Introduction to F#

Basics of Functional Programming

Remark

- For beginners only.

About the Speaker

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- **Financial Engineer**, Numerical Technologies

What is Functional Programming (FP)?

- Based on combinatory **logic**
- Uses **functions** to solve problem

- Other Good Properties (depend on language)
  - Purity/Type-check/Recursive/Lazy-evaluation/homoiconicity

FP Languages

- Ancestor:
  - ML (1973)
  - **Haskell** (1990)

- Cousins:
  - OCaml(1996)
  - Scala (2004)
  - **F#** (2005)
  - Elm (2012)
  - ReasonML (2018)

- Remark: Some also considers LISP (1958) and their dialects (e.g. Clojure 2007) functional languages.

Who uses FP?

Haskell

Standard
Chartered

Clojure / F#

Walmart
jet

Jane
Street

OCaml

Scala

Why Learn FP?

- Concise code
- Ability to reason
- Unlock problems

- Better Salary

This Talk: F#

There are also Scala, Haskell, Clojure, Elm Meetups in Singapore.

Should I switch from C# to F#?

- Eager Learner: Yes!
  - Fun! Easy to Learn!
  - Access other FP languages!
  - Change the way you think.
  - Use functional-technique in C# code.

- Skeptics: Yes.
  - A lot of new features in C# comes from F#.
  - F# has better syntax to learn these concepts.

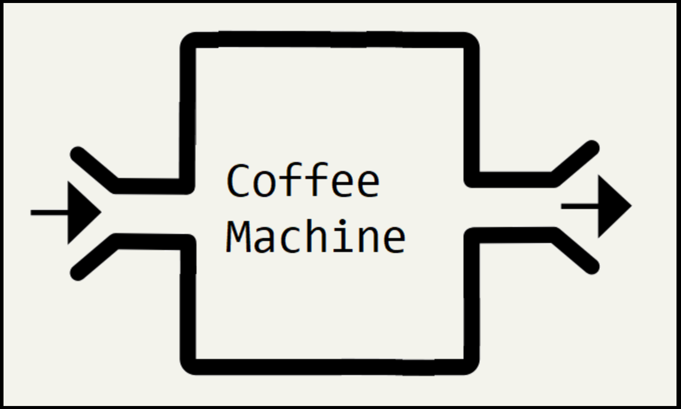
Core Concept

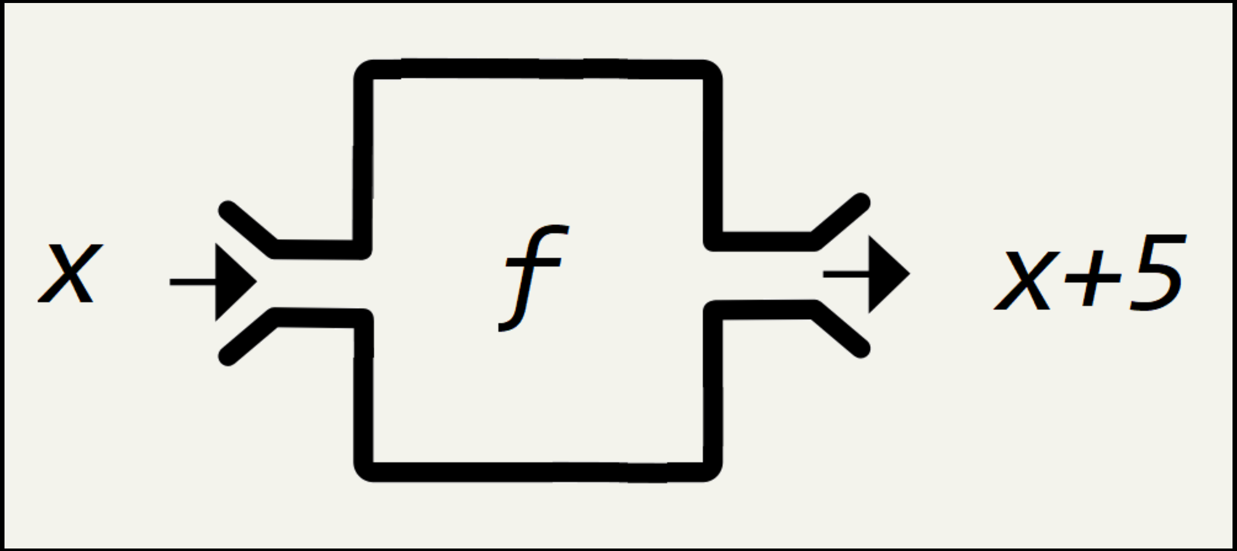
- Functions are things

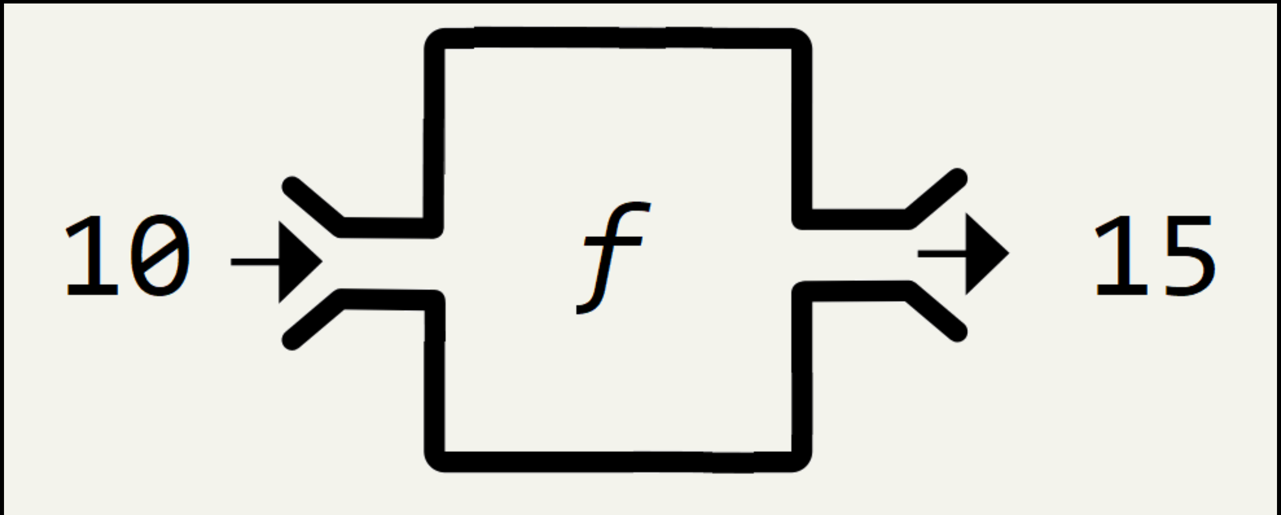
- Compose functions

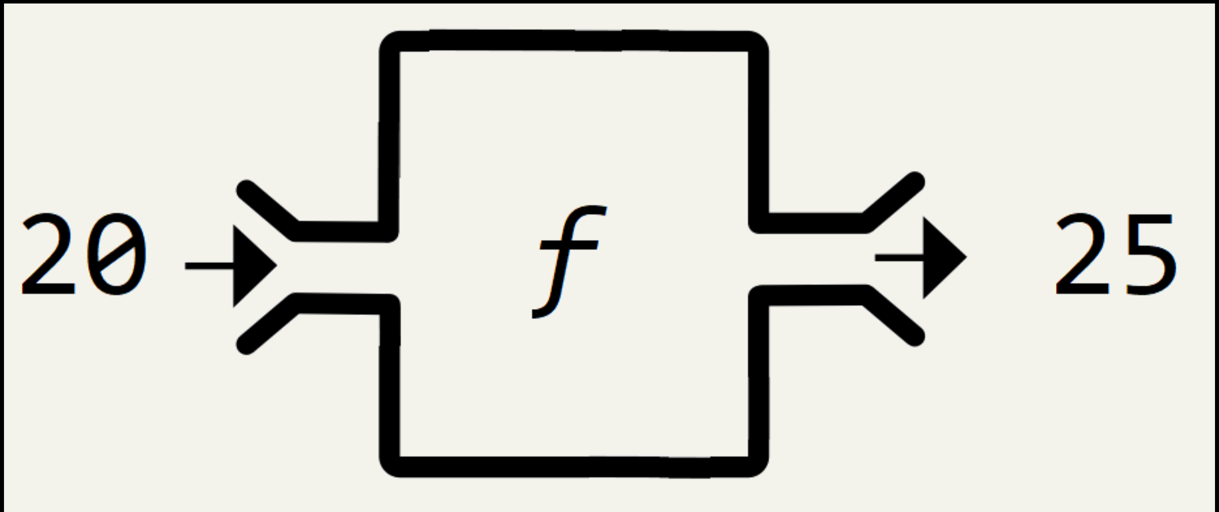
What is a function?

