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
– Instances 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

```java
class A {
    int m(){ return 0; }
}
class B extends A {
    int x;
    int m(){ return x; }
}
```

**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):

```java
class Pair<T1,T2> {
    T1 x;
    T2 y;
    Pair(T1 _x,T 2 _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`)

```java
class LamePair {
    Object x;
    Object y;
    LamePair(Object _x, Object _y){ x=_x; y=_y; }
    LamePair swap() { return new LamePair(y,x); }
}
```

// error caught only at run-time:
```java
String s = (String)(new LamePair("hi",4).y);
```

**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"}
```

Cumbersome 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 $T_1$ that is a subtype of $T_2$”
  – Called bounded polymorphism
  – Lets you do things naturally you cannot do with generics or subtyping separately

Example

Method that takes a list of points and a circle (center point, radius)
  – Return new list of points in argument list that lie within circle

Basic method signature:

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

Java implementation straightforward assuming `Point` has a `distance` method:

```java
List<Point> result = new ArrayList<Point>();
for(Point pt : pts)
  if(pt.distance(center) < r)
    result.add(pt);
return result;
```

Subtyping?

```java
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?

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

• We could change the method to be

```java
<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:

```java
<T> List<T> inCircle(List<T> pts,
                      Point 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:

```java
<T extends Pt> List<T> inCircle(List<T> pts,
                                Pt center,
                                double r) { … }
```

• 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