Comparative Programming Languages
CM20318

Russell Bradford

2023/24

### 1. Object Oriented Languages

#### Method Composition

The level of support for method composition varies between languages

* The super keyword in Smalltalk allows a method to call the next most specific method
* call-next-method in Lisp and super() in Python are similar
* many languages only have composition in constructors

### 2. Object Oriented Languages

#### Method Composition

* 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
* You can use call-next-method to get at the original method from an around method
* Some languages allow arbitrary user-defined method composition: we shall talk about *metaobject protocols* soon

### 3. Object Oriented Languages

#### Method Composition

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

### 4. Object Oriented Languages

#### Multiple Inheritance

Next there is another question to tackle: method (and attribute) selection when we have multiple inheritance in the class hierarchy

This applies to both single and multiple dispatch method calls

Take care here: MI is classes having multiple parents, while multiple dispatch is choosing a method using multiple arguments

Of course, we can have multiple dispatch with SI, and single dispatch with MI, and multiple dispatch with MI

### 5. Object Oriented Languages

#### Multiple Inheritance

In single inheritance with single dispatch the job is easy: if the class of the current object has a method defined, use it; else recurse to the parent class

But with MI you can inherit behaviour or structure from more than one parent

When you have more than one parent, how do you choose which superclass to inherit from?

More generally: for method composition we need an order on *all* the superclasses

### 6. Object Oriented Languages

#### Multiple Inheritance



Inheritance diamond



Inheritance diamond reversed

Suppose a method sleep is defined in both B and C, but not A

If sleep is called with argument in class A should it use the method from B or C?

B, perhaps, as that is on the left, and we read left-to-right?

But other people read right-to-left, and what if we had happened to draw the same hierarchy in a different way?

### 7. Object Oriented Languages

#### Multiple Inheritance



Inheriting from different “levels”

Or suppose sleep is only defined in D and C

Going up the hierarchy in a depth-first search on the left we get to D first; going up on the right we get to C first

Doing a breadth-first search, we find C first

What should A do?

### 8. Object Oriented Languages

#### Multiple Inheritance



Inheritance diamond

This is called the *diamond problem*

When there is more than one candidate method to call, how does the compiler (or interpreter) choose which one?

But, remember, the programmer also has to understand how a method is chosen

### 9. Object Oriented Languages

#### Multiple Inheritance

There have been many attempts to address this question

Every MI language needs a way of choosing, or forcing the programmer to choose

Some languages force you to disambiguate yourself, e.g., D::sleep()

While many languages have a built-in algorithm to choose for you (see linearisation, below)

### 10. Object Oriented Languages

#### Multiple Inheritance

But does this built-in algorithmic choice reflect the expectations of the programmer?

Usually yes in simple cases, but what about more complex hierarchies?

The fact there are many linearisation algorithms tells us something!

### 11. Object Oriented Languages

#### Multiple Inheritance

For example, in simple cases, Common Lisp makes a choice by looking at how the classes were defined

### 12. Object Oriented Languages

#### Multiple Inheritance

If the definition was

(defclass D () ...)
(defclass B (D) ...)
(defclass C (D) ...)
(defclass A (B C) ...)

it might order the diamond of superclasses of A as (A B C D).

This is a *linearisation* of the superclasses

And the resulting order (A B C D) is called the *class precedence list* (CPL) for A

Thus — for this order — a method defined in B is preferred over one defined in C

And similarly for B vs. D

### 13. Object Oriented Languages

#### Multiple Inheritance

On the other hand, if we happened to define

(defclass D () ...)
(defclass B (D) ...)
(defclass C (D) ...)
(defclass A (C B) ...)

Common Lisp would create a CPL of (A C B D)

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

Remember this is a tiny example: in reality the code will be much more complicated

### 14. Object Oriented Languages

#### Multiple Inheritance

A class precedence list helps the language decide which method to use

It will give us the *method resolution order* (MRO)

Namely the ordering of the applicable methods so we (a) can pick the right method and (b) have an ordered list of methods for method composition

### 15. Object Oriented Languages

#### Multiple Inheritance

In object-receiver languages, usually the method chosen is the earliest found following the CPL

Thus if the CPL is (A B C D) and both B and C define sleep, then pick the method from B

If just D and C define sleep, then pick the method from C

### 16. Object Oriented Languages

#### Multiple Inheritance

Or method*s* if we have method composition

Again, this is why we need the whole CPL, not just a single class

It’s not the whole story if we have multiple method dispatch as we have extra complication over multiple argument classes

With object receiver, the MRO is just the CPL; with multimethods calculating the MRO is harder (coming soon!)

### 17. Object Oriented Languages

#### Multiple Inheritance

Computing a good CPL is not straightforward: what about D and E in

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

### 18. Object Oriented Languages



MI graph with no disambiguating definition

There is no disambiguating defclass to guide us to order D and E

We might want D before E as B is before C

Or not

And do we want D before or after C?

