Bounded Polymorphism and Classless OOP
You have grading to do

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I am going to distribute course evaluation forms so you may rate the quality of this course. Your participation is voluntary, and you may omit specific items if you wish. To ensure confidentiality, do not write your name of the forms. There is a possibility your handwriting on the yellow written comment sheet will be recognizable; however, I will not see the results of this evaluation until after the quarter is over and you have received your grades. Please be sure to use a No. 2 PENCIL ONLY on the scannable form.

I have chosen (name) to distribute and collect the forms. When you are finished, he/she will collect the forms, put them into an envelope and mail them to the Office of Educational Assessment. If there are no questions, I will leave the room and not return until all the questionnaires have been finished and collected. Thank you for your participation.

I’ll come back at 10:45.

Dan Grossman  CSE505 Fall 2003, Lecture 17
Revenge of Type Variables

Sorted lists in ML (partial):

make : ('a -> 'a -> int) -> 'a slist
cons : 'a slist -> 'a -> 'a slist
find : 'a slist -> ('a -> bool) -> 'a option

Getting by with OO subtyping (assuming null has any type):

interface Cmp { Int f(Object, Object); }
interface Pred { Bool g(Object); }
class SList {
    constructor (Cmp x) {...}
    Slist cons(Object x) {...}
    Object find(Pred x) {...}
}
Wanting Type Variables

Will downcast (potential run-time exception) the arguments to $f$, the argument to $g$, and the result of $\text{find}$.

We are not enforcing list-element type-equality.

OO-style subtyping is no replacement for parametric polymorphism; we can have both:

```haskell
interface 'a Cmp  { Int f('a,'a); }  // Cmp not a type
interface 'a Pred { Bool g('a); }  // Pred not a type
class 'a SList    { // SList not a type (Int SList is)
                       constructor ('a Cmp x) {...}
                       'a Slist cons('a x) {...}
                       'a      find('a Pred x) {...}
}
```

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Same Old Story

- Interface and class declarations are parameterized; they produce types.
- The constructor is polymorphic (for all $T$, given a $T\text{ Cmp}$, it makes a $T\text{ SList}$).
- If $o$ has type $T\text{ SList}$, its cons method takes a $T$ and returns a $T\text{ SList}$.

No more downcasts; the best of both worlds.
Complications

“Interesting” interaction with overloading and multimethods

class B {
    unit f(Int C x) {...}
    unit f(String C x) {...}
}

class 'a C { unit g(B x) { x.f(self); } }

- For $T$ C where $T$ is neither Int nor String, can have no match found.
- Cannot resolve static overloading at compile-time without code duplication.
- To resolve overloading or multimethods at run-time, need run-time type information \textit{including the instantiation} $T$.

Alternately, could just reject the call as unresolvable.
Wanting bounds

Even without overloading or multimethods, there are compelling reasons to *bound* the instantiation of type variables.

Simple example: Use at supertype without losing that it's a subtype

```java
interface I { unit print(); }

class ('a < I) Logger { // must apply to subtype of I
    'a item;
    'a get_it() { syslog(item.print()); item }
}
```

Without polymorphism or downcasting, client could only use get_it result for printing.

Without bound or downcasting, Logger could not print.
Fancy Example

With forethought and structural (non-named) subtyping, bounds can avoid some subtyping limitations.
(Example lifted from “A Theory of Objects” Abadi/Cardelli)

interface Omnivore { unit eat(Food); }
interface Herbivore { unit eat(Veg); } // Veg <= Food

Allowing Herbivore \leq Omnivore could make a vegetarian eat meat (unsound)! But this works:

interface (\texttt{'a} < Food) Omnivore { unit eat('a); }
interface (\texttt{'a} < Veg) Herbivore { unit eat('a); }

If T Herbivore is legal, then T Omnivore is legal and
(T Herbivore) \leq (T Omnivore)!
Bounded Polymorphism

This “bounded polymorphism” is useful in any language with universal types and subtyping. Instead of $\forall \alpha. \tau$ and $\Lambda \alpha. e$, we have $\forall \alpha < \tau'. \tau$ and $\Lambda \alpha < \tau'. e$:

- In $e$ you can subsume from $\alpha$ to $\tau'$
- $e_1[\tau_1]$ typechecks only if $\tau_1$ “satisfies the bound” in the type of $e_1$.

