CSC7203 : Advanced Object Oriented Development

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Generics (in Java)

…/~gibson/Teaching/CSC7203/CSC7203-AdvanceOO-L5-Generics.pdf

1 Generics - Some History

M.D. McIlroy: *Mass-Produced Software Components*, **Proceedings of the 1st International Conference on Software Engineering**, Garmisch Pattenkirchen, Germany, **1968**

Joseph A. Goguen: *Parameterized Programming*. **IEEE Trans. Software Eng. 10(5) 1984**

David R. Musser, Alexander A. Stepanov: *Generic Programming*. **ISSAC 1988**

Charles W Kreuger, *Software Reuse*, **ACM Computing Surveys, 1992**

Ronald Garcia et al, *A Comparative Study of Language Support for Generic Programming*, **OOPSLA03, 2003**

1 Generics - Some Java History

Martin Odersky and **Philip Wadler**. *Pizza into Java: translating theory into practice*. In Proceedings of the 24th ACM SIGPLAN-SIGACT symposium on Principles of programming languages (**POPL '97**).

Pizza

Gilad Bracha, Martin Odersky, David Stoutamire, and **Philip Wadler**. *Making the future safe for the past: adding genericity to the Java programming language*. ***SIGPLAN Not.* 33, 10 (October 1998)**,

GJ

May 1999 - Sun proposes to Add Generics to Java, based on GJ. The activity (named JSR 14) is headed by Gilad Bracha

JSR-000014 Adding Generics to the Java™ Programming Language **(Close of Public Review: 01 August 2001)**
http://jcp.org/aboutJava/communityprocess/review/jsr014/index.html

JSR-000014

Mads Torgersen et al., *Adding wildcards to the Java programming language*, Proceedings of the **2004 ACM symposium on Applied computing**.

JDK1.5

Recently : push for simplifying/eliminating wildcards!!!

1 Why are generics useful

Re-usable patterns (like higher order functions):

foldl (+) 0 [1..5] = 15
foldl (append) "" ["a", "b", "c"] = " abc"

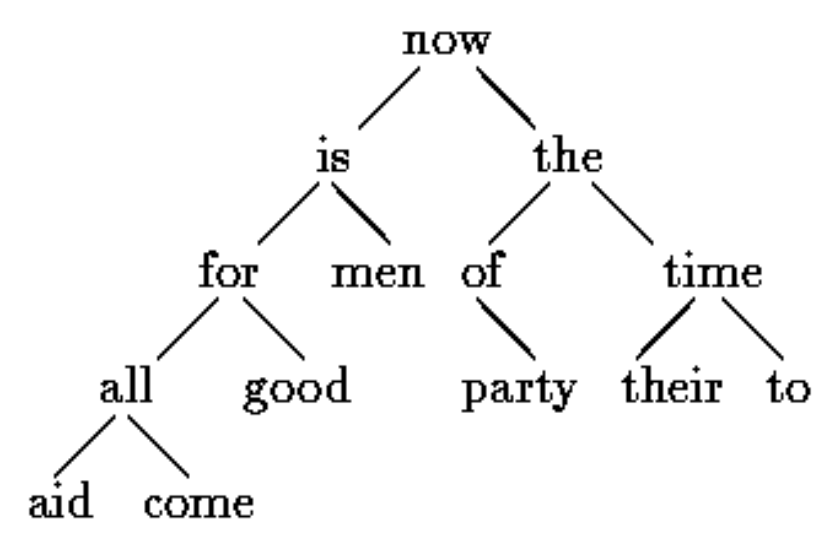
filter (odd) [1,3,5,2,4] = [1,3,5]
filter (animal) [cow, dog, cake] = [cow, dog]

