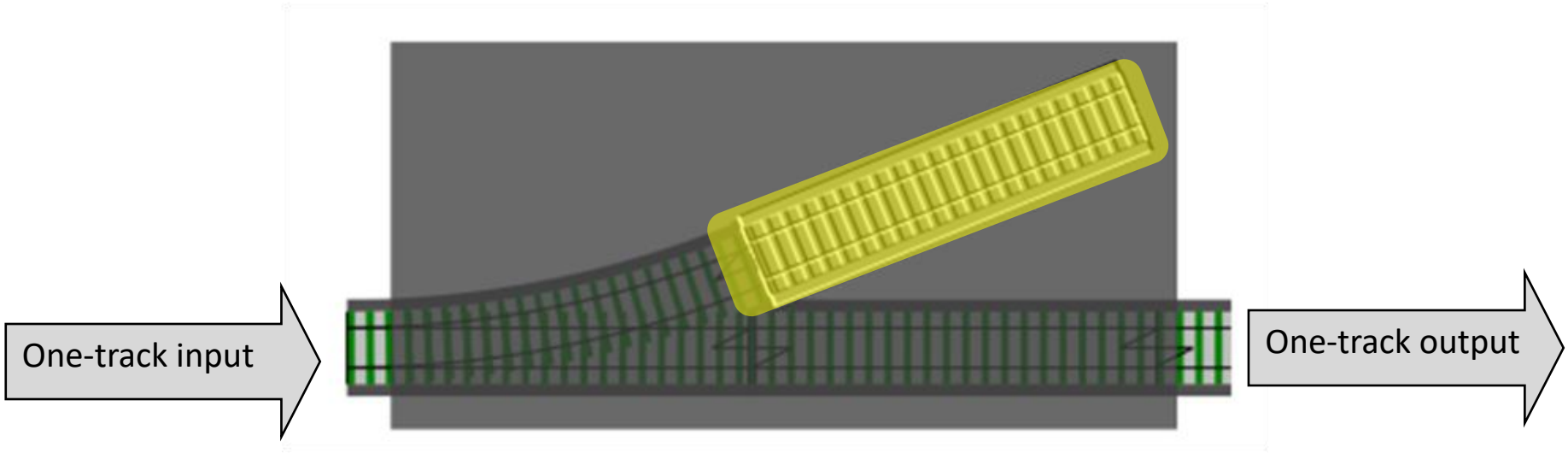
A function that doesn't return anything— a "dead-end" function.



