CS412/CS413

Introduction to Compilers

Tim Teitelbaum

Lecture 15: Objects
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Records

- Objects combine features of records and abstract data types
- Records = aggregate data structures
  - Combine several variables into a higher-level structure
  - Type is essentially Cartesian product of element types
  - Need selection operator to access fields
  - Pascal records, C structures
- Example: struct {int x; float f; char a,b,c; int y } A;
  - Type: {int x; float f; char a,b,c; int y }
  - Selection: A.x = 1; n = A.y;

Objects as Records

- Objects have fields
- … in addition, they have methods = procedures that manipulate the data (fields) in the object
- Hence, objects combine data and computation

```
class List {
    int len;
    Cell head, tail;

    int length();
    List append(int d);
    int first();
    List rest();
}
```


ADTs

- Abstract Data Types (ADT): separate implementation from specification
  - Specification: provide an abstract type for data
  - Implementation: must match abstract type
- Example: linked list

implementation

```
Cell = { int data; Cell next; }
List = {int len; Cell head, tail; }

int length() { return l.len; }
int first() { return head.data; }
List rest() { return head.next; }
List append(int d) { … }
```

specification

```
int length();
List append (int d);
int first();
List rest();
```


Objects as ADTs

- Specification: public methods and fields of the object
- Implementation: Source code for a class defines the concrete type (implementation)

```
class List {
    private int len;
    private Cell head, tail;

    public static int length() {…};
    public static List append(int d) {…};
    public static int first() {…} ;
    public static List rest() {…};
}
```


Objects

- What objects are:
  - Aggregate structures that combine data (fields) with computation (methods)
  - Fields have public/private qualifiers (can model ADTs)
- Need special support in many compilation stages:
  - Type checking
  - Static analysis and optimizations
  - Implementation, run-time support
- Features:
  - inheritance, subclassing, polymorphism, subtyping, overriding, dynamic dispatch, abstract classes, interfaces, etc.

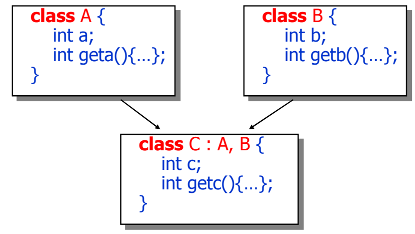
Inheritance

- Inheritance = mechanism that exposes common features of different objects
- Class B extends class A = "B has the features of A, plus some additional ones", i.e., B inherits the features of A
  – B is subclass of A; and A is superclass of B

```
class Point {
        float x, y;
        float getx(){ … };
        float gety(){ … };
}
class ColoredPoint extends Point {
        int color;
        int getcolor(){ … };
}
```


Single vs. Multiple Inheritance

- Single inheritance: inherit from at most one other object (Java)
- Multiple inheritance: may inherit from multiple objects (C++)

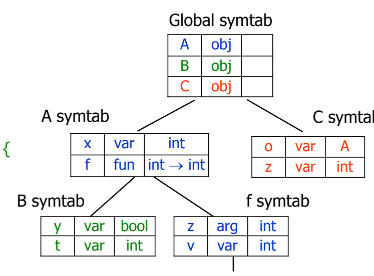


Inheritance and Scopes

- How do objects access fields and methods of:
  – Their own?
  – Their superclasses?
  – Other unrelated objects?
- Each class declaration introduces a scope
  – Contains declared fields and methods
  – Scopes of methods are sub-scopes
- Inheritance implies a hierarchy of class scopes
  – If B extends A, then scope of A is a parent scope for B

Example

```
class A {
   int x;
   int f(int z) {
      int v; …
   }
}
class B extends A {
   bool y;
   int t;
}
class C {
   A o;
   int z;
}
```



Class Scopes

- Resolve an identifier occurrence in a method:
  – Look for symbols starting with the symbol table of the current block in that method
- Resolve qualified accesses:
  – Accesses o.f, where o is an object of class A
  – Walk the symbol table hierarchy starting with the symbol table of class A and look for identifier f
  – Special keyword this refers to the current object, start with the symbol table of the enclosing class

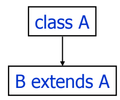
Class Scopes

- Multiple inheritance:
  – A class scope has multiple parent scopes
  – Which should we search first?
  – Problem: may find symbol in both parent scopes!
- Overriding fields:
  – Fields defined in a class and in a subclass
  – Inner declaration shadows outer declaration
  – Symbol present in multiple scopes

Inheritance and Typing

- Classes have types
  - Type is Cartesian product of field and method types
  - Type name is the class name
- What is the relation between types of parent and inherited objects?

- Subtyping: if class B extends A then
  - Type B is a subtype of A
  - Type A is a supertype B

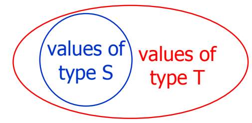


- Notation: B <: A

Subtype ≈ Subset

"A value of type S may be used wherever a value of type T is expected"

S <: T → values(S) ⊆ values(T)



Subtype Properties

- If type S is a subtype of type T (S <: T), then:
  a value of type S may be used wherever a value of type T is expected (e.g., assignment to a variable, passed as argument, returned from method)

```
Point x;
ColoredPoint y;
x = y;
```

ColoredPoint <: Point

subtype ↑ ColoredPoint, supertype ↑ Point

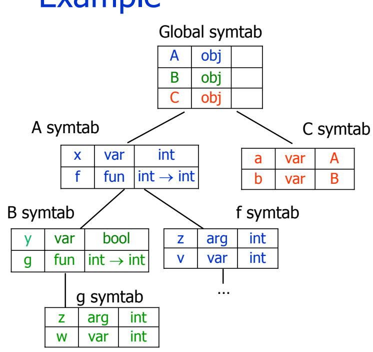
- Polymorphism: a value is usable as several types
- Subtype polymorphism: code using T's can also use S's; S objects can be used as S's or T's.

