NTNU – Trondheim
Norwegian University of
Science and Technology

Derived and abstract data types

Where we were

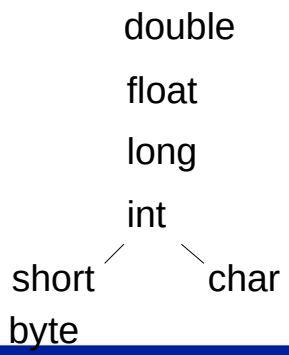
- We’ve looked at static semantics for primitive types
  - and how it relates to type checking
- We’ve hinted at derived types
  - using a multidimensional array declaration as example
- We’ll round of with a quick look at more complicated derived types, and what they do to the type system

Type expressions

- We’ve touched upon this

  int[2][3] consists of a basic type int, and (array-of-2 (array-of-3))
- Types can be constructed from basic types
- We’ve also mentioned that types can be converted into each other according to a hierarchy

  (short + char) converts into their least upper bound (int), we can write it that as a function, lub(short,char)



Arrays can be many things

- Unbounded

  Java: `public static void main ( String args[] )`

  No idea how many entries here

- Fixed size

  C: `char mystring[256];`

  (Type of mystring contains its size)

- Ranges

  Ada: `array[2 .. 5] of integer`

  (Type contains offset for indexing)

- Multidimensional

  Fortran: `REAL, dimension(2,3) :: A`

  (Type contains shape, to check that B is (3,2) and C is (2,2) if you write C=matmul(A,B))

Records

- Records are collections of names and types

  { id1:T1, id2:T2, … , idn:Tn}

- C calls them *struct*
- *Objects*, at their simplest, are just records extended with references (pointers) to the functions which manipulate their contents

  ...and some calling syntax that doesn't let you invoke its methods without passing an instance to manipulate...

Type constructors

- When the program can define types, the compiler must be able to construct representations of them, to
  - Put in symbol tables
  - Consult for conversions
  - *etc.*
- Generate a structure representing the type at its declaration
- Bind names to these structures when variables are determined to be of the matching type

Object types

- The type of a record is the Cartesian product of all its component types
- Looking at objects as glorified records, their types are the same way, just add method signatures

```
Class Point {
    float x, y;
    float getX() { return x; }
    float getY() { return y; }
}
```

becomes

{ x: float, y: float, getX : fun(Point → float), getY : fun(Point→float) }

Wait a minute...

{ x: float, y: float,
getX : fun(**Point** → float), getY : fun(**Point** → float)
}

These are not in the argument lists of float getX() or float getY()

- Implementation generates one static lump of code for taking x-s out of Points
- The reason it acts differently with different instances is that the instance is passed as a hidden argument:

  Point p = new Point(3,2);

  p.getX() ↔ Point.getX (p)
- Inside the method body, the hidden argument can go by the name "*this*"

Objects imply more

```
Class ColoredPoint extends Point {
    int color;
    int getColor() { return color; }
}
```

seen as an extended record works out to

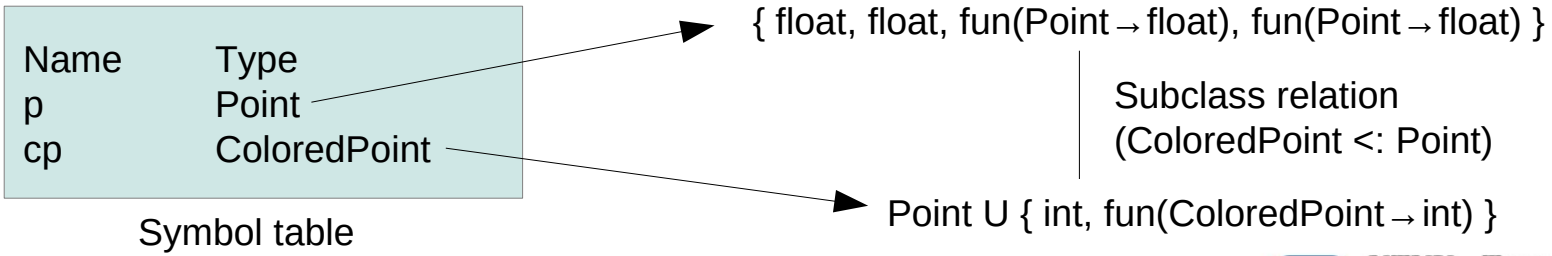
{ x: float, y: float, color: int, getX : fun(Point → float), getY : fun(Point→float), getColor : fun(ColoredPoint → int) }