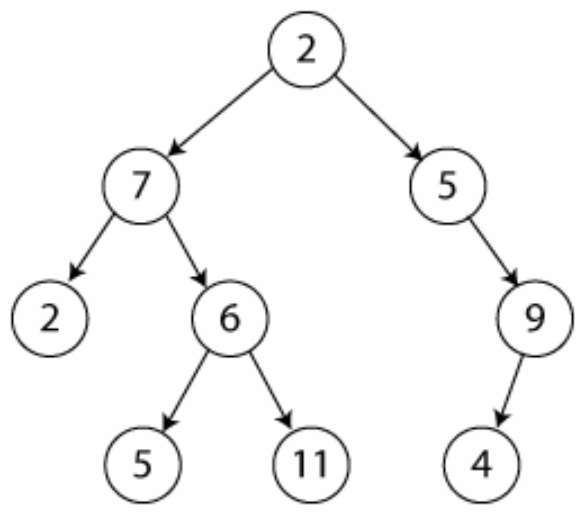
map (double) [1,3,5,2,4] = [2,6,10,4,8]
map (capitalize) ["aBc", "BBc"] = ["ABC", "BBC"]

QUESTION: what are the types of these 3 functions?

1 Why are generics useful

Re-usable data structures, eg binary tree of things:





With generic algorithms/functions, eg depth

1 Why are generics useful

Re-usable classes, eg (ordered) list of things:

- Combines generic data and generic functions in a **generic class**
- **Unconstrained genericity** – no restriction on type/class of generic parameter
- **Constrained genericity** – the generic parameter must be a type/class which is a subtype/subclass of a specified class

NOTE: Genericity is usually extended to allow multiple generic parameters (but then they may/may not be mutually constrained)

1 Why are generics useful: a classic Java example

```
List myIntList = new LinkedList();
myIntList.add(new Integer(0));
Integer x = (Integer) myIntList.iterator().next();
```

```
List<Integer> myIntList = new LinkedList<Integer>();
myIntList.add(new Integer(0));
Integer x = myIntList.iterator().next();
```

QUESTION: Which code do you prefer, and why?

NOTE: The 2nd example uses the Java **List** collections class

Why are generics useful: Java List example, continued:

```
public interface List<E> {
void add(E x);
Iterator<E> iterator();
}
```

The declaration of the *formal type parameters of the interface List*

You might ***imagine*** that an IntegerList defined as List<Integer> stands for a version of List where E has been uniformly replaced by Integer:

```
public interface IntegerList {
void add(Integer x)
Iterator<Integer> iterator();
}
```

This intuition may be useful, but it may also be misleading. (This is closer to the type of macro expansion in the C++ STL)

Java generics implemented by erasure

Generics are implemented by the Java compiler as a front-end conversion called *erasure. You can (almost) think of it as a source-to-source* translation (syntactic sugar), whereby the generic version of code is converted to the non-generic version.

As a result, **the type safety and integrity of the Java virtual machine are never at risk, even in the presence of unchecked warnings.**

Basically, erasure gets rid of (or *erases) all generic type information. All the type* information between angle brackets is thrown out, so, for example, a parameterized type like List<String> is converted into List. All remaining uses of type variables are replaced by the upper bound of the type variable (usually Object). And, whenever the resulting code isn't type-correct, a cast to the appropriate type is inserted.

How To Implement Generics – many choices (see referenced papers)

While generics look like the C++ templates, it is important to note that they are not (implemented) the same.

Java generics simply provide compile-time type safety and eliminate the need for casts.

Generics use a technique known as type erasure as described above, and the compiler keeps track of the generics internally, and all instances use the same class file at compile/run time.

A C++ template on the other hand is just a fancy macro processor; whenever a template class is instantiated with a new class, the entire code for the class is reproduced and recompiled for the new class.

