# CMSC 330: Organization of Programming Languages

Polymorphism

## Polymorphism

- Definition
  - Feature that allows values of different data types to be handled using a uniform interface
- Applicable to
  - Functions
    - Same function applied to different data types
    - Example

```
let id = function x -> x
```

  - Data types
    - Same data type can contain different data types
    - Example

```
type 'a option =
   None
 | Some of 'a
```



## Two Kinds of Polymorphism

- Described by Strachey in 1967
- Ad hoc and Subtype polymorphism
  - Range of types is finite
  - Combinations must be specified in advance
  - Behavior may differ based on type of arguments
- Parametric polymorphism
  - Code written without mention of specific type
  - May be transparently used with arbitrary # of types
  - Behavior is same for different types of arguments



## Polymorphism Overview

- Subtype (for OO languages)
  - Sometimes considered ad-hoc
- Ad-hoc
  - Overloading
    - Operator overloading
    - Method name overloading
- Parametric
  - ML types
  - A.k.a. generic programming (for OO languages)
    - Bounded parametric polymorphism combines subtype and parametric polymorphism

## Subtype Polymorphism

- Any context expecting an object of type A can be given an object of type B where B is a subtype of A
  - Example: Function parameter has type A
  - So it may be called with arguments of type B
- Subtyping enabled by inheritance

```
class A { … }
class B extends A { … } // subclass
static void f(A arg) { … }
A a = new A();
B b = new B();
f(a); f(b); // f accepts arg of type A or B
```



## Subtype Polymorphism

- More generally, B is a subtype of A if it can "do" everything A can
  - Has the "same" fields, methods
- Java interfaces also support subtyping

```
interface A { … }
class B implements A { … }
class C implements A { … }
static void f(A arg) { … }
B b = new B();
C c = new C();
f(b); f(c); // f accepts arg of type B or C
```



## When can we extend or implement?

- When can A extend B?
  - Complicated!
  - Roughly: When it overrides methods such that the overriding types are subtypes of original
    - Otherwise, the methods of the same name will simply be overloaded; discussed later
- When can A implement B?
  - When it has methods whose types are the same as those required by the interface



## Overloading

- Multiple copies of function
  - Same function name
  - But different number / type of parameters
- Arguments determine function actually invoked
  - Function is uniquely identified not by function name, but by name + order & number of argument type(s)
    - print(Integer i)→ print_Integer(…)
    - print(Float f) → print_Float(…)

```
static void print(Integer arg) { … }
static void print(Float arg)   { … }
print(1);        // invokes 1st print
print(3.14);     // invokes 2nd print
```

## Overloading and Overriding

- Interaction is confusing
  - Common mistake is inadvertently overload when you mean to override

```
public class Point {
  private int x = 0, y = 0;
  public boolean equals(Point p) { //overloads
    return (p.x == x) && (p.y == y);
  }
  public static void main(String args[]) {
    Point p1 = new Point();
    Point p2 = new Point();
    Object o = p1;
    System.out.println(o.equals(p2)); //prints false
    System.out.println(p1.equals(p2)); //prints true
  }
}
```



## Operator Overloading

- Treat operators as functions
  - With special syntax for invocations
  - Behavior different depending on operand type
- Example
  - + in Java

```
    1 + 2            // integer addition
  1.0 + 3.14         // float addition
"Hello" + "world"    // string concatenation
```



## Operator Overloading (cont.)

- User-specified operator overloading
  - Supported in languages such as Ruby, C++
    - Works using standard dynamic dispatch
- Examples
  - Defining function for ^ operator

```
class MyS
  def ^ (arg)
    ...
  end
end
```

Ruby

```
class MyS {
  MyS operator^(MyS arg){
    ...
  }
}
```

C++



## Parametric Polymorphism

- Found in statically typed functional languages
  - OCaml, ML, Haskell
  - Example

```
let hd = function (h::_) -> h
```

'a list -> 'a

- Also used in object oriented programming
  - Known as generic programming
  - Example: Java, C++

## An Integer Stack Implementation

```
class Stack {
  class Entry {
    Integer elt; Entry next;
    Entry(Integer i, Entry n) { elt = i; next = n; }
  }
  Entry theStack;
  void push(Integer i) {
    theStack = new Entry(i, theStack);
  }
  Integer pop() throws EmptyStackException {
    if (theStack == null)
      throw new EmptyStackException();
    else {
      Integer i = theStack.elt;
      theStack = theStack.next;
      return i;
}}}
```



## Integer Stack Client

```
Stack is = new Stack();
Integer i;
is.push(new Integer(3));
is.push(new Integer(4));
i = is.pop();
```

If we also want a stack of Floats, do we need to write a Float Stack class?