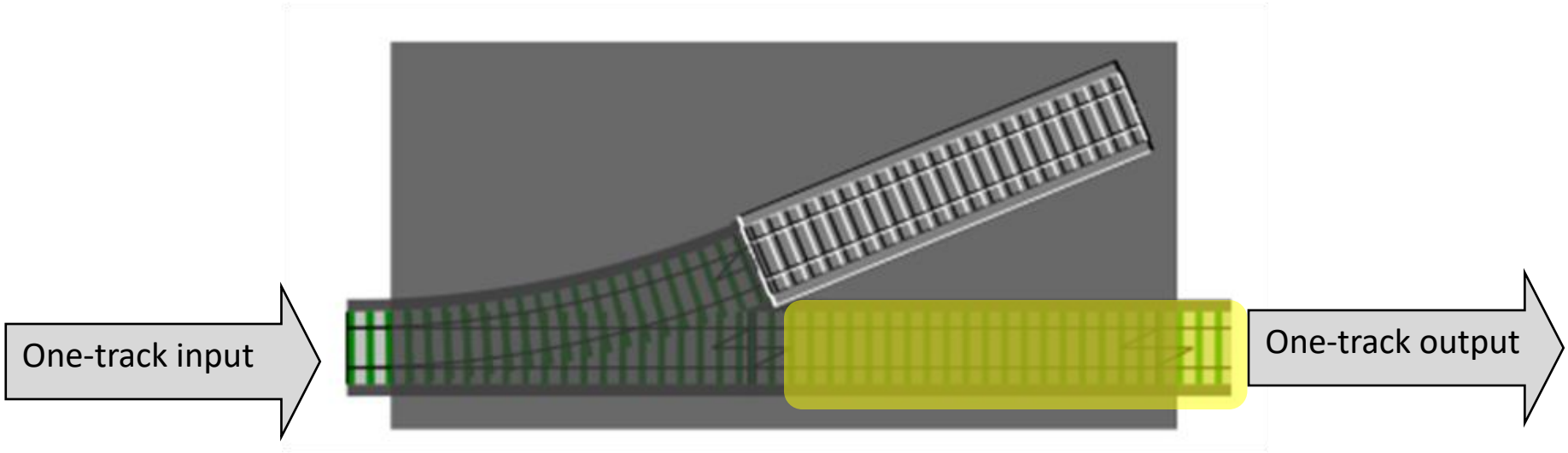
Won't compose



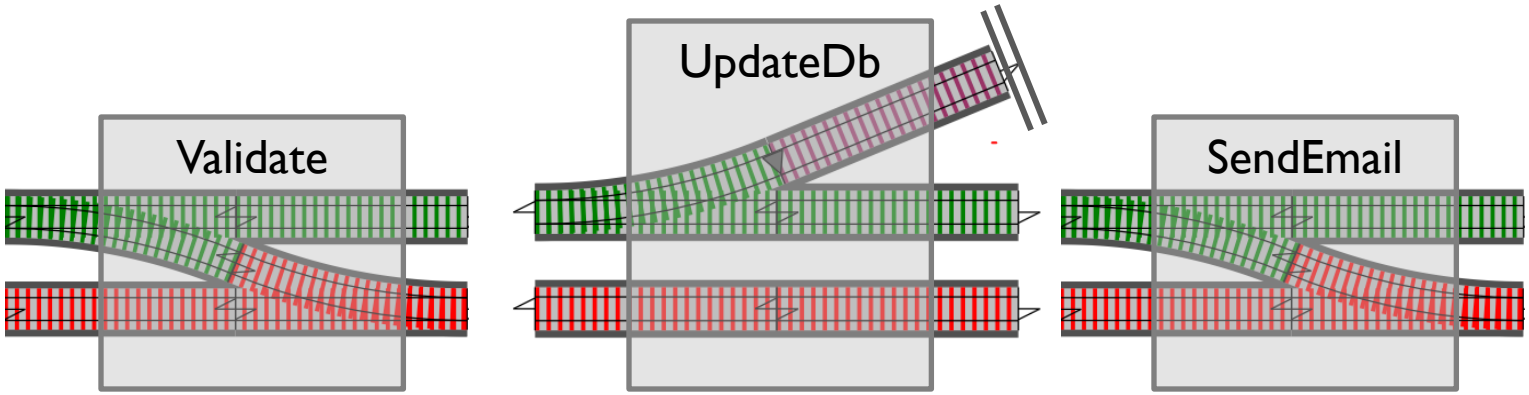
Slot for dead end function




```
let tee deadEndFunction oneTrackInput =
    deadEndFunction oneTrackInput
    oneTrackInput
```

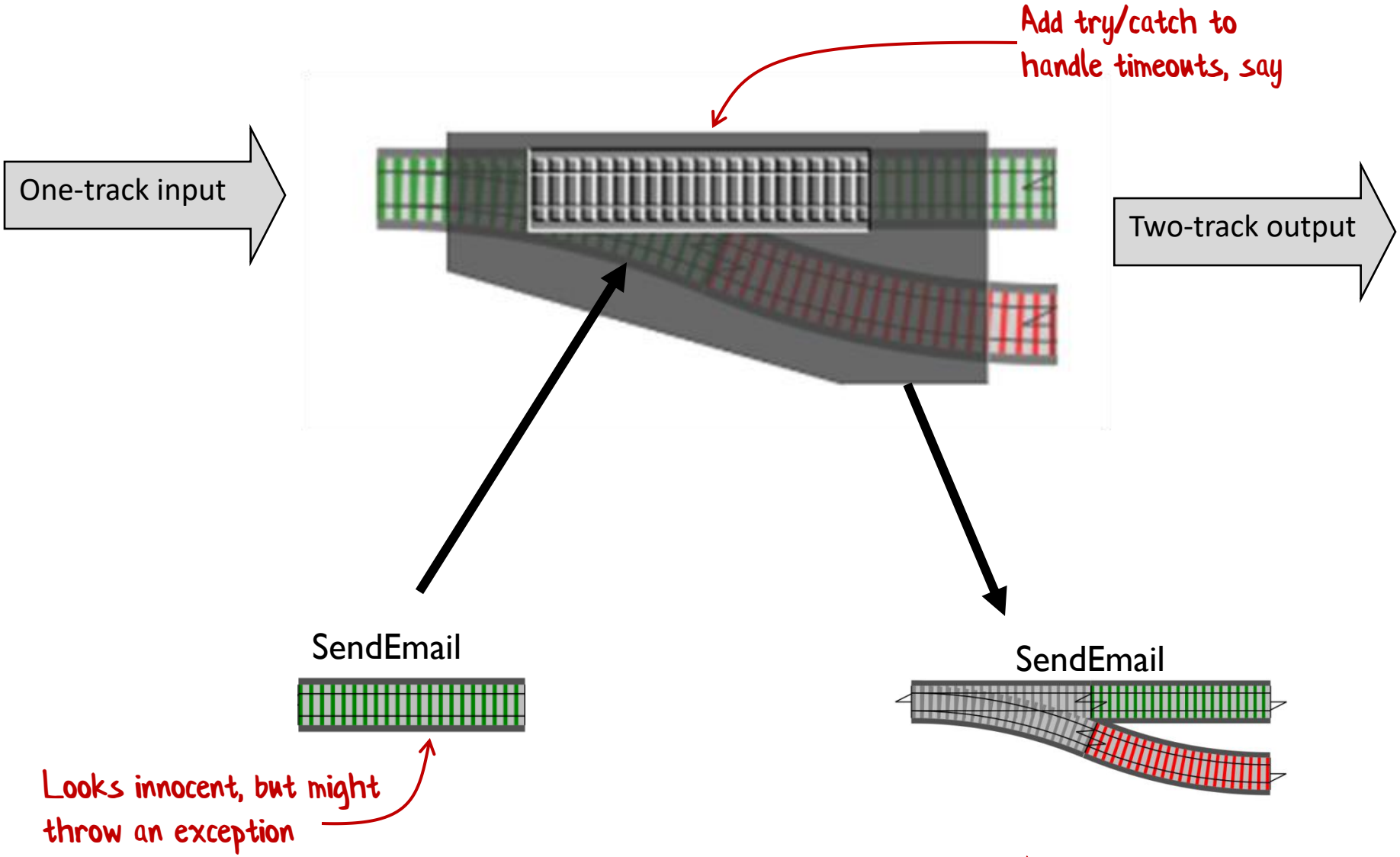



```
let tee deadEndFunction oneTrackInput =
    deadEndFunction oneTrackInput
    oneTrackInput
```



Will compose

Working with functions that throw exceptions


Add try/catch to handle timeouts, say
One-track input
Two-track output
SendEmail
SendEmail
Looks innocent, but might throw an exception
Don't bother handling all possible exceptions:
E.g. FileNotFound, yes. OutOfMemory, no.

