Funktionale Programmierung in F# (2)

Grundlagen & Railway Oriented Programming

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Programm

- Hausaufgaben
- Algorithmen
  - Operationen auf einer Liste
  - Wiederholung (Pattern Matching, Rekursion)
- ROP (Railway Oriented Programming)
  - Umgang mit fehlende Daten (Option)
  - Umgang mit Fehlern (Result)

Two-Fer

```
let twoFer (input: string option): string =
    input
    |> Option.defaultValue "you"
    |> sprintf "One for %s, one for me."

let test1 = [twoFer None; twoFer (Some "Alice"); twoFer (Some "Bob")]
```

```
val twoFer: input: string option -> string
val test1: string list =
  ["One for you, one for me."; "One for Alice, one for me.";
   "One for Bob, one for me."]
```

Leap

```
let (|IsDivisibleBy|_|) divisor n =
    if n % divisor = 0 then Some () else None

let leapYear year =
    match year with
    | IsDivisibleBy 400 -> true
    | IsDivisibleBy 100 -> false
    | IsDivisibleBy   4 -> true
    | _ -> false

let test1 = [leapYear 1900; leapYear 1996]
let test2 = [leapYear 2000; leapYear 2019; leapYear 2020]
```

```
val (|IsDivisibleBy|_|) : divisor: int -> n: int -> unit option
val leapYear: year: int -> bool
val test1: bool list = [false; true]
val test2: bool list = [true; false; true]
```

Isogram

```
let isIsogram (str: string) =
    let letters =
        str.ToLowerInvariant()
        |> Seq.filter System.Char.IsLetter
        |> Seq.toList
    letters
    |> Seq.distinct
    |> Seq.length
    |> (=) letters.Length
let test1 = [isIsogram ""; isIsogram "isogram"]
let test2 = [isIsogram "eleven"; isIsogram "subdermatoglyphic"]
```

```
val isIsogram: str: string -> bool
val test1: bool list = [true; true]
val test2: bool list = [false; true]
```

Sum Of Multiples

```
let multiplesOf max n =
    if n = 0 then [0] else [n .. n .. (max - 1)]
let sum (numbers: int list) (upperBound: int): int =
    numbers
    |> List.collect (multiplesOf upperBound)
    |> List.distinct
    |> List.sum
#time "on"
let test = [sum [3; 5] 1000; sum [2; 3; 5; 7; 11] 10000]
#time "off"
```

```
val multiplesOf: max: int -> n: int -> int list
val sum: numbers: int list -> upperBound: int -> int


--> Timing now on

Real: 00:00:00.001, CPU: 00:00:00.001, GC gen0: 0, gen1: 0, gen2: 0
val test: int list = [233168; 39614537]


--> Timing now off
```

length

```
let rec length' list =
    match list with
    | [] -> 0
    | _::xs -> 1 + length' xs
let length list =
    let rec _length list acc =
        match list with
        | [] -> acc
        | _::xs -> _length xs (acc + 1)
    _length list 0

let test1 = [length' []; length' [1; 2; 3; 4]]
let test2 = [length []; length [1; 2; 3; 4]]
```

```
val length': list: 'a list -> int
val length: list: 'a list -> int
val test1: int list = [0; 4]
val test2: int list = [0; 4]
```

reverse

```
let reverse list =
    let rec _reverse list acc =
        match list with
        | [] -> acc
        | x::xs -> _reverse xs (x::acc)
    _reverse list []

let test1 = reverse [1; 3; 5; 7]
let test2 = reverse [[1; 2]; [3]; []; [4..8]]
```

```
val reverse: list: 'a list -> 'a list
val test1: int list = [7; 5; 3; 1]
val test2: int list list = [[4; 5; 6; 7; 8]; []; [3]; [1; 2]]
```

map

```
let map f list =
    let rec _map f list acc =
        match list with
        | [] -> acc |> reverse
        | x::xs -> _map f xs ((f x)::acc)
    _map f list []

let test = map (fun x -> x + 1) [1; 3; 5; 7]
```

```
val map: f: ('a -> 'b) -> list: 'a list -> 'b list
val test: int list = [2; 4; 6; 8]
```