Some Java “Details” : all instances of a generic class have the same run-time class

What does the following code fragment print?

```
List <String> l1 = new ArrayList<String>();
List <Integer> l2 = new ArrayList<Integer>();
System.out.println(l1.getClass() ==
l2.getClass());
```

Some Java "Details" : all instances of a generic class have the same run-time class

What does the following code fragment print?

```
List <String> l1 = new ArrayList<String>();
List <Integer> l2 = new ArrayList<Integer>();
System.out.println(l1.getClass() ==
l2.getClass());
```

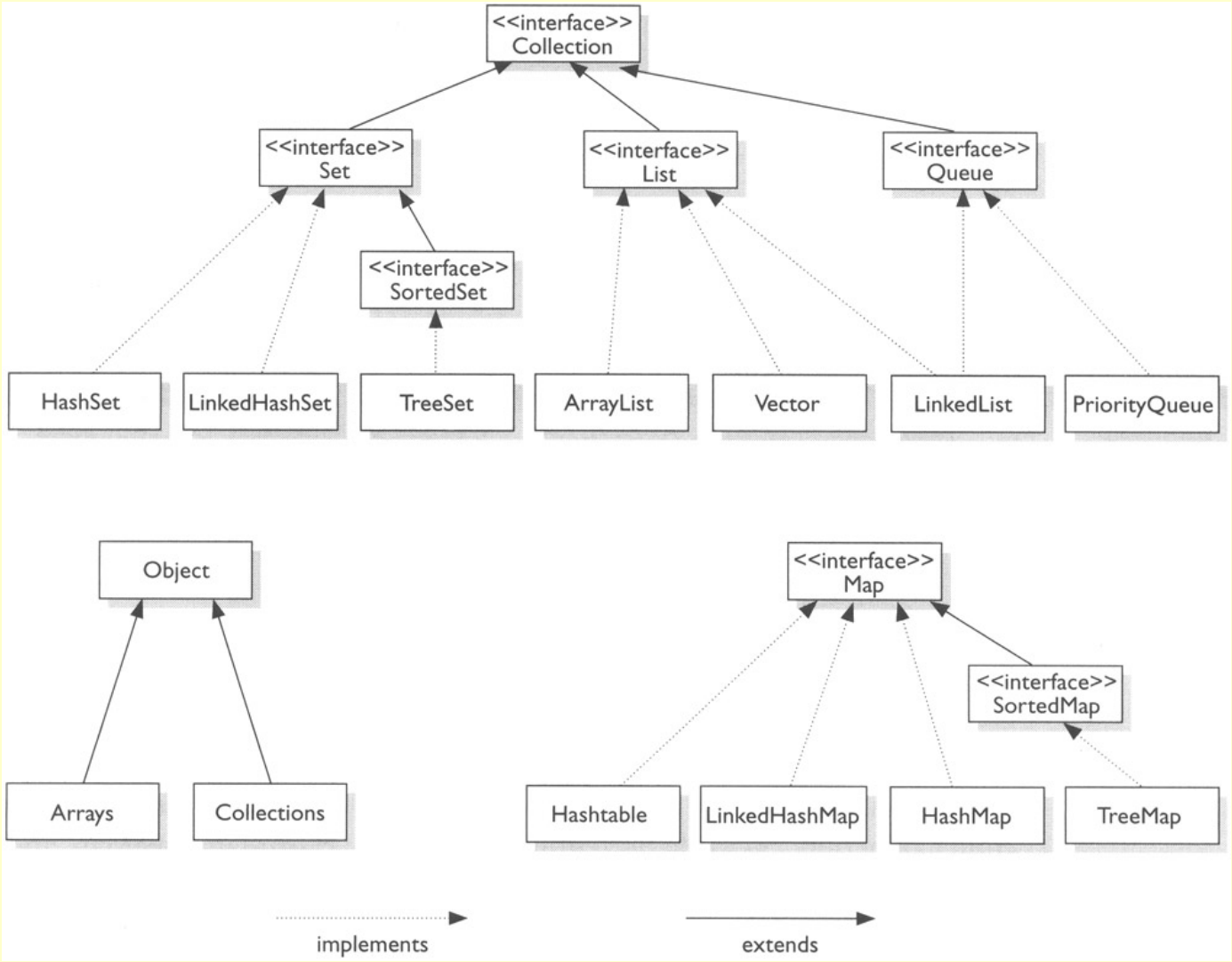
It prints true, because all instances of a generic class have the same run-time class, regardless of their actual type parameters.