Guideline: Convert exceptions into Failures

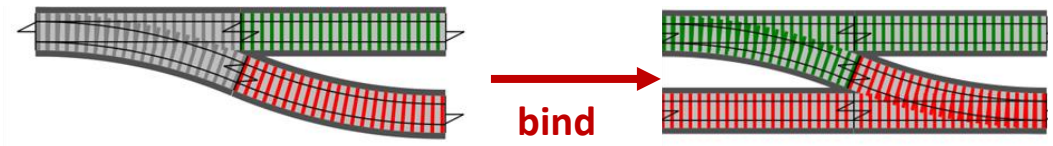
Even Yoda recommends not to use exception handling for control flow:

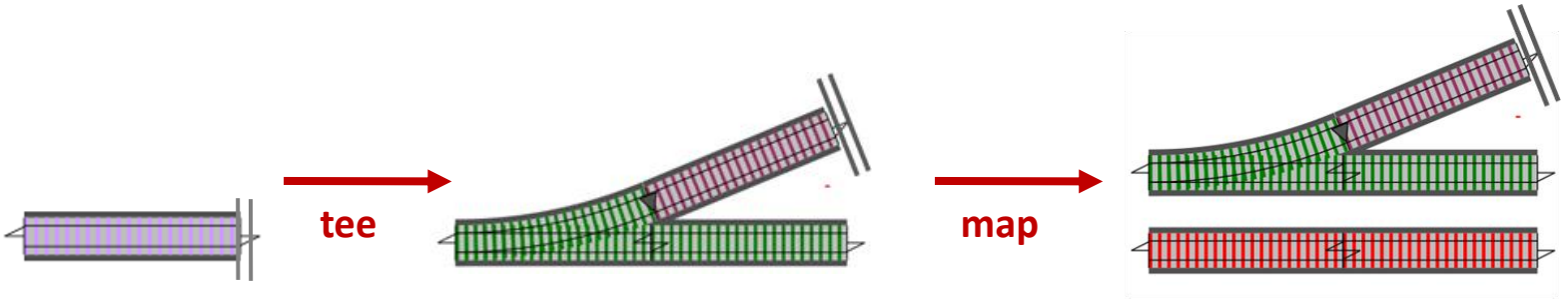
"Do or do not, there is no try".

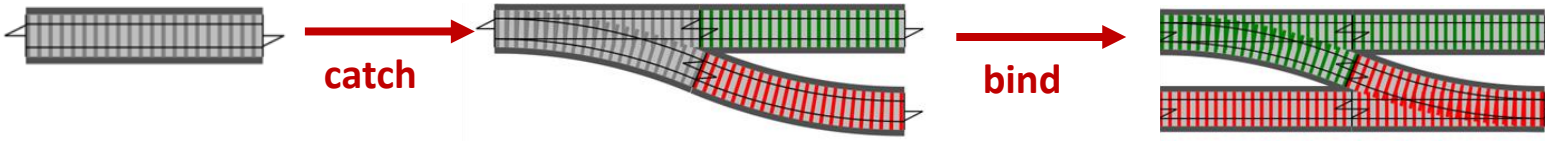
Functions won't compose?

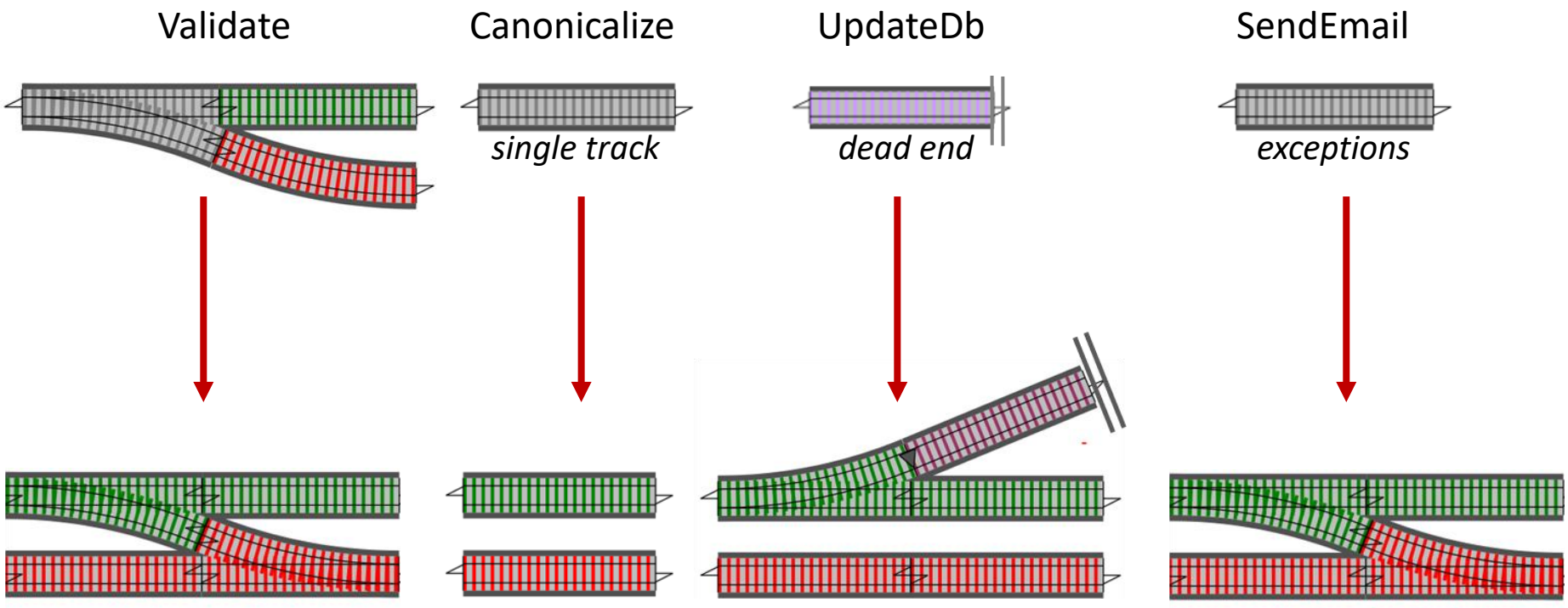
Use "function transformers" to change their shape!