- Function is a machine that **take an input**, and **returns an output**


Coffee
Machine


x
f
x+5


10
f
15


20
f
25

F# Example

- `let f x = x + 5`

- `f 30      // 35`
- `f 100     // 105`

Notation

- (To Define)
- In Math:

  `let f(x) = x + 5`

- In F#:
- `let f x = x + 5`

No Brackets (())

Notation

- (To Use)
- In Math:

  ```
  let y = f(100)
  ```

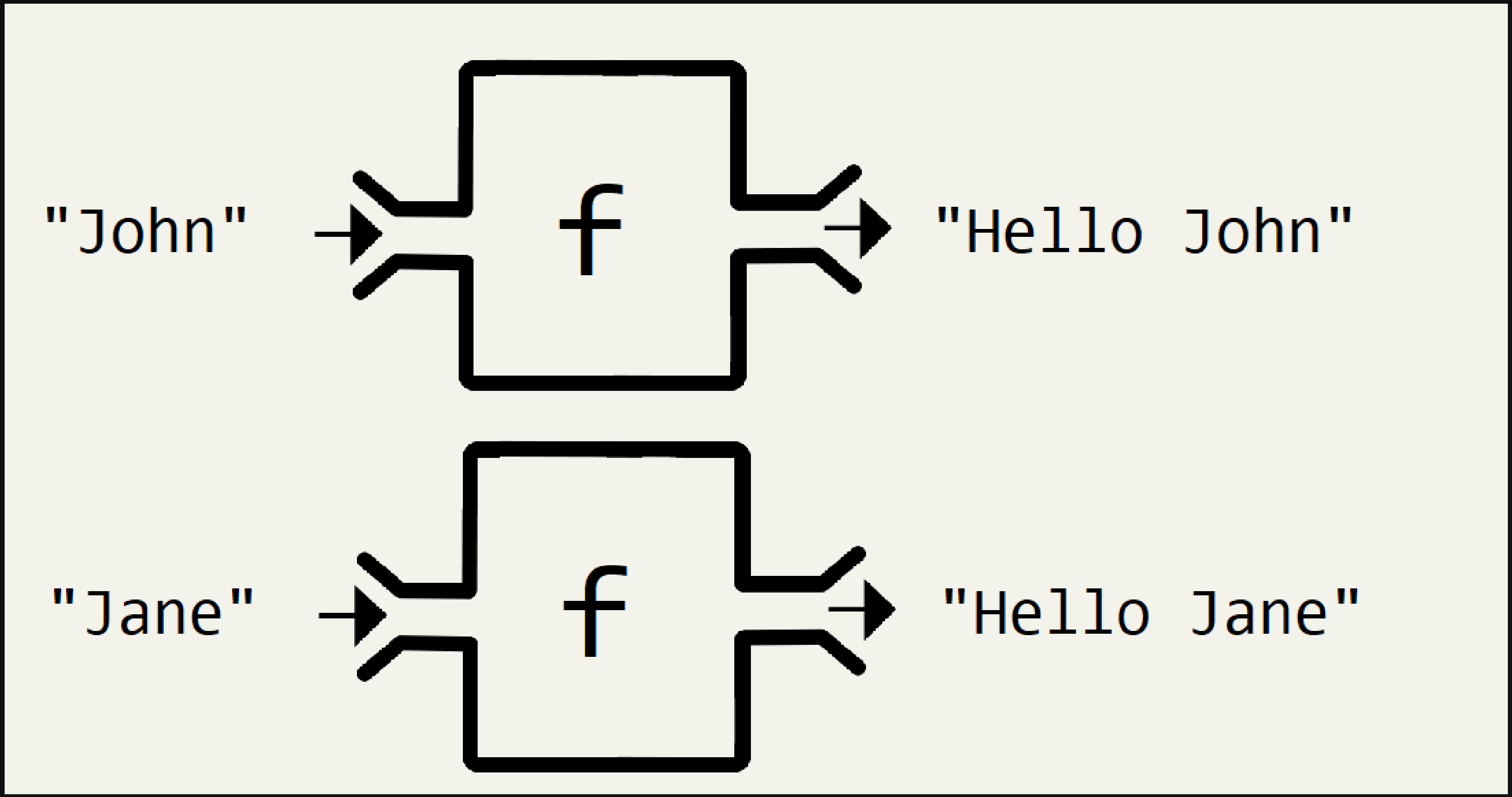
- In F#:
- `let y = f 100`

No Brackets (())

Example

- `let f x = “Hello ” + x`

- `f “John”      // “Hello John”`
- `f “Jane”      // “Hello Jane”`



"John" → f → "Hello John"

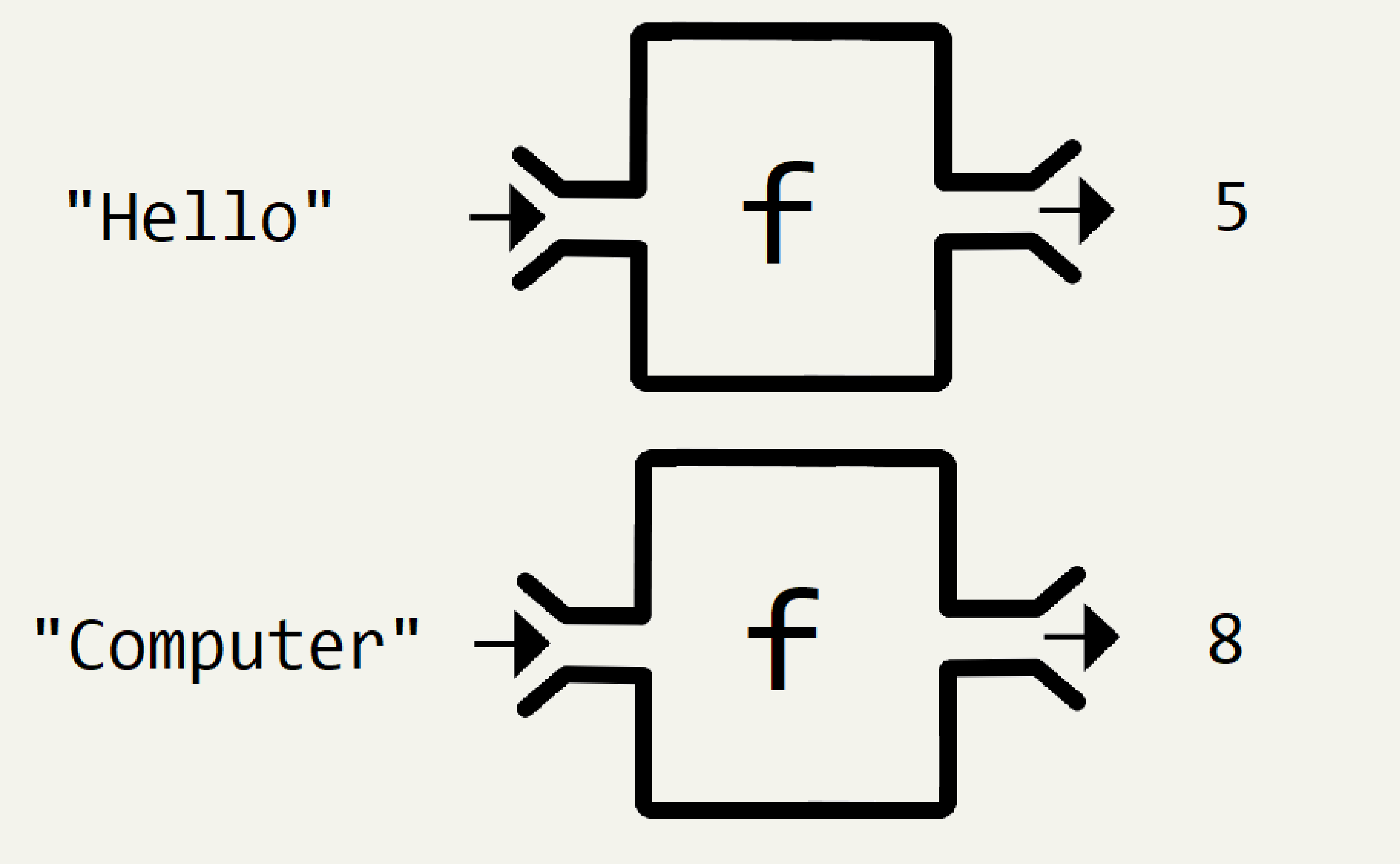
"Jane" → f → "Hello Jane"

