Now…

Use what we learned about subtyping for records and functions to understand subtyping for class-based OOP
– Like in Java/C#

Recall:
– Class names are also types
– Subclasses are also subtypes
– Substitution principle: Instance of subclass should usable in place of instance of superclass

An object is…

• Objects: mostly records holding fields and methods
  – Fields are mutable
  – Methods are immutable functions that also have access to self

• So could design a type system using types very much like record types
  – Subtypes could have extra fields and methods
  – Overriding methods could have contravariant arguments and covariant results compared to method overridden
    • Sound only because method “slots” are immutable!

Actual Java/C#…

Compare/contrast to what our “theory” allows:
1. Types are class names and subtyping are explicit subclasses
2. A subclass can add fields and methods
3. A subclass can override a method with a covariant return type
   – (No contravariant arguments; instead makes it a non-overriding method of the same name)

(1) Is a subset of what is sound (so also sound)
(3) Is a subset of what is sound and a different choice (adding method instead of overriding)

Classes vs. Types

• A class defines an object’s behavior
  – Subclassing inherits behavior and changes it via extension and overriding

• A type describes an object’s methods’ argument/result types
  – A subtype is substitutable in terms of its field/method types

• These are separate concepts: try to use the terms correctly
  – Java/C# confuse them by requiring subclasses to be subtypes
  – A class name is both a class and a type
  – Confusion is convenient in practice

Optional: More details

Java and C# are sound: They do not allow subtypes to do things that would lead to “method missing” or accessing a field at the wrong type

Confusing (?) Java example:
– Subclass can declare field name already declared by superclass
– Two classes can use any two types for the field name
– Instance of subclass have two fields with same name
– “Which field is in scope” depends on which class defined the method
self/this is special

• Recall our Racket encoding of OOP-style
  – “Objects” have a list of fields and a list of functions that take self as an explicit extra argument

• So if self/this is a function argument, is it contravariant?
  – No, it is covariant: a method in a subclass can use fields and methods only available in the subclass: essential for OOP

  – Sound because calls always use the “whole object” for self
  – This is why coding up your own objects manually works much less well in a statically typed languages

What are generics good for?

Some good uses for parametric polymorphism:

• Types for functions that combine other functions:
  
  ```
  fun compose (g,h) = fn x => g (h x) (* compose : ('b -> 'c) * ('a -> 'b) -> ('a -> 'c) *)
  ```

• Types for functions that operate over generic collections
  
  ```
  val length : 'a list -> int
  val map : ('a -> 'b) -> 'a list -> 'b list
  val swap : ('a * 'b) -> ('b * 'a)
  ```

• Many other idioms

• General point: When types can “be anything” but multiple things need to be “the same type”

Generics in Java

• Java generics a bit clumsier syntactically and semantically, but can express the same ideas
  – Without closures, often need to use (one-method) objects
  – See also earlier optional lecture on closures in Java/C

• Simple example without higher-order functions (optional):

  ```
  class Pair<T1,T2> {
    T1 x;
    T2 y;
    Pair(T1 _x, T2 _y){ x = _x; y = _y; }
    Pair<T2,T1> swap() { return new Pair<T2,T1>(y,x); }
    ...
  }
  ```

Subtyping is not good for this

• Using subtyping for containers is much more painful for clients
  – Have to downcast items retrieved from containers
  – Downcasting has run-time cost
  – Downcasting can fail: no static check that container holds the type of data you expect
  – (Only gets more painful with higher-order functions like map)

What is subtyping good for?

Some good uses for subtype polymorphism:

• Code that “needs a Foo” but fine to have “more than a Foo”

• Geometry on points works fine for colored points

• GUI widgets specialize the basic idea of “being on the screen” and “responding to user actions”

Awkward in ML

ML does not have subtyping, so this simply does not type-check:

```ml
(* {x:real, y:real} -> real *)
fun distToOrigin ({x=x,y=y}) = Math.sqrt(x*x + y*y)
val five = distToOrigin {x=3.0,y=4.0,color="red"}

(* ('a -> real) * ('a -> real) * 'a -> real *)
fun distToOrigin (getx, gety, v) = Math.sqrt((getx v)*(getx v) + (gety v)*(gety v))
```

Cumbrous workaround: have caller pass in getter functions:

```ml
(* ('a -> real) * ('a -> real) * 'a -> real *)
fun distToOrigin (getx, gety, v) = Math.sqrt((getx v)*(getx v) + (gety v)*(gety v))
```

– And clients still need different getters for points, color-points
Wanting both

- Could a language have generics and subtyping?
  - Sure!

- More interestingly, want to combine them
  - “Any type T1 that is a subtype of T2”
  - Called bounded polymorphism
  - Lets you do things naturally you cannot do with generics or subtyping separately

Subtyping?

```
List<Point> inCircle(List<Point> pts, Point center, double r) { ... }
```

- Would like to use inCircle by passing a List<ColorPoint> and getting back a List<ColorPoint>
- Java rightly disallows this: While inCircle would “do nothing wrong” its type does not prevent:
  - Returning a list that has a non-color-point in it
  - Modifying pts by adding non-color-points to it

Generics?

```
<T> List<T> inCircle(List<T> pts, Point center, double r) { ... }
```

- We could change the method to be

```
<T> List<T> inCircle(List<T> pts, Point center, double r) { ... }
```

  - Now the type system allows passing in a List<Point> to get a List<Point> returned or a List<ColorPoint> to get a List<ColorPoint> returned
  - But cannot implement inCircle properly: method body should have no knowledge of type T

Bounds

- What we want:

```
<T extends Pt> List<T> inCircle(List<T> pts, Pt center, double r) where T <: Point
{ ... }
```

  - Caller uses it generically, but must instantiate T with some subtype of Point (including Point)
  - Callee can assume T <: Point so it can do its job
  - Callee must return a List<T> so output will contain only elements from pts

Real Java

- The actual Java syntax:

```
<T extends Pt> List<T> inCircle(List<T> pts, Pt center, double r) {
List<T> result = new ArrayList<T>();
for(T pt : pts)
  if(pt.distance(center) < r)
    result.add(pt);
return result;
}
```

- Note: For backward-compatibility and implementation reasons, in Java there is actually always a way to use casts to get around the static checking with generics
  - With or without bounded polymorphism