Here are the transformations we used so far





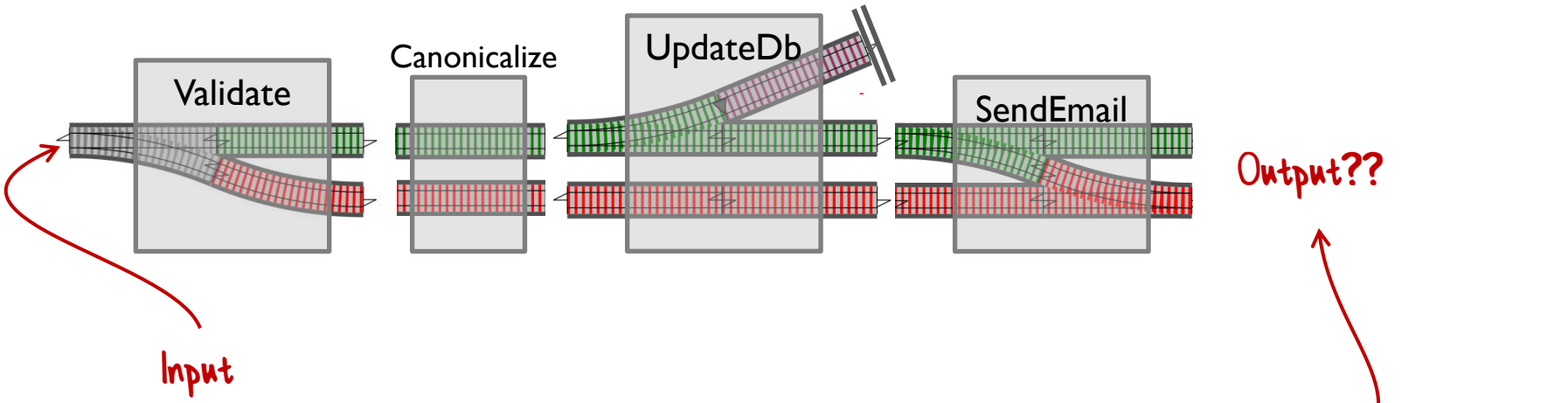




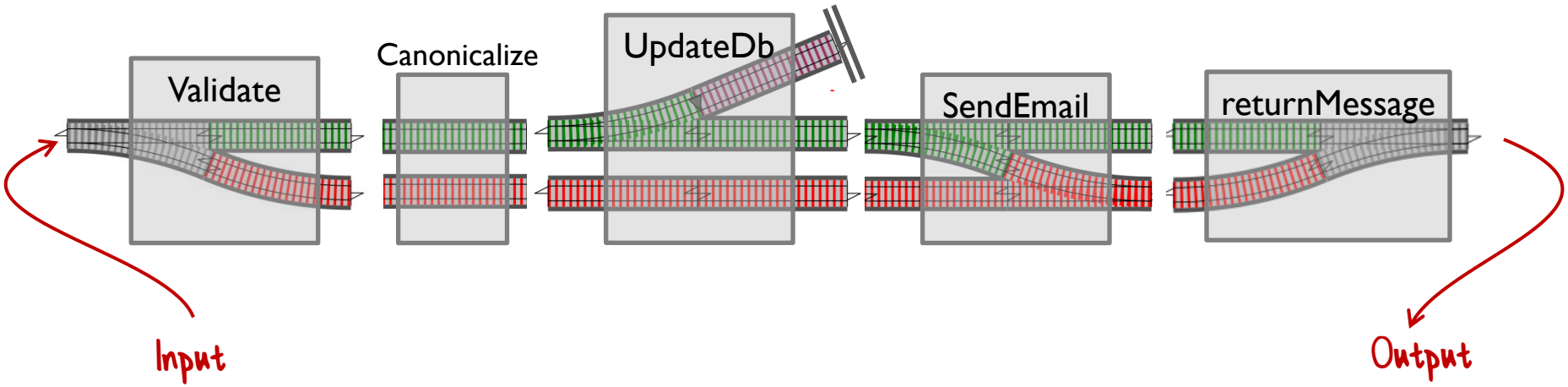
Now we *can* compose them easily!

Putting it all together into a pipeline

Putting it all together



Putting it all together

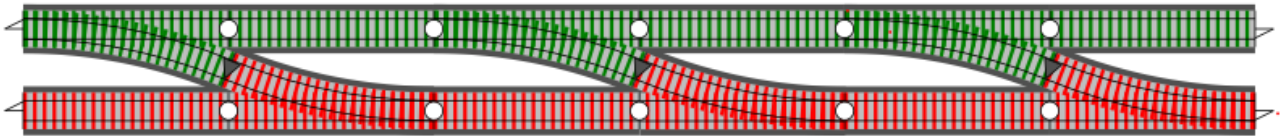



```
let returnMessage result =
  match result with
  | Ok obj -> "200" + obj.ToJson()
  | Error errorMsg -> "400" + errorMsg
```

Demo #4:

The complete pipeline

```
let updateCustomerWithErrorHandling =
  receiveRequest()
  |> validateRequest
  |> canonicalizeEmail
  |> updateDbFromRequest
  |> sendEmail
  |> returnMessage
```



As promised at the beginning!