That alone doesn't tell us what to do here:

```
ColoredPoint cp = new ColoredPoint ( 3.0, 4.0, red );
Point p;
p = cp;
```

Things to support

- Inheritance, subclassing, polymorphism, overloading, abstract classes, interfaces, *etc.* create a hierarchy of derived types
- Type-checking of comparisons, method calls, assignments, *etc.* must take this programmer-defined hierarchy into account



Assignment, revisited

- We had

$$\frac{id : T \vdash E : T}{id : T \vdash id = E : T}$$

- Adding subclasses, it becomes

$$\frac{id : T \vdash E : S \quad \text{where } S <: T}{id : T \vdash id = E : T}$$

Impact on static checking

- The type of an object reference isn't known at compile time
  - That's what a class hierarchy is for, different types can step in for each other
- Overridden methods appear with multiple implementations

  and *sligthly* different call signatures
- Resolution requires some policy on how much dynamic information to account for

An example with Java

```
class Animal {
    String voice; void speak() {
        System.out.println ( voice );
    }
}
```

gives type { voice : String, speak : fun(Animal → void) }

```
class Cat extends Animal {
    String voice = “meow”;
}
```

gives type { voice : String, speak : fun(Animal → void) }

Same field name, inherited method

- Fields are statically resolved, not overridden
- Method calls are dynamically dispatched using the run-time type of the instance, and parameter list + return type

Statically resolved

```
class Animal {
      String voice;
      void speak() { println ( voice ); }
}
class Cat extends Animal {
      String voice = “meow”;
}

(new Cat()).speak();            // ← this prints “null”
// Looking at the Cat type redirects the method call to Animal.speak
```

Overridden method

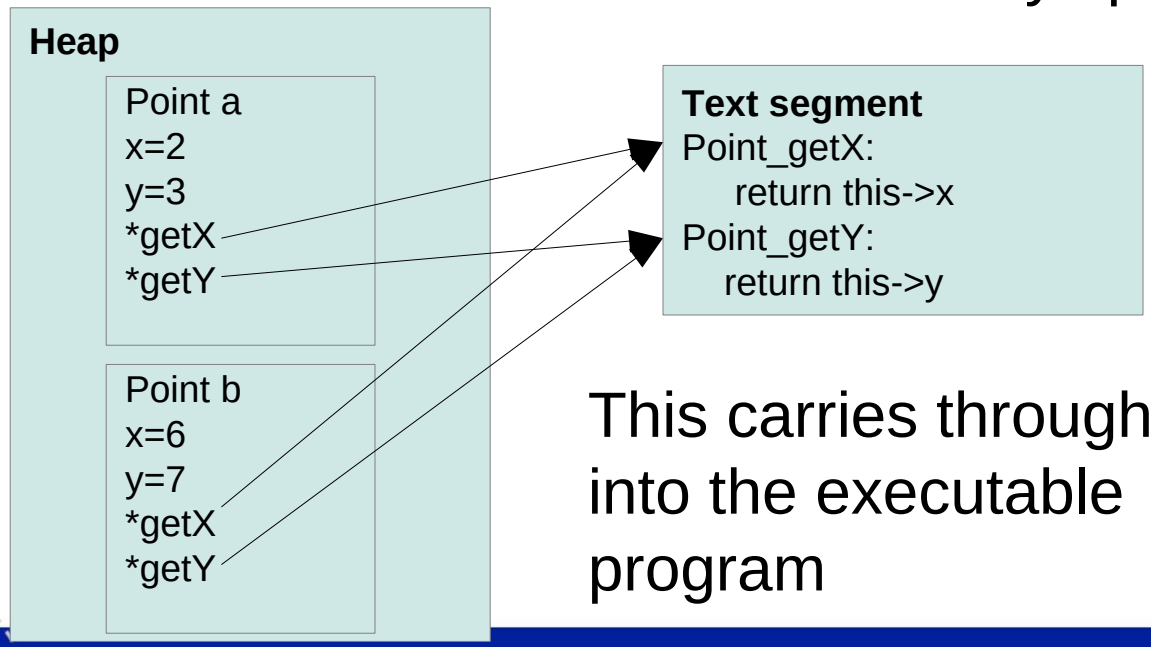
```
class Animal {
      String voice;
      void speak() { println ( voice ); }
}
class Cat extends Animal {
      String voice = “meow”;
      void speak() { println ( voice ); }
}
```

