CS412/CS413

Introduction to Compilers
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Lecture 15: Classes and 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;

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 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();
}
```


Objects as ADTs

- Specification: signatures of public methods and fields of 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, overloading, dynamic dispatch, abstract classes, interfaces, etc.

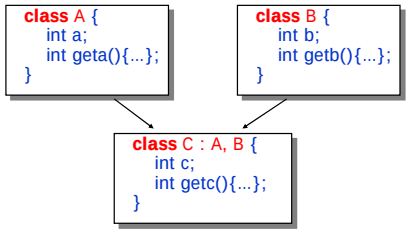
Inheritance

- 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++)

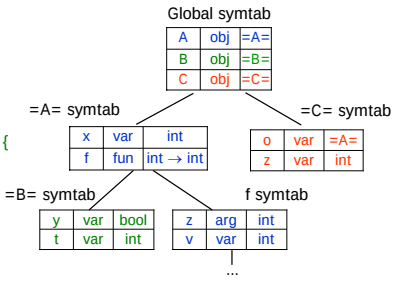


Inheritance and Scopes

- 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

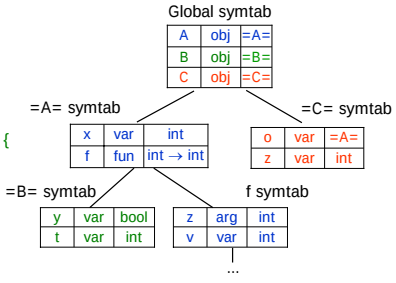
Example

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



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

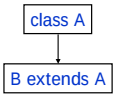
- Resolve an identifier occurrence in a method:
  - Look for symbols starting with the symbol table of the current block in that method
- Resolve qualified accesses:
  - Accesses o.f, where o is an object of class A
  - Walk the symbol table hierarchy starting with the symbol table of class A and look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

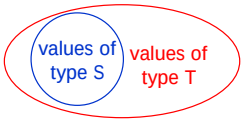
- Classes have types
  - Type is Cartesian product of field and method types
  - Type name is the class name
- What is the relation between types of parent and inherited objects?
- Subtyping: if class B extends A then
  - Type B is a subtype of A
  - Type A is a supertype B
- Notation: B <: A



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 supertype

- 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.

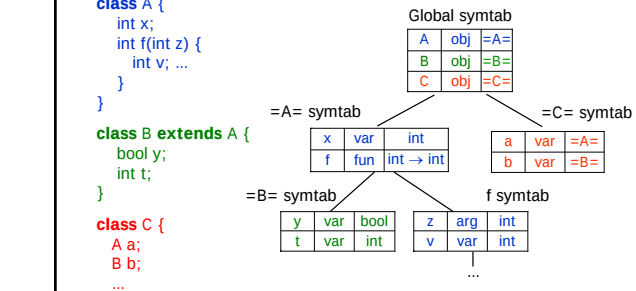
Assignment Statements (Revisited)

$$\frac{A, id{:}T \vdash E : T}{A, id{:}T \vdash id = E : T} \quad \text{(original)}$$

$$\frac{A, id{:}T \vdash E : S \quad \text{where } S<:T}{A, id{:}T \vdash id = E : T} \quad \text{(with subtyping)}$$

How To Test the SubType Relation

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



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); in support of static type checking, a method m overrides m' only if the signatures are "nearly" identical --- the same number and types of parameters, and the return type of m a subtype of the return type of m'

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 ...
}
```

Global symtab

A	obj	=A=
B	obj	=B=
C	obj	=C=

=A= symtab

x	var	int
f	fun	int → int

C symtab

a	var	=A=
b	var	=B=

=B= symtab

y	var	bool
g	fun	int → int

f symtab

z	arg	int
v	var	int

...

g symtab

z	arg	int
w	var	int

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 ...
}
```

Global symtab

A	obj	=A=
B	obj	=B=
C	obj	=C=

=A= symtab

x	var	int
f	fun	int → int

=C= symtab

a	var	=A=
b	var	=B=

=B= symtab

x	var	bool
f	fun	int → int

f symtab

z	arg	int
v	var	int

...

f symtab

z	arg	int
w	var	int

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) ...
}
```

Global symtab

A	obj	=A=
B	obj	=B=
C	obj	=C=

=A= symtab

x	var	int
f	fun	int → int

=C= symtab

a	var	=A=
b	var	=B=

=B= symtab

x	var	bool
f	fun	int → int

f symtab

z	arg	int
v	var	int

...

f symtab

z	arg	int
w	var	int

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 {...}
```

B <: A

- Objects can implement interfaces

```
class C implements A {...}
```

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	C_2
|	|	|
I_1	C	C_1
I_1 <: I_2	C <: I	C_1 <: C_2

Subtype Hierarchy

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