Part V:

Designing error types

Unhappy paths are requirements too

```
let validateInput input =
    if input.name = "" then
        Error "Name must not be blank"
    else if input.email = "" then
        Error "Email must not be blank"
    else
        Ok input  // happy path



// returns Result<Input,string> =
```

Using strings is not good

```
let validateInput input =
    if input.name = "" then
        Error NameMustNotBeBlank
    else if input.email = "" then
        Error EmailMustNotBeBlank
    else
        Ok input  // happy path

type ErrorMessage =
    | NameMustNotBeBlank
    | EmailMustNotBeBlank

// returns Result<Input,ErrorMessage> =
```

Defined a special type rather than string

```
let validateInput input =
    if input.name = "" then
        Error NameMustNotBeBlank
    else if input.email = "" then
        Error EmailMustNotBeBlank
    else if (input.email doesn't match regex) then
        Error EmailNotValid input.email
    else
        Ok input  // happy path
```

Add invalid email as data

```
type ErrorMessage =
    | NameMustNotBeBlank
    | EmailMustNotBeBlank
    | EmailNotValid of EmailAddress
```

```
type ErrorMessage =
   | NameMustNotBeBlank
   | EmailMustNotBeBlank
   | EmailNotValid of EmailAddress
```

```
type ErrorMessage =
   | NameMustNotBeBlank
   | EmailMustNotBeBlank
   | EmailNotValid of EmailAddress
   // database errors
   | UserIdNotValid of UserId
   | DbUserNotFoundError of UserId
   | DbTimeout of ConnectionString
   | DbConcurrencyError
   | DbAuthorizationError of ConnectionString * Credentials
   // SMTP errors
   | SmtpTimeout of SmtpConnection
   | SmtpBadRecipient of EmailAddress
```

Documentation of everything that can go wrong --

And it's type-safe documentation that can't go out of date!

Also triggers important DDD conversations

Designing for errors - review

```
type ErrorMessage =
   | NameMustNotBeBlank
   | EmailMustNotBeBlank
   | EmailNotValid of EmailAddress
   // database errors
   | UserIdNotValid of UserId
   | DbUserNotFoundError of UserId
   | DbTimeout of ConnectionString
   | DbConcurrencyError
   | DbAuthorizationError of ConnectionString * Credentials
   // SMTP errors
   | SmtpTimeout of SmtpConnection
   | SmtpBadRecipient of EmailAddress
```

Documentation of everything that can go wrong.

Type-safe -- can't go out of date!

Surfaces hidden requirements.

Test against error codes, not strings.

Makes translation easier.

Demo #5:

Pipeline with error type and language translation

What errors should be modeled?

Three kinds of errors

- **Domain errors** are to be expected as part of the business process
- **Panics** leave the system in an unknown state
- **Infrastructure errors** are expected as part of the architecture

Kinds of error: Domain errors

- **Domain errors** are to be expected as part of the business process
  - Must be included in the design of the domain, just like anything else.
- How to handle? Use existing procedures.
  - The business will already have procedures in place to deal with this kind of error, and so the code will need to reflect these processes.
- Debugging?
  - Diagnostics/Stack trace are not needed

Kinds of error: Panics

- **Panics** leave the system in an unknown state
  - System errors (e.g. “out of memory”) or programmer oversight (e.g. “divide by zero,” “null reference”).
- How to handle? Use "Fail fast"
  - Abandon the workflow and raise an exception to be caught and logged at the highest appropriate level.
- Debugging?
  - Diagnostics/Stack trace are needed

Kinds of error: Infrastructure error

- **Infrastructure errors** are expected as part of the architecture.
  - They are not part of any business process and are not included in the domain.
  - Network timeout, authentication failure, etc.
- How to handle?
  - Sometimes modeled as part of the domain, and sometimes treated as panics. If in doubt, ask a domain expert!

Design tip:
Be aware of different kinds of errors

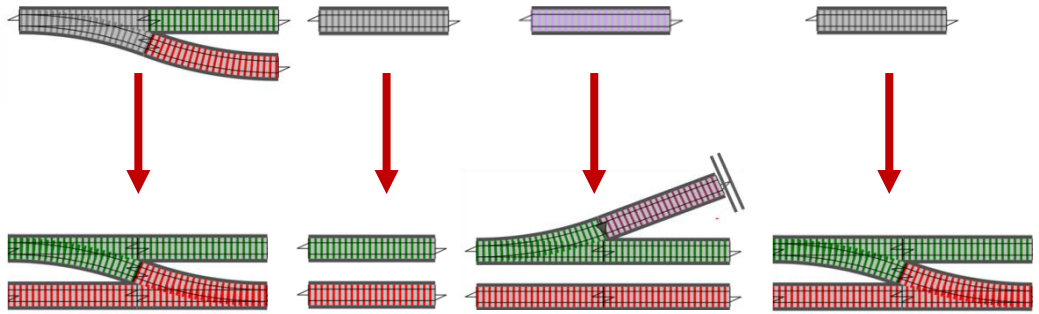
Don't always use Result for everything!

I have a blog post called
"Against Railway-Oriented Programming" ☺

Conclusion

Review of error handling in FP

- Errors are part of the domain model too!
- Use two-track error handling rather than exceptions
- Use "function transformers" to change the shape of a function so they can be composed

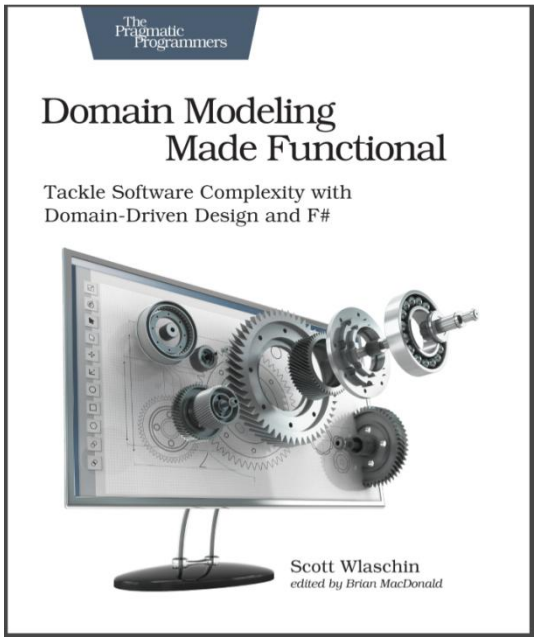


Thanks!