One meta-theory drawback: Contravariant bounds are sound, but make subtyping undecidable. Requiring invariant bounds (more restrictive) regains decidability.
Classless OOP

OOP gave us code-reuse via inheritance and extensibility via late-binding.

But it also gave us a clunky, heavyweight class and named-type mechanism we had to use to get it.

Can we throw out classes and still get OOP? Yes.

Can it have a type system that prevents “no match found” and “no best match” errors? Yes, but we won’t get there.

We will make up syntax as we go along!

This is mind-opening/bending stuff if you’ve never seen it.
Make objects directly

Everything is an object. You can make objects directly:

let p = [
    field x = 7;
    field y = 9;
    right_quad(){ x.gt(0) && y.gt(0) } // cf. 0.lte(y)
]

p is now an object in scope; can invoke its methods (and assign fields (see hw – that’s just method invocation)

No classes: Constructors are easy to encode

let make_p = [
    doit(x0,y0) { [ field x=x0; field y=y0;... ] } ]
Inheritance and Override

Building objects from scratch won’t get us late-binding and code reuse. Here’s the trick:

- clone method produces a (shallow) copy of an object.
- method “slots” can be mutable

```
let o1 = [ // still have late-binding
  odd(x) {if x.eq(0) then false else self.even(x-1)}
  even(x) {if x.eq(0) then true else self.odd(x-1)} ]
let o2 = o1.clone()
o2.even(x) := (x.mod(2)).eq(0)
```

Language doesn’t grow (just methods and mutable “slots”)  
Can use for constructors too (clone and assign fields)
Extension

But that trick doesn’t work to add slots to an object, a common use of subclassing.

Having something like “extend e1 (x=e2)” that mutates e1 to have a new slot is problematic semantically (what if e1 has a slot named x) and for efficiency (may not be room where e1 is allocated)

Instead, we can build a new object with a special parent slot: [parent=e1; x=e2]

parent is very special because definition of method-lookup (the issue in OO) depends on it (else this isn’t inheritance)
Method Lookup

To find the \textit{m} method of \textit{o}:

- Look for a slot named \textit{m}
- If not found, look in object held in parent slot

But we still have late-binding: for method in parent slot, we still have \texttt{self} refer to the original \textit{o}.

Two \textit{inequivalent} ways to define parent=\texttt{e1}:

- Delegation: parent refers to result of \texttt{e1}
- Embedding: parent refers to result of \texttt{e1.clone()}

Mutation of result of \texttt{e1} (or its parent or grandparent or ...) exposes the difference. We’ll assume delegation.
Oh so flexible

Delegation is way more flexible (and simple!) (and dangerous!) than class-based OO: The object being delegated to is usually used like a class, but its slots may be mutable.

- Assigning to a slot in a delegated object changes every object that delegates to it (transitively)
  - Clever change-propagation but as dangerous as globals (and more subtle?)
- Assigning to a parent slot is “dynamic inheritance” (changes where slots are inherited from)

Classes restrict what you can do and how you think (never thinking of clever run-time modifications of inheritance)
Rarely what you want

We have the essence of OOP in a tiny language with more flexibility than we usually want.

Avoid it via careful coding idioms:

- Create *trait/abstract* objects: Just immutable methods (cf. abstract classes)
- Extend with *prototype/template* objects: Add mutable fields but don’t mutate them (cf. classes)
- Clone prototypes to create *concrete/normal* objects (cf. constructors)

Traits can extend other traits and prototypes other prototypes (cf. subclasses)
Coming full circle

Without separating first two roles, objects don’t share method slots (wastes space), but immutability avoids danger.

Late-binding still makes method-override work correctly.

This idiom is so important, it’s worth having a type system that enforces it.

For example, a template object cannot have its members accessed (except clone).

We end up getting close to classes, but from first principles and still allowing the full flexibility when you want it.

And we still have just objects, roles, and types.
A word on types

Untyped languages work (the OO of Scheme) – may get a “no match found” exception at run-time. Very flexible.

But we can develop type systems that restrict the language and prevent getting stuck without developing a class system.

Can base types on “derived from the same object,” which can form the basis for multimethods.

Summary: Pure classless OO a liberating way to think, especially if you learn workarounds in more restrictive languages.