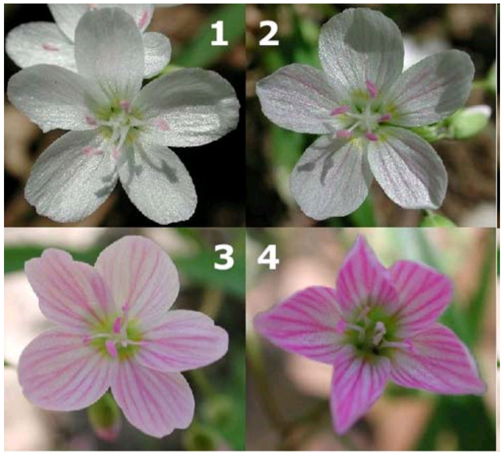
CMSC330

Polymorphism

Polymorphism



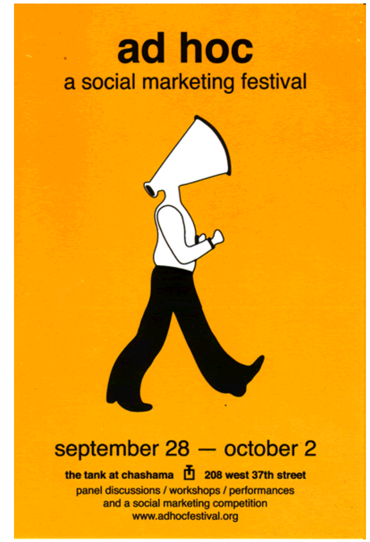
- Definition
  - Feature that allows values of different data types to be handled using a uniform interface
- Applicable to
  - Functions
    - Same function applied to different data types
    - Example

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

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

```
type optional_int =
    None
  | Some of int
```

Two Kinds of Polymorphism



- Ad hoc parallelism
  - Range of types is finite
  - Combinations must be specified in advance
  - Behavior may differ based on type of arguments
- Parametric parallelism
  - 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)
  - Overloading
    - Operator overloading

- Parametric
  - Generic programming (for OO languages)
    - Bounded parametric parallelism

Subtype Polymorphism

- Found in object-oriented programming languages
  - Supported through inheritance
- Any function with an 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
```

Overloading

- Multiple copies of function
  - Same function name
  - But different number / type of parameters
- Arguments determines 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
```

Operator Overloading (cont.)

- User-specified operator overloading
  - Supported in languages such as Ruby, C++
  - Makes user data types appear more like native types
- Examples
  - Defining function for ^ operator

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

Ruby

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

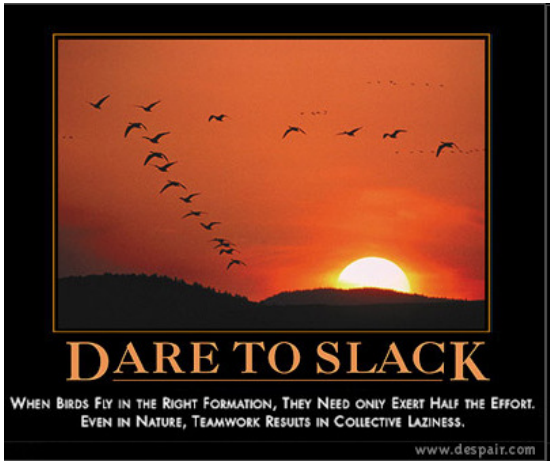
C++

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;
  }}}
```

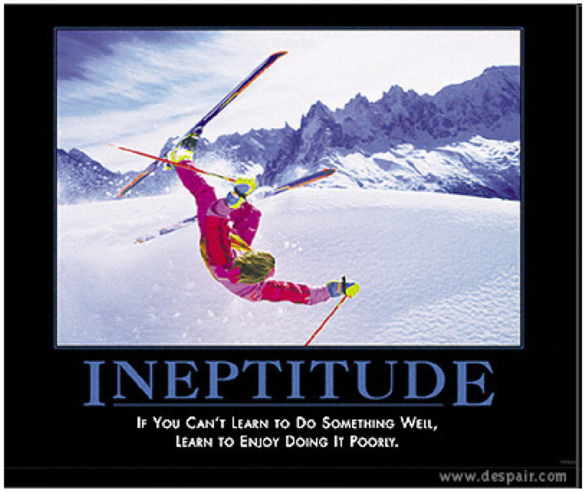
New Stack Client

```
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 feature 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

Parametric Polymorphism for Methods

- **`String`** is a subtype of **`Object`**

```
1.static Object function(Object x){ return x; }
2.static Object function (String x){ return x; }
3.static String  function (Object x){ return x; }
4.static String  function (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 `function()` doesn't care about the type of `x`
  - It works for any type
- So parameterize the static method

