CS-XXX: Graduate Programming Languages

Lecture 23 —
Types for OOP;
Static Overloading and Multimethods

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So far...

Last lecture (among other things):

- The difference between OOP and "records of functions with shared private state" is *dynamic-dispatch* (a.k.a. *late-binding*) of `self`
- (Informally) defined *method-lookup* to implement dynamic-dispatch correctly: use run-time tags or code-pointers

Now:

- Purpose of static typing for (pure) OOP
- Subtyping and contrasting it with subclassing
- Static overloading
- Multimethods

Type-Safety in OOP

Remember the two main goals we had with static type systems:

- Prevent "getting stuck" which is how we encode language-level errors in our operational semantics
  - Without rejecting too many useful programs
- Enforce abstractions so programmers can hide application-level things and enforce invariants, preconditions, etc.
  - Subtyping and parametric polymorphism do this in complementary ways, assuming no downcasts or other run-time type tests

Pure OOP has only method calls (and field accesses)

- A method-lookup is stuck if receiver has no method with right name/arity (no match)
- (If we add overloading,) a method-lookup is stuck if receiver has no "best" method (no best match)

Structural or Nominal

A straightforward *structural* type system for OOP would be like our type system with record types and function types

- An object type lists the methods that objects of that type have, plus the the types of the argument(s) and result(s) for each method
- Sound subtyping just as we learned
  - Width, permutation, and depth for object types
  - Contravariant arguments and covariant result for each method type in an object type

A *nominal* type system could give named types and explicit subtyping relationships

- Allow a subset of the subtyping (therefore sound) of the structural system (see lecture 11 for plusses/minuses)
- Common to reuse class names as type names and require subclasses to be subtypes...

Subclassing is Subtyping

Statically typed OOP languages often purposely "confuse" classes and types: C is a class and a type and if C extends D then C is a subtype of D

Therefore, if C overrides `m`, the type of `m` in C must be a subtype of the type of `m` in D

Just like functions, method subtyping allows contravariant arguments and covariant results

- If code knows it has a C, it can call methods with "more" arguments and know there are "fewer" results

Subtyping and Dynamic Dispatch

We defined dynamic dispatch in terms of functions taking `self` as an argument

But unlike other arguments, `self` is *covariant*!!

- Else overriding method couldn't access new fields/methods
- Sound because `self` must be passed, not another value with the supertype

This is the key reason *encoding* OOP in a *typed* $\boldsymbol{\lambda}$-calculus requires ingenuity, fancy types, and/or run-time cost

More subtyping

With single-inheritance and the class/type confusion, we don't get all the subtyping we want

- Example: Taking any object that has an `m` method from `int` to `int`

Interfaces help somewhat, but class declarations must still *say* they implement an interface

- An interface is just a named type independent of the class hierarchy

Why subsume?

Subsuming to a supertype allows reusing code expecting the supertype

It also allows hiding *if* you don't have downcasts, etc. Example:

```
interface I { int distance(Point1 p); }
class Point1 implements I { ... I f() { self } ... }
```

But again objects are awkward for many binary methods

- `distance` takes a `Point1`, not an `I`

More subclassing

Breaking one direction of "subclassing = subtyping" allowed more subtyping (so more code reuse and/or information hiding)

Breaking the other direction ("subclassing does not imply subtyping") allows more inheritance (so more code reuse)

Simple idea: If C extends D and overrides a method in a way that makes $C \leq D$ unsound, then $C \not\leq D$. This is useful:

```
class P1 { ... Int get_x(); Bool compare(P1); ... }
class P2 extends P1 { ... Bool compare(P2); ... }
```

But this is *not* always correct...

