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

  - 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 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

- Ad-hoc
  - Subtype (for OO languages)
    - Sometimes not considered ad-hoc, but referred to as **subtype polymorphism**
  - Overloading
    - Operator overloading
- Parametric
  - ML types
  - A.k.a. generic programming (for OO languages)
    - **Bounded parametric polymorphism** combines subtype and parametric polymorphism

Subtype Polymorphism

- Found in object-oriented programming languages
  - Supported through inheritance
- Any function w/ object as parameter is polymorphic
  - If formal parameter is of class A
  - Argument may be any object from subclass of A

```
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
```


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.
  - Note this speaks not just to the **types** of methods, but their overall **behavior**. At *least* the types must match

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
```


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
```


User-defined operators

- Supported in languages such as Ruby, C++
  - Makes user data types appear more like native types
  - Not overloading; rather, non-alphabetic method names
- Examples
  - Defining function for ^ operator
    - o ^ p is really just o.^(p)

```
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

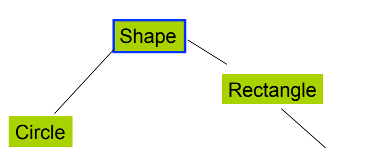
- We want drawAll to take a Collection of anything that is a subtype of shape
  - this includes Shape itself

```
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.)

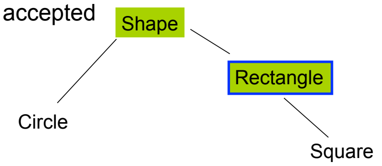
- Should the following be allowed?

```
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
  - T is included
- ? super Rectangle 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