filter (Übung)

```
// filter : f:('a -> bool) -> list:'a list -> 'a list
let filter f list =
    ...
    match list with
    | [] -> ...
    | x::xs -> ...

let test = filter (fun x -> x % 2 = 1) [1..1000]
```

```
val filter : f:('a -> bool) -> list:'a list -> 'a list
val test : int list =
  [1; 3; 5; 7; 9; 11; 13; 15; 17; 19; 21; 23; 25; 27; 29; 31; 33; 35; 37; 39;
   41; 43; 45; 47; 49; 51; 53; 55; 57; 59; 61; 63; 65; 67; 69; 71; 73; 75; 77;
   79; 81; 83; 85; 87; 89; 91; 93; 95; 97; 99; 101; 103; 105; 107; 109; 111;
   113; 115; 117; 119; 121; 123; 125; 127; 129; 131; 133; 135; 137; 139; 141;
   143; 145; 147; 149; 151; 153; 155; 157; 159; 161; 163; 165; 167; 169; 171;
   173; 175; 177; 179; 181; 183; 185; 187; 189; 191; 193; 195; 197; 199; ...]
```

filter (Lösung 1)

```
let rec filter f list =
    match list with
    | [] -> []
    | x::xs ->
        match f x with
        | true -> x :: filter f xs
        | false -> filter f xs
let test = filter (fun x -> x % 2 = 1) [1..10_000]
```

```
val filter: f: ('a -> bool) -> list: 'a list -> 'a list
val test: int list =
  [1; 3; 5; 7; 9; 11; 13; 15; 17; 19; 21; 23; 25; 27; 29; 31; 33; 35; 37; 39;
   41; 43; 45; 47; 49; 51; 53; 55; 57; 59; 61; 63; 65; 67; 69; 71; 73; 75; 77;
   79; 81; 83; 85; 87; 89; 91; 93; 95; 97; 99; 101; 103; 105; 107; 109; 111;
   113; 115; 117; 119; 121; 123; 125; 127; 129; 131; 133; 135; 137; 139; 141;
   143; 145; 147; 149; 151; 153; 155; 157; 159; 161; 163; 165; 167; 169; 171;
   173; 175; 177; 179; 181; 183; 185; 187; 189; 191; 193; 195; 197; 199; ...]
```

filter (Lösung 2)

```
let filter f list =
    let rec _filter f list acc =
        match list with
        | [] -> acc |> reverse
        | x::xs ->
            match f x with
            | true -> _filter f xs (x::acc)
            | false -> _filter f xs acc
    _filter f list []
let test = filter (fun x -> x % 2 = 1) [1..10_000]
```

```
val filter: f: ('a -> bool) -> list: 'a list -> 'a list
val test: int list =
  [1; 3; 5; 7; 9; 11; 13; 15; 17; 19; 21; 23; 25; 27; 29; 31; 33; 35; 37; 39;
   41; 43; 45; 47; 49; 51; 53; 55; 57; 59; 61; 63; 65; 67; 69; 71; 73; 75; 77;
   79; 81; 83; 85; 87; 89; 91; 93; 95; 97; 99; 101; 103; 105; 107; 109; 111;
   113; 115; 117; 119; 121; 123; 125; 127; 129; 131; 133; 135; 137; 139; 141;
   143; 145; 147; 149; 151; 153; 155; 157; 159; 161; 163; 165; 167; 169; 171;
   173; 175; 177; 179; 181; 183; 185; 187; 189; 191; 193; 195; 197; 199; ...]
```

Große Zahlen (Übung)

- Berechne $5^{4^{3^2}}$
- Wie lang ist die Zahl?
- Gib die ersten und letzten 20 Ziffern an!

