Object Oriented Languages

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Repeat until we find an applicable method, or we run out of superclasses, when we report "no applicable method"

In this context “applicable” means “of the given name” and suitable arguments

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So `obj.foo(42)` looks for methods with the name `foo` that can be applied to an integer

Object Oriented Languages

Aside

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Meaning no lookup overhead at runtime: the method has already been selected by the compiler and is directly called with no more ado

Other languages, mostly those with dynamic types, e.g., JavaScript and Lisp, the method can only be chosen at *runtime* as the class or object relationships may change during the running of the program

Object Oriented Languages

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This is trading dynamic behaviour against speed of execution

If there are generic functions or multiple inheritance we have to work a bit harder

Object Oriented Languages

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Essentially we make a list of all the applicable methods from the arguments' classes and their superclasses, sort them into some useful order, then use the first in the list

Object Oriented Languages

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In principle easy, but a lot of detail in reality

Object Oriented Languages

Method Dispatch

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We need to know all the superclasses of the class of an object: the *class precedence list* of an argument in a method call is a list of all the superclasses starting with the class of the argument

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So, for example, an argument of 42 might have CPL `(<fpi> <integer> <number> <object>)`

There will be need to make some choices in the case of multiple inheritance, where there is no clear “closer” class: if `A` inherits directly from both `B` and `C`, do we want `(A B C ...)` or `(A C B ...)`?

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More on this in a moment

Object Oriented Languages

Method Dispatch

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A method is *applicable* to a call with arguments $(a_1, a_2, \ldots)$ if it is defined for classes $(A_1, A_2, \ldots)$ where for each i, the class of a_i is a subclass of A_i

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So a method with *domain* `(<integer> <number>)` is applicable to a call with arguments `(23 42)` as these arguments have classes `(<integer> <integer>)`

But not to a call with arguments `(4.0 99)` as `4.0` has class `<double-float>` which is not a subclass of `<integer>`

Object Oriented Languages

Method Dispatch

A method with domain $(A_1, A_2, \ldots, A_n)$ is *more specific* than a method with domain $(B_1, B_2, \ldots, B_n)$ for the arguments $(a_1, a_2, \ldots, a_n)$ if

1. they are both applicable and
2. there is an k with $A_i = B_i$ for $i < k$, but
3. A_k appears before B_k in the CPL for argument a_k

In simpler terms, one method is more specific than another if the class in the first place they differ is more specific

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Or even “c♡9” before “c♣1” if “♡” is before “♣”. Each character position has its own alphabet

This is the situation for method ordering: each argument position has its own “alphabet”, with order specified by the CPL for the object in that position

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Example. Calling a method with arguments `(1 1.0)` of classes `<fpi>` and `<double-float>`

The CPL for the first argument is `(<fpi> <integer> <number> <object>)`

The CPL for the second argument is `(<double-float> <float> <number> <object>)`

A method with domain `(<integer> <float>)` is more specific than one with domain `(<integer> <number>)`

Object Oriented Languages

Method Dispatch

A method with domain (`<integer> <float>`) is more specific than one with domain (`<integer> <number>`)

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Object Oriented Languages

Method Dispatch

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Object Oriented Languages

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Just as “cup” is before “dog”: even though the second argument is very unspecific, the first argument prevails

A method with domain `(<float> <float>)` is not applicable unless the language allows automatic coercion of types: a huge extra complication

So the way to choose a method for a given set of arguments is

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

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Note this reduces to what we expect in an object-receiver language that has only a single object dispatch on

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Object Oriented Languages

Method Dispatch

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Object Oriented Languages

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For example, a lot of effort has been put into JavaScript on precisely this point

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Object Oriented Languages

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When making an instance of `B`, a constructor method for `B` does not *replace* (override) the constructor method for `A`, but *both* are called: first `A`'s then `B`'s

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In this case, a more specific method does not override a less specific one, but is *composed* with it

Object Oriented Languages

Method Composition

Similarly C++ has *destructors* that get called when an object is deleted, and they are called in the *opposite order*, `B`'s then `A`'s

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In these cases the composition is to run both methods, in an appropriate order

Object Oriented Languages

Method Composition

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- Common Lisp also has *before*, *after* and *around* composition: they call it method *combination*. These add a method to a generic function that runs before, or after, or instead of the existing method
- Some languages allow arbitrary user-defined method composition: we shall talk about *metaobject protocols* soon

Object Oriented Languages

Method Composition

This another reason is why methods are different from functions: methods need to know about other applicable methods, while functions live in isolation

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Object Oriented Languages

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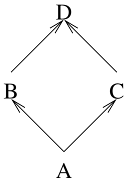
The basic idea of MI is that you can inherit behaviour or structure from more than one parent

But when you have more than one parent, how do you order the superclasses when determining the CPL?

