# CSC 347 - Concepts of Programming Languages

## Inheritance and Dynamic Dispatch

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# Learning Objectives

❓ How do we support code sharing between classes?

❓ What should happen when methods have the same name?

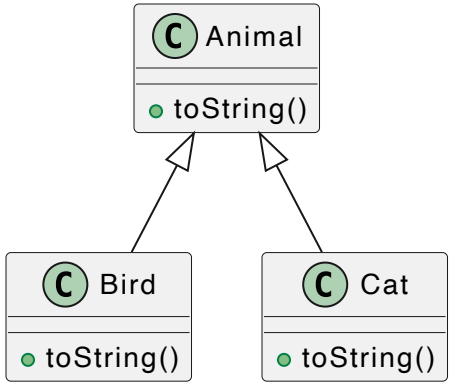
- Identify classes and inheritance
- Describe the difference between static and dynamic dispatch

# Scala: Which `toString`?

❓ What is the type of `x`? Which `toString` is invoked?

```
1 class Animal              { override def toString () = "Animal" }
2 class Bird extends Animal { override def toString () = "Bird" }
3 class Cat  extends Animal { override def toString () = "Cat" }
4
5 val xs = Array[Animal] (new Bird(), new Cat ())
6 for (x <- xs) println (x.toString())
```

- `x` has
  - static type `Animal`
  - dynamic type `Bird` / `Cat`
- Dynamic dispatch, late binding: use dynamic type (of object)




- Output at runtime

```
1 Bird
2 Cat
```

# Java: Which `toString`?

❓ What is the type of `x`? Which `toString` is invoked?

```
1 class Animal              { public  String toString () { return "Animal"; } }
2 class Bird extends Animal { public  String toString () { return "Bird"; } }
3 class Cat  extends Animal { public  String toString () { return "Cat"; } }
4
5 Animal[]  xs = { new Bird(), new Cat () };
6 for (Animal  x : xs) System.out.println (x.toString());
```

- `x` has
  - static type `Animal`
  - dynamic type `Bird` / `Cat`
- Dynamic dispatch, late binding: use dynamic type (of object)
- Output at runtime

```
1 Bird
2 Cat
```

# C++: Which `toString`?

❓ What is the type of `x`? Which `toString` is invoked?

```
1 class Animal              { public: string to_string() { return "Animal"; } };
2 class Bird: public Animal { public: string to_string() { return "Bird"; } };
3 class Cat:  public Animal { public: string to_string() { return "Cat"; } };
4
5 Animal *xs[] = { new Bird(), new Cat() };
6 for (Animal *x : xs) cout << x->to_string() << endl;
```

- `x` has
  - static type `Animal`
  - dynamic type `Bird` / `Cat`
- Static dispatch, early binding: use static type (of variable)

- Output at runtime

```
1 Animal
2 Animal
```

# C++: Which `toString`?

❓ What is the type of `x`? Which `toString` is invoked?

```
1 class Animal              { public: virtual string to_string() { return "Animal"; }
2 class Bird: public Animal { public: virtual string to_string() { return "Bird"; } }
3 class Cat:  public Animal { public: virtual string to_string() { return "Cat"; } }
4
5 Animal *xs[] = { new Bird(), new Cat() };
6 for (Animal *x : xs) cout << x->to_string() << endl;
```

- `x` has
  - static type `Animal`
  - dynamic type `Bird` / `Cat`
- Output at runtime

```
1 Bird
2 Cat
```

- C++ dynamically dispatches `virtual` methods **only when** object accessed with a pointer/reference

# C++: Which `toString`?

❓ What is the type of `x`? Which `toString` is invoked?

```
1 class Animal               { public: virtual string to_string() { return "Animal"; }
2 class Bird: public Animal { public: virtual string to_string() { return "Bird"; }
3 class Cat:  public Animal { public: virtual string to_string() { return "Cat"; }
4
5 Animal  xs[] = {     Bird(),     Cat() };
6 for (Animal  x : xs) cout <<  x.to_string() << endl;
```

- `x` has
  - static type `Animal`
  - dynamic type `Animal`
- Output at runtime

```
1 Animal
2 Animal
```

- Truncated object, stored in place: C++ **truncates** the object, coercing to parent class

# Which Object?

❓ Which object are we accessing when invoking `g()` and `f(x-1)` in line 4?

- Class definition

```
1 class A:
2   def f(x: Int) =
3     println(s"A.f($x)");
4     if x == 0 then g() else f(x - 1)
5
6   def g() = println("A.g()")
```

```
1 val x: A = new A()
2 x.f(2);
```

- Output at runtime

```
1 A.f(2) // x.f
2 A.f(1) // f(x-1)
3 A.f(0) // f(x-1)
4 A.g()  // g()
```

- The object referenced by `x`; what is its explicit name inside class `A`?

# Which Object: `this`

❓ What are the static and dynamic types of `this`?

