Introduction to F#

Basics of Functional Programming

Remark

- For beginners only.

About the Speaker

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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)

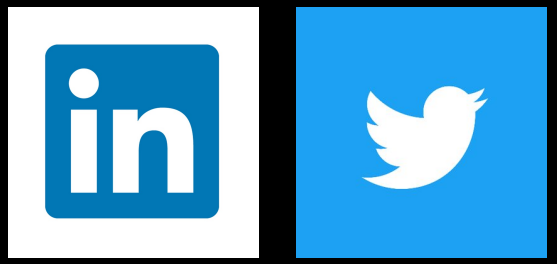
- Remark: Some also considers LISP (1958) and their dialects (e.g. Clojure 2007) functional languages.

Who uses FP?

Haskell

Clojure / F#

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.
  - Call F# function from C#!

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

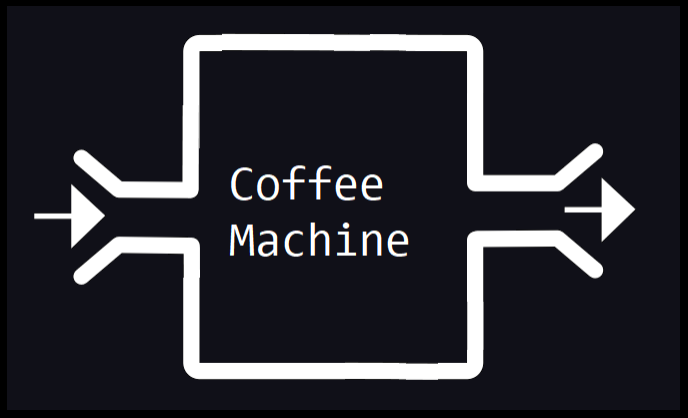
Core Concept

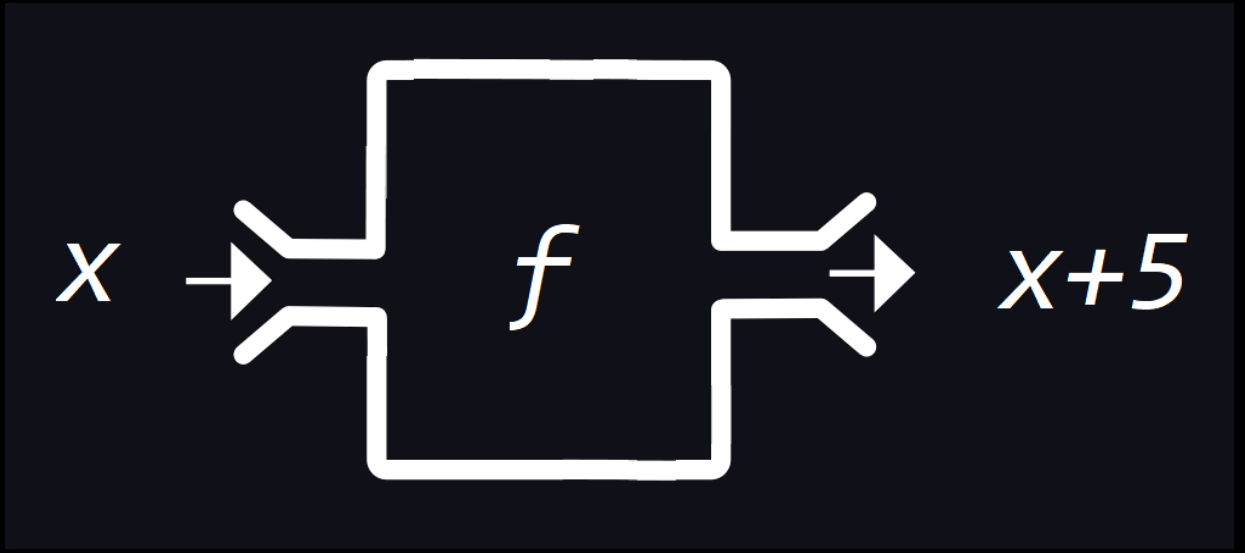
- Functions are things

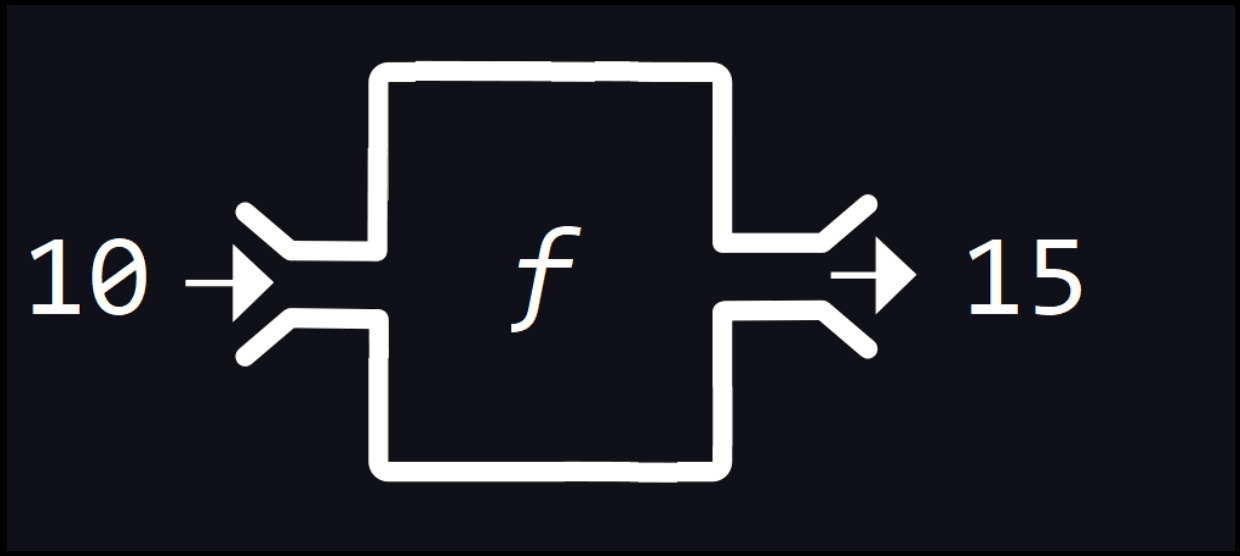
- Compose functions

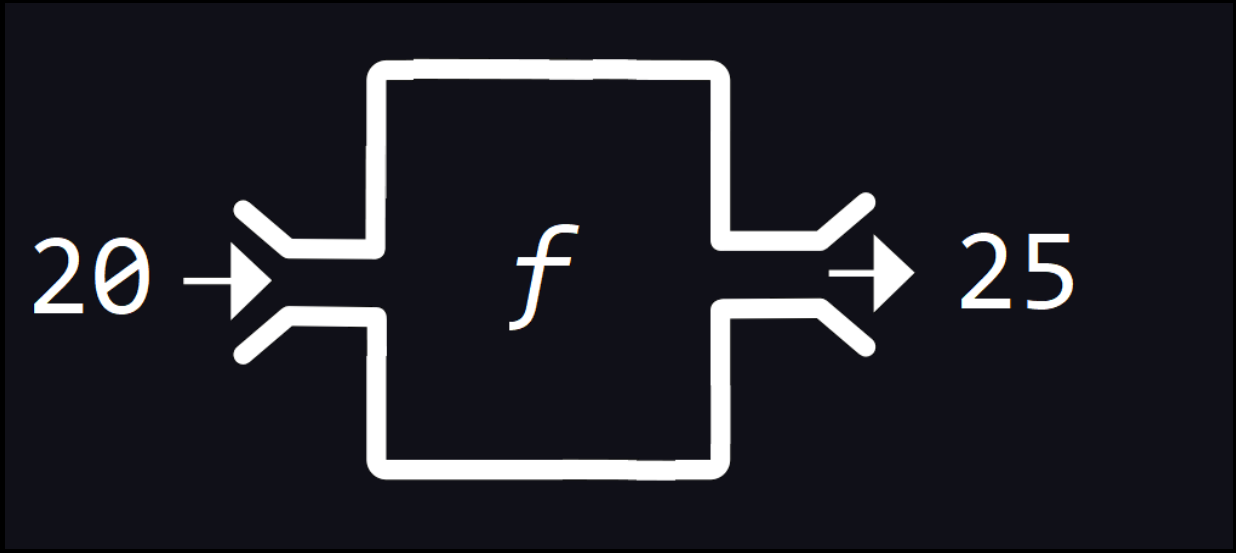
What is a function?

