CSE 331
SOFTWARE DESIGN & IMPLEMENTATION
GENERICS/PARAMETRIC POLYMORPHISM

Autumn 2011

Why?

- Hide details
  - Avoid distraction
  - Permit the details to change later
- Give a meaningful name to a concept
- Permit reuse in new contexts
  - Avoid duplication: error-prone, confusing
  - Programmers hate to repeat themselves – "lazy"

Varieties of abstraction

- Abstraction over computation: procedures
  - `int x1, y1, x2, y2;`
  - `Math.sqrt(x1*x1 + y1*y1);`
  - `Math.sqrt(x2*x2 + y2*y2);`
- Abstraction over data: ADTs (classes, interfaces)
  - `Point p1, p2;`
- Abstraction over types: polymorphism (generics)
  - `Point<Integer>, Point<Double>`
  - Applies to both computation and data

Parametric polymorphism

- Ability to write a function or type so that it handles values identically without depending on knowledge of their types
- These are generic functions or generic data types – they take a type as a parameter
  - That is, they allow for substitutability of types under some conditions
  - First introduced in ML language in 1976, although the concept has been around since (at least) LISP
  - Now part of many other languages (Haskell, Java C#, Delphi)
  - C++ templates are similar but lack various features/flexibility
- Parametric polymorphism allows you to write flexible, general code without sacrificing type safety
  - Most commonly used in Java with collections
  - Also used in reflection (seen later)

Type Parameters (Generics)

- `List<Type> name = new ArrayList<Type>();`
- Since Java 1.5, a constructor of `java.util.ArrayList` can (and almost always does) specify the type of elements it will contain
  - The type that is passed is called the *type parameter*

```
List<String> names = new ArrayList<String>();
names.add("Krysta");
names.add("Emily");
String ta = names.get(0); // good element type
Point oops = (Point) names.get(1); // error --
                                   // need String
                                   // not Point
```

- Use of the "raw type" `ArrayList` (with no type is passed) leads to warnings (which can be controlled by options in Eclipse or on the command line)

Programs include a group of abstractions

```
interface ListOfNumbers {
  boolean add(Number elt);
  Number get(int index);
}
interface ListOfIntegers {
  boolean add(Integer elt);
  Integer get(int index);
}
```

… and many, many more

```
interface List<E> {
  boolean add(E n);
  E get(int index);
}
```

Declares a new **variable**, called a **formal parameter**

Instantiate by passing an `Integer`: `l.add(7); myList.add(myInt);`

The type of `add` is Integer → boolean

Declares a new **type variable**, called a **type parameter**

Instantiate by passing a type: `List<Float>` `List<List<String>>` `List<T>`

The type of `List` is Type → Type

Declaring and instantiating generics

```
// a parameterized (generic) class
public class name<Type> {
  or
public class name<Type, Type, ..., Type> {
```

- Putting the **Type** in **< >** states that any client that constructs your object must supply one or more type parameters
  - Just like a "regular" method's parameters state that any client invoking it must supply objects of the proper type
- It is essentially a constructor for the generic class
- The rest of the class's code refers to that type by name
  - The convention is to use a 1-letter name such as **T** for **Type**, **E** for **Element**, **N** for **Number**, **K** for **Key**, **V** for **Value**, or **M** for **Murder**
- The type parameter is instantiated by the client. (e.g. **E** → **String**), essentially invoking the generic class constructor

Using type variables

- Implementation code of the generic class can perform any operation permitted by the type variable

```
interface MyList1<E extends Object> {
  void m(E arg) {
    arg.asInt();       // compiler error, E might not
                       // support asInt
  }
}

interface MyList2<E extends Number> {
  void m(E arg) {
    arg.asInt();  // OK, since Number and its
                  // subtypes support asInt
  }
}
```

Invocations by clients are restricted

```
boolean add1(Object elt);
boolean add2(Number elt);
add1(new Date());  // OK
add2(new Date());  // compile-time error

interface MyList1<E extends Object> {…}
interface MyList2<E extends Number> {…}
MyList1<Date>      // OK, Date is a subtype
                   // of Object
MyList2<Date>      // compile-time error,
                   // Date is not a subtype
                   // of Number
```