More at fsharpforfunandprofit.com/rop

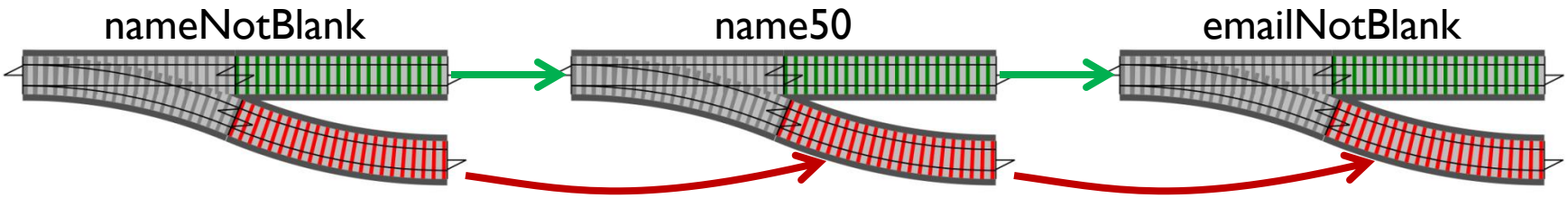
Code at https://github.com/swlaschin/TechTrain2021

My book!



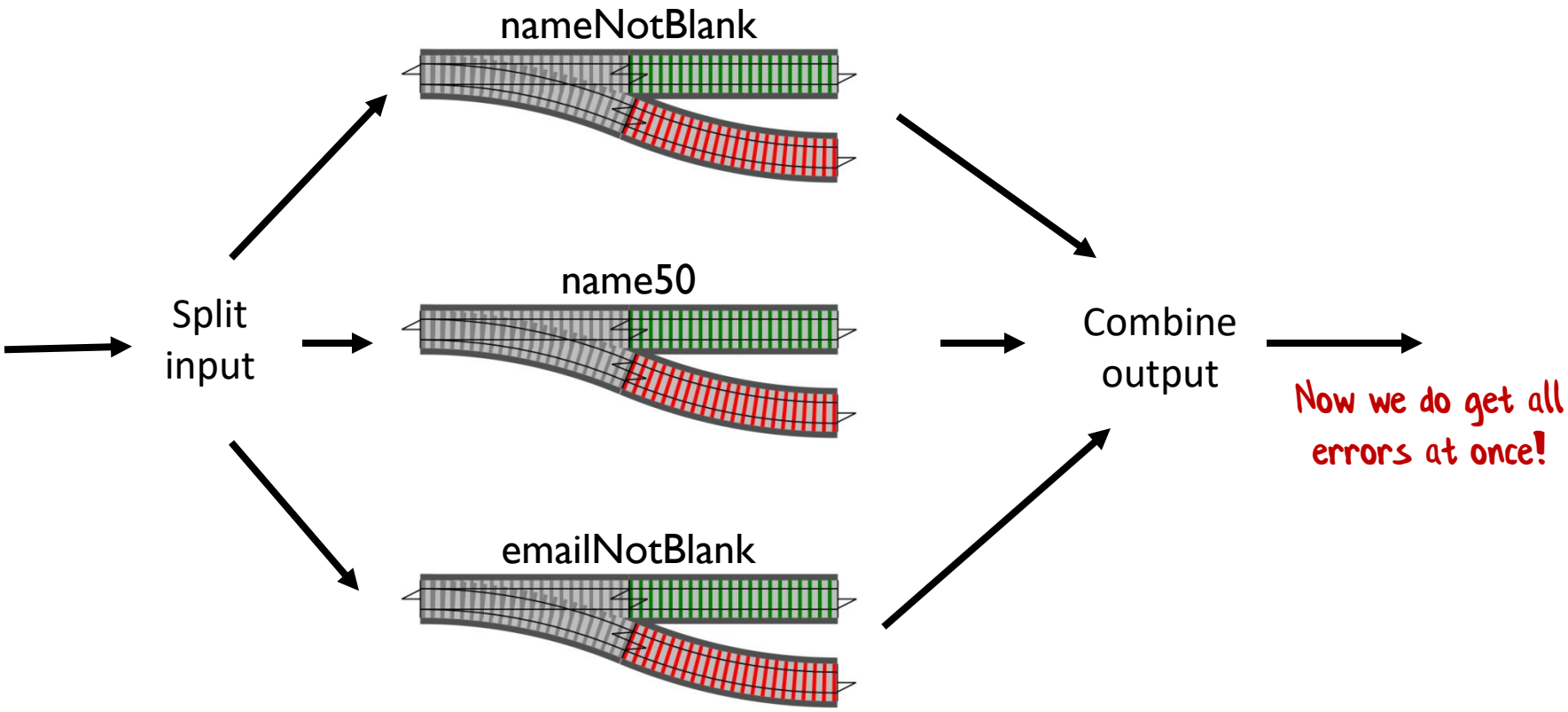
Bonus! Part VI:

Validation



Problem: Validation done in series.
So only one error at a time is returned

It would be nice to return all validation errors at once.


nameNotBlank
Split input
name50
Combine output
emailNotBlank
Now we do get all errors at once!
... But how to combine?

