Comparative Programming Languages
CM20318

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2023/24

### 1. Object Oriented Languages

#### Method Dispatch

So (at last!) the way to choose a method for a given set of arguments is

1. find the CPLs for each argument
2. find all the applicable methods
3. sort the applicable methods in decreasing order of specificity according to the CPLs of the arguments
4. take the first (most specific) in the list

The sorted method list is useful for later when we want to be more inventive on using methods, such as method composition

### 2. Object Oriented Languages

#### Method Dispatch

Note this algorithm reduces to what we expect in the SI, single-dispatch case

**Exercise** Check this!

### 3. Object Oriented Languages

#### Method Dispatch

**Exercise** Given

(defgeneric foo (x y))
(defmethod foo ((x <number>) (y <number>)) 1)
(defmethod foo ((x <integer>) (y <integer>)) 2)
(defmethod foo ((x <number>) (y <float>)) 3)
(defmethod foo ((x <float>) (y <integer>)) 4)

work through the above algorithm to determine which method gets called on various arguments, such as (foo 7 11), (foo 7.0 11), (foo 7.0 11.0), and so on.

### 4. Object Oriented Languages

#### Method Dispatch

This rather complex dispatch calculation will be done for *every* method call in your code

Either at compile time (for a fixed class hierarchy), meaning no run-time overhead

Or at run-time, meaning some considerable execution overhead

…unless clever tricks are employed, e.g., caching

For example, a lot of effort has been put into JavaScript on precisely this point (and JavaScript is single dispatch!)

### 5. Object Oriented Languages

#### Multiple Inheritance

More on the question of multiple inheritance: languages have variations on MI. In C++

class D { ... }
class B: public D { ... }
class C: public D { ... }
class A: public B, public C { ... }

has the additional peculiarity that class A is defined to inherit *two* copies of D, one via B and one via C

This is because occasionally we want two copies

For example, an IOstream inherits from both Istream and Ostream, which both inherit from Stream: we might want separate file pointers for input and output

### 6. Object Oriented Languages

#### Multiple Inheritance

If we want only a single copy, C++ requires what it calls *virtual inheritance*

class B: public virtual D { ... }
class C: public virtual D { ... }
class A: public B, public C { ... }

Now the single copy of D is inherited by A

This is the most common usage, so should have been the default!

### 7. Object Oriented Languages

#### Multiple Inheritance

**Exercise** Find out how C++ addresses the diamond problem

**Exercise** Find out how Eiffel addresses the diamond problem

### 8. Object Oriented Languages

#### Multiple Inheritance

Java is one of several languages that avoid the complexities of MI not having it

Instead, it supports *interfaces*

As discussed in traits, this often just a list of method signatures, i.e., no code to go with the names

### 9. Object Oriented Languages

#### Multiple Inheritance

So, for example the interface (*not* class) Istream might name methods like read and get\_file\_position

And the interface Ostream might name methods like write and get\_file\_position

And then we might have

class IOstream extends Stream
 implements Istream, Ostream {
...
}

The class IOstream must implement — directly or inherited from (the single parent) Stream — all the methods mentioned in the definitions of interfaces Istream and Ostream

### 10. Object Oriented Languages

#### Multiple Inheritance

So, for this example, IOstream will possibly implement read, write and inherit get\_file\_position

In Java, a class can derive from multiple interfaces, but not multiple classes

There is no possibility of inheriting multiple methods of the same name, as the class can still only inherit a method from at most one parent class—and nothing from the interfaces

There is no problem with being told more than once that a class needs to implement a method of a given name and signature

**Exercise** What happens if you derive from two interfaces and they ask for different signatures for the same method name?

