Generics

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Introduction

Introduction

Lecture topics

- Arrays as a simple generic data type
- Class generators: generics
- Interfaces and generics
- Generic lists: a concrete example
- Lambda

Arrays as a simple generic data type

Arrays as a simple generic data type

Introduction

- A very common necessity when programming is storing multiple values in a variable
- There actually is a built-in datatype in most programming languages to do so
- This datatype is called **array**

Arrays as a simple generic data type

Introduction

- An array is declared with the type of the element, followed by square brackets
- The array is then initialized by specifying the number of elements it can store
- The elements are then written and accessed given their position in the array
- The array cannot change size: reading or writing an elements out of bounds gives an error

Arrays as a simple generic data type

An array is declared with the type of the element, followed by square brackets

```
1 int[] x;
```

Arrays as a simple generic data type

Which in Java then becomes:

```
1 int[] x;
```

Arrays as a simple generic data type

The array is then initialized by specifying the number of elements it can store

```
1 int[] x = new int[10];
```

Arrays as a simple generic data type

Which in Java then becomes:

```
1 int[] x = new int[10];
```

Arrays as a simple generic data type

The elements are then written and accessed given their position in the array

```
1 int[] x = new int[10];
2 x[5] = 100;
3 Console.WriteLine(x[5]);
```

Arrays as a simple generic data type

Which in Java then becomes:

```
1 int[] x = new int[10];
2 x[5] = 100;
3 System.out.println(x[5]);
```

Arrays as a simple generic data type

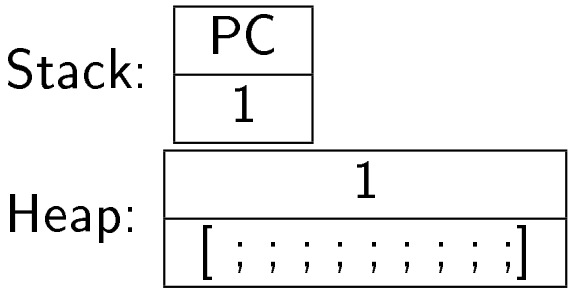

```
1 int[] x = new int[10];
2 x[5] = 100;
3 Console.WriteLine(x[5]);
```

Stack:

PC
1

Arrays as a simple generic data type


```
1 int[] x = new int[10];
2 x[5] = 100;
3 Console.WriteLine(x[5]);
```



Arrays as a simple generic data type


```
1 int[] x = new int[10];
2 x[5] = 100;
3 Console.WriteLine(x[5]);
```

Stack:

PC	x
2	ref 1

Heap:

1
[; ; ; ; ; ; ; ; ;]

Arrays as a simple generic data type


```
1 int[] x = new int[10];
2 x[5] = 100;
3 Console.WriteLine(x[5]);
```

Stack:

PC	x
3	ref 1

Heap:

1
[; ; ; ; ;100 ; ; ; ;]

Arrays as a simple generic data type


```
1 int[] x = new int[10];
2 x[5] = 100;
3 Console.WriteLine(x[5]);
```

Stack:

PC	x
4	ref 1

Heap:

1
[; ; ; ; ;100 ; ; ; ;]

Output: 100

Arrays as a simple generic data type

The array cannot change size: reading or writing an elements out of bounds gives an error

The program below would just crash at runtime with an *array out of bounds error*

```
1 int[] x = new int[10];
2 x[15] = 100;
3 Console.WriteLine(x[15]);
```

Arrays as a simple generic data type

Which in Java then becomes:

```
1 int[] x = new int[10];
2 x[15] = 100;
3 System.out.println(x[15]);
```

Arrays as a simple generic data type

Arrays of various types?

- Arrays can come in all sorts of types
- `int[]`, `float[]`, `bool[]`, `string[]`, `Car[]`, ...

Arrays as a simple generic data type

So what is common to all arrays, independently of their specific content?

Arrays as a simple generic data type

So what is common to all arrays, independently of their specific content?

- An array `T[]` contains a series of elements **of any type** `T`
- It is initialized with `new T[n]`, where `n` is the number of stored elements
- We access the `i`-th element of array `a` of type `T[]` with `a[i]`; `a[i]` has type `T`
- We set the `i`-th element of array `a` of type `T[]` with `a[i] = e`; `e` has type `T`

Arrays as a simple generic data type

Arrays of various types?