Example

- let f x = String.length x

- f “Hello”   // 5
- f “Computer”   // 8

- f : string -> int

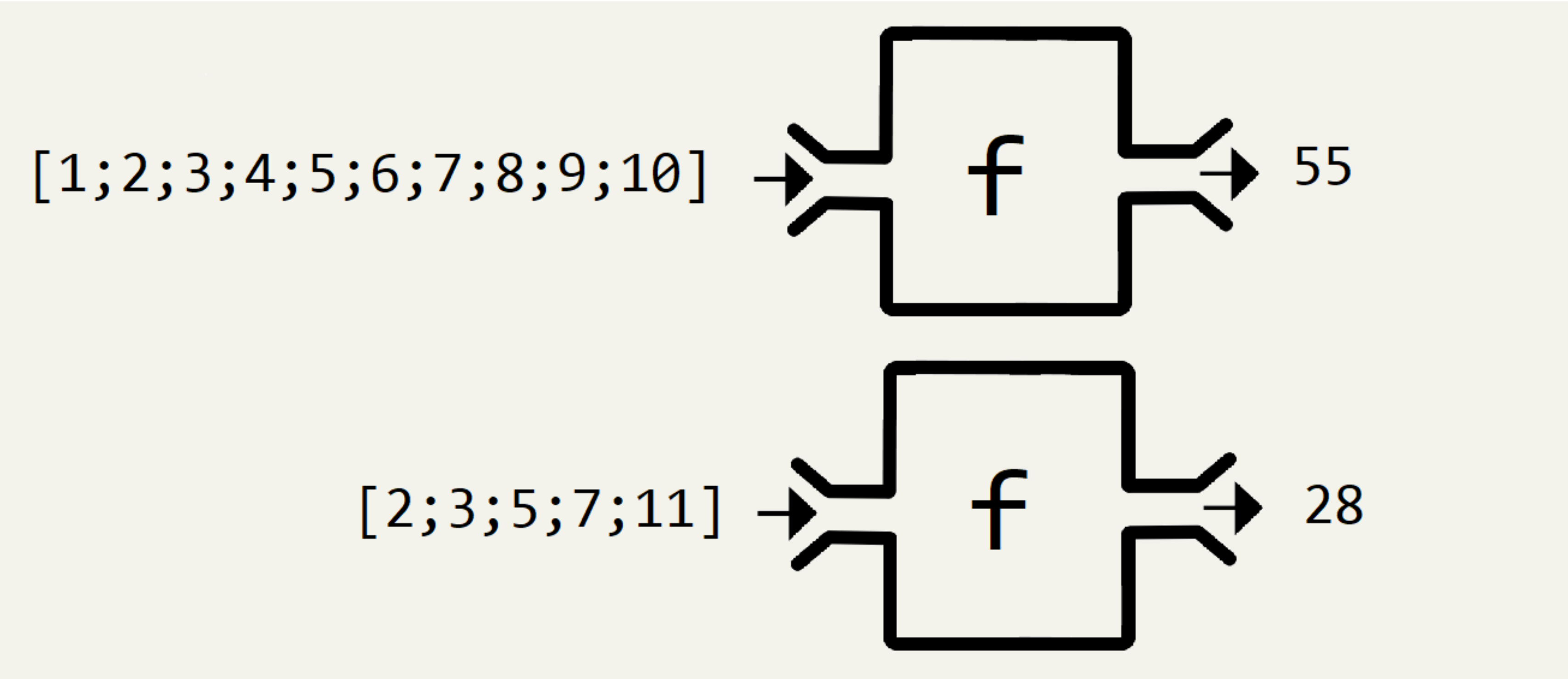

"Hello"
f
5
"Computer"
f
8

Example

- `let f xs = List.sum xs`

- `f [1..10]      // 55`
- `f [2;3;5;7;11] // 28`

- `f : List<int> -> int`



[1;2;3;4;5;6;7;8;9;10] → f → 55

[2;3;5;7;11] → f → 28

Multiple inputs

- `let f x y = x + y`

- `f 2 3      // 5`
- `f 30 70    // 100`

- `f : int -> int -> int`

Notation

- (To Define)
- In Math:

```
let f(x,y) = x + y
```

- In F#:
- `let f x y = x + y`

No Brackets (())
No Commas ,

Notation

- (To Use)
- In Math:

```
let z = f(2,3)
```

- In F#:
- `let z = f 2 3`

No Brackets (())
No Commas ,

Multiple inputs

- `let f x y z = x + y + z`

- `f 2 3 7        // 12`
- `f 30 70 200    // 300`

- `f : int -> int -> int -> int`

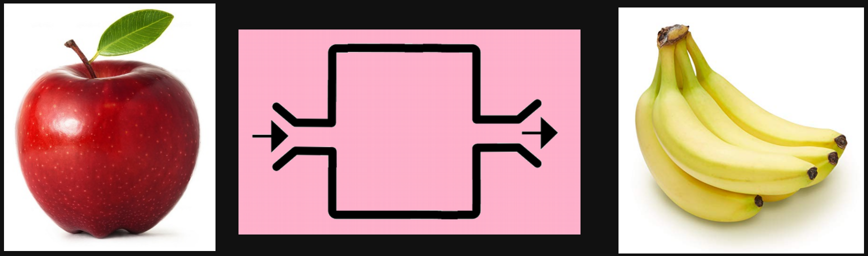
Multiple inputs

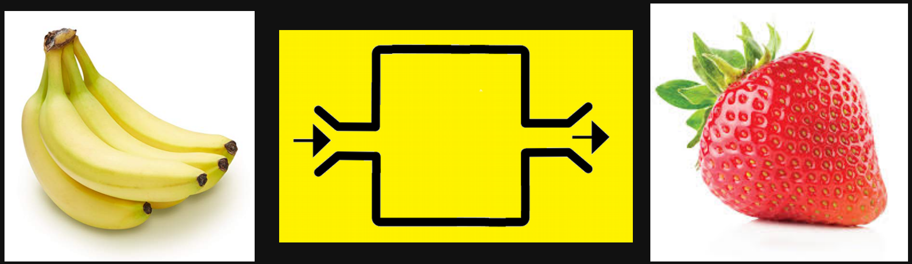
- `let f a b c d = ......`

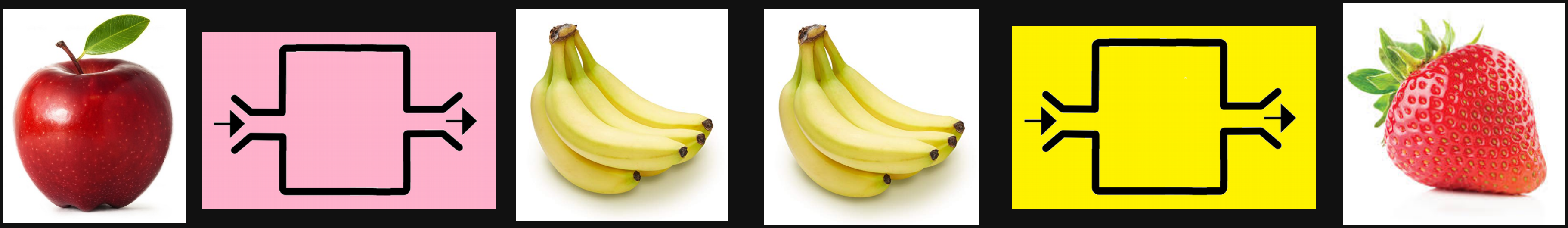
- `f : A -> B -> C -> D -> output`

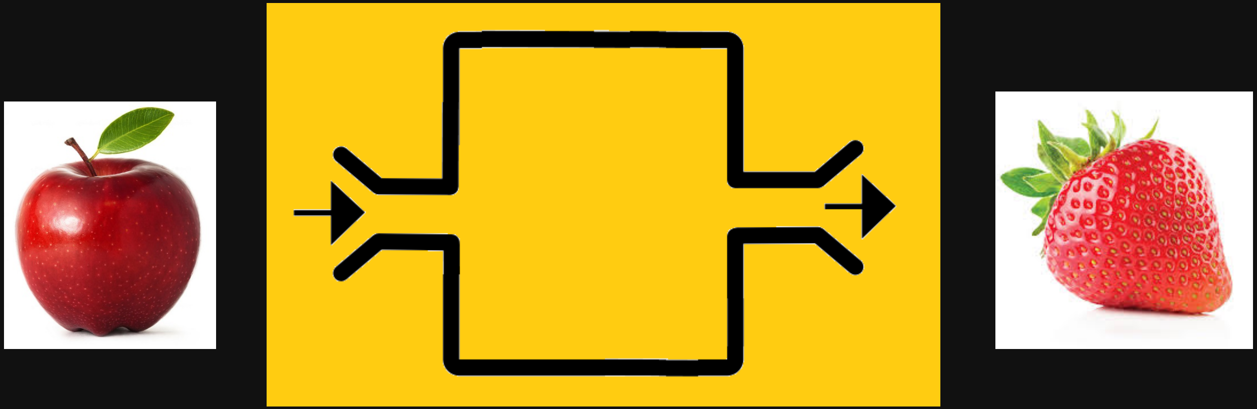
Function Composition

- Functions can be “connected” if the first output is the input of the second function.