### 11. Object Oriented Languages

#### Multiple Inheritance

An interface like this is more like a list of requirements for a class than about inheriting things

But interfaces provide all of the MI functionality that most people need: they describe the required behaviour of a class, taking from multiple places

Without all the complexity of MI forcing some variety of inheritance on your code

**Exercise** Later standards for Java allows default methods to be defined in interfaces, thus re-introducing the diamond problem. Find out how Java addresses this

### 12. Object Oriented Languages

#### Class Composition

Some people say MI is too complex, hard to implement properly, produces unexpected results, and can have performance issues, so you should not have it or use it

They say if you want multiple behaviours, you can use SI with *class composition*

An IOstream should be a new, independent class, *containing* instances of Istream and Ostream

*Not* inheriting

Note **class** composition is completely different from **method** composition!

### 13. Object Oriented Languages

#### Class Composition

class IOStream: public Istream, public Ostream { ... }

**inheriting** from Istream and Ostream becomes

class IOStream: { public: Istream i; Ostream o; ... }

**containing** Istream and Ostream

And we need to write str.i.ptr or str.o.ptr as appropriate to get the stream pointers

This can be used by SI languages, too, such as Java

### 14. Object Oriented Languages

#### Class Composition

We lose the convenience of the compiler doing automatic inheritance and automatic method selection, but many people argue multiple inheritance is too problematic to use correctly anyway

So class composition is much more like delegation and prototyping OO

And we can combine behaviours arbitrarily, not being confined to a hierarchy

And no diamond problem

### 15. Object Oriented Languages

#### Class Composition

Many people say not to use MI as it has problems

But that doesn’t mean that *all* inheritance is problematic!

A lot of code successfully uses single inheritance

And a fair amount of code successfully uses MI!

### 16. Object Oriented Languages

#### Class Composition

But, of course, some people go further and say you should not even be using single inheritance, but should use class composition for everything

A class inheritance hierarchy makes you share both structure (slots) and behaviour (methods), and you always get both when you inherit from a class

We don’t always want both: example shortly

### 17. Object Oriented Languages

#### Multiple Inheritance/Class Composition

Composition has several claimed downsides:

* Lack of code reuse: but composition is also a way of avoiding code re-implementation, a kind of hand-crafted inheritance. Code is written once and reused
* Runtime overheads: same as inheritance, which can mean none if the compiler can statically determine which method to call
* Initialising an instance harder: composition calls (super)constructors, but so does inheritance

### 18. Object Oriented Languages

#### Multiple Inheritance/Class Composition

* Method/slot lookup: done at coding time, by the programmer, rather than by the compiler (recall str.i.ptr or str.o.ptr above), only a problem if you care about getting the right slot value
* Perhaps some lose a bit of encapsulation as “subclasses” need to be accessible
* Always get multiple versions of a slot, so composition is better with just behaviour (like traits/mixins!)

Of course, in contrast, inheritance can only adhere to the existing hierarchy, composition is not restricted

### 19. Object Oriented Languages

#### Liskov

We know MI has problems with inheritance

But so does SI: the world is not arranged in a nice neat hierarchy

Recall the Liskov substitution principle, a property we want from OO and inheritance:

Suppose S is a subtype of T. Then whenever we need an instance of type T we can use an instance of type S, and our code should still operate correctly

Here is an example where it goes wrong: or, rather, where inheritance is not helpful

### 20. Object Oriented Languages

#### Circle-Ellipse

The *circle-ellipse problem* (also known as the *square-rectangle problem*)

Is a circle an ellipse with special properties?

Or is an ellipse a circle with extra properties?

The way you might use inheritance depends on your point of view

### 21. Object Oriented Languages

#### Circle-Ellipse

A circle is a special ellipse

Class ellipse {
 double rx, ry;
 ellipse(double x, double y) {... rx=x; ry=y...}
 void scale\_x(double s) { rx = rx\*s; }
 void scale\_y(double s) { ry = ry\*s; }
 double area() { return Pi\*rx\*ry; }
}

// a special ellipse where radii are equal
Class circle extends ellipse {
 circle(x: double) {... rx=x; ry=x; ...}
}

### 22. Object Oriented Languages

#### Circle-Ellipse

Circle inherits the scale\_x method: what should it do?