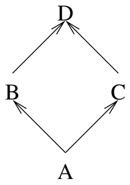
Object Oriented Languages

Multiple Inheritance



Object Oriented Languages

Multiple Inheritance



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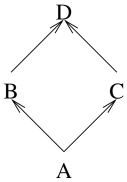
Object Oriented Languages

Multiple Inheritance



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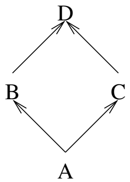

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In simple cases, the choice can be made by looking at how the classes were defined

If the definition was

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(defclass D () ...)
(defclass B (D) ...)
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(defclass A (B C) ...)
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the CPL might be `(A B C D)`

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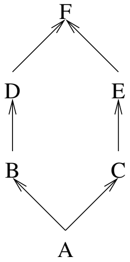
the CPL might be `(A C B D)`

This makes the resolution of `B` versus `C` consistent with the (perhaps unconscious) choice of the programmer

But what about `D` and `E` in

```
(defclass F () ...)
(defclass E (F) ...)
(defclass D (F) ...)
(defclass B (D) ...)
(defclass C (E) ...)
(defclass A (B C) ...)
```

Object Oriented Languages



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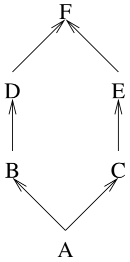

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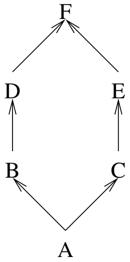

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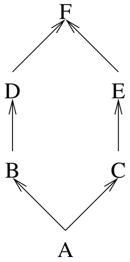

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Or not

And do we want `D` before or after `C`?

Object Oriented Languages

The class definitions do not help here, so we need a little more help

Object Oriented Languages

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We have two dimensions: left-right and up-down, and different people have different ideas on which should be used to resolve the order

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Object Oriented Languages

Multiple Inheritance

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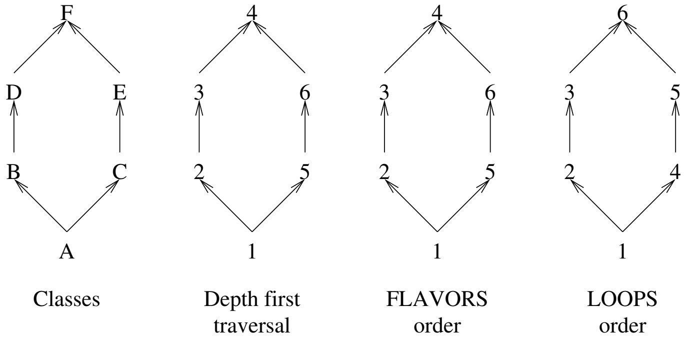

The position of each class in the linearised CPL

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Exercise. Look it up and try it on the examples above

Exercise. Think about

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(defclass BC (B C) ...)
(defclass CB (C B) ...)
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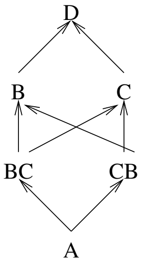

Object Oriented Languages

Multiple Inheritance

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class B: public D { ... }
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An `IOstream` inherits from both `Istream` and `Ostream`, which both inherit from `Stream`: we might want separate file pointers for input and output

Object Oriented Languages

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Exercise. Find out how C++ (and other MI languages) address the CPL linearisation issue

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An interface is a list of method names, but no implementation, i.e., no code to go with the names

So, for example the interface (*not* class) `Istream` might name methods like `read` and `get_file_position`

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class IOstream extends Stream
               implements Istream, Ostream {
...
}
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Object Oriented Languages

Multiple Inheritance

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

So, for this example, `IOstream` must implement `read`, `write` and `get_file_position`

Object Oriented Languages

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

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Interfaces provide all of the MI functionality that most people need

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Exercise. Go (Golang) also has interfaces. Read about them

Object Oriented Languages

Multiple Inheritance

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Object Oriented Languages

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Mixins, unlike interfaces, *can* implement methods

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Other languages have explicit mixin mechanisms

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Exercise. Compare traits and mixins

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Not inheriting

Object Oriented Languages

Multiple Inheritance

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class IOStream: public Istream, public Ostream { ... }
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```
class IOStream: { public: Istream i; Ostream o; ... }
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Exercise. See *anonymous structures* in C11 and similar languages that help a little in this regard by allowing unambiguous abbreviations of nested structure accesses

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So this becomes much more like prototyping OO

Object Oriented Languages

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- use differential inheritance (clone and add or change behaviour)
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- live with it

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Just because a language designer has said this language should have that kind of OO, should we be stuck with it?