```
static <T> T function(T x) { return x; }
Integer i = function(new Integer(3));
```

  - Notice no need to instantiate `function`; 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)

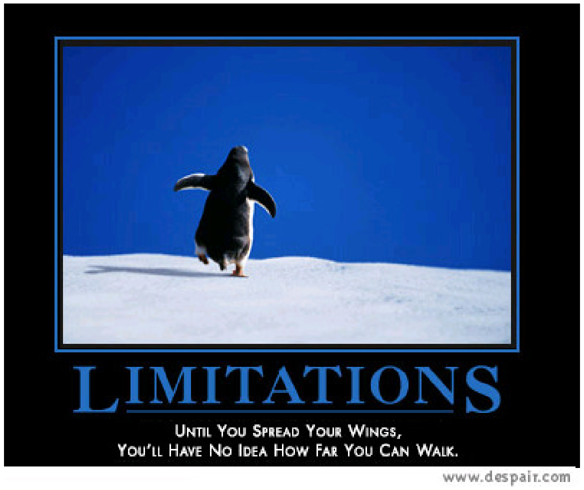
- Part of Java 1.5 (called “generics”)
  - Comes with replacement for java.util.*
    - `class LinkedList<A> { ...}`
    - `class HashMap<A, B> { ... }`
    - `interface Collection<A> { ... }`
  - Excellent tutorial listed on references page

- 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/`instanceof`s that use `T`
    - Only ones the compiler can figure out are allowed

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)
    s.draw();
}
```

Bounded Wildcards

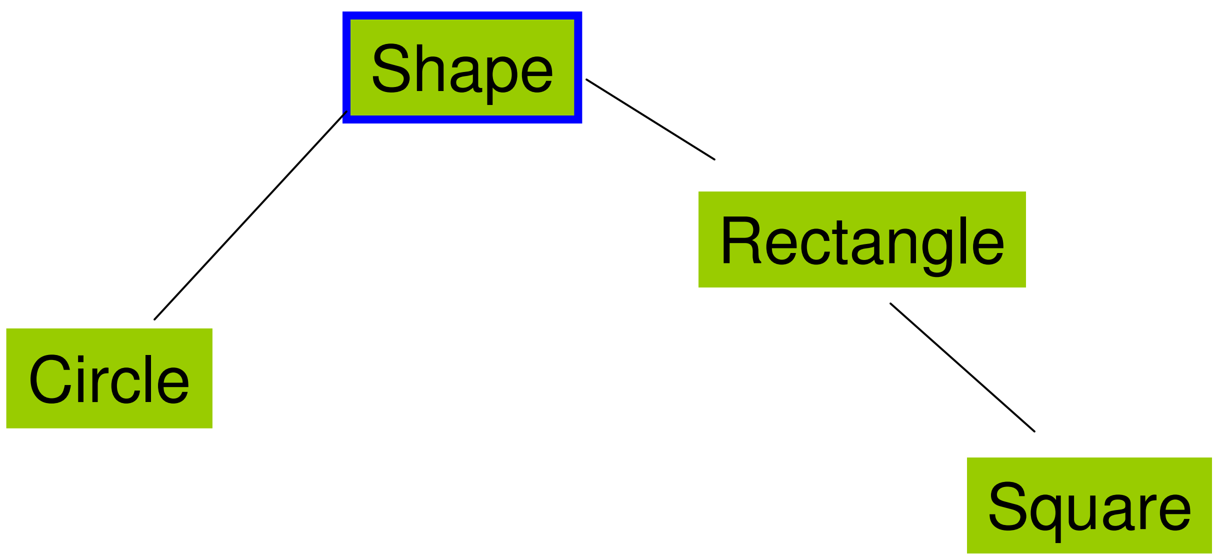
- We want `drawAll` to take a `Collection` of anything that is a subtype of `Shape`
  - this includes `Shape` itself

```
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.)

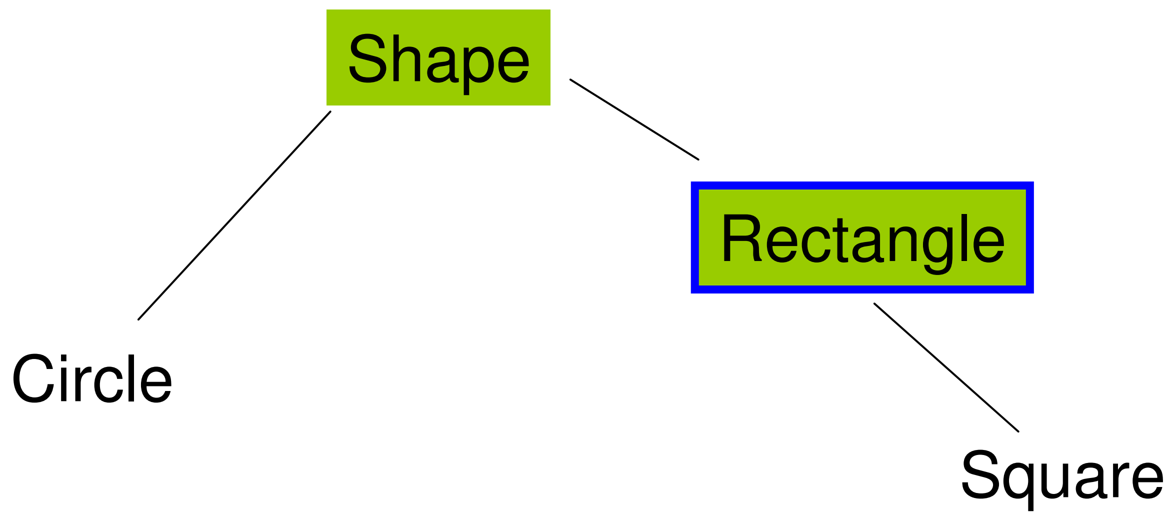
- Should the following be allowed?

```
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`
- `? 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

Done for today

- Quiz tomorrow
  - Ocaml
- Midterm next Wednesday
  - Everything from Ocaml through Objects/functional programming (Monday’s lecture)
- Project 4 due next Friday