* Should it be overridden to scale ry as well to maintain the constraint on the axes? Then scaling x by 2 unexpectedly quadruples the area, not doubles
* Should the method be inapplicable — breaking Liskov?

### 23. Object Oriented Languages

#### Circle-Ellipse

Just scaling x alone breaks the requirement that the two radii in a circle are equal: a circle with different rx and ry

And note that ellipse(1.0,1.0) is actually of a different class to circle(1.0)

Exceptionally, some languages (e.g., Common Lisp) can change the class of an object: you can code things so that if you scale an instance of circle it becomes an instance of ellipse

But this is very rare: most languages don’t do this

### 24. Object Oriented Languages

#### Circle-Ellipse

Alternatively, an ellipse a generalised circle

Class circle {
 double radius;
 circle(double x) {...r=x;...}
 double area() { return pi\*radius\*radius; }
}

Class ellipse extends circle {
 double radius2;
 ellipse(double x, double y) {... radius=x; radius2=y ...}
 scale\_x(double s) { radius = radius\*s; }
 scale\_y(double s) { radius2 = radius2\*s; }
 double area() { return pi\*radius\*radius2; }
}

### 25. Object Oriented Languages

#### Circle-Ellipse

This is not a natural use of inheritance, as ellipses don’t really have a radius

radius doesn’t naturally correspond uniquely to one of rx or ry

And we have to override all circle methods that depend on the radius

Thus losing most of the benefit of inheritance

### 26. Object Oriented Languages

#### Circle-Ellipse

Liskov asks: can we can we use an instance of the subclass with every method for the superclass?

A circle is a special ellipse: possibly not, e.g., using scale\_x

An ellipse a generalised circle: maybe, if we override most circle methods, so not really using inheritance

### 27. Object Oriented Languages

#### Circle-Ellipse

Even though we feel that circles and ellipses have some sort of relationship, we can’t capture that well using inheritance

Alternatives include class composition: e.g., ellipse contains circle

Though this isn’t much better than inheritance

### 28. Object Oriented Languages

#### Circle-Ellipse

We could use traits:

Class circle { double radius; }
Class ellipse { double rx, ry; }

trait Area { ... }
impl Area for circle { ... }
impl Area for ellipse { ... }

trait ScaleX { ... }
impl ScaleX for ellipse { ... }
// no ScaleX for circle

This works as traits separate behaviour from the classes, but there is no code sharing going on here (maybe there *can’t* be any sharing?)

### 29. Object Oriented Languages

#### Circle-Ellipse

Other “fixes”:

* Make all instances constant, thus not modifiable
* so scale\_x could return a new instance of ellipse or circle when called on either circles or ellipses, but this would require the implementer of ellipse to know the class extension circle will also exist
* ellipse scale\_x(double s)
{
 if (s\*rx == ry) { return circle(ry); }
 else { return ellipse(s\*rx,ry); }
}

### 30. Object Oriented Languages

#### Circle-Ellipse

* Only use ellipse: the common case of circles becomes more noisy and error-prone to code for
* scale\_x is not applicable, or returns an error, or an exception when called on a circle: breaking Liskov
* Change the hierarchy to have, say, RoundObject containing the commonality and circle and ellipse being sibling subclasses of RoundObject: but rewriting an existing hierarchy is not always possible; and the commonality might be less than you think
* Or just have no OO relationship between the two!

### 31. Object Oriented Languages

#### Choose the Right Tool

We are at the point that inheritance is not helping us

We might end up making our code worse trying to squeeze it into the OO paradigm

So OO is the wrong tool in such cases. Find a different approach

### 32. Object Oriented Languages

#### Choose the Right Tool

**Exercise** For games programmers: read about the *entity-component-system* (ECS) design pattern that favours composition over inheritance, used for at least the last two decades in games engines

**Exercise** React, the JavaScript platform for building UIs, is not OO, but is reasonably functional in style. Read about it