How can we combine errors?

```
type PersonalName = {
    First: String10
    Last: String10
    }
```

A record to be constructed.
It uses constrained types

These values are
NOT normal values

```
let firstOrError = validateFirst first
  // Validation<First,_>
let lastOrError = validateLast last
  // Validation<Last,_>
```

How can we combine errors?

```
type PersonalName = {
    First: String10
    Last: String10
    }

let firstOrError = validateFirst first
  // Validation<First,_>
let lastOrError = validateLast last
  // Validation<Last,_>

let name = {
    First = firstOrError
    Last = lastOrError
    }
```

We will get a compiler error trying to assign them☹

A different approach

```
let firstOrError = validateFirst first
  // Validation<First,_>
let lastOrError = validateLast last
  // Validation<Last,_>

// make a constructor for the record
let createPerson first last =
  {First=first; Last=last}

let personOrError =
  createPerson firstOrError lastOrError
```

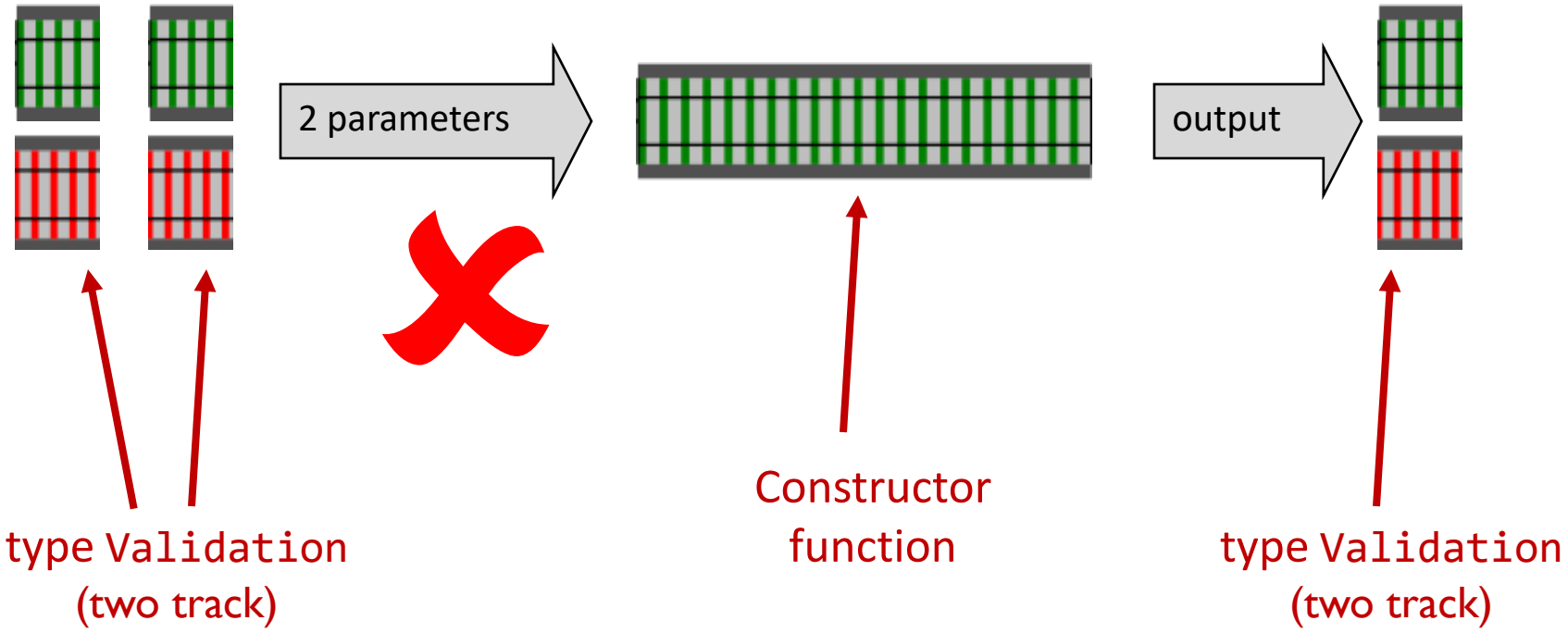
These parameters are normal values

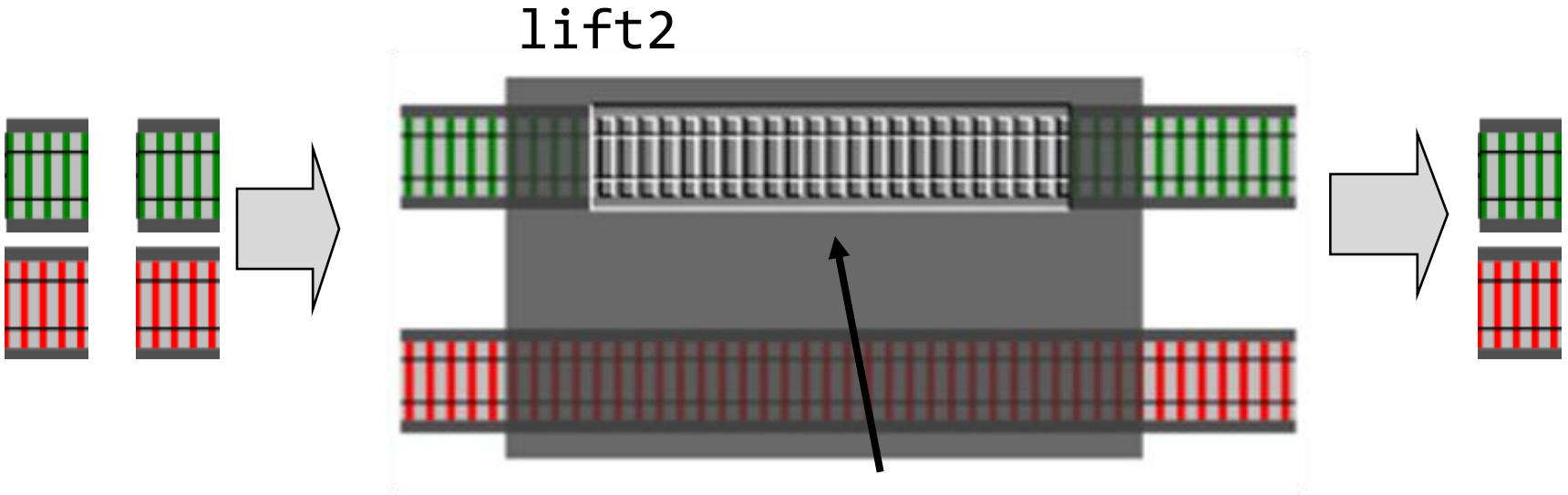
We still get a compiler error when passing validation values in☹