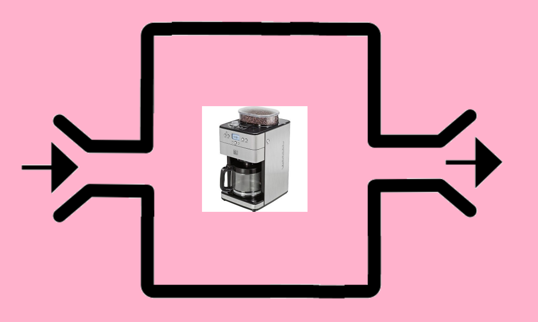




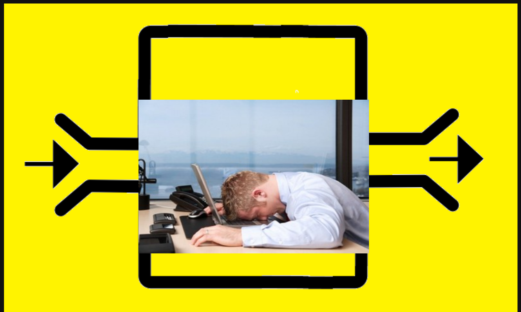
A bigger machine/function!

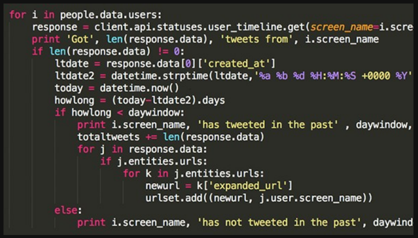
Banana is “hidden”

Coffee Machine



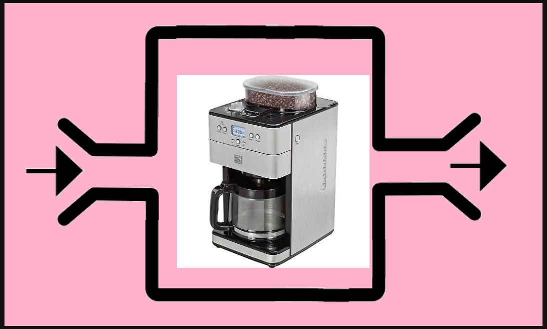
Programmer





```
for i in people.data.users:
    response = client.api.statuses.user_timeline.get(screen_name=i.scre
    print 'Got', len(response.data), 'tweets from', i.screen_name
    if len(response.data) != 0:
        ltdate = response.data[0]['created_at']
        ltdate2 = datetime.strptime(ltdate,'%a %b %d %H:%M:%S +0000 %Y'
        today = datetime.now()
        howlong = (today-ltdate2).days
        if howlong < daywindow:
            print i.screen_name, 'has tweeted in the past' , daywindow,
            totaltweets += len(response.data)
            for j in response.data:
                if j.entities.urls:
                    for k in j.entities.urls:
                        newurl = k['expanded_url']
                        urlset.add((newurl, j.user.screen_name))
        else:
            print i.screen_name, 'has not tweeted in the past', daywind
```

Coffee Machine



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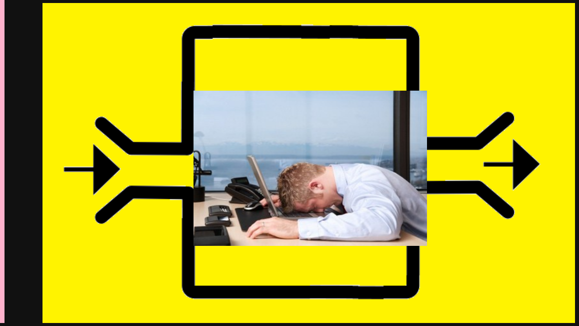

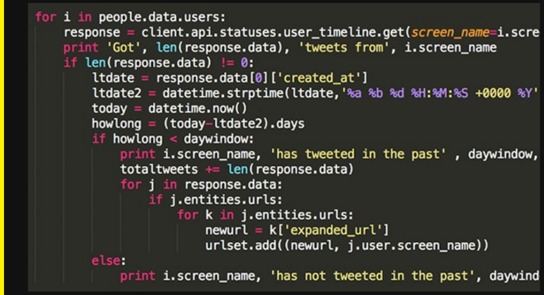

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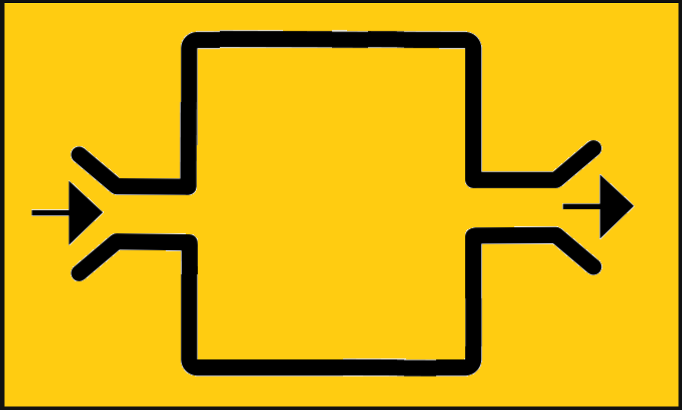

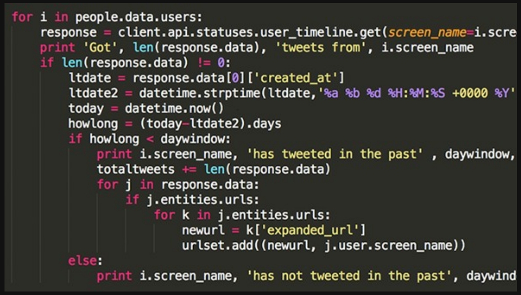

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            totaltweets += len(response.data)
            for j in response.data:
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                    for k in j.entities.urls:
                        newurl = k['expanded_url']
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        else:
            print i.screen_name, 'has not tweeted in the past', daywind
```

- `f : A -> B`
- `g :       B -> C`