Große Zahlen (Lösung)

```
#time "on"
let answer = 5I **(int (4I ** (int (3I ** 2))));;
let sans = answer.ToString()
let l = sans.Length
let prefix = sans.Substring(0,20)
let suffix = sans.Substring(l-20)
#time "off"
printfn "Length = %d, digits %s ... %s" l prefix suffix
```

```
let sans = answer.ToString()
let l = sans.Length
let prefix = sans.Substring(0,20)
let suffix = sans.Substring(l-20)
#time "off"
printfn "Length = %d, digits %s ... %s" l prefix suffix;;
Real: 00:00:00.797, CPU: 00:00:00.757, GC gen0: 0, gen1: 0, gen2: 0
val sans: string =
  "62060698786608744707483205572846793091942192651991171731773 83"+[183170 chars
val l: int = 183231
val prefix: string = "62060698786608744707"
val suffix: string = "92256259918212890625"
```

foldl

```
let rec foldl folder state list =
    match list with
    | [] -> state
    | x::xs -> foldl folder (folder state x) xs

let test1 = foldl (+) 0 [1..1_000]
let test2 = foldl (*) 1I [1I..42I]
```

```
val foldl: folder: ('a -> 'b -> 'a) -> state: 'a -> list: 'b list -> 'a
val test1: int = 500500
val test2: Numerics.BigInteger =
  1405006117752879898543142606244511569936384000000000
```

foldr

```
let flip f b a = f a b
let rec foldr folder state list =
    foldl (flip folder) state (reverse list)

let test = foldr (+) 5 [1; 2; 3; 4]
```

```
val flip: f: ('a -> 'b -> 'c) -> b: 'b -> a: 'a -> 'c
val foldr: folder: ('a -> 'b -> 'b) -> state: 'b -> list: 'a list -> 'b
val test: int = 15
```

append

```
let append xs ys = foldr (fun x acc -> x :: acc) ys xs

let test = append [1..5] [6..10]
```

```
let append xs ys = foldr (fun x acc -> x :: acc) ys xs

let test = append [1..5] [6..10];;
val append: xs: 'a list -> ys: 'a list -> 'a list
val test: int list = [1; 2; 3; 4; 5; 6; 7; 8; 9; 10]
```

concat (1)

```
let concat xs = foldr append [] xs
let rec concat' xs =
    match xs with
    | [] -> []
    | []::ys -> concat' ys
    | (x::xs)::ys -> x:: (concat' (xs::ys))
let concat'' xs =
    let rec _concat xs acc =
        match xs with
        | [] -> acc |> reverse
        | []::ys -> _concat ys acc
        | (x::xs)::ys -> _concat (xs::ys) (x::acc)
    _concat xs []
```

```
val concat: xs: 'a list list -> 'a list
val concat': xs: 'a list list -> 'a list
val concat'': xs: 'a list list -> 'a list
```

concat (2)

```
let test1 = concat [[1; 2]; [3]; []; [4; 5; 6]]
let test2 = concat' [[1; 2]; [3]; []; [4; 5; 6]]
let test3 = concat'' [[1; 2]; [3]; []; [4; 5; 6]]

let test1b = concat [[[1]; [2]]; [[3]]; [[]]; [[4; 5; 6]]]
let test2b = concat' [[[1]; [2]]; [[3]]; [[]]; [[4; 5; 6]]]
let test3b = concat'' [[[1]; [2]]; [[3]]; [[]]; [[4; 5; 6]]]
```

```
let test1 = concat [[1; 2]; [3]; []; [4; 5; 6]]
let test2 = concat' [[1; 2]; [3]; []; [4; 5; 6]]
let test3 = concat'' [[1; 2]; [3]; []; [4; 5; 6]]

let test1b = concat [[[1]; [2]]; [[3]]; [[]]; [[4; 5; 6]]]
let test2b = concat' [[[1]; [2]]; [[3]]; [[]]; [[4; 5; 6]]]
let test3b = concat'' [[[1]; [2]]; [[3]]; [[]]; [[4; 5; 6]]];;
val test1: int list = [1; 2; 3; 4; 5; 6]
val test2: int list = [1; 2; 3; 4; 5; 6]
val test3: int list = [1; 2; 3; 4; 5; 6]
val test1b: int list list = [[1]; [2]; [3]; []; [4; 5; 6]]
val test2b: int list list = [[1]; [2]; [3]; []; [4; 5; 6]]
val test3b: int list list = [[1]; [2]; [3]; []; [4; 5; 6]]
```