Type variables are types

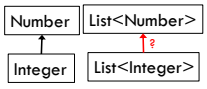
```
class MySet<T> implements Set<T> {
  // rep invariant:
  //   non-null, contains no duplicates
  List<T> theRep;
}
```

Declaration

Use

Generics and subtyping

- **Integer** is a subtype of **Number**
- Is **List<Integer>** a subtype of **List<Number>**?
- Use subtyping rules (stronger, weaker) to find out



List<Number> and List<Integer>

```
interface List<Number> {
  boolean add(Number elt);
  Number get(int index);
}
interface List<Integer> {
  boolean add(Integer elt);
  Integer get(int index);
}
```

- Java subtyping is covariant (less tolerant) with respect to generics

But covariant subtyping is restrictive

```
interface Set<E> {
  // Adds all of the elements in c to this set
  // if they're not already present (optional operation)
  void addAll(Set<E> c);
}

interface Set<E> {
  void addAll(Collection<E> c);
}

interface Set<E> {
  void addAll(Collection<? extends E> c);
}
```

A "Collection of unknown"type that extends E

Problem 1:

```
Set<Number> s;
List<Number> l;
s.addAll(l);
```

Problem 2:

```
Set<Number> s;
List<Integer> l;
s.addAll(l);
```

Using wildcards

```
class HashSet<E> implements Set<E> {
  void addAll(Collection<? extends E> c) {
    // What can this code assume about c?
    // What operations can this code invoke on c?
    ...
  }
}
```

- Wildcards are written at declarations, not uses
  - The use defines the ? as a parameter when it the type is instantiated
- A missing **`extends`** clause means **`extends Object`**

Wildcards

- ? indicates a wild-card type parameter, one that can be any type
  `List<?> list = new List<?>(); // anything`
- Difference between `List<?>` and `List<Object>`
  - `?` can become any particular type; `Object` is just one such type
  - `List<Object>` is restrictive; wouldn't take a `List<String>`
- Difference between `List<Foo>` and `List<? extends Foo>`
  - The latter binds to a particular `Foo` subtype and allows ONLY that
    - Ex: `List<? extends Animal>` might store only `Giraffes` but not `Zebras`
  - The former allows anything that is a subtype of `Foo` in the same list
    - Ex: `List<Animal>` could store both `Giraffes` and `Zebras`

Another example

```
public class Graph<N> implements Iterable<N> {
  private final Map<N, Set<N>> node2neighbors;
  public Graph(Set<N> nodes, Set<Tuple<N,N>> edges) {
    ...
  }
}

public interface Path<N, P extends Path<N,P>>
  extends Iterable<N>, Comparable<Path<?, ?>> {
  public Iterator<N> iterator();
}
```

Bounded type parameters

- **`<Type extends SuperType>`**
  An upper bound; accepts the given supertype or any of its subtypes
  Works for multiple superclass/interfaces with **`&`**
  `<Type extends ClassA & InterfaceB & InterfaceC & ...>`
- **`<Type super SuperType>`**
  - A lower bound; accepts the given supertype or any of its supertypes
- Example

```
// tree set works for any comparable type
public class TreeSet<T extends Comparable<T>> {
    ...
}
```

Complex bounded types

- **`public static <T extends Comparable<T>>`**
  `T max(Collection<T> c)`
  - Find max value in any collection (if the elements can be compared)
- **`public static <T> void copy(`**
  `List<T2 super T> dst, List<T3 extends T> src)`
  - Copy all elements from **`src`** to **`dst`**
  - **`dst`** must be able to safely store anything that could be in **`src`**
  - This means that all elements of **`src`** must be of **`dst`**'s element type or a subtype
- **`public static <T extends Comparable<T2 super T>>`**
  `void sort(List<T> list)`
  - Sort any list whose elements can be compared to the same type or a broader type

Reminder: what's the point?