-
  ```
       g (f a)
  // = g ( b )
  // = c
  ```

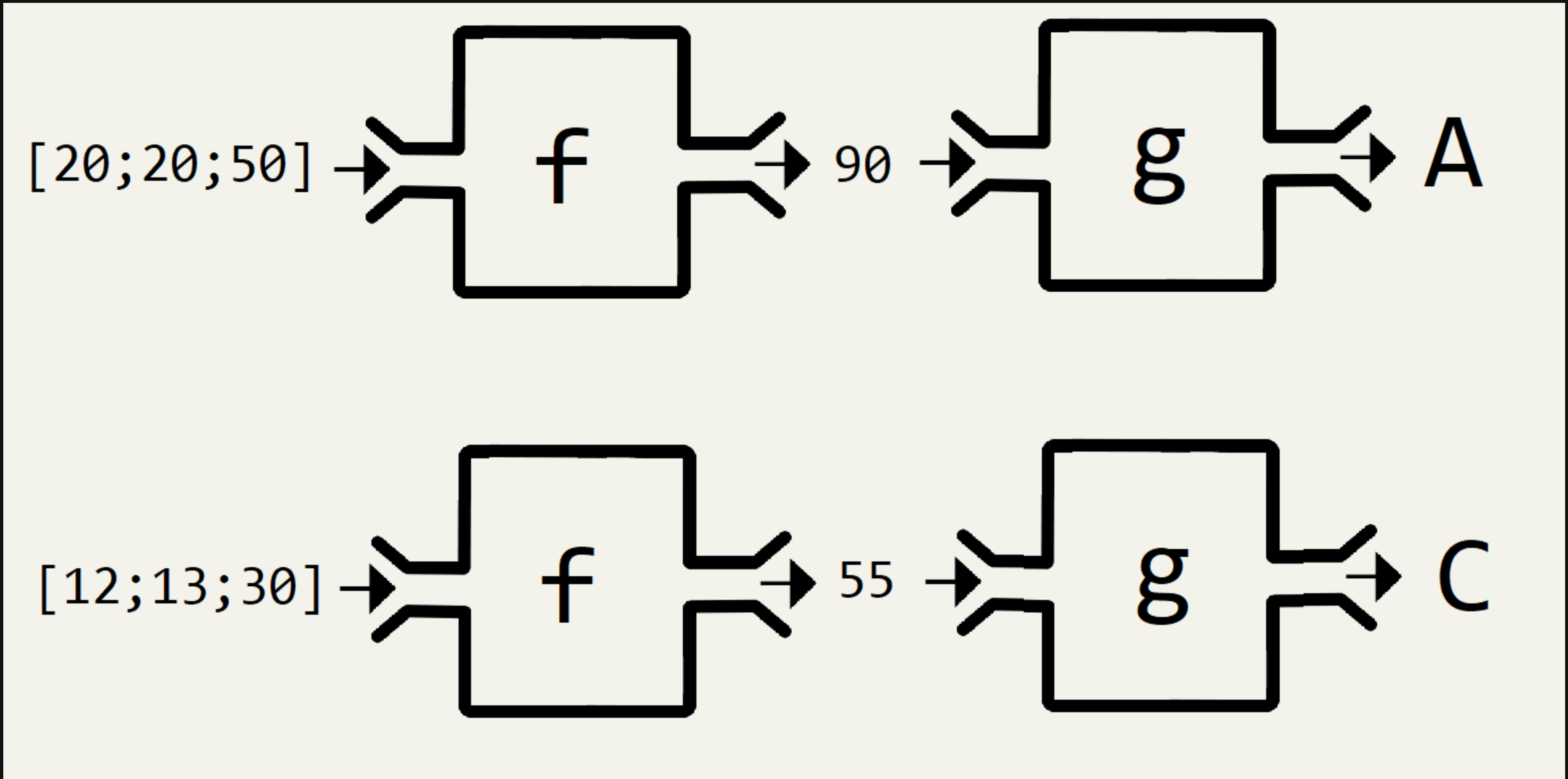
Example

```
let f xs = List.sum xs

let g x =
    if        x > 80 then “A”
    else if x > 60 then “B”
    else                “C”
```

```
f : List<int> -> int

g :              int -> string
```



[20;20;50] → f → 90 → g → A

[12;13;30] → f → 55 → g → C

-
  ```
  let f xs = List.sum xs
  ```

-
  ```
  let g x =
      if      x > 80 then “A”
      else if x > 60 then “B”
      else                “C”
  ```

-
  ```
  g (f [20; 20; 50])  // g (90)
                      // “A”
  ```

Types must match

- `f : A -> B`
- `g :       C -> D`

- `g (f a)                  ERROR!`

- `Output of f not accepted by g`

|>

Key idea in F#

Pipe-forward operator

What does pipe-forward do?

- Change the **order** of the function and input

- `let f x = x + 5`
- `f 100     // 105`
- `100 |> f  // 105`

- `f : A -> B`
- `g :      B -> C`

- `g (f a)`

- `a |> f |> g`

-
  ```
  f : A -> B
  ```

-
  ```
  g :      B -> C
  ```

-
  ```
  g (f a)
  ```

-
  ```
  a
  |> f
  |> g
  ```

- `f : A -> B`
- `g :       B -> C`

- `g (f a)`

-
  ```
  a
  (then do) f
  (then do) g
  ```

-
  ```
  x
    |> f
    |> g
  ```

- Start with input x,
  Apply input to f,
  Apply previous result to g.

-
  ```
  x
  |> f
  |> g
  |> h
  ```

- Start with input x,
  Apply input to f,
  Apply previous result to g,
  Apply previous result to h.

-
  ```
  x
  |> f
  |> g
  |> h
  |> k
  ```

- Start with input x,
  Apply input to f,
  Apply previous result to g,
  Apply previous result to h,
  Apply previous result to k.

-
  ```
  x
  |> f
  |> g
  |> h
  |> k
  ```

1st output = 2nd input
2nd output = 3rd input
etc.

- Start with input x,
  Apply input to f,
  Apply previous result to g,
  Apply previous result to h,
  Apply previous result to k.

- x

  ```
  |> f
  |> g
  |> h
  |> k
  ```

- In C#:
- `x.Pipe(f).Pipe(g).Pipe(h).Pipe(k);`
- You can do it in C#, but not as natural.

Benefit

- Express Logic Step-by-Step
- Easier to read

Example

- Questions from Project Euler
- https://projecteuler.net/

- (Question 1) Find the sum of all the multiples of 3 or 5 below from 1 to 999.

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-
```
[1 .. 999]
|> List.filter (fun x -> x % 3 = 0 || x % 5 = 0)
|> List.sum
```

- (Question 1) Find the sum of all the multiples of 3 or 5 below from 1 to 999.

-
  ```
  [1 .. 999]
  |> List.filter (fun x -> x % 3 = 0 || x % 5 = 0)
  |> List.sum
  ```

- Start with a list from 1 to 999
- (then do) filter to keep the numbers you want
- (then do) sum those remaining numbers.

- (Question 1) Find the sum of all the multiples of 3 or 5 below from 1 to 999.

-
  ```
  [1 .. 999]
  |> List.filter (fun x -> x % 3 = 0 || x % 5 = 0)
  |> List.sum
  ```

- C# LINQ

-
  ```
  Enumerable.Range(1, 999)
  .Where(x => x % 3 == 0 || x % 5 == 0)
  .Sum();
  ```

- (Question 6 Modified)

  Calculate $1^2 + 2^2 + \ldots + 100^2$

- (Question 6 Modified)

  Calculate $1^2 + 2^2 + ... + 100^2$

-
  ```
  [1 .. 100]
  |> List.map (fun x -> x * x)
  |> List.sum
  ```

- (Question 6 Modified)

  Calculate $1^2 + 2^2 + \ldots + 100^2$

-
  ```
  [1 .. 100]
  |> List.map (fun x -> x * x)
  |> List.sum
  ```

- Start with a list from 1 to 100
  (then do) convert each element to its square
  (then do) sum up the previous list.

- (Question 6 Modified)

  Calculate $1^2 + 2^2 + … + 100^2$

-
  ```
  [1 .. 100]
  |> List.map (fun x -> x * x)
  |> List.sum
  ```

- C# LINQ:
-
  ```
  Enumerable.Range(1,100)
  .Select(x => x * x)
  .Sum();
  ```

- (Additional Example)
- Calculate Squares of Prime Numbers
- Calculate $2^2 + 3^2 + 5^2 + 7^2 + 11^2 + 13^2 + 17^2 + \ldots + 97^2$

- (Additional Example)
- Calculate Squares of Prime Numbers
- Calculate $2^2 + 3^2 + 5^2 + 7^2 + 11^2 + 13^2 + 17^2 + \ldots + 97^2$

-
```
[1 .. 100]
|> List.filter (fun x -> isPrime x)
|> List.map (fun x -> x * x)
|> List.sum
```

Need “isPrime”
Helper Function

Example

- There are three events, each will occur with probability 0.2, 0.3, 0.4 respectively (independent of each other)

- What is the probability of no event happening?

  (1 - 0.2) x (1 - 0.3) x (1 - 0.4)

- There are three events, each will occur with probability 0.2, 0.3, 0.4 respectively (independent of each other)

- What is the probability of no event happening?

  (1 - 0.2) x (1 - 0.3) x (1 - 0.4)

- What is the probability of at least one event happening?
- 1 - [(1 - 0.2) x (1 - 0.3) x (1 - 0.4)]

- There are multiple events, each will occur with probability p_1, p_2, ……, p_n respectively (independent of each other)

- What is the probability of no event happening?

$(1 - p_1) \times (1 - p_2) \times \ldots\ldots \times (1 - p_n)$

- What is the probability of at least one event happening?
- $1 - [\ (1 - p_1) \times (1 - p_2) \times \ldots\ldots \times (1 - p_n)\ ]$

- Given a list of number p_i , how do you calculate:
- $1 - [(1 - p_1) x (1 - p_2) x \ldots\ldots x (1 - p_n)]$

-
  ```
  xs
  |> List.map (fun x -> 1.0 - x)
  |> List.product
  |> fun z -> 1.0 - z
  ```

Need to self define “List·product”

- Given a list of number p_i , how do you calculate:
- $1 - [\,(1 - p_1) \times (1 - p_2) \times \ldots\ldots \times (1 - p_n)\,]$
- xs