### 19. Object Oriented Languages

This is the basic problem with MI: it is not clear, and different programmers may have different expectations of what should happen

The class definitions do not help in this example, so we need a little more help

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

### 20. Object Oriented Languages

#### Multiple Inheritance

These ideas were first explored in Lisp, and different people made different choices, of course

FLAVORS: do a depth-first traversal of the graph, keep the leftmost of any duplicates

The traversal is A B D F C E F, which becomes the CPL (A B D F C E)

LOOPS: do a depth-first traversal of the graph, keep the rightmost of any duplicates

The same traversal becomes the CPL (A B D C E F)

### 21. Object Oriented Languages

#### Multiple Inheritance

Neither are satisfactory algorithms

For example, FLAVORS has F before C in the CPL for A even though C is a subclass of F

And both produce undesirable behaviour in complicated hierarchies

### 22. Object Oriented Languages

#### Multiple Inheritance

For example, if S has CPL with T before U, we might hope that a subclass R of S also has a consistent CPL with T and U in the same order

If the CPL for S is (S ... T ... U ...), the CPL for R would be (R ... T ... U ...)

This would be a *monotonic* CPL: the CPL of a class is consistent with the CPL of its parents

### 23. Object Oriented Languages

#### Multiple Inheritance

Being monotonic is a desirable property as it agrees with intuition of the programmer on how inheritance should happen

But many linearisation algorithms don’t guarantee that: they might give non-monotonic CPLs

### 24. Object Oriented Languages

#### Multiple Inheritance

All of LOOPS, FLAVORS and the more complex algorithm actually used by Common Lisp can produce non-monotonic CPLs, even on quite small examples

**Exercise** Look up the CLOS algorithm and find some non-monotonic examples

### 25. Object Oriented Languages

#### Multiple Inheritance

**Exercise** Think about

|  |
| --- |
| (defclass D () ...) |
| (defclass B (D) ...) |
| (defclass C (D) ...) |
| (defclass BC (B C) ...) |
| (defclass CB (C B) ...) |
| (defclass A (BC CB) ...) |



A problematic MI graph

### 26. Object Oriented Languages

#### Multiple Inheritance

Many languages have moved to a linearisation algorithm called C3

It is fairly easy to implement and is monotonic

Together with a few other desirable properties

It is now used in Python, Perl and several other MI languages

**Exercise** Read about C3 linearization

### 27. Object Oriented Languages

#### Multiple Inheritance

Some examples of “typical” MI hierarchies, from “A Monotonic Superclass Linearization for Dylan”, Barrett et al., 1996:

|  | classes | MI joins |
| --- | --- | --- |
| LispWorks | 507 | 70 |
| CLIM | 842 | 184 |
| database | 38 | 4 |
| emulator | 571 | 205 |
| proprietary | 665 | 124 |
| Watson | 673 | 114 |

### 28. Feet

* Dylan: tries to shoot you in the foot like Scheme while enviously watching Java eat its lunch

### 29. Object Oriented Languages

#### Method Dispatch

We now know enough to talk about how to pick methods, that is, determine the method resolution order (MRO) for multimethods

We need to find the right method to call given a bunch of arguments

This needs various bits of infrastructure to work

### 30. Object Oriented Languages

#### Method Dispatch

We need to know all the superclasses of the classes of the objects involved, thus we need to compute their CPLs using your favourite linearisation algorithm

For example, the arguments (4.0 99)

The argument of 4.0 might have CPL
(double float number object)

While the argument of 99 might have CPL
(int integer number object)

### 31. Object Oriented Languages

#### Method Dispatch

If we call a generic function on arguments $\left(a\_{1},a\_{2},…,a\_{n}\right)$ we first need to find those methods on the GF that it makes sense to consider

A method is *applicable* to a call with arguments $\left(a\_{1},a\_{2},…,a\_{n}\right)$ if it is defined for classes $\left(A\_{1},A\_{2},…,A\_{n}\right)$ where for each $i$, the class of $a\_{i}$ is a subclass of $A\_{i}$

### 32. Object Oriented Languages

#### Method Dispatch

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

Here, int is a subclass of integer, and int is a subclass of number

But not applicable to a call with arguments (4.0 99) as 4.0 has class double which is not a subclass of integer

Nor a call (4 "hello"), even though 4, with class int is a subclass of integer, we see that string is not a subclass of number

### 33. Object Oriented Languages

#### Method Dispatch

Next, a method with domain $\left(A\_{1},A\_{2},…,A\_{n}\right)$ is *more specific* than a method with domain $\left(B\_{1},B\_{2},…,B\_{n}\right)$ for the arguments $\left(a\_{1},a\_{2},…,a\_{n}\right)$ if

1. they are both applicable to $\left(a\_{1},a\_{2},…,a\_{n}\right)$ 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 $a\_{k}$

### 34. Object Oriented Languages

#### Method Dispatch

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

This is a kind of alphabetical ordering, where the alphabet is specified by the CPL

In a normal alphabetic order, we put “can” before “cat” as this is determined by the first place the words differ: namely “n” comes before “t”

We naturally extend to, say, “cat1” before “cat3” as “1” comes before “3”. But now there is more than one order in play

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

### 35. Object Oriented Languages

#### Method Dispatch

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

Example. Calling a method with arguments (1 1.0) of classes int and double

The CPL for the first argument is (int integer number object)

The CPL for the second argument is (double float number object)

### 36. Object Oriented Languages

#### Method Dispatch

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

A method with domain (int object) is more specific than one with domain (integer double)

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

A method with domain (float float) is not applicable for those arguments unless the language allows automatic coercion of types: a huge extra complication that we shall ignore