CMSC 330: Organization of Programming Languages

Java and Java Generics

Java

- Developed in 1995 by Sun Microsystems
  - Started off as Oak, a language aimed at software for consumer electronics
  - Then the web came along...
- Java incorporated into web browsers
  - Java source code compiled into Java byte code
  - Executed (interpreted) on Java Virtual Machine
    - Portability to different platforms
    - Safety and security much easier, because code is not directly executing on hardware
- These days, Java used for a lot of purposes
  - Server side programming, general platform, etc.

Java Versions

- Java has evolved over the years
  - Virtual machine quite stable, but source language has been getting new features
- Will use the latest version of Java for this class
  - If you've got an older version, you might want to upgrade

Subtyping

- Both inheritance and interfaces allow one class to be used where another is specified
  - This is really the same idea: subtyping
- We say that A is a *subtype* of B if
  - A extends B or a subtype of B, or
  - A implements B or a subtype of B

Liskov Substitution Principle

If for each object *o1 of type S there is an object o2 of type T such that for all programs P defined in terms of T, the behavior of P is unchanged when o1 is substituted for o2 then S is a subtype of T.*

- I.e, if anyone expecting a T can be given an S, then S is a subtype of T.
- Does our definition of subtyping in terms of extends and implements obey this principle?

Polymorphism

- Subtyping is a kind of polymorphism
  - Sometimes called *subtype polymorphism*
  - Allows method to accept objects of *many* types
- We saw *parametric polymorphism* in OCaml
  - It's polymorphism because polymorphic functions can be applied to many different types
- *Ad-hoc polymorphism* is overloading
  - Operator overloading in C++
  - Method overloading in Java

Polymorphism Using Object

```
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;
  }}}
```


Stack Client

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

- Now Stacks are 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

- This is a general feature of *subtype* polymorphism

Parametric Polymorphism (for Classes)

- In Java 1.5 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

- 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?

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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

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Limitations of Translation

- Some type information not available at run-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)
- Also produces some oddities
  - LinkedList<Integer>.class == LinkedList<String>.class
    - (These are uses of reflection to get the class object)

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[]
- Lets us 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 Stack<?>?
- Answer:
  - Wildcards permit “reading” but not “writing”

Example: Can read but cannot write

```
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

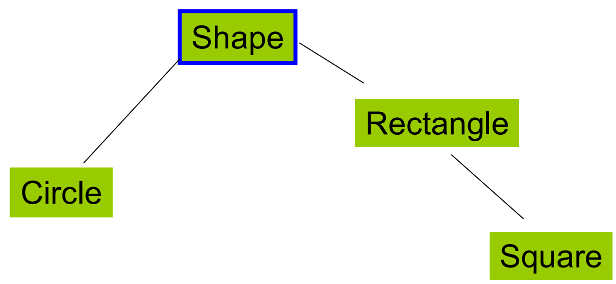
- We want drawAll to take a Collection of anything that is a *subtype* of shape
  – this includes Shape itself

```
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 e 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'd)

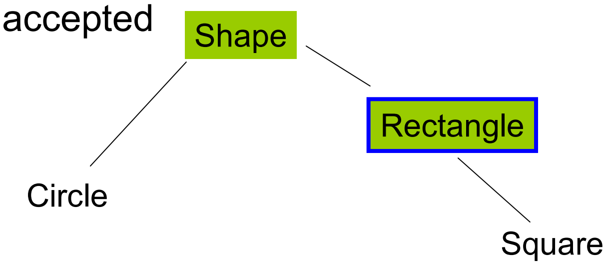
- Should the following be allowed?

```
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
  - T is included
- ? super Rectangle gives a lower bound on the type accepted



Lower Bounded Wildcards (cont'd)

- But the following is allowed:

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

A more realistic example

```
public interface Comparable<T> {
  int compareTo(T o);
}
// e.g., Boolean implements Comparable<Boolean>
public static <T extends Comparable<? super T>>
  void sort(List<T> list) {
    Object a[] = list.toArray();
    Arrays.sort(a);
    ListIterator<T> i = list.listIterator();
    for(int j=0; j<a.length; j++) {
       i.nextIndex();
       i.set((T)a[j]);
    }
  }
```

- I'm modifying the list via the Iterator. Why is this OK?