So it makes perfect sense to speak about arrays in terms which are **generic** with respect to the type of the elements!

Class generators: generics

Class generators: generics

Introduction

- We can define classes that follow the same philosophy just explained for arrays
- These classes only specify a structure, but are independent of the type of their content
- These classes are called **generic classes**

Class generators: generics

Suppose we wish to define a class that stores two elements together.

- It can be useful in many places when we want to couple two things together
- Return two values from a function
- Store a list of relationships
- ...

Class generators: generics

Storing two elements together should be independent of their type. We do not want to define a new version of the class for each possible combination, such as:

- `int` and `bool`
- `float` and `float`
- `bool` and `string`
- `Car` and `int`
- `Person` and `Dog`
- `Man` and `Woman`
- `Woman` and `Man`
- `Woman` and `Woman`
- `Man` and `Man`
- ...

Class generators: generics

We can define such a class by specifying that it depends on the types of its fields:

```
1  class Pair<T, U> {
2    private T x;
3    private U y;
4    public Pair(T x,U y) {
5      this.x = x;
6      this.y = y;
7    }
8    public T First() {
9      return this.x;
10   }
11   public U Second() {
12     return this.y;
13   }
14 }
```

Class generators: generics

Which in Java then becomes:

```
1  class Pair<T, U> {
2    private T x;
3    private U y;
4    public Pair(T x,U y) {
5      this.x = x;
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7    }
8    public T First() {
9      return this.x;
10   }
11   public U Second() {
12     return this.y;
13   }
14 }
```

Class generators: generics

We can then use this class by specifying what the types of its fields are concretely:

```
1  class Pair<T, U> {
2    private T x;
3    private U y;
4    public Pair(T x,U y) {
5      this.x = x;
6      this.y = y;
7    }
8    public T First() {
9      return this.x;
10   }
11   public U Second() {
12     return this.y;
13   }
14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
16 Console.WriteLine(p.First());
17 Console.WriteLine(p.Second());
```

Class generators: generics

Which in Java then becomes:

```
1  class Pair<T, U> {
2    private T x;
3    private U y;
4    public Pair(T x,U y) {
5      this.x = x;
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15 Pair<int, bool> p = new Pair<int, bool>(10,true);
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Class generators: generics


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1  class Pair<T, U> {
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14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
16 Console.WriteLine(p.First());
17 Console.WriteLine(p.Second());
```

Stack:

PC
1

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
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4    public Pair(T x,U y) {
5      this.x = x;
6      this.y = y;
7    }
8    public T First() {
9      return this.x;
10   }
11   public U Second() {
12     return this.y;
13   }
14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
16 Console.WriteLine(p.First());
17 Console.WriteLine(p.Second());
```

Stack:

PC
15

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
3    private U y;
4    public Pair(T x,U y) {
5      this.x = x;
6      this.y = y;
7    }
8    public T First() {
9      return this.x;
10   }
11   public U Second() {
12     return this.y;
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14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
16 Console.WriteLine(p.First());
17 Console.WriteLine(p.Second());
```

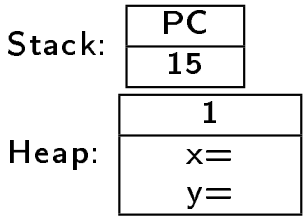

Class generators: generics


```
1  class Pair<T, U> {
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11   public U Second() {
12     return this.y;
13   }
14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
16 Console.WriteLine(p.First());
17 Console.WriteLine(p.Second());
```

Stack:

PC	...		PC	ret	this	x	y
15	...		5	null	ref 1	10	true

Heap:

1
x= y=

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
3    private U y;
4    public Pair(T x,U y) {
5      this.x = x;
6      this.y = y;
7    }
8    public T First() {
9      return this.x;
10   }
11   public U Second() {
12     return this.y;
13   }
14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
16 Console.WriteLine(p.First());
17 Console.WriteLine(p.Second());
```

Stack:

PC	...		PC	ret	this	x	y
15	...		6	null	ref 1	10	true

Heap:

1
x=10 y=

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
3    private U y;
4    public Pair(T x,U y) {
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7    }
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15 Pair<int, bool> p = new Pair<int, bool>(10,true);
16 Console.WriteLine(p.First());
17 Console.WriteLine(p.Second());
```