```
.Select(x => 1.0 - x)
.Product()
.Then(z => 1.0 - z)
```

Need to self define "Product"
or use "LINQ.Aggregate"

Need to self define "Then"

Partial Application

Useful Language Design

- `let AddAll w x y z = w + x + y + z`
- `let result = AddAll 1 2 3 4`

  `// result = 10`

- `let AddAll w x y z = w + x + y + z`
- `let result = AddAll 1 2 3`

  `// Missing one variable?`

-
  ```
  let AddAll w x y z = w + x + y + z
  ```

-
  ```
  let result = AddAll 1 2 3
  ```

  ```
  // No compilation error.
  // result : int -> int
  ```

If a function/machine:

- Needs 5 inputs
- But only 1 inputs provided,

- Still needs 4 additional inputs.

If a function/machine:

- Needs 5 inputs
- But only 2 inputs provided,

- Still needs 3 additional inputs.

If a function/machine:

- Needs 5 inputs
- But only 2 inputs provided,

- Becomes a brand new function/machine that needs 3 inputs.

If a function/machine:

- Needs 5 inputs
- But only 1 inputs provided,

- Becomes a brand new function/machine that needs 4 inputs.

- `let f u v w x y = ......`
- `let result = f u v`

  `// result : W -> X -> Y -> output`

in C#

-
  ```
  public static int Add (int x, int y){
      return x + y;
  }
  ```

-
  ```
  Add(1);
  Compile ERROR!
  ```

Special Case (n - 1)

- `f u v w a = b`
- `g x y z b = c`

-
  ```
  f u v w : a -> b
  ```

-
  ```
  g x y z :       b -> c
  ```

-
  ```
  a
  |> f u v w
  |> g x y z
  ```

Special Case (n - 1)

- `f u v w a = b`
- `g x y z b = c`

- `f u v w : a -> b`
- `g x y z :      b -> c`

-
  ```
  a
  |> f u v w
  |> g x y z
  ```

Assemble almost everything except the final component

Special Case (n - 1)

-
  ```
  [1 .. 100]
  |> List.filter (fun x -> x % 3 = 0 || x % 5 = 0)
  |> List.map (fun x -> x * x)
  |> List.sum
  ```

Special Case (n - 1)

-
  ```
  [1 .. 100]
  |> List.filter (fun x -> x % 3 = 0 || x % 5 = 0)
  |> List.map (fun x -> x * x)
  |> List.sum
  ```

Assemble almost everything except the final component

Special Case (n - 1) “this”

- `public static B1 f(this A1 a1, A2 a2, A3 a3){......}`
- `public static C1 g(this B1 b1, B2 b2, B3 b3){......}`
- `public static D1 h(this C1 c1, C2 c2, C3 c3){......}`

```
• f: A1,A2,A3 -> B1
• g:             B1,B2,B3 -> C1
• h:                         C1,C2,C3 -> D1
```

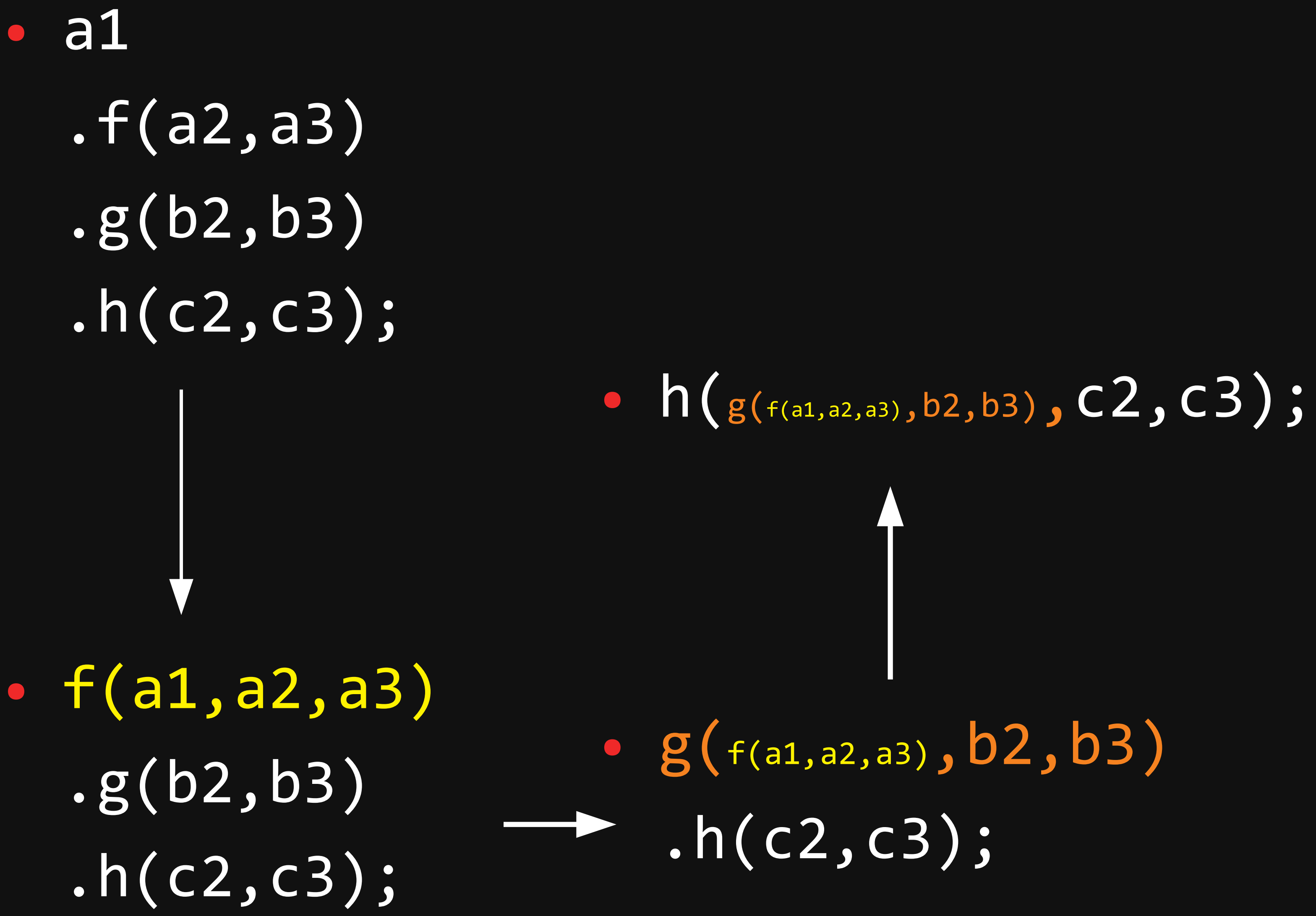
Special Case (n - 1) “this”

-
  ```
  a1
  .f(a2,a3)
  .g(b2,b3)
  .h(c2,c3);
  ```

-
  ```
  f: A1,A2,A3 -> B1
  ```

-
  ```
  g:             B1,B2,B3 -> C1
  ```

-
  ```
  h:                         C1,C2,C3 -> D1
  ```



-
  ```
  a1
  .f(a2,a3)
  .g(b2,b3)
  .h(c2,c3);
  ```

-
  ```
  f(a1,a2,a3)
  .g(b2,b3)
  .h(c2,c3);
  ```

-
  ```
  g(f(a1,a2,a3),b2,b3)
  .h(c2,c3);
  ```

-
  ```
  h(g(f(a1,a2,a3),b2,b3),c2,c3);
  ```

“Currying”

- `Func<A, Func<B,Func<C,Func<D,Z>>>>`
- Flexible

- `Func<A,B,C,D,Z>`
- Not flexible (need to assemble everything)

- Func<A, Func<B,Func<C,Func<D,Z>>>>

- Func<A, Func<B,Func<C,Func<D,Z>>>>

- Func<A, Func<B,Func<C,Func<D,Z>>>>

- Func<A, Func<B,Func<C,Func<D,Z>>>>

“Currying”

-
  ```
  Func<A, Func<B,Func<C,Func<D,Z>>>> Curry
  (Func<A,B,C,D,Z> f) {
      return a => b => c => d => f(a,b,c,d);
  }
  ```

- `var g = Curry(f);`
- `g(a)` Compiles!
- `g(a)(b)` Compiles!
- `g(a)(b)(c)` Compiles!

Example

Dependency Injection

- Let’s say you want a function with this signature:
- `f: CustomerId -> CustomerName`

- However, you are given the following function instead:
- `g : DbConnection -> CustomerId -> CustomerName`

- `f: CustomerId -> CustomerName`
- `g : DbConnection -> CustomerId -> CustomerName`

- `f: CustomerId -> CustomerName`
- `g : DbConnection -> CustomerId -> CustomerName`

- If you partially apply the function “g”, and define:

- `let h = g dbConnection`

- Then “h” has the required signature as “f”
- `h :                CustomerId -> CustomerName`

- `f: CustomerId -> CustomerName`

- On the other hand, if you are given the following function:

- `j: Dictionary<...> -> CustomerId -> CustomerName`

- `f: CustomerId -> CustomerName`

  `j: Dictionary<...> -> CustomerId -> CustomerName`