Implications of Subtyping

- We don't statically know the types of object references
  - Can be the declared class or any subclass
  - Precise types of objects known only at run-time
- Problem: overriden fields / methods
  - Declared in multiple classes in hierarchy. Don't know statically which declaration to use at compile time
  - Java solution:
    - statically resolve fields using declared type of reference; no field overriding
    - dynamically resolve methods using the object's type (dynamic dispatch); require identical signatures for all overridden methods to support static type checking

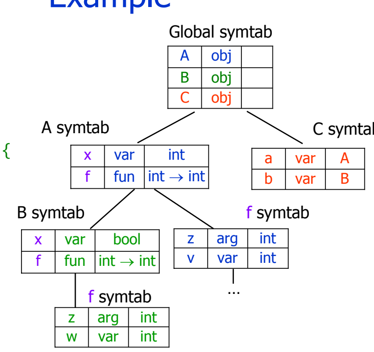
Example

```
class A {
   int x;
   int f(int z) {
     int v; …
   }
}
class B extends A {
   bool y;
   int g(int z) {
     int w; …
   }
}
class C {
   A a = new B();
   B b = new B();
   … a.x …
   … b.y …
}
```



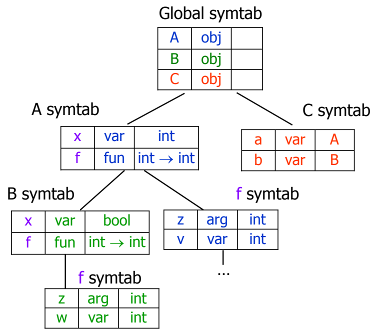
Example

```
class A {
   int x;
   int f(int z) {
     int v; …
   }
}
class B extends A {
   bool x;
   int f(int z) {
     int w; …
   }
}
class C {
   A a = new B();
   B b = new B();
   … a.x …
   … b.x …
}
```



Example

```
class A {
    int x;
    int f(int z) {
      int v; …
    }
}
class B extends A {
    bool x;
    int f(int z) {
      int w; …
    }
}
class C {
   A a = new B();
   B b = new B();
   … a.f(1) …
   … b.f(1) …
}
```



Objects and Typing

- Objects have types
  – … but also have implementation code for methods
- ADT perspective:
  – Specification = typing
  – Implementation = method code, private fields
  – Objects mix specification with implementation
- Can we separate types from implementation?

Interfaces

- Interfaces are pure types; they don't give any implementation

implementation

```
class MyList implements List {
   private int len;
   private Cell head, tail;

   public int length() {…};
   public List append(int d) {…};
   public int first() {…} ;
   public List rest() {…};
}
```

specification

```
interface List {
   int length();
   List append(int d);
   int first();
   List rest();
}
```


Multiple Implementations

- Interfaces allow multiple implementations

```
interface List {
      int length();
      List append(int);
      int first();
      List rest(); }
```

⇨

```
class SimpleList implements List {
   private int data;
   private SimpleList next;
   public int length()
      { return 1+next.length() } …
```

⇩

```
class LenList implements List {
      private int len;
      private Cell head, tail;
      private LenList() {…}
      public List append(int d) {…}
      public int length() { return len; }
      …
```


Implementations of Multiple Interfaces

```
interface A {
          int foo();
          }
interface B {
          int bar();
          }
class AB implements A, B {
          int foo(){ … }
          int bar(){ … }
          }
```


Subtyping vs. Subclassing

- Can use inheritance for interfaces
  – Build a hierarchy of interfaces

```
interface A {…}
interface B extends A {…}
```

$\boxed{B <: A}$

- Objects can implement interfaces

```
class C implements A {…}
```

$\boxed{C <: A}$

- Subtyping: interface inheritance
- Subclassing: object (class) inheritance
  – Subclassing implies subtyping

Abstract Classes

- Classes define types and some values (methods)
- Interfaces are pure object types
- Abstract classes are halfway:
  - define some methods
  - leave others unimplemented
  - no objects (instances) of abstract class

Subtypes in Java

interface I_1 **extends** I_2 { … }

class C **implements** I { … }

class C_1 **extends** C_2

I_2 | I_1

I | C

C_2 | C_1

I_1 <: I_2

C <: I

C_1 <: C_2

Subtyping Properties

- Subtype relation is reflexive: T <: T
- Transitive: R <: S and S <: T implies R <: T
- Anti-symmetric:

$$T_1 <: T_2 \ \& \ T_2 <: T_1 \Rightarrow T_1 = T_2$$

- Defines a partial ordering on types!
- Use diagrams to describe typing relations

Subtype Hierarchy

- Introduction of subtype relation creates a hierarchy of types: subtype hierarchy