Subclass not a subtype

```
class P1 {
  Int x;
  Int get_x() { x }
  Bool compare(P1 p) { self.get_x() == p.get_x() }
}
class P2 extends P1 {
  Int y;
  Int get_y() { y }
  Bool compare(P2 p) { self.get_x() == p.get_x() &&
                       self.get_y() == p.get_y() }
}
```

- As expected, P2≤P1 is *unsound* (assuming `compare` in `P2` is overriding unlike in Java or C++)

Subclass not a subtype

- Can still inherit implementation (need not reimplement `get_x`)
- We cannot always do this: what if `get_x` called `self.compare`? Possible solutions:
  - Re-typecheck `get_x` in subclass
  - Use a "Really Fancy Type System"

There may be little use in allowing subclassing that is not subtyping

Summary of subclass vs. subtype

Separating types and classes expands the language, but clarifies the concepts:

- Typing is about interfaces, subtyping about broader interfaces
- Subclassing is about inheritance and code-sharing

Combining typing and inheritance restricts both

- Most OOP languages purposely confuse subtyping (about type-checking) and inheritance (about code-sharing), which is reasonable in practice
- But please use *subclass* to talk about inheritance and *subtype* to talk about static checking

Static Overloading

So far, we have assumed every method had a different name

- Same name implied overriding and required a subtype

Many OOP languages allow the same name for different methods with *different argument types*:

```
A f(B x) { ... }
C f(D x, E y) { ... }
F f(G x, H z) { ... }
```

Complicates definition of method-lookup for `e1.m(e2,...,en)`

Previously, we had dynamic-dispatch on `e1`: method-lookup a function of the *class* of the object `e1` evaluates to (*at run-time*)

We now have *static overloading*: Method-lookup is *also* a function of the *types* of `e2,...,en` (*at compile-time*)

Static Overloading Continued

Because of subtyping, multiple methods can match a call!

"Best-match" can be roughly "Subsume fewest arguments. For a tie, allow subsumption to *immediate* supertypes and recur"

Ambiguities remain (no best match):

- `A f(B)` vs. `C f(B)` (usually rejected)
- `A f(I)` vs. `A f(J)` for `f(e)` where `e` has type T, $T \leq I$, $T \leq J$ and I,J are incomparable (possible with multiple interfaces or multiple inheritance)
- `A f(B,C)` vs. `A f(C,B)` for `f(e1,e2)` where $B \leq C$, and `e1` and `e2` have type B

Type systems often reject ambiguous calls or use *ad hoc* rules to give a best match (e.g., "left-argument precedence")

Multiple Dispatch

Static overloading saves keystrokes from shorter method-names

- We know the compile-time types of arguments at each call-site, so we could call methods with different names

Multiple (dynamic) dispatch (a.k.a. multimethods) is more interesting: Method-lookup a function of the run-time types of arguments

It's a natural generalization: the "receiver" argument is no longer treated differently!

So `e1.m(e2,...,en)` is just sugar for `m(e1,e2,...,en)`

- It wasn't before, e.g., when `e1` is `self` and may be a subtype

Example

```
class A { int f; }
class B extends A { int g; }
Bool compare(A x, A y) { x.f == y.f }
Bool compare(B x, B y) { x.f == y.f && x.g == y.g }
Bool f(A x, A y, A z) { compare(x,y) && compare(y,z) }
```

Neat: late-binding for both arguments to `compare` (choose second method if both arguments are subtypes of B, else first method)

With power comes danger. Tricky question: Can we add "`&& compare(x,z)`" to body of `f` and have an equivalent function?

- With static overloading?
- With multiple dispatch?

Pragmatics

Not clear where multimethods should be defined

- No longer "belong to a class" because receiver isn't special

Multimethods are "more OOP" because dynamic dispatch is the essence of OOP

Multimethods are "less OOP" because without a distinguished receiver the analogy to physical objects is reduced

Nice paper in OOPSLA08: "Multiple Dispatch in Practice"

Revenge of Ambiguity

The "no best match" issues with static overloading exist with multimethods and ambiguities arise at run-time

It's undecidable if "no best match" will happen:

```
// B <= C
A f(B,C) {...}
A f(C,B) {...}
unit g(C a, C b) { f(a,b); /* may be ambiguous */ }
```

Possible solutions:

- Raise exception when no best match
- Define "best match" such that it always exists
- A conservative type system to reject programs that might have a "no best match" error when run