-
  ```
  f: CustomerId -> CustomerName
  j: Dictionary<...> -> CustomerId -> CustomerName
  ```

- If you partially apply the function “ j ”, and define:

-
  ```
  let k = j dictionary
  ```

- Then “k” has the required signature as “ f ”

-
  ```
  k :                   CustomerId -> CustomerName
  ```

- `f: CustomerId -> CustomerName`
- `g : DbConnection -> CustomerId -> CustomerName`

- If you partially apply the function “g”, and define:

- `let h = g dbConnection`

- Then “h” has the required signature as “f”
- `h :                 CustomerId -> CustomerName`

Higher Order Functions

Function as inputs

Primitive Types

- `public double f(double a, int b, string c) {......}`

- Basic data types as inputs/outputs

Functions as input

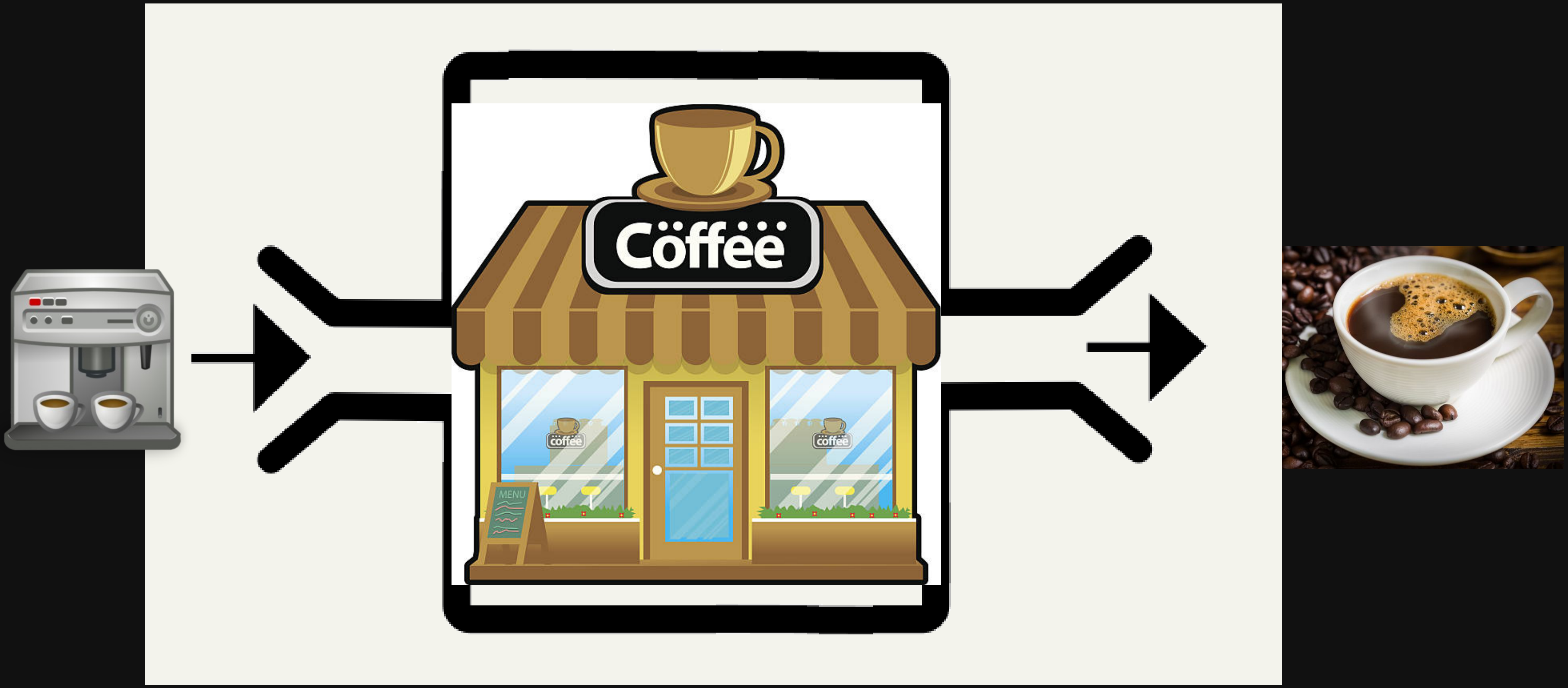
- `public double f(Func<double,int> g, string c) {......}`

- Function “f” accepts another function “g” as input.

Functions as output

- `public Func<int,double> f(double a, int b, string c){......}`

- Function “f” returns another function as output.


Cöffee
coffee
coffee
MENU

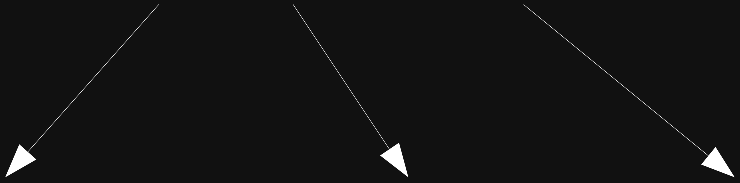
filter, map

-
  ```
  [1 .. 999]
  |> List.filter (fun x -> x % 3 = 0 || x % 5 = 0)
  |> List.sum
  ```

-
  ```
  [1 .. 100]
  |> List.map (fun x -> x * x)
  |> List.sum
  ```

Filter

- `let filter f xs = ......`

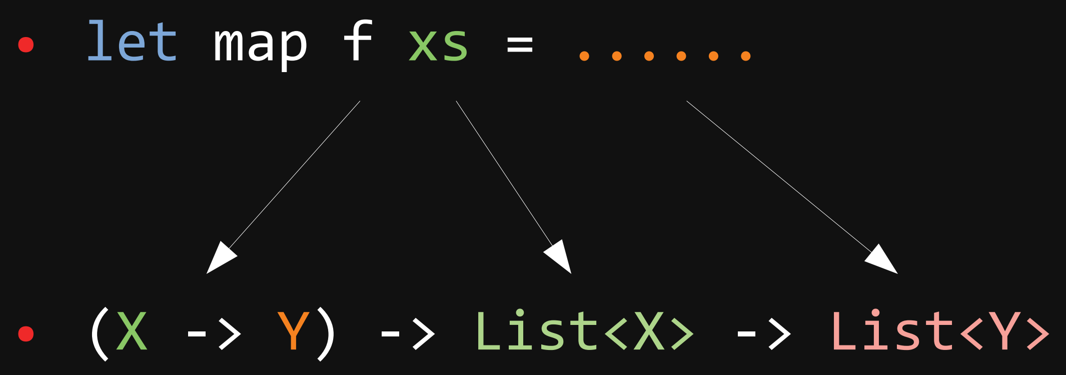


- `(X -> bool) -> List<X> -> List<X>`

- `List<X> filter(Func<X,bool> f, List<X> xs)`

- `LINQ.Where`

Map



- `let map f xs = ......`
- `(X -> Y) -> List<X> -> List<Y>`

- `List<Y> map(Func<X,Y> f, List<X> xs)`
- `LINQ.Select`

Example

Insurance Pricing Example

- How much to charge a customer for an insurance product?

- `let Price = ......`

-
  ```
  let Price =
      ......
  ```

- e.g. Depends on Age.

-
  ```
  let Price age =
      ......
  ```

-
  ```
  age : int
  ```

-
  ```
  int -> $$$
  ```

- e.g. Depends on probability of injury.

-
  ```
  let Price age prob =
        ......
  ```

-
  ```
  age : int
  ```

-
  ```
  prob: double
  ```

-
  ```
  int -> double -> $$$
  ```

- What if the probability depends on time?