## An Object Stack Implementation

```
class Stack {
  class Entry {
    Object elt; Entry next;
    Entry(Object i, Entry n) { elt = i; next = n; }
  }
  Entry theStack;
  void push(Object i) {
    theStack = new Entry(i, theStack);
  }
  Object pop() throws EmptyStackException {
    if (theStack == null)
      throw new EmptyStackException();
    else {
      Object i = theStack.elt;
      theStack = theStack.next;
      return i;
}}}
```



## New Stack Client

```
Stack is = new Stack();
Integer i;
is.push(new Integer(3));
is.push(new Integer(4));
i = (Integer) is.pop();
```

- Object stacks are polymorphic & reusable
  - push() works the same
  - But now pop() returns an Object
    - Have to downcast back to Integer
      - Not checked until run-time

## General Problem

- When we move from an X container to an Object container
  - Methods that take X's as input parameters are OK
    - If you're allowed to pass Object in, you can pass any X in
  - Methods that return X's as results require downcasts
    - You only get Objects out, which you need to cast down to X
- General characteristic of subtype polymorphism



## Parametric Polymorphism (for Classes)

- Java 1.5 introduced generics
- We can parameterize the Stack class by its element type
- Syntax
  - Class declaration: class A<T> { ... }
    - A is the class name, as before
    - T is a *type variable*, can be used in body of class (...)
  - Client usage declaration: A<Integer> x;
    - We *instantiate* A with the Integer type



## Parametric Polymorphism for Stack

```
class Stack<ElementType> {
  class Entry {
    ElementType elt; Entry next;
    Entry(ElementType i, Entry n) { elt = i; next =
   n; }
  }
  Entry theStack;
  void push(ElementType i) {
    theStack = new Entry(i, theStack);
  }
  ElementType pop() throws EmptyStackException {
    if (theStack == null)
      throw new EmptyStackException();
    else {
      ElementType i = theStack.elt;
      theStack = theStack.next;
      return i;
  }}}
```



## Stack<Element> Client

```
Stack<Integer> is = new Stack<Integer>();
Integer i;
is.push(new Integer(3));
is.push(new Integer(4));
i = is.pop();
```

- No downcasts
- Type-checked at compile time
- No need to duplicate Stack code for every usage
  - line i = is.pop(); can stay the same even if the type of is isn't an integer in every path through the program

## Parametric Polymorphism for Methods

- String is a subtype of Object
  1. static Object id(Object x) { return x; }
  2. static Object id(String x) { return x; }
  3. static String id(Object x) { return x; }
  4. static String id(String x) { return x; }

- Can't pass an Object to 2 or 4
- 3 doesn't type check
- Can pass a String to 1 but you get an Object back



## Parametric Polymorphism, Again

- But id() doesn't care about the type of x
  - It works for any type

- So parameterize the static method

  static <T> T id(T x) { return x; }

  Integer i = id(new Integer(3));

  - Notice no need to instantiate id; compiler figures out the correct type at usage
  - The formal parameter has type T, the actual parameter has type Integer



## Standard Library, and Java 1.5 (and later)

- Part of Java 1.5 (called "generics")
  - Comes with replacement for java.util.*
    - class LinkedList<A> { ...}
    - class HashMap<A, B> { ... }
    - interface Collection<A> { ... }
  - Excellent tutorial listed on references page

- But they didn't change the JVM to add generics
  - How was that done?



## Translation via Erasure

- Replace uses of type variables with Object
  - class A<T> { ...T x;... } becomes
  - class A { ...Object x;... }
- Add downcasts wherever necessary
  - Integer x = A<Integer>.get(); becomes
  - Integer x = (Integer) (A.get());
- So why did we bother with generics if they're just going to be removed?
  - Because the compiler still did type checking for us
  - We know that those casts will not fail at run time

## Limitations of Translation

- Some type information not available at compile-time
  - Recall type variables T are rewritten to Object
- Disallowed, assuming T is type variable
  - new T() would translate to new Object() (error)
  - new T[n] would translate to new Object[n] (warning)
  - Some casts/instanceofs that use T
    - Only ones the compiler can figure out are allowed



## Using with Legacy Code

- Translation via type erasure
  - class A <T> becomes class A
- Thus class A is available as a "raw type"
  - class A<T> { ... }
  - class B { A x; } // use A as raw type
- Sometimes useful with legacy code, but...
  - Dangerous feature to use, plus unsafe
  - Relies on implementation of generics, not semantics



## Subtyping and Arrays

- Java has one funny subtyping feature
  - If S is a subtype of T, then
  - S[ ] is a subtype of T[ ]
- Let's write methods that take arbitrary arrays

```
public static void reverseArray(Object [] A) {
  for(int i=0, j=A.length-1; i<j; i++,j--) {
    Object tmp = A[i];
    A[i] = A[j];
    A[j] = tmp;
  }
}
```



## Problem with Subtyping Arrays

```
public class A { ... }
public class B extends A { void newMethod(); }
...
  void foo(void) {
     B[] bs = new B[3];
     A[] as;

     as = bs;             // Since B[] subtype of A[]
     as[0] = new A();     // (1)
     bs[0].newMethod();   // (2) Fails since not type B
  }
```

- Program compiles without warning
- Java must generate run-time check at (1) to prevent (2)
  - Type written to array must be subtype of array contents