A *metaobject protocol* (MOP) is a means by which we describe what kind of object protocol we want

The metaobject protocol exposes the internal mechanisms of how objects are structured, how methods are chosen, how properties are inherited (if we have inheritance) and so on

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Object Oriented Languages

Metaobject Protocols

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Early experiments with MOPs in Simula were developed in Smalltalk and led to CLOS: the *Common Lisp Object System*, a fully reflective object system

Recall: *reflective* means a system can look at itself and even change itself

And the best way to describe an OO system?

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Using itself!

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Using itself!

In CLOS (as in other MOP languages) there are

- classes that describe the structure and behaviour of classes
- methods that describe how objects should be created and initialised
- methods that describe how methods are looked up
- methods that describe how methods should be inherited or overridden or combined
- and so on for all aspects of an OO system

Exercise. Think about the bootstrap problem of a MOP

We shall take examples from Telos, the EuLisp Object System, as it is much simpler than CLOS

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Object Oriented Languages

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Object Oriented Languages

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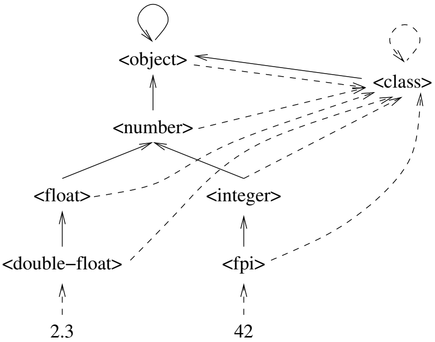
There are standard classes and methods that describe standard structure, inheritance, method selection and so on

These implement OO behaviour as you might expect from other languages

The class `<simple-class>` and its methods describe these standard things

It is a subclass of the topmost (abstract) class `<class>`

Previously we saw:

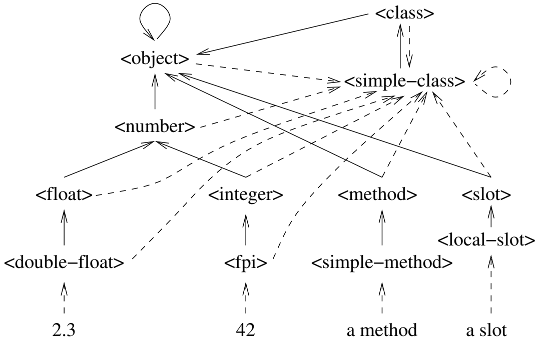


Part of the EuLisp Class Hierarchy (simplified)

Dotted arrow is *instance of*/*member of*/*is a*; solid arrow is *inherits from*/*subclass*/*extends*/*subset*

Object Oriented Languages

Metaobject Protocols



Part of the EuLisp Class Hierarchy (not so simplified)

Dotted arrow is *instance of* or *member of* or *is a*; solid arrow is *inherits from* or *subclass* or *extends*

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Thus the class `<string>` is an instance of `<simple-class>`

Just as strings are instances of `<string>`

Making a new class:

```
(defclass <myclass> () ... class: <simple-class>)
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using the `class:` keyword to indicate this is an instance of `simple-class` (the default)

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Or `(defclass <myclass> (<simple-class>) ... class: <simple-class>)`

if you want to inherit `simple-class`'s default structure and behaviour

Then we can add methods to the generic functions that comprise the metaobject protocol to implement our new functionality

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We can now define classes that have this new functionality by

```
(defclass <weirdobject> () ...  class: <myclass>)

(make <weirdobject> ...)
```

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There is a method on this for `<simple-class>` that does the standard thing with CPLs, as described previously

Methods: how do we find the right method to apply?

We need to find the class precedence list for an argument

So Telos provides a generic function
`compute-class-precedence-list`

There is a method on this for `<simple-class>` that does the standard thing with CPLs, as described previously

You can add a method yourself if you want to something different, e.g., reverse the order, or omit some classes, or add some strange kind of multiple inheritance, etc.

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And so on