- Class definition

```
1 class A:
2   def f (x: Int) =
3     println(s"A.f($x)")
4     if x == 0 then this.g() else this.f(x - 1)
5
6   def g () = println("A.g()")
```

```
1 val x: A = new A()
2 x.f(2)
```

- Output at runtime

```
1 A.f(2) // x.f
2 A.f(1) // this.f
3 A.f(0) // this.f
4 A.g()  // this.g
```

- Reference `this` has
  - static type of enclosing class (here: `A`)
  - dynamic type of object (here: `A`)

# Static and Dynamic Type of `this`

❓ What are the static and dynamic types of `x` and `this`?

- Class `B` inherits `f`, overrides `g`

```
1 class A:
2   def f(x: Int) =
3     println(s"A.f($x)")
4     if x == 0 then this.g() else this.f(x - 1)
5
6   def g() = println("A.g()")
7
8 class B extends A:
9   def g () = println("B.g()")
```

- `x` has static type `B`, dynamic type `B`
- `this` (line 4) has static type `A`, dynamic type `B`

```
1 val x: B = new B()
2 x.f(2)
```

- Output at runtime

```
1 A.f(2) // x.f
2 A.f(1) // this.f
3 A.f(0) // this.f
4 B.g()  // this.g
```

# Static and Dynamic Type of `this`

- What are the static and dynamic types of `x` and `this`?

```
1 class A:
2   def f(x: Int) =
3     println(s"A.f($x)")
4     if x == 0 then this.g() else this.f(x - 1)
5   def g() = println("A.g()")
6
7 class B extends A:
8   def f(x: Int) = { println(s"B.f($x)"); this.f(x) }
9   def g()         = println("B.g()")
```

```
1 val x: A = new B()
2 x.f(1)
```

❓ What happens?

- Output at runtime

```
1 B.f(1) // x.f
2 B.f(1) // this.f
3 ...    // infinite loop
```

- ❓ Why?
- `x`: static type `A`, dynamic type `B`
- `this` (l. 4): static `A`, dynamic `B`
- `this` (l. 9): static `B`, dynamic `B`

# How to Access Method in Super-Class?

- Access `A.f` with `super`

```
1 class A:
2   def f(x: Int) =
3     println(s"A.f($x)");
4     if x == 0 then this.g() else this.f(x - 1)
5   def g() = println("A.g()")
6
7 class B extends A:
8   def f(x: Int) = { println(s"B.f($x)"); super.f(x) }
9   def g()       = println("B.g()")
```

```
1 val x: A = new B ()
2 x.f(1)
```

❓ What happens?

- Output at runtime

```
1 B.f(1) // x.f
2 A.f(1) // super.f
3 B.f(0) // this.f
4 A.f(0) // super.f
5 B.g()  // this.g
```

❓ Why?

- `x` : static `A` , dynamic `B` , so `x.f` selects `B.f`
- `super` (line 8) explicitly requests `f` of super-class
- `this` (line 4): static `A` , dynamic `B` , so `this.f` selects `B.f`

# Code Modularity and Reuse

## OOP: Classes, Inheritance, and Overriding

```
1 class A:
2   def f(x: Int) =
3     println(s"A.f($x)")
4     if x == 0 then g() else f(x - 1)
5
6   def g() =
7     println("A.g()")
```

```
1 class B extends A:
2   def f(x: Int) =
3     println(s"B.f($x)")
4     super.f(x)
5
6   def g() =
7     println("B.g()")
```

## FP: Functions and Pattern Matching

```
 1 def f(a: A, x: Int) = a match
 2   case _: B =>
 3     println(s"B.f($x)")
 4     fbase(a, x)
 5   case _ =>
 6     fbase(a, x)
 7
 8 def fbase(a: A, x: Int) =
 9   println(s"A.f($x)")
10   if x == 0 then g(a) else f(a, x - 1)
11
12 def g(a: A) = a match
13   case _: B => println("B.g()")
14   case _    => println("A.g()")
```

# Document and Check Inheritance

❓ Let programmers specify how classes can be instantiated?

❓ Let programmers decide which methods can/must/cannot be overridden?