Statically resolved

```
(new Cat()).speak();            // ← this prints “meow”
// At run time, look at instance and detect that speak : fun(→void) means
// fun ( Cat→void ) instead of fun(Animal→void)
```

Objects as records

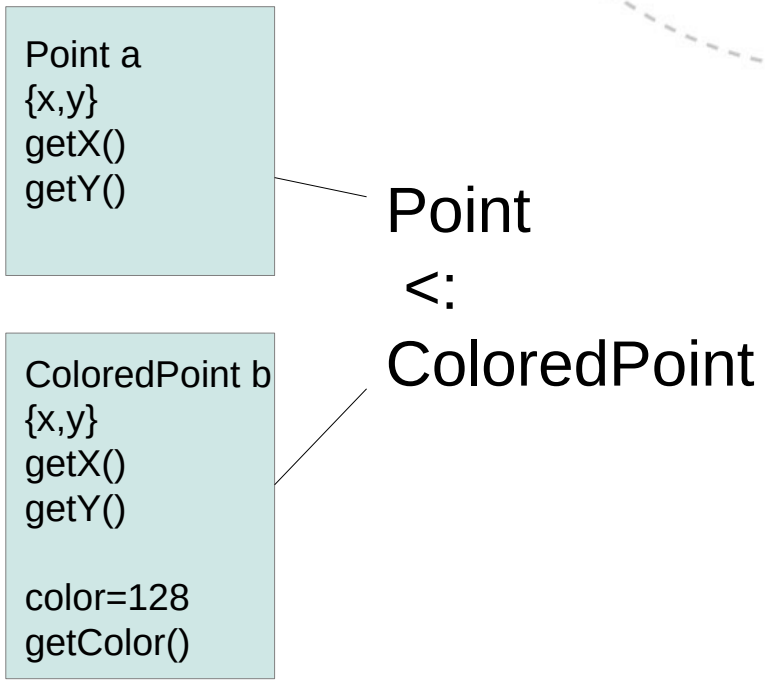
- One thing the compiler must deal with is how to lay out instances in memory
- The types of fields and methods indicate what instances must look like in a flat memory space



This carries through into the executable program

Objects as abstract data types

- Checking, say, that
  a.getX() == b.getY()
  is correctly typed
  requires a structure that
  shows how both have
  methods like that, and
  that they return comparable
  numbers



This may be discarded
after compilation
(well, depending on the language)

Summary of the week (in reverse)

- Representation of types
  - Objects make the compiler build a class hierarchy
  - Derived types make the compiler construct user-defined type descriptors
  - Basic types can be hard-coded in a predefined hierarchy
- Static type checking
  - Static type checking goes through all expressions to determine that the syntax attaches them to meaningful types
  - With an attribute grammar, it can be done during parsing
- *(Static semantics are a subset of natural semantics)*
  - *You just remove the states*

That’s a lot to take in

- m’kay, I’m almost finished prattling on about types now
- All that remains is to take one short peek at how a simple single inheritance scheme and dynamic call dispatch can map into low-level code
  - After we’ve looked closer at low-level code

Is all this really necessary?

- Erm… I know we've been skipping along the borderline of the syllabus here.
- If you know your L and S attributions and can suggest how to represent simple things in symbol tables, it'll be just fine

What was it for, then?

- Most practical languages define a far richer notion of types than just skipping around the syntax tree and seeing that there are ints and bools in the right places
- Those are what people actually use
- Starting from a vague guess at how their compilers and run-time systems work, it’s easier to make improved guesses over time
  - The ability to second-guess compilers and run-time systems is a coveted skill among software developers

Next time

- Three-address code
  - Which is an abstract cousin of assembly programming