-
  ```
  let Price age prob =
      ......
  ```

- `age : int`
- `prob: ??????`

- `int -> ?????? -> $$$`

- Pass in a function

-
  ```
  let Price age probFunc =
        ......
  ```

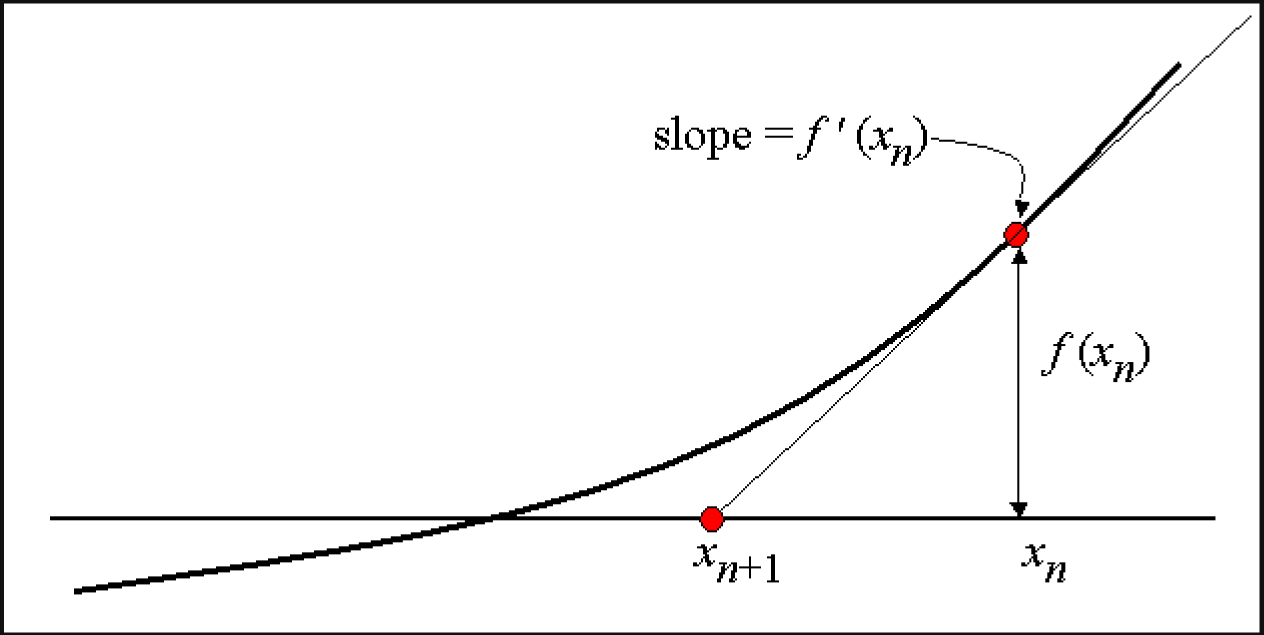
- `age : int`
- `probFunc: DateTime -> double`

- `int -> (DateTime -> double) -> $$$`

Example

Newton’s Method Example

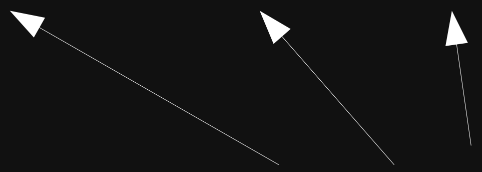
$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$



Newton’s Method Example

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$

- `float -> Func -> Func -> float`

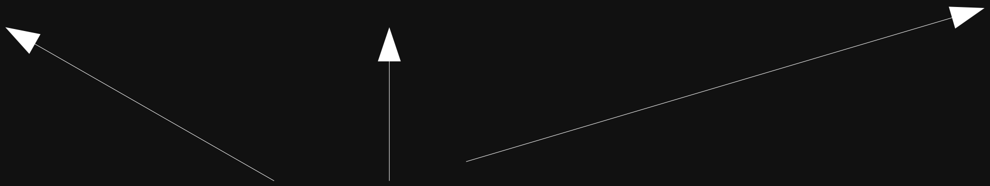


-
  ```
  let Newton start f df =
      let mutable counter = start
      while (......) do
          counter <- counter - (f counter) / (df counter)
  ```

Newton’s Method Example

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$

- `float -> (float -> float) -> (float -> float) -> float`



-
  ```
  let Newton start f df =
      let mutable counter = start
      while (......) do
          counter <- counter - (f counter) / (df counter)
  ```

Example

Strategy Pattern

-
  ```
  public class Package{
      private IShippingStrategy iShippingMethod;
      public double postalCost(Order order){
          return iShippingMethod.Calculate(order);
      }
  }
  ```

-
  ```
  public class FedexStrategy : IShippingStrategy{
      public double iShippingMethod.Calculate(....)
          {......}
  }
  ```

-
  ```java
  public class Package{
      private IShippingStrategy iShippingMethod;
      public double postalCost(Order order){
          return iShippingMethod.Calculate(order);
      }
  }
  ```

-
  ```
  iShippingMethod.Calculate:
      Order -> double
  ```

```
public class Package{
     private Func<Order,double> iShippingMethod;
     public double postalCost(Order order){
          return iShippingMethod(order);
     }
}
```

```
public class Package{

    public double postalCost(Order order,
        Func<Order, double> iShippingMethod)
    {
        return iShippingMethod(order);
    }
}
```

```
public double postalCost(Order order,
    Func<Order, double> iShippingMethod)
{
    return iShippingMethod(order);
}
```

```
public double postalCost(Order order,
    Func<Order, double> f)
{
    return f(order);
}
```

```
public double postalCost(A a,
    Func<A, double> f)
{
    return f(a);
}
```

```
public B postalCost(A a,
    Func<A, B> f)
{
    return f(a);
}
```

```
public B postalCost(A a, Func<A, B> f)
{ return f(a); }
```

```
public B postalCost(A a, Func<A, B> f)
{ return f(a); }
```

```
postalCost a f = f a
postalCost a f = f a
postalCost a f = f a
   (|>)    a f = f a
```

Summary

Summary of Tricks

- Chain/pipe functions as much as possible.
- Use partial application for get a new function.
  - “this” keyword for special case (n-1)
- Higher order functions.
  - Use Functions as inputs and outputs.

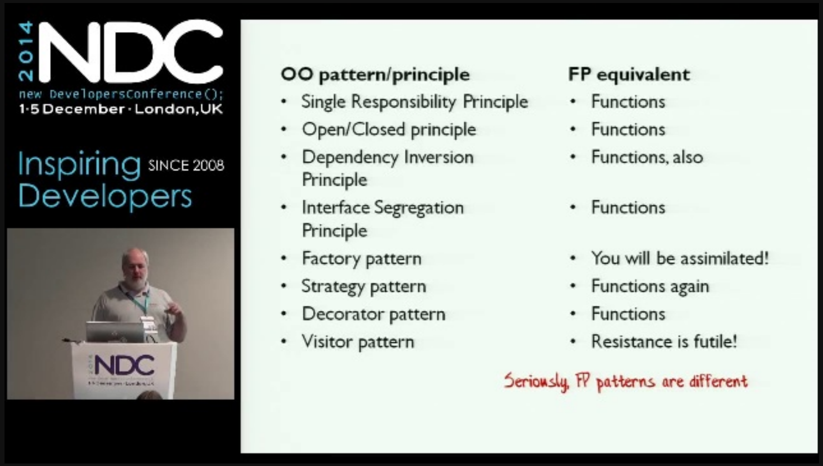
Future Topics

- Sets, Lists, Dictionary
- Pattern Matching
- Union Type, Tuples, Records
- Option Type (Missing/null Values)
- Async
- Impure Operations

Where to learn?

- FSharpforfunandprofit blog
  - https://fsharpforfunandprofit.com/
- Real-World Functional Programming
  - https://www.manning.com/books/real-world-functional-programming

Conference videos?



2014 NDC

new DevelopersConference();

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Inspiring SINCE 2008 Developers

OO pattern/principle	FP equivalent
Single Responsibility Principle	Functions
Open/Closed principle	Functions
Dependency Inversion Principle	Functions, also
Interface Segregation Principle	Functions
Factory pattern	You will be assimilated!
Strategy pattern	Functions again
Decorator pattern	Functions
Visitor pattern	Resistance is futile!

Seriously, FP patterns are different

- Scott Wlaschin (author for F#forfunandprofit)
  - Great tech educator.
  - Given many good talks during NDC Conference. (Available on Youtube)

How to learn?

- FSharpForFunAndProfit blog
- Try out Project Euler Questions.
- I have some training materials for interns.

Sources (Who uses FP)

- https://www.janestreet.com/technology/
- https://reasonml.github.io/
- https://fsharp.org/testimonials/
- https://devblogs.nvidia.com/jet-gpu-powered-fulfillment/
- https://www.scala-lang.org/old/node/1658
- https://clojure.org/community/companies
- https://www.slideshare.net/naughty_dog/statebased-scripting-in-uncharted-2-among-thieves

Q&A