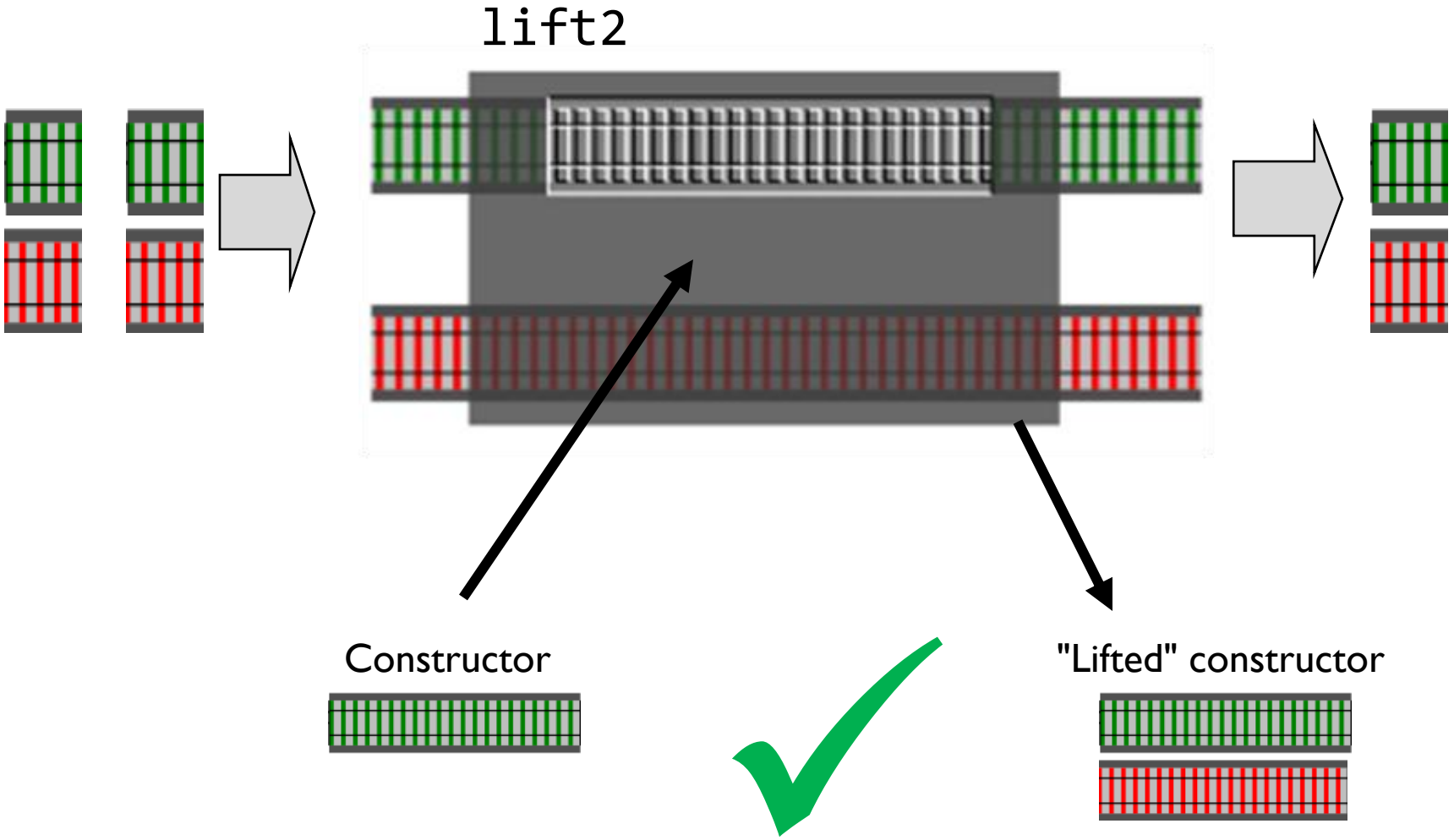
A different approach, fixed!

```
let firstOrError = validateFirst first
  // Validation<First,_>
let lastOrError = validateLast last
  // Validation<Last,_>

// make a constructor for the record
let createPerson first last =
  {First=first; Last=last}

let personOrError =
  (lift2 createPerson) firstOrError lastOrError
  // returns Validation<Person,_>
```

Use "lift" to fix the mismatch


2 parameters
output
type Validation
(two track)
Constructor
function
type Validation
(two track)


lift2
Slot for constructor function


lift2
Constructor
"Lifted" constructor

The "recipe" for validation

You have a bunch of `Validation` errors, so

a) Define a constructor for your record
b) Use `lift2/lift3/lift4` functions to "adapt" the constructor to handle the validation results

Demo #6:
Validation

End