## Subtyping for Generics

- Is Stack<Integer> a subtype of Stack<Object>?
  - We could have the same problem as with arrays
  - Thus Java forbids this subtyping
- Now consider the following method:

```
int count(Collection<Object> c) {
  int j = 0;
  for (Iterator<Object> i = c.iterator(); i.hasNext(); ) {
    Object e = i.next(); j++;
  }
  return j;
}
```

  - Not allowed to call count(x) where x has type Stack<Integer>



## Solution I: Use Polymorphic Methods

```
<T> int count(Collection<T> c) {
 int j = 0;
 for (Iterator<T> i = c.iterator(); i.hasNext(); ) {
   T e = i.next(); j++;
 }
 return j;}
```

- But requires a “dummy” type variable that isn’t really used for anything



## Solution II: Wildcards

- Use ? as the type variable
  - Collection<?> is “Collection of unknown”

```
int count(Collection<?> c) {
  int j = 0;
  for (Iterator<?> i = c.iterator(); i.hasNext(); ) {
    Object e = i.next(); j++;
  }
  return j; }
```

- Why is this safe?
  - Using ? is a contract that you’ll never rely on having a particular parameter type
  - All objects subtype of Object, so assignment to e ok



## Legal Wildcard Usage

- Reasonable question:
  - Stack<Integer> is not a subtype of Stack<Object>
  - Why is Stack<Integer> a subtype of Collection<?>?
- Answer:
  - Wildcards permit “reading” but not “writing”

## Example: Can Read But Cannot Write c

```
int count(Collection<?> c) {
  int j = 0;
  for (Iterator<?> i = c.iterator(); i.hasNext(); ) {
    Object e = i.next();
    c.add(e); // fails: Object is not ?
    j++;
  }
  return j; }
```



## For Loops

- Java 1.5 has a more convenient syntax for this standard for loop

```
int count(Collection<?> c) {
  int j = 0;
  for (Object e : c)
    j++;
  return j;
}
```

  - This loop will get the standard iterate and set e to each element of the list, in order



## More on Generic Classes

- Suppose we have classes Circle, Square, and Rectangle, all subtypes of Shape

```
void drawAll(Collection<Shape> c) {
  for (Shape s : c)
    s.draw();
}
```

  - Can we pass this method a Collection<Square>?
    - No, not a subtype of Collection<Shape>
  - How about the following?

```
void drawAll(Collection<?> c) {
  for (Shape s : c)   // not allowed,
    s.draw();         assumes ? is
}                     Shape
```



## Bounded Wildcards

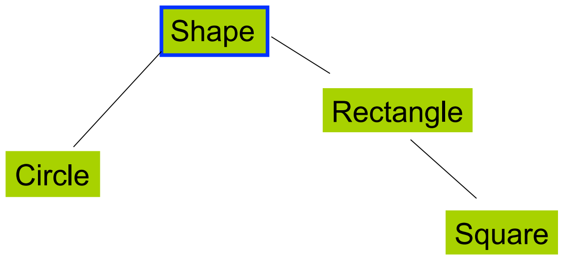
- We want drawAll to take a Collection of anything that is a subtype of shape
  - this includes Shape itself

```
void drawAll(Collection<? extends Shape> c) {
  for (Shape s : c)
    s.draw();
}
```

  - This is a bounded wildcard
  - We can pass Collection<Circle>
  - We can safely treat s as a Shape

## Upper Bounded Wild Cards

- ? extends Shape actually gives an upper bound on the type accepted
- Shape is the upper bound of the wildcard






## Bounded Wildcards (cont.)

- Should the following be allowed?

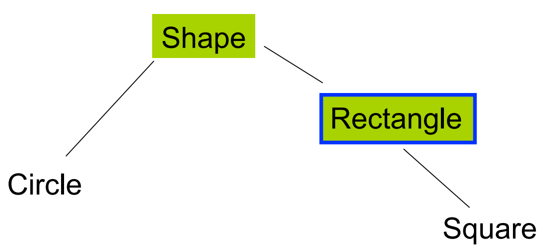
```
void foo(Collection<? extends Shape> c) {
  c.add(new Circle());
}
```

  - No, because c might be a Collection of something that is not compatible with Circle
  - This code is forbidden at compile time



## Lower Bounded Wildcards

- Dual of the upper bounded wildcards
- ? super Rectangle denotes a type that is a supertype of Rectangle
  - Type Rectangle is included
  - Gives a lower bound on the type accepted






## Lower Bounded Wildcards (cont.)

- Now the following is allowed

```
void foo(Collection<? super Circle> c) {
  c.add(new Circle());
  c.add(new Rectangle()); // fails
}
```

  - Because c is a Collection of something that is always compatible with Circle

# Bounded Type Variables

- You can also add bounds to regular type vars

```
<T extends Shape> T getAndDrawShape(List<T> c) {
  c.get(1).draw();
  return c.get(2);
}
```

  - This method can take a List of any subclass of Shape
    - This addresses some of the reason that we decided to introduce wild cards
    - Once again, this only works for methods