Stack:

PC	...		PC	ret	this	x	y
15	...		6	null	ref 1	10	true

Heap:

1
x=10 y=true

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
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4    public Pair(T x,U y) {
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14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
16 Console.WriteLine(p.First());
17 Console.WriteLine(p.Second());
```

Stack:

PC	...		PC	ret
15	...		6	ref 1

Heap:

1
x=10 y=true

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
3    private U y;
4    public Pair(T x,U y) {
5      this.x = x;
6      this.y = y;
7    }
8    public T First() {
9      return this.x;
10   }
11   public U Second() {
12     return this.y;
13   }
14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
16 Console.WriteLine(p.First());
17 Console.WriteLine(p.Second());
```

Stack:

PC	p
16	ref 1

Heap:

1
x=10 y=true

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
3    private U y;
4    public Pair(T x,U y) {
5      this.x = x;
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8    public T First() {
9      return this.x;
10   }
11   public U Second() {
12     return this.y;
13   }
14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
16 Console.WriteLine(p.First());
17 Console.WriteLine(p.Second());
```

Stack:

PC	...		PC	ret	this
16	...		9	null	ref 1

Heap:

1
x=10 y=true

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
3    private U y;
4    public Pair(T x,U y) {
5      this.x = x;
6      this.y = y;
7    }
8    public T First() {
9      return this.x;
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11   public U Second() {
12     return this.y;
13   }
14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
16 Console.WriteLine(p.First());
17 Console.WriteLine(p.Second());
```

Stack:

PC	...		PC	ret
16	...		9	10

Heap:

1
x=10 y=true

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
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4    public Pair(T x,U y) {
5      this.x = x;
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10   }
11   public U Second() {
12     return this.y;
13   }
14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
16 Console.WriteLine(p.First());
17 Console.WriteLine(p.Second());
```

Stack:

PC	p
17	ref 1

Heap:

1
x=10 y=true

Output: 10

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
3    private U y;
4    public Pair(T x,U y) {
5      this.x = x;
6      this.y = y;
7    }
8    public T First() {
9      return this.x;
10   }
11   public U Second() {
12     return this.y;
13   }
14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
16 Console.WriteLine(p.First());
17 Console.WriteLine(p.Second());
```

Stack:

PC	...		PC	ret	this
17	...		12	null	ref 1

Heap:

1
x=10 y=true

Output: 10

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
3    private U y;
4    public Pair(T x,U y) {
5      this.x = x;
6      this.y = y;
7    }
8    public T First() {
9      return this.x;
10   }
11   public U Second() {
12     return this.y;
13   }
14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
16 Console.WriteLine(p.First());
17 Console.WriteLine(p.Second());
```

Stack:

PC	...		PC	ret
17	...		12	true

Heap:

1
x=10 y=true

Output: 10

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
3    private U y;
4    public Pair(T x,U y) {
5      this.x = x;
6      this.y = y;
7    }
8    public T First() {
9      return this.x;
10   }
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14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
16 Console.WriteLine(p.First());
17 Console.WriteLine(p.Second());
```

Stack:

PC	p
18	ref 1

Heap:

1
x=10 y=true

Output:

10	true

Class generators: generics

An example: arbitrary pairs

- In Java, generic arguments cannot be all those primitive types with non-reference values that sit directly on the stack
- This means that we cannot write `Pair<int,int>` in Java
- The standard library contains **reference versions** of those types, starting with a capital letter, such as `Integer`, etc.
- Those types are like the primitive types, but their values are references that point to the actual value on the heap
- We can then write `Pair<Integer,Integer`

Class generators: generics

The types of the fields can change, but the class implementation always remains the same:

```
1 Pair<int, bool> p = new Pair<int, bool>(10,true);
2 Pair<float, bool> p = new Pair<float, bool>(10,false);
3 Pair<bool, bool> p = new Pair<bool, bool>(false,true);
4 Pair<string, int> p = new Pair<string, int>("First item",5);
5 ...
```

Class generators: generics

Which in Java then becomes:

```
1 Pair<int, bool> p = new Pair<int, bool>(10,true);
2 Pair<float, bool> p = new Pair<float, bool>(10,false);
3 Pair<bool, bool> p = new Pair<bool, bool>(false,true);
4 Pair<string, int> p = new Pair<string, int>("First␣item",5);
5 ...
```