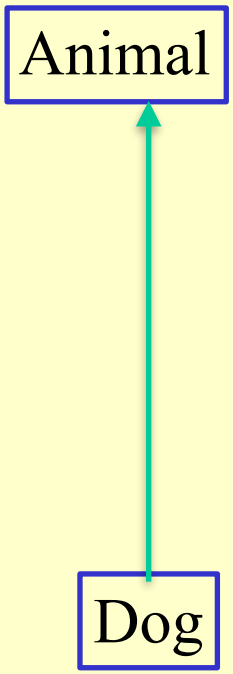
As consequence, *the static variables and methods of a class are also shared among all the instances*.

Generics and Subtyping

QUESTION: What does the following code output?

```
class Animal{}
class Dog extends Animal{ }

public class InheritanceTester {
private static void message(Collection<Animal> animals)
{ System.out.println("You gave me a collection of
animals."); }

private static void message(Object object)
{ System.out.println("You gave me an object.");
}

public static void main(String[] args) {
 List<Dog> animals1 = new ArrayList<Dog>();
 message(animals1);

 List<Amnimals> animals2 = new ArrayList<Dog>();
 message(animals2);
}}
```





Dog is subclass of Animal, List is subclass of Collection
Is a *List of Dogs* a subclass of a *Collection of Animals*???

Generics and Subtyping

In general, if Foo is a subtype (subclass or subinterface) of Bar, and G is some generic type declaration, it is **not the case that G<Foo> is a subtype of G<Bar>.**

All OO languages handle the integration of genericity and subclassing differently

This is probably the hardest thing you need to learn about (Java) generics … and how it relates to the concept of wildcards

TEST: What are contravariance and covariance??

Example: drawing shapes in a canvas

Typically , a drawing will contain a number of shapes.

Assuming that the shapes are stored in a list, it would be convenient to have a method in Canvas that draws them all:

```
public void drawAll(List<Shape> shapes) {
 for (Shape s: shapes) { s.draw(this); }
}
```

Now, the type rules (as we saw on previous slide) say that drawAll() can only be called on lists of exactly Shape: it cannot, for instance, be called on a List<Circle>.

That is unfortunate, since all the method does is read shapes from the list, so it could just as well be called on a List<Circle>…

Java wildcards were introduced to overcome this problem.

Wildcards – drawing shapes in a canvas

What we really want is for the method to accept a list of **any** kind of shape:

```
public void drawAll(List<? extends Shape> shapes)
{ ... }
```

There is a small but very important difference here: we have replaced the type List<Shape> with List<? **extends** Shape>.

Now drawAll() will accept lists of any subclass of Shape (or Shape itself), so we can now call it on a List<Circle> if we want.

List<? **extends** Shape> is an example of a *bounded wildcard*.

We say that Shape is the *upper bound* of the wildcard.

Java Wildcards

There are three types of wildcards in Java:

1. "? extends Type": Denotes a family of subtypes of type Type. This is the most useful wildcard

2. "? super Type": Denotes a family of supertypes of type Type.

3. "?": Denotes the set of all types or *any*

Question: can you think of a use of the second wildcard type?

Java Wildcards PECS: *Producer Extends, Consumer Super*

```
public class Collections {
  public static <T> void
    copy(List<? super T> dest, List<? extends T> src)
  {
      for (int i=0; i<src.size(); i++)
        dest.set(i,src.get(i));
  }
}
```

"Producer Extends" - If you need a List to produce T values (you want to read Ts from the list), you need to declare it with ? extends T, e.g. List<? extends Integer>. But you cannot add to this list.

"Consumer Super" - If you need a List to consume T values (you want to write Ts into the list), you need to declare it with ? super T, e.g. List<? super Integer>. But there are no guarantees what type of object you may read from this list.

If you need to both read from and write to a list, you need to declare it exactly with no wildcards, e.g. List<