Pause

> There is no programming language, no matter how structured, that will prevent programmers from making bad programs.
>
> –Larry Flon (1975)

ROP

⇝ Railway Oriented Programming

–Scott Wlashin: F# for Fun and Profit

Option

```
type BillingDetails = {
    name : string
    billing :  string
    delivery : string option }
let order1 = {
    name = "Adam Smith"
    billing = "112 Fibonacci Street\n35813"
    delivery = None }
let order2 = {
    name = "John Doe"
    billing = "314 Pi Avenue\n35999"
    delivery = Some "16 Planck Parkway\n62291" }
```

Option

```
let addressForPackage (details : BillingDetails) =
    let address =
        match details.delivery with
        | Some s -> s
        | None -> details.billing
    sprintf "%s\n%s" details.name address
printfn "%s" (addressForPackage order1)
printfn "%s" (addressForPackage order2)
```

```
  let addressForPackage (details : BillingDetails) =
  ---------------------------------^^^^^^^^^^^^^^

/Users/kirchnerg/Desktop/courses/course.2026.hwr.fun/slides/stdin(1242,34): err
```

Option bind and map

```
open System
let tryLastLine (address : string) =
    let parts = address.Split([|'\n'|],
    ↪  StringSplitOptions.RemoveEmptyEntries)
    parts |> Array.tryLast
let tryPostalCode (codeString : string) =
    match Int32.TryParse(codeString) with
    | true, i -> i |> Some
    | false, _ -> None
let postalCodeHub (code : int) =
    if code = 62291 then "Hub 1" else "Hub 2"
let tryHub (details : BillingDetails) =
    details.delivery
    |> Option.bind tryLastLine
    |> Option.bind tryPostalCode
    |> Option.map postalCodeHub
```

Option

```
let test1 = order1 |> tryHub
let test2 = order2 |> tryHub
```

```
let test1 = order1 |> tryHub
------------^^^^^^
```

```
/Users/kirchnerg/Desktop/courses/course.2026.hwr.fun/slides/stdin(1251,13): err
```

Result (Imperativ)

```
open System
let checkString (s : string) =
    if isNull(s) then
        raise <| ArgumentNullException("Must not be null")
    elif String.IsNullOrEmpty(s) then
        raise <| ArgumentException("Must not be empty")
    elif String.IsNullOrWhiteSpace(s) then
        raise <| ArgumentException("Must not be white space")
    else
        s
//checkString null
//checkString ""
checkString " "
```

```
System.ArgumentException: Must not be white space
   at FSI_0321.checkString(String s) in /Users/kirchnerg/Desktop/courses/course
   at <StartupCode$FSI_0321>.$FSI_0321.main@() in /Users/kirchnerg/Desktop/cour
   at System.RuntimeMethodHandle.InvokeMethod(ObjectHandleOnStack target, Void*
   at System.RuntimeMethodHandle.InvokeMethod(ObjectHandleOnStack target, Void*
   at System.Reflection.MethodBaseInvoker.InterpretedInvoke_Method(Object obj,
   at System.Reflection.RuntimeMethodInfo.Invoke(Object obj, BindingFlags invok
Stopped due to error
```

Result (Result<'Success,'Failure>)

```
open System
let notEmpty (s : string) =
    if isNull(s) then Error "Must not be null"
    elif String.IsNullOrEmpty(s) then Error "Must not be empty"
    elif String.IsNullOrWhiteSpace(s) then Error "Must not be white
    ↪  space"
    else Ok s
let t1 = notEmpty null;;
let t2 = notEmpty "";;
let t3 = notEmpty " ";;
t1, t2, t3
```

```
t1, t2, t3;;
val it: Result<string,string> * Result<string,string> * Result<string,string>
= (Error "Must not be null", Error "Must not be empty",
   Error "Must not be white space")
```