- 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)
```

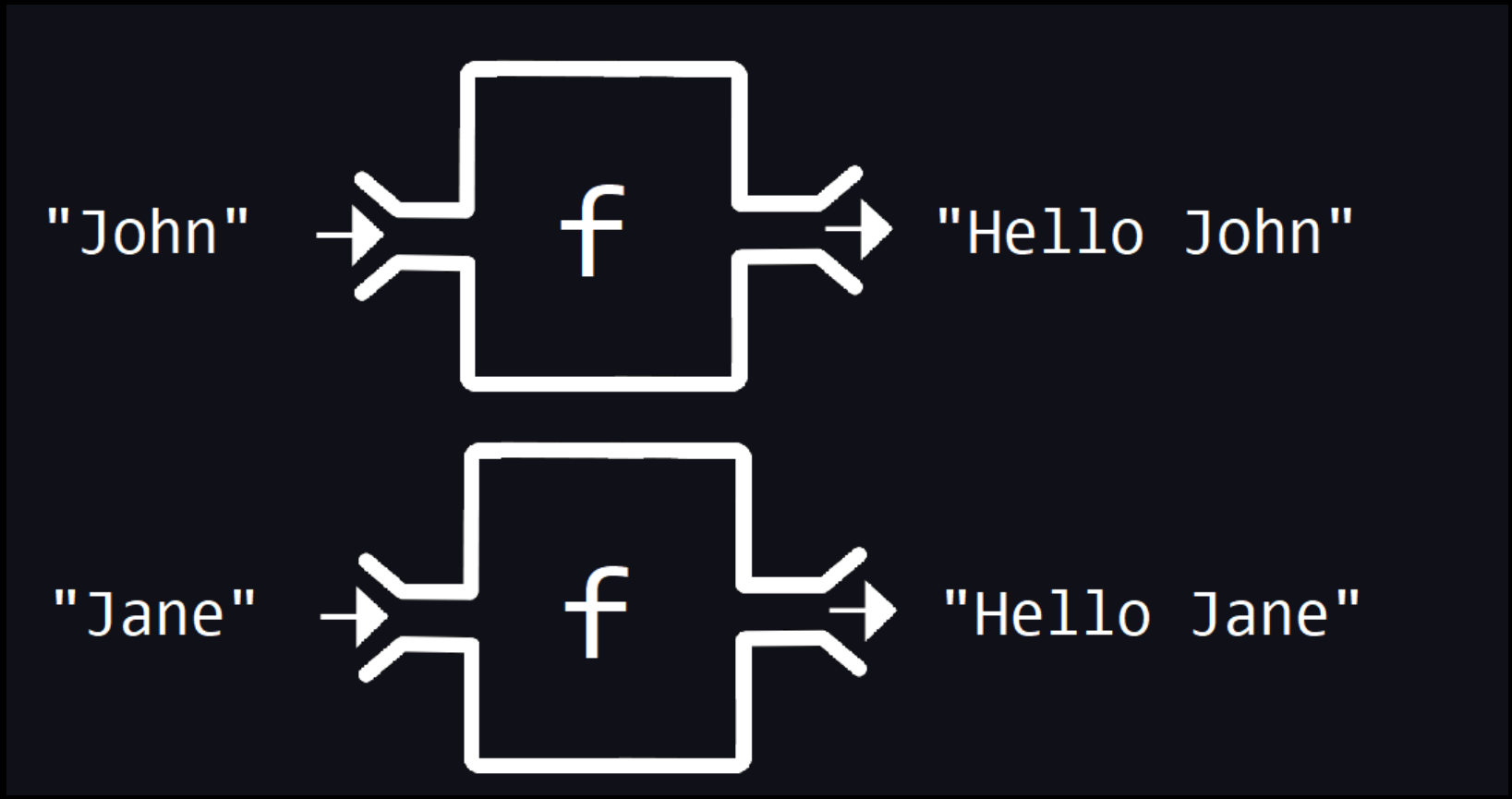
- In F#:
- `let y = f 100`

No Brackets (())

Example

- `let f x = “Hello ” + x`

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

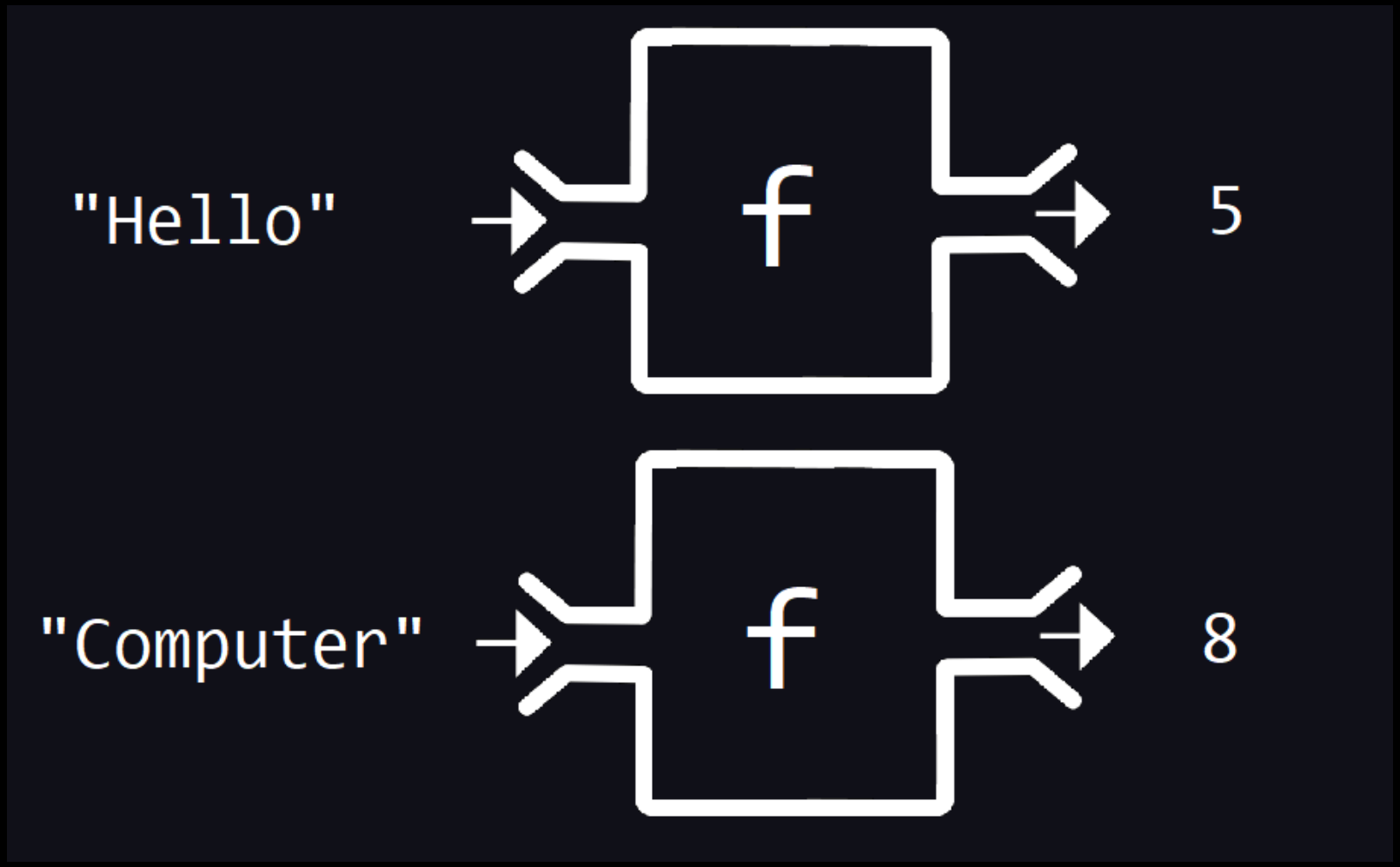

"John"
f
"Hello John"
"Jane"
f
"Hello Jane"

Example

- `let f x = String.length x`

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

- `f : string -> int`

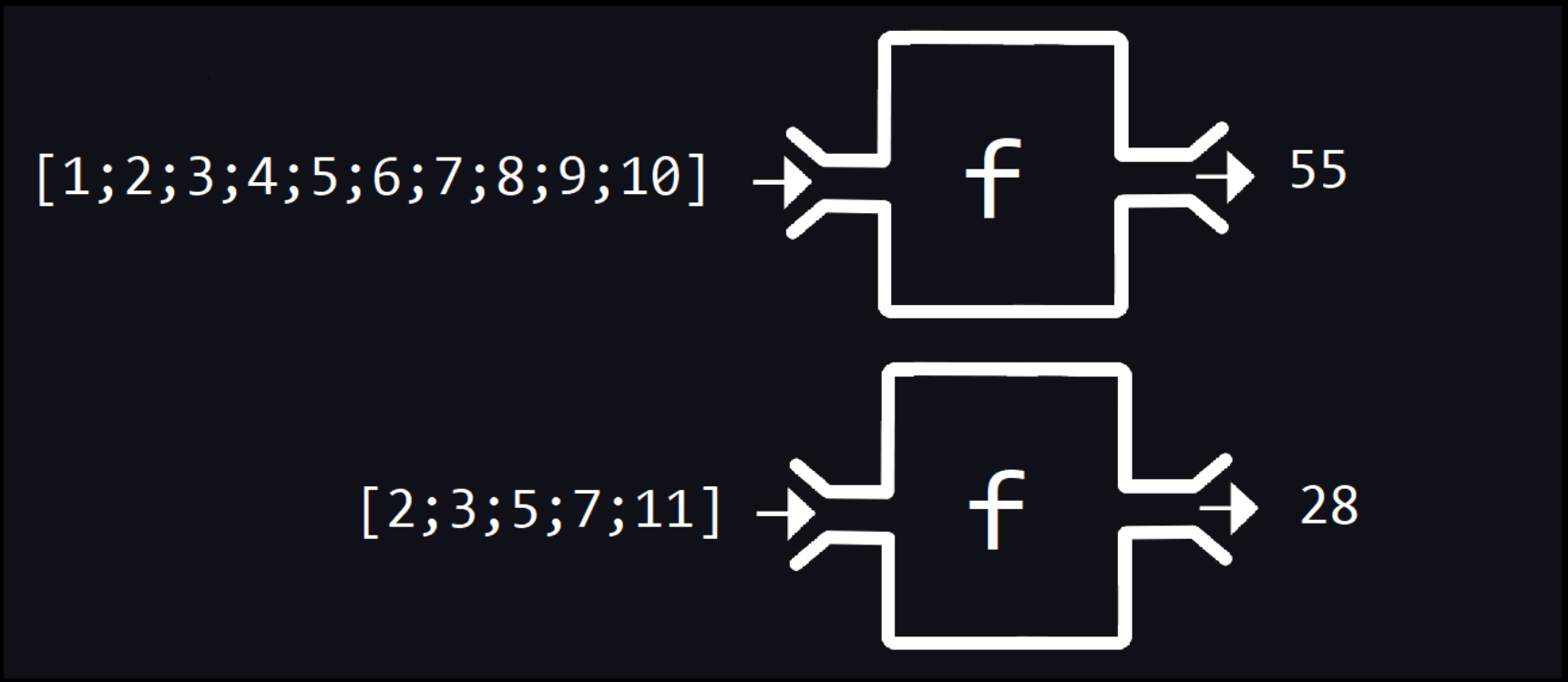

"Hello"
f
5
"Computer"
f
8

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`

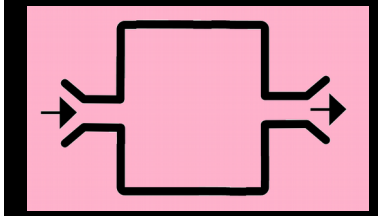
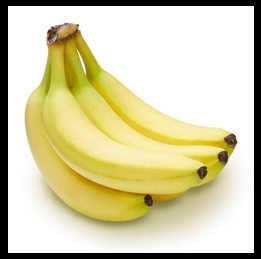
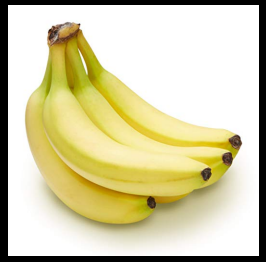
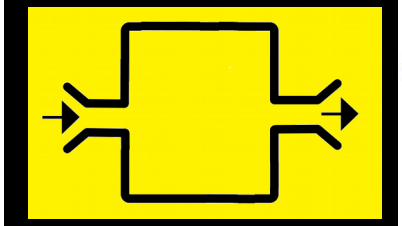
Multiple inputs

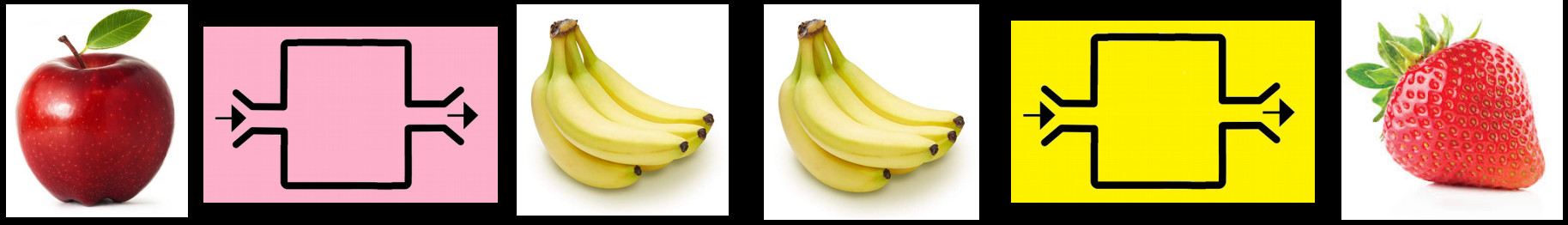
- `let f a b c d = ......`

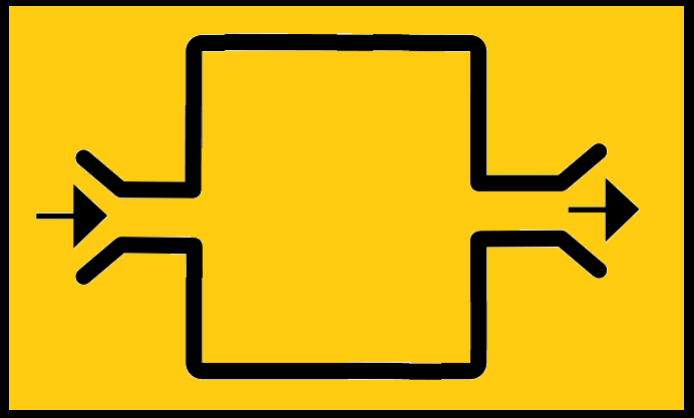
- `f : A -> B -> C -> D -> output`

Function Composition

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

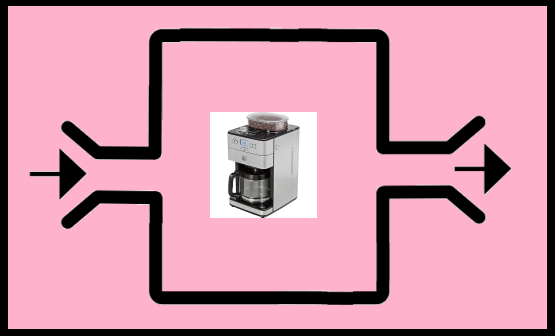





A bigger machine/function!

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

Programmer

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    response = client.api.statuses.user_timeline.get(screen_name=i.scre
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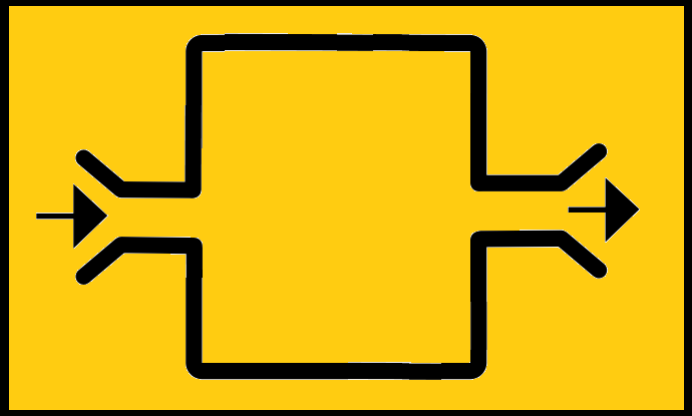
```



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        else:
            print i.screen_name, 'has not tweeted in the past', daywind
```

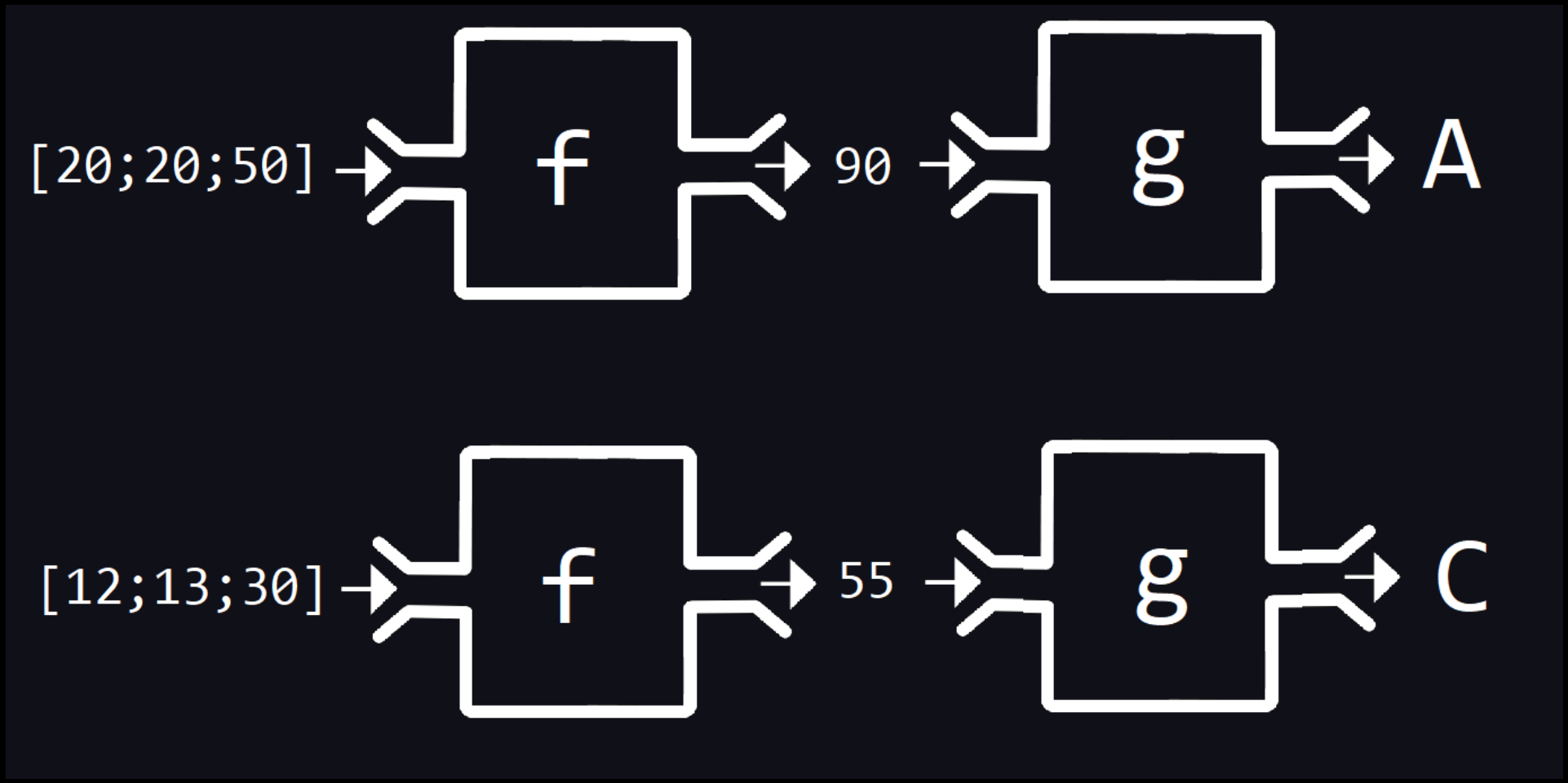
- `f : A -> B`
- `g :      B -> C`

- ```
  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”
  ```

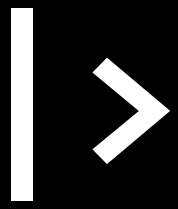
- ```
  g (f [20; 20; 50])  // g (90)
                      // “A”
  ```

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
  .Then(f)
  .Then(g)
  .Then(h)
  .Then(k);

Need to self define "Then"

Benefit

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

Example

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

Project Euler.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
  ```

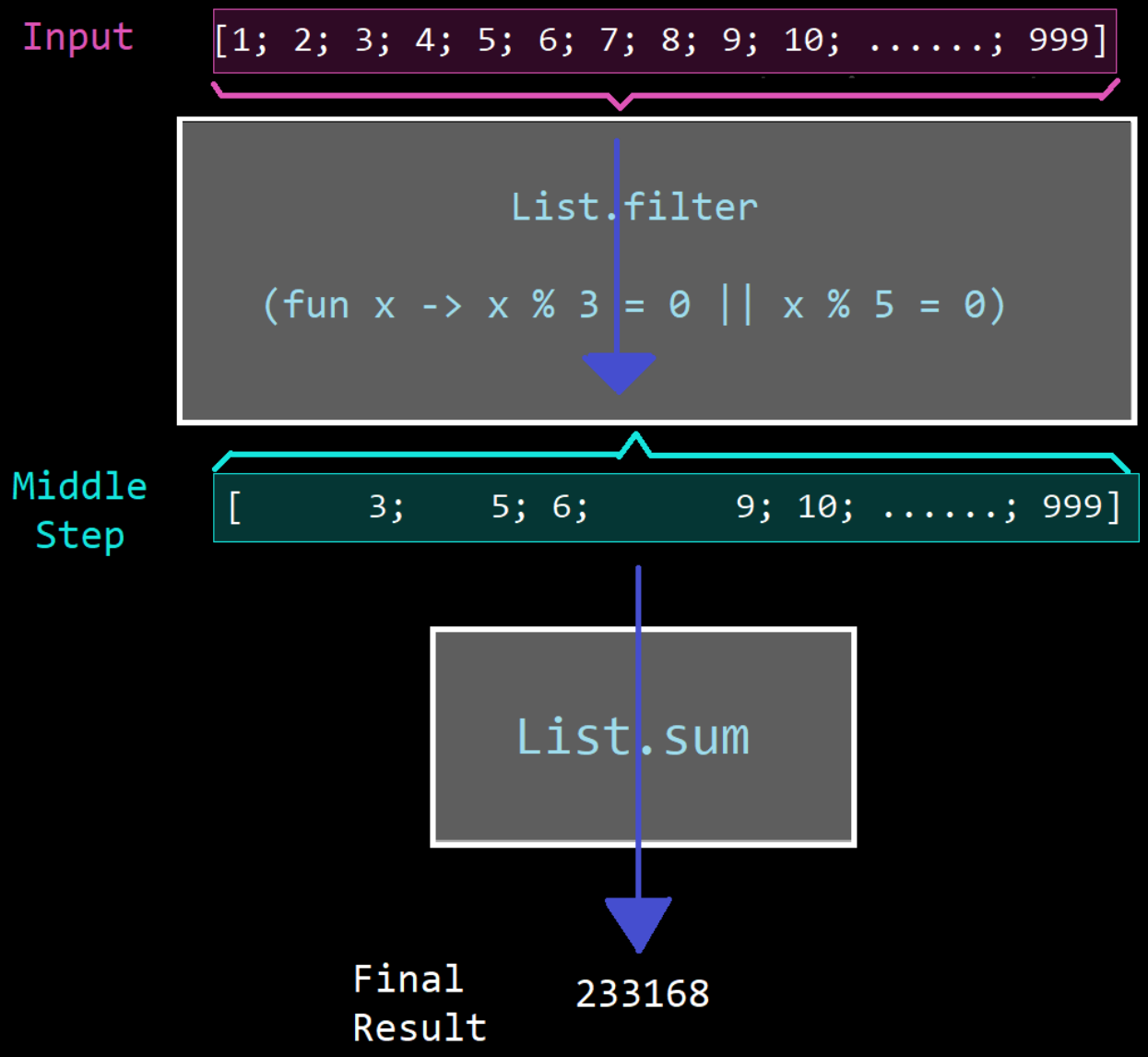
- Start with a list from 1 to 999
- (then do) filter to keep the numbers you want
- (then do) sum those remaining numbers.
  ```

- (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();
  ```

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



- (Question 6 Modified)

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

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

- ```
  [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.
  ```

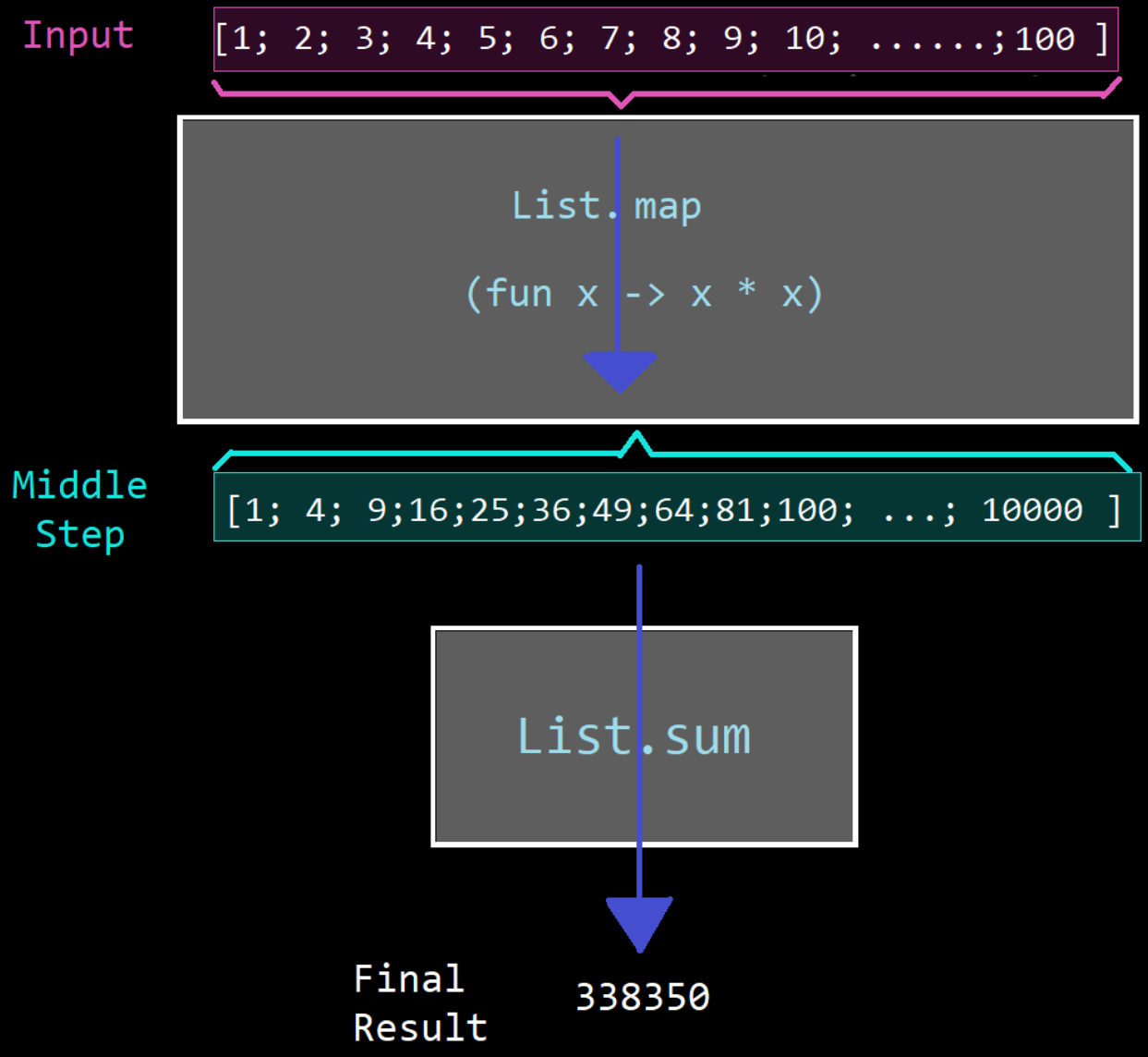
- (Question 6 Modified)

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

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

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

- ```
  [1 .. 100]
  |> List.map (fun x -> x * x)
  |> List.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:
- $1 - [(1 - p_1) \times (1 - p_2) \times \ldots\ldots \times (1 - p_n)]$

- ```
  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 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.