- To decrease the chance that programmers make mistakes about types during execution
- More complicated declarations and instantiations, along with added compile-time checking is the cost
- Generics usually clarify the implementation
  - sometimes ugly: wildcards, arrays, instantiation
- Generics always make the client code prettier and safer

```
interface Map {
  Object put(Object key, Object value);
  equals(Object other);
}

interface Map<Key,Value> {
  Value put(Key key, Value value);
  equals(Object other);
}
```


Example: a generic interface

```
// Represents a list of values
public interface List<E> {
    public void add(E value);
    public void add(int index, E value);
    public E get(int index);
    public int indexOf(E value);
    public boolean isEmpty();
    public void remove(int index);
    public void set(int index, E value);
    public int size();
}

public class ArrayList<E> implements List<E> { ...

public class LinkedList<E> implements List<E> { ...
```

Generic methods

```
public static <Type> returnType name(params) {
```

- When you want to make just a single (often static) method generic in a class, precede its return type by type parameter(s)

```
public class Collections {
  ...
  public static <T> void copy(List<T> dst, List<T> src) {
    for (T t : src) {
      dst.add(t);
    }
  }
}
```

Type erasure

- All generic types become type **`Object`** once compiled
  - One reason: backward compatibility with old byte code
  - So, at runtime, all generic instantiations have the same type

```
List<String>  lst1 = new ArrayList<String>();
List<Integer> lst2 = new ArrayList<Integer>();
lst1.getClass() == lst2.getClass()  // true
```

- You cannot use **`instanceof`** to discover a type parameter

```
Collection<?> cs = new ArrayList<String>();
if (cs instanceof Collection<String>) {
  // illegal
}
```

Generics and casting

- Casting to generic type results in a warning

```
List<?> l = new ArrayList<String>();  // ok
List<String> ls = (List<String>) l;   // warn
```

- The compiler gives an unchecked warning, since this isn't something the runtime system is going to check for you
- Usually, if you think you need to do this, you're wrong
- The same is true of type variables:

```
public static <T> T badCast(T t, Object o) {
  return (T) o;   // unchecked warning
}
```

Generics and arrays

```
public class Foo<T> {
    private T myField;                  // ok
    private T[] myArray;                // ok

    public Foo(T param) {
        myField = new T();              // error
        myArray = new T[10];            // error
    }
}
```

- You cannot create objects or arrays of a parameterized type

Generics/arrays: a hack

```
public class Foo<T> {
    private T myField;                  // ok
    private T[] myArray;                // ok

    @SuppressWarnings("unchecked")
    public Foo(T param) {
        myField = param;                // ok
        T[] a2 = (T[]) (new Object[10]); // ok
    }
}
```

- You can create variables of that type, accept them as parameters, return them, or create arrays by casting `Object[]`
  - Casting to generic types is not type-safe, so it generates a warning
  - You almost surely don't need this in common situations!

Comparing generic objects

```
public class ArrayList<E> {
    ...
    public int indexOf(E value) {
        for (int i = 0; i < size; i++) {
        // if (elementData[i] == value) {
           if (elementData[i].equals(value)) {
               return i;
           }
        }
        return -1;
    }
}
```

- When testing objects of type `E` for equality, must use `equals`

Tips when writing a generic class

- Start by writing a concrete instantiation
  - It's often easier to reason about a concrete instance than an abstraction of that instance
- Get it correct (testing, reasoning, etc.)
- Consider writing a second concrete version
  - It's still often easier to reason about a concrete instance than an abstraction of that instance
- Generalize it by adding type parameters
  - Think about which types are the same & different
  - Not all ints are the same, nor are all Strings
  - The compiler will help you find errors
- Eventually, it will be easier to write the code generically from the start
  - but maybe not yet

Next steps

- Assignment 4: out, due Wednesday November 9, 2011 at 11:59PM
- Lectures: W, reasoning about code; F, holiday (Veterans' Day)