## Abstract Class

```
1 abstract class A:
2   def f(x: Int) = // ...
3   def g() = // ...
```

```
1 val x: A = new A()
```

- Disallowed: cannot instantiate `A`

## Abstract Method

```
1 abstract class A:
2   def f(x: Int) = // ...
3   def g() : Unit // abstract method
```

```
1 class B extends A
```

- Disallowed: must override `g` in `B` (or declare `abstract class B`)

## Final Methods

```
1 abstract class A:
2   final def f(x: Int) = // ...
3   def g() : Unit
```

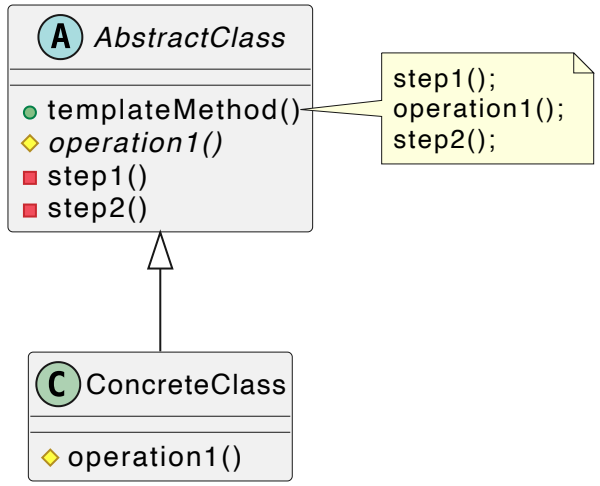
```
1 class B extends A:
2   override def f(x: Int) = // ...
3   override def g() = // ...
```

- Disallowed: cannot override `f`

# Use Case: Design Pattern Template Method

**Defines the skeleton of an algorithm, deferring varying steps to subclasses**

- Factor common behavior into a base class to avoid code duplication
- Implement algorithm structure once, varying behavior in subclasses




```
1 abstract class AbstractClass {
2   public final void templateMethod() {
3     step1();
4     operation1();
5     step2();
6   }
7   protected abstract void operation1();
8   private void step1() { /* ... */ }
9   private void step2() { /* ... */ }
10 }
11 class ConcreteClass extends AbstractClass {
12   @override
13   protected void operation1() { /* ... */ }
14 }
```

? In functional programming?

Higher-order functions

# Summary

- **Inheritance: links classes statically** at compile time

**Static Dispatch**

- Early binding at compile time
- Select method **based on type of reference**

**Dynamic Dispatch**

- Late binding at runtime
- Select method **based on type of object**

- Design patterns often provide object-oriented solutions of functional paradigms
- GoF: Favor *object composition* over *class inheritance*
- See Design Patterns, Design Pattern Catalog, and Design Principles

# Static and Dynamic Types

```
1 interface Fn { int apply (int x); }
```

## Lambda notation

```
1 Fn[] fs = new Fn[2];
2 for (int i = 0;
3       i < fs.length;
4       i++) {
5   int j = i + 1;
6   fs[i] = x -> x + j;
7 }
```

- `fs[i]` : static type `Fn`, anonymous dynamic type of `x->x+j`

## Anonymous classes

```
 1 Fn[] fs = new Fn[2];
 2 for (int i = 0;
 3       i < fs.length;
 4       i++) {
 5   int j = i + 1;
 6   fs[i] = new Fn() {
 7     int apply (int x) {
 8       return j + x;
 9     }
10   }
11 }
```

- `fs[i]` : static type `Fn`, anonymous dynamic type of `new Fn() ...`

## Explicit classes

```
 1 Fn[] fs = new Fn[2];
 2
 3 class F implements Fn {
 4   public int apply(int x) {
 5     return x + 1;
 6   }
 7 }
 8 class G implements Fn {
 9   public int apply(int x) {
10     return x + 2;
11   }
12 }
13
14 fs[0] = new F();
15 fs[1] = new G();
```

- `fs[i]` : static type `Fn`, dynamic type `F` or `G`

# Examples: C++

```
1 class Animal               { public: virtual string to_string() { return "Animal"; } };
2 class Bird: public Animal { public: virtual string to_string() { return "Bird"; } };
3 class Cat:  public Animal { public: virtual string to_string() { return "Cat"; } };
```

- Pointers + `virtual`:

```
1 Animal* a = new Bird ();
2 cout << a->to_string() << endl;
3 a = new Cat ();
4 cout << a->to_string() << endl;
```

- Reference + `virtual`:

```
1 void print(Animal& a) {
2   cout << a.to_string() << endl;
3 }
4
5 Bird b = Bird ();
6 Cat c = Cat ();
7
8 print(b);
9 print(c);
```

- Static types:

```
1 Bird* b = new Bird ();
2 cout << b->to_string() << endl;
3 b = new Cat ();
4 cout << b->to_string() << endl;
```

# Examples: Scala

```scala
class A:
  def f () = { println("A.f"); this.g () }
  def g () = { println("A.g"); this.h () }
  def h () = println("A.h")
class B extends A:
  override def f () = { println("B.f"); super.f () }
  override def h () = println("B.h")
  def i ()          = println("B.i")
```

- Static `A`, dynamic `A`

```scala
val a:A = new A()
a.f()
a.g()
a.h()
a.i()
```

- Static `A`, dynamic `B`

```scala
val a:A = new B()
a.f()
a.g()
a.h()
a.i()
```

- Static `B`, dynamic `B`

```scala
val b:B = new B()
b.f()
b.g()
b.h()
b.i()
```