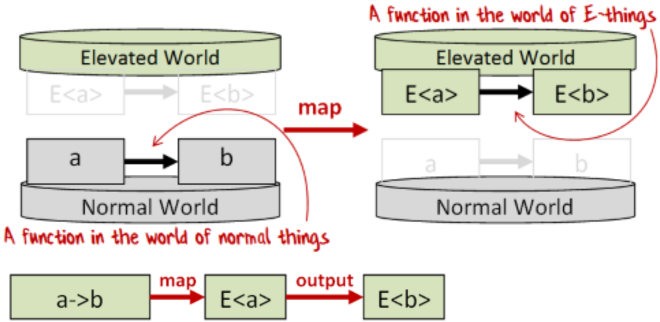
Result (Error-Types DU)

```
open System
type ValidationError =
    | MustNotBeNull
    | MustNotBeEmpty
    | MustNotBeWhiteSpace
let notEmpty (s : string) =
    if isNull(s) then Error MustNotBeNull
    elif String.IsNullOrEmpty(s) then Error MustNotBeEmpty
    elif String.IsNullOrWhiteSpace(s) then Error MustNotBeWhiteSpace
    else Ok s
let t1 = notEmpty null;;
let t2 = notEmpty "";;
let t3 = notEmpty "  ";;
notEmpty, t1, t2, t3
```

```
notEmpty, t1, t2, t3;;
val it:
  (string -> Result<string,ValidationError>) * Result<string,ValidationError> *
  Result<string,ValidationError> * Result<string,ValidationError> =
  (<fun:it@1292-88>, Error MustNotBeNull, Error MustNotBeEmpty,
   Error MustNotBeWhiteSpace)
```

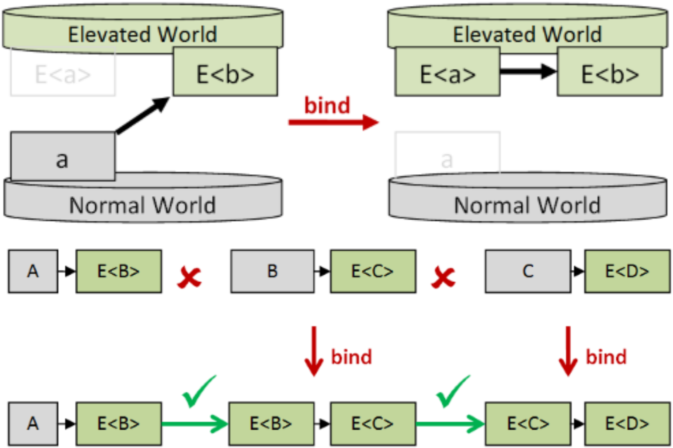
Map

- E.map (<$>): `(a->b) -> E<a> -> E<b>`



Bind

- E.bind (>>=): `(a->E<b>) -> E<a> -> E<b>`



Pause

> Applications programming is a race between software engineers, who strive to produce idiot-proof programs, and the universe which strives to produce bigger idiots. So far the Universe is winning.
>
> – Rick Cook (1989)

Zusammenfassung

- funktionale Operationen auf Listen (Tail-Rekursion)
- funktionaler Umgang mit fehlenden Daten (Option)
- funktionaler Umgang mit Fehlern (Result)

Links

- fsharp.org
- docs.microsoft.com/../dotnet/fsharp
- F# weekly
- fsharpforfunandprofit.com
- github.com/../awesome-fsharp

Hausaufgabe

- exercism.io (bis 02.03)
  - ☐ Queen Attack
  - ☐ Raindrops
  - ☐ Gigasecond
  - ☐ Bank Account
- exercism.io (bis 16.03)
  - ☐ Accumulate
  - ☐ Space Age
- exercism.io (bis 23.03)
  - ☐ Poker (Programmieraufgabe)

Termine

- ☒ 18.02 13:00 - 17:15
- ☒ 25.02 13:00 - 17:15
- ☐ 04.03 13:00 - 17:15
- ☐ 18.03 13:00 - 17:15
- ☐ 25.03 13:00 - 17:15