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

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

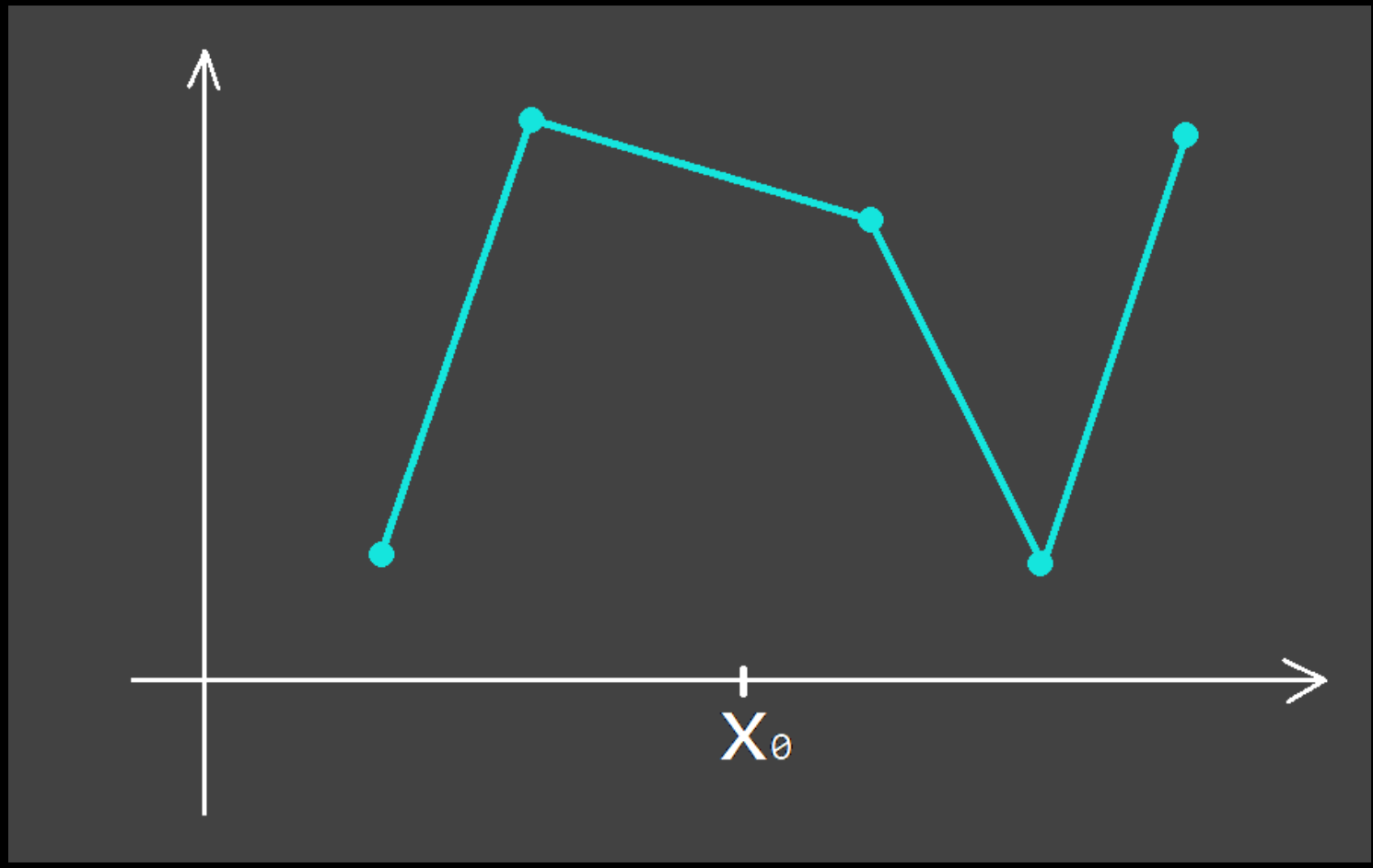
in C#

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

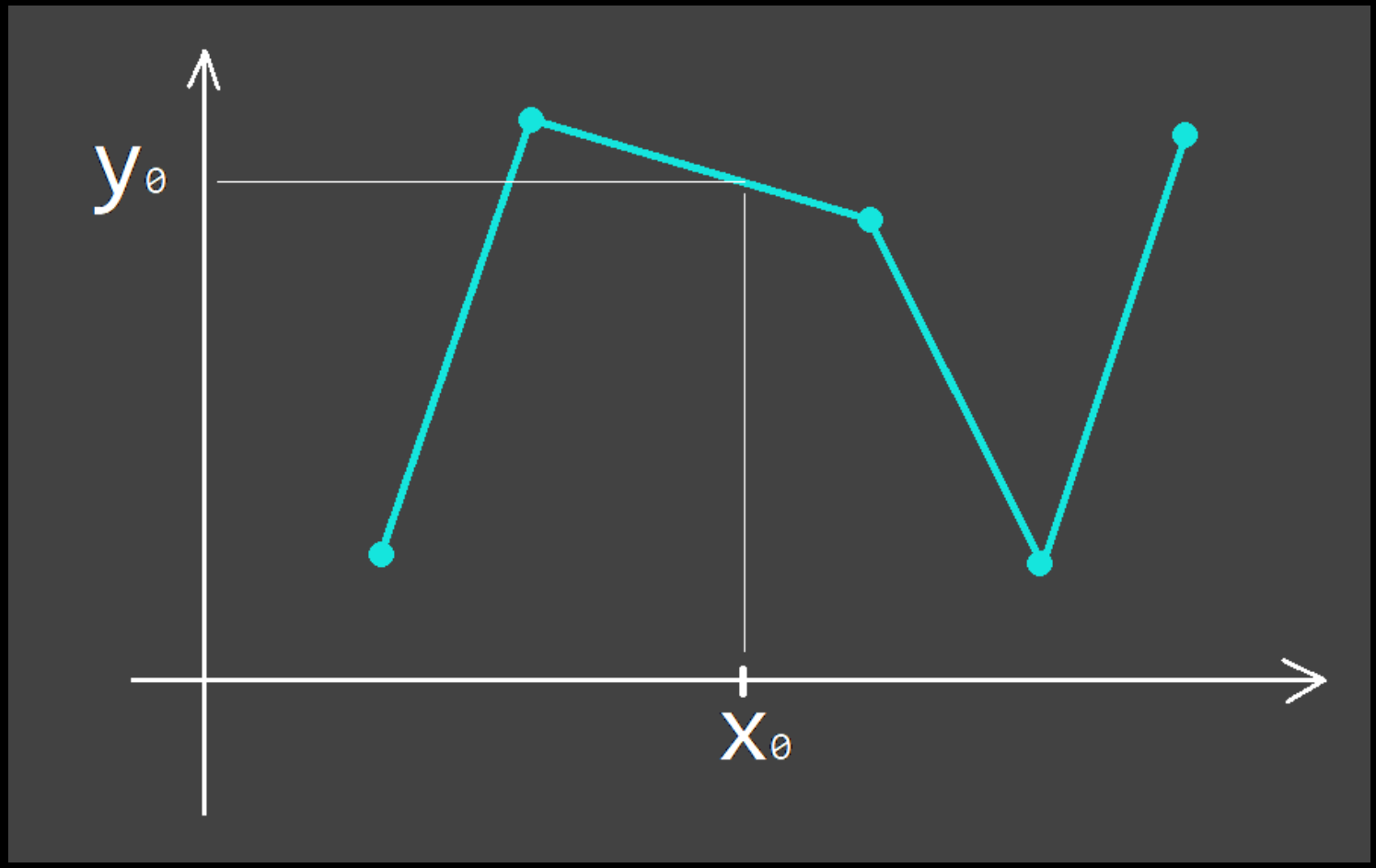
- ```
  var z = Add(1);
  ```
  Compile ERROR!

Example

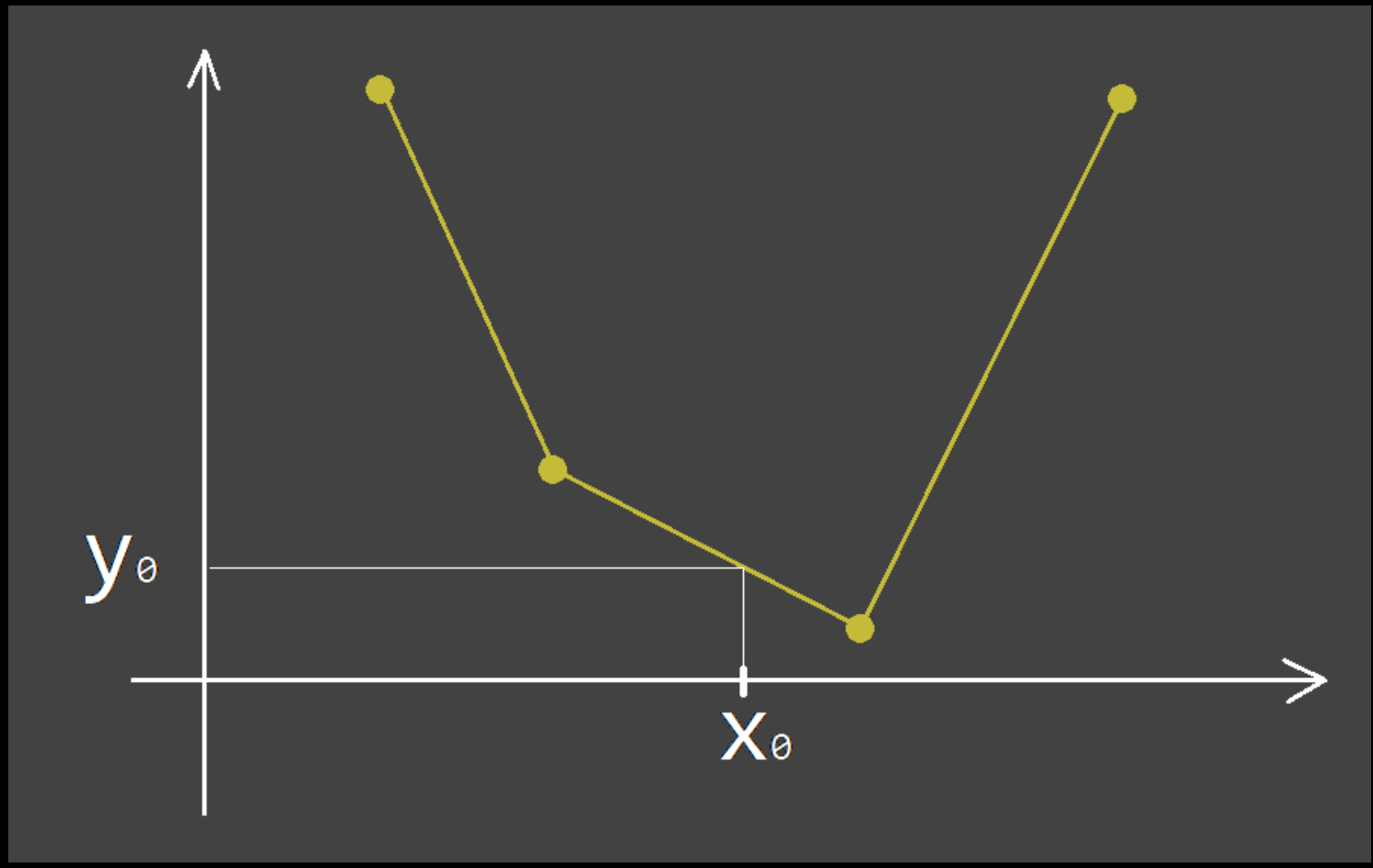
Linear Interpolation



Linear Interpolation



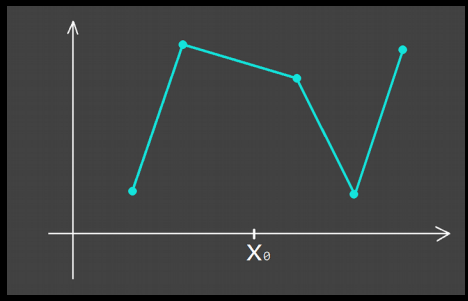
Linear Interpolation



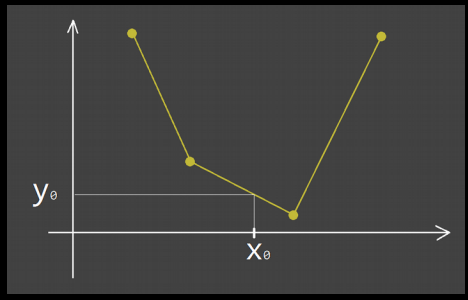
- `let Interpolate dataSet x0 =`

  `......`

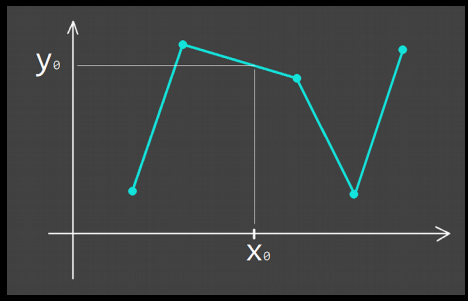
- `let Interpolate dataSet x0 =`
  `......`



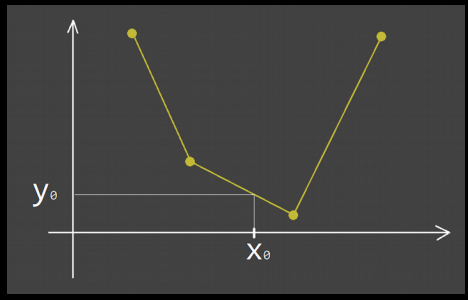
- `let f = Interpolate dataSet1`
- `let g = Interpolate dataSet2`



- `let Interpolate dataSet x0 =`
  `......`



- `let f = Interpolate dataSet1`
- `let g = Interpolate dataSet2`



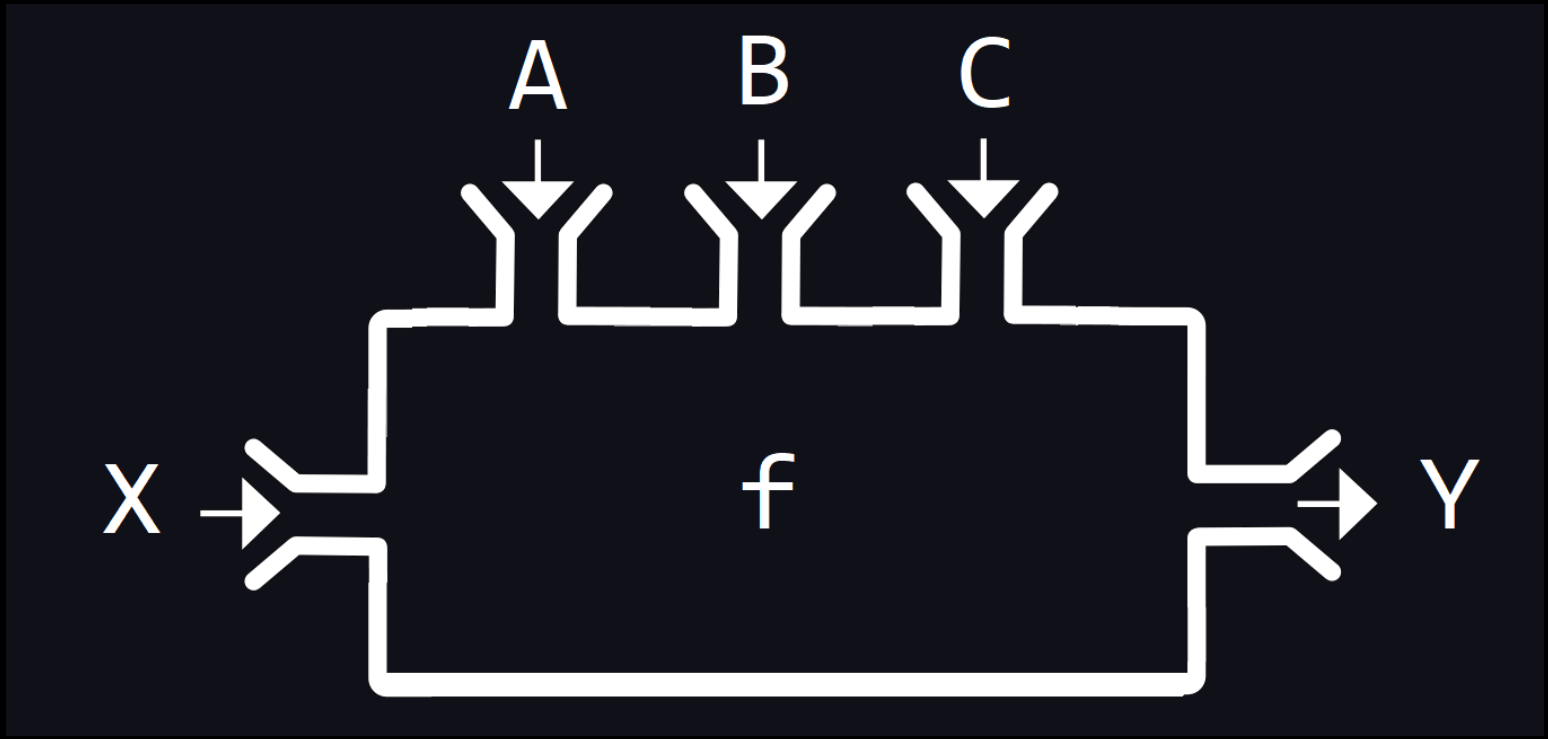
- `f: x0 -> y0`
- `g: x0 -> y0`

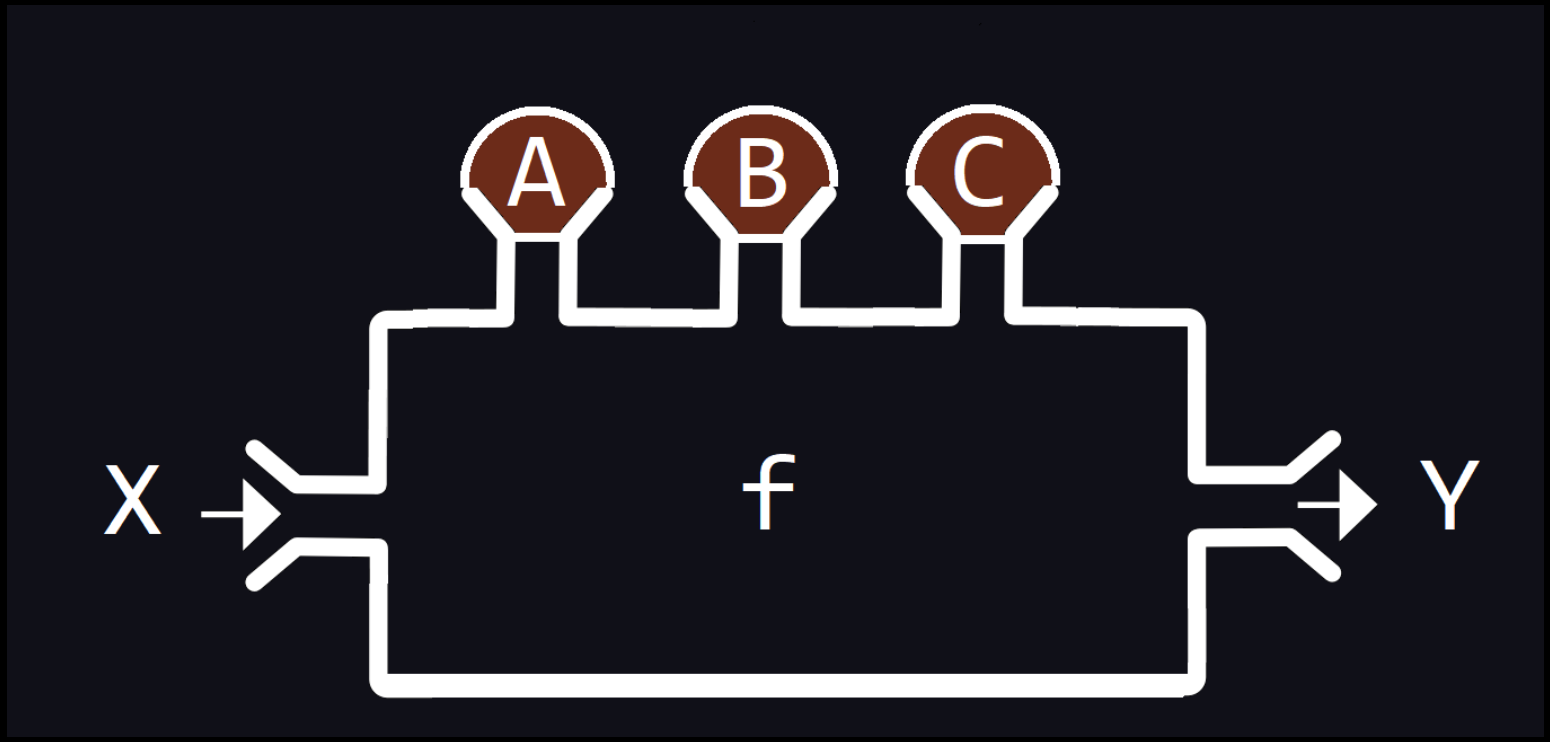
Special Case

Special Case (n - 1)

- A function that needs `n` inputs,
- but only given `(n-1)` inputs,
- then you still need `1` more input.

- i.e. a brand new 1-input, 1-output function.


A
B
C
X
f
Y


A
B
C
X
f
Y


X
f
Y

- `f a b c x = y`

- `f a b c   : X -> Y`

Assemble almost everything except the final component

- `f a b c x = y`
- `g m n o y = z`

- `f a b c   : X -> Y`
- `g m n o   :      Y -> Z`

- `f a b c x = y`
- `g m n o y = z`

- `f a b c   : X -> Y`
- `g m n o   :      Y -> Z`

- `x`
  `|> f a b c`
  `|> g m n o`

- `f a b c x = y`
- `g m n o y = z`

- `f a b c   : X -> Y`
- `g m n o   :      Y -> Z`

- `x`
  `|>` `f a b c`
  `|>` `g m n o`

Assemble almost everything except the final component

Example (n - 1)

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

Example (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
  ```

C# Extension Method “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

C# Extension Method “this”

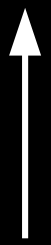
- a1
  .f(a2,a3)
  .g(b2,b3)
  .h(c2,c3);

- 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);

Syntactic sugar

General Case

General Case in C#

- `Func<A,B,C,D,Z> f(a,b,c,d)`

- `f(a)` `// COMPILE ERROR!`
- `f(a,b)` `// COMPILE ERROR!`
- `f(a,b,c)` `// COMPILE ERROR!`

“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 >>>`

“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!

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

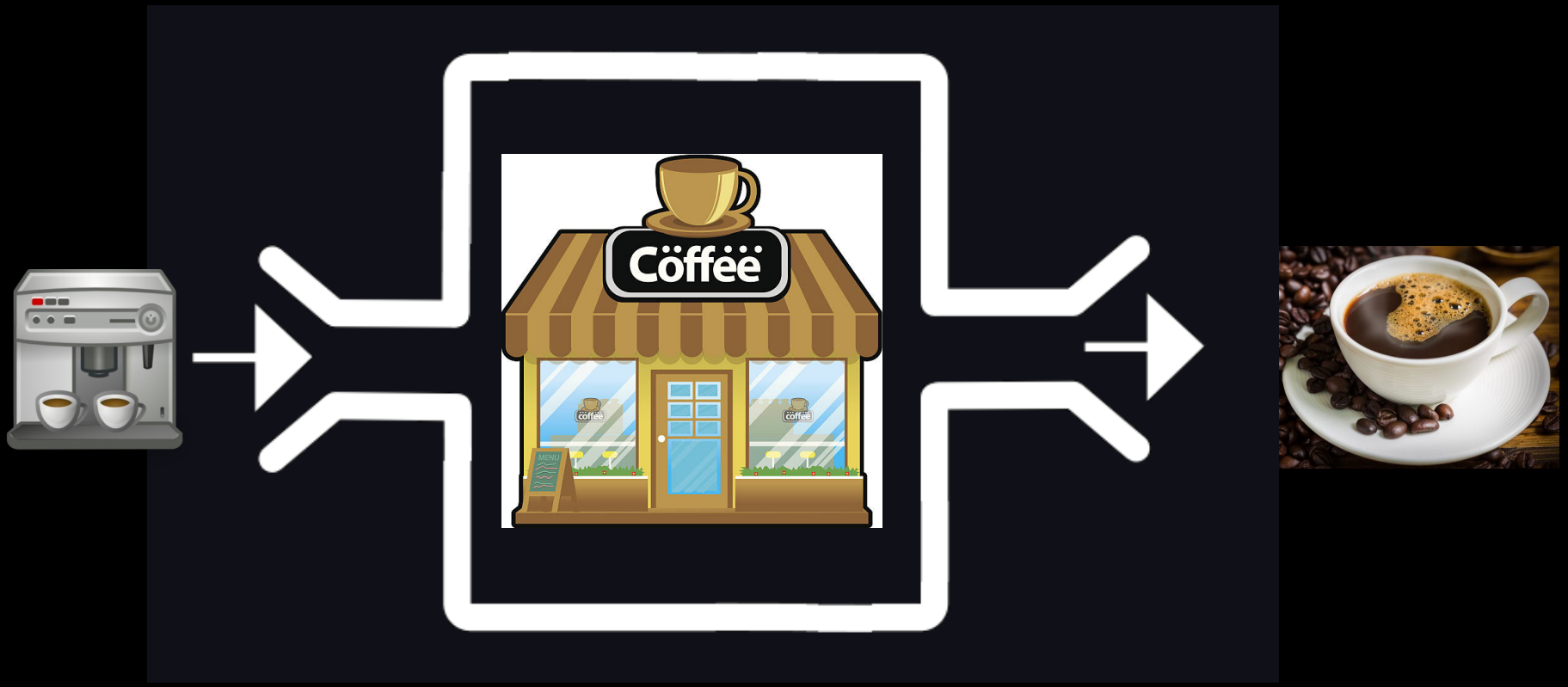
- `public double f(Func<double,int> g, string c) {.....}`

- 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.


Cöffëë
MENU

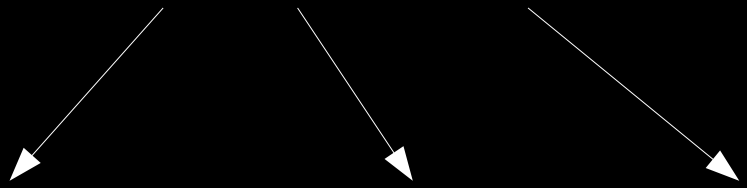
filter, map

- ```
  [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 = ......`



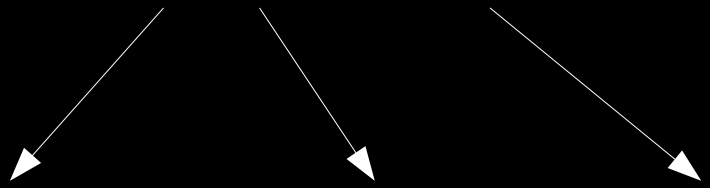
- `(X -> bool) -> List<X> -> List<X>`

- `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 =
      ......
  ```

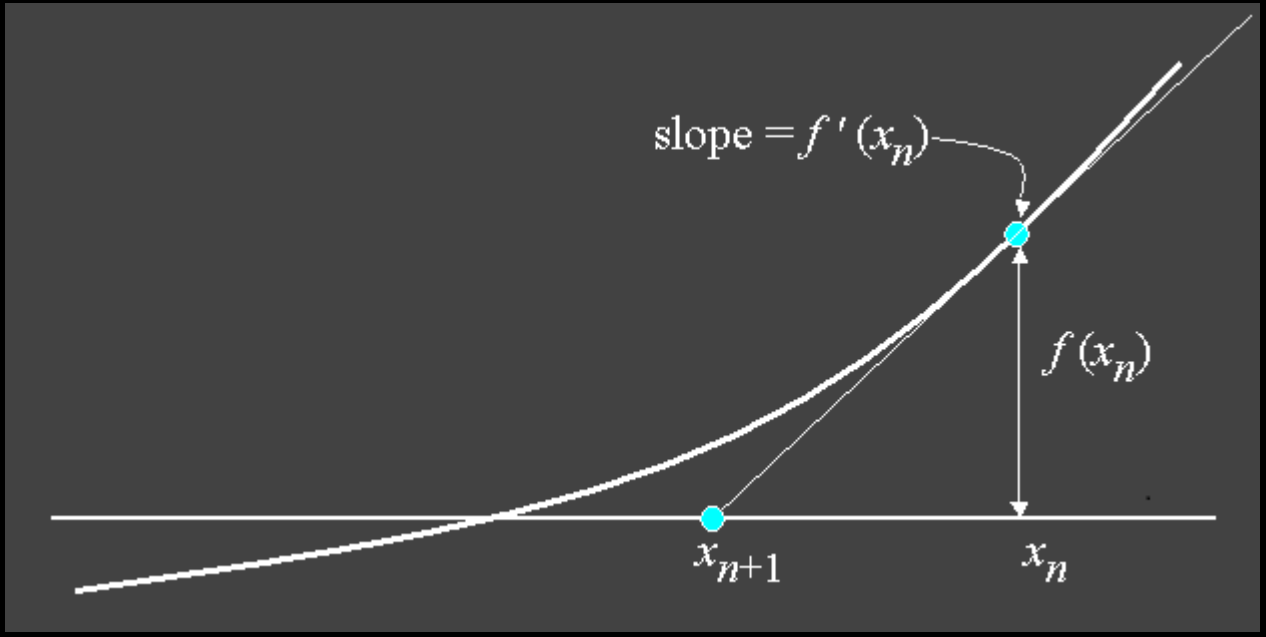
- `age : int`
- `probFunc: DateTime -> double`

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

Example

Newton's Method Example

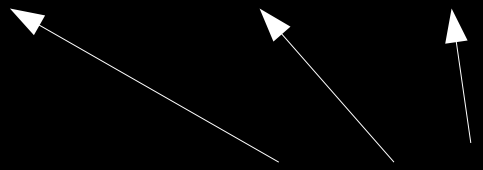
$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$



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)
  ```
  ```

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.

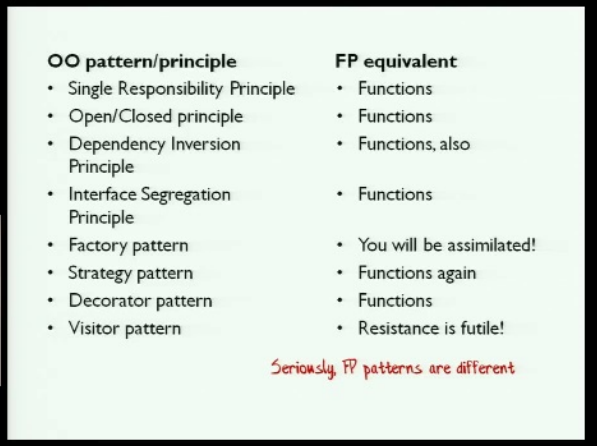
Future Topics

- 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?



- 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