Class generators: generics

Typechecking of generic classes

- Typecheking is simply a form of **substitution**
- When the class is instantiated with types as arguments, a new version of the class is created
- The created class has the concrete versions of these parameters in it

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
3    private U y;
4    public Pair(T x,U y) {
5      this.x = x;
6      this.y = y;
7    }
8    public T First() {
9      return this.x;
10   }
11   public U Second() {
12     return this.y;
13   }
14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
```

Declarations:

PC
1

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
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4    public Pair(T x,U y) {
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6      this.y = y;
7    }
8    public T First() {
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10   }
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12     return this.y;
13   }
14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
```

Declarations:

PC	this	x	y
5	Pair	T	U

Classes:

Pair
First=Pair $\rightarrow$ T Pair=(Pair$\times$T$\times$U) $\rightarrow$ Pair Second=Pair $\rightarrow$ U x=T y=U

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
3    private U y;
4    public Pair(T x,U y) {
5      this.x = x;
6      this.y = y;
7    }
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12     return this.y;
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14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
```

Declarations:

PC	this	x	y
6	Pair	T	U

Classes:

Pair
First=Pair → T Pair=(Pair×T×U) → Pair Second=Pair → U x=T y=U

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
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4    public Pair(T x,U y) {
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14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
```

Declarations:

PC	this	x	y
7	Pair	T	U

Classes:

Pair
First=Pair → T Pair=(Pair×T×U) → Pair Second=Pair → U x=T y=U

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
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4    public Pair(T x,U y) {
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11   public U Second() {
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14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
```

Declarations:

PC	this
10	Pair

Classes:

Pair
First=Pair $\rightarrow$ T
Pair=(Pair$\times$T$\times$U) $\rightarrow$ Pair
Second=Pair $\rightarrow$ U
x=T
y=U

Class generators: generics


```
1  class Pair<T, U> {
2    private T x;
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4    public Pair(T x,U y) {
5      this.x = x;
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14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
```

Declarations:

PC	this
12	Pair

Classes:

Pair
First=Pair $\rightarrow$ T
Pair=(Pair$\times$T$\times$U) $\rightarrow$ Pair
Second=Pair $\rightarrow$ U
x=T
y=U

Class generators: generics


```
1  class Pair<T, U> {
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15 Pair<int, bool> p = new Pair<int, bool>(10,true);
```

Declarations:

PC
15

Classes:

Pair
First=Pair $\rightarrow$ T
Pair=(Pair$\times$T$\times$U) $\rightarrow$ Pair
Second=Pair $\rightarrow$ U
x=T
y=U

Class generators: generics


```
1  class Pair<T, U> {
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12     return this.y;
13   }
14 }
15 Pair<int, bool> p = new Pair<int, bool>(10,true);
```

Declarations:

PC	p
16	Pair<int, bool>

Classes:

Pair
First=Pair $\rightarrow$ T Pair=(Pair$\times$T$\times$U) $\rightarrow$ Pair Second=Pair $\rightarrow$ U x=T y=U

Class generators: generics

This means that the compiler would actually generate code that behaves like the following:

```
1  class PairIntBool {
2    private x int;
3    private y bool;
4    public PairIntBool(int x,boolean y) {
5      this.x = x;
6      this.y = y;
7    }
8    public int First() {
9      return this.x;
10   }
11   public bool Second() {
12     return this.y;
13   }
14 }
15 PairIntBool p = new PairIntBool(10,true);
```

Class generators: generics

Which in Java then becomes:

```
1  class PairIntBool {
2    private x int;
3    private y bool;
4    public PairIntBool(int x,boolean y) {
5      this.x = x;
6      this.y = y;
7    }
8    public int First() {
9      return this.x;
10   }
11   public bool Second() {
12     return this.y;
13   }
14 }
15 PairIntBool p = new PairIntBool(10,true);
```

Interfaces and generics

Interfaces and generics

Introduction

- Interfaces can also be defined generically.
- When implementing a generic interface, we need to provide the types of its generic arguments.

Interfaces and generics

We can define a generic interface as follows:

```
1  interface IPair<T, U> {
2    private x T;
3    private y U;
4    public Pair(T x,U y) {
5      this.x = x;
6      this.y = y;
7    }
8    public T First() {
9      return this.x;
10   }
11   public U Second() {
12     return this.y;
13   }
14 }
```

Interfaces and generics

Which in Java then becomes:

```
1  interface IPair<T, U> {
2    private x T;
3    private y U;
4    public Pair(T x,U y) {
5      this.x = x;
6      this.y = y;
7    }
8    public T First() {
9      return this.x;
10   }
11   public U Second() {
12     return this.y;
13   }
14 }
```

Interfaces and generics

The generic interface can then be implemented by a class (generic or not) as follows:

```
1  ...
2  class Pair<T, U> : IPair {
3    private x T;
4    private y U;
5    public Pair(T x,U y) {
6      this.x = x;
7      this.y = y;
8    }
9    public T First() {
10     return this.x;
11   }
12   public U Second() {
13     return this.y;
14   }
15 }
16 IPair<int, bool> p = new Pair<int, bool>(10,true);
```

Interfaces and generics

Which in Java then becomes:

```
1  ...
2  class Pair<T, U> implements IPair {
3    private x T;
4    private y U;
5    public Pair(T x,U y) {
6      this.x = x;
7      this.y = y;
8    }
9    public T First() {
10     return this.x;
11   }
12   public U Second() {
13     return this.y;
14   }
15 }
16 IPair<int, bool> p = new Pair<int, bool>(10,true);
```

Generic lists: a concrete example

Generic lists: a concrete example

Ingredients

- We need an `List<T>` generic interface
- We then need two generic classes that implement the interface: `Empty<T>` and `Node<T>`
- In `Empty` the methods fail with a (descriptive) error.

Generic lists: a concrete example

Ingredients

Live coding demo: generic lists.

Lambda functions

Lambda functions

Introduction

- Both C# and (since very recently) Java feature anonymous functions
- They are very handy whenever we need to implement an interface with a single method, such as `PerformAction` or similar.

Lambda functions

In C# lambda functions have types:

- `Func<T,U>` for a function that takes as input a parameter of type `T`, and which returns a value of type `U`
- `Func<T1,T2,U>` for a function that takes as input parameters of type `T1` and `T2`, and which returns a value of type `U`
- ...

- `Action<T>` for a function that takes as input a parameter of type `T`, and which returns nothing (`void`)
- `Action<T1,T2>` for a function that takes as input parameters of type `T1` and `T2`, and which returns nothing (`void`)
- ...

Lambda functions

In Java lambda functions have many more types (see the documentation for the full list):

- `Function<T,R>` for a function that takes as input a parameter of type `T`, and which returns a value of type `R`
- `BiFunction<T1,T2,R>` for a function that takes as input parameters of type `T1` and `T2`, and which returns a value of type `R`
- `Predicate<T>` for a function that takes as input a parameter of type `T`, and which returns a boolean value
- ...

Lambda functions

Declaration of lambda functions is quite simple: the parameters are separated from the body by an ASCII arrow.

Calling lambda functions is also simple: just brackets with the argument in C#, and an appropriate method in Java (see documentation).

```
1 Func<int,int> f = x => (x + 2);
2 Console.WriteLine(f(10));
```

Lambda functions


```
1 Func<int,int> f = x => (x + 2);
2 Console.WriteLine(f(10));
```

Stack:

PC
1

Lambda functions


```
1 Func<int,int> f = x => (x + 2);
2 Console.WriteLine(f(10));
```

Stack:

PC	f
2	(x) => return (x + 2);

Lambda functions


```
1 Func<int,int> f = x => (x + 2);
2 Console.WriteLine(f(10));
```

Stack:

PC	...		ret	x
2	...		null	10

Lambda functions


```
1 Func<int,int> f = x => (x + 2);
2 Console.WriteLine(f(10));
```

Stack:

PC	...		ret
2	...		12

Lambda functions


```
1 Func<int,int> f = x => (x + 2);
2 Console.WriteLine(f(10));
```

Stack:

PC	f
3	(x) => return (x + 2);

Output: 12

Lambda functions

Introduction

Live coding demo: generic lists with map, filter, and fold.

Conclusion

Conclusion

Looking back

- Generics make it possible to define a class once, but use it with multiple types as arguments
- It is particularly useful for containers such as arrays, tuples, lists, etc.
- It is particularly useful for relationships such as functions

This is it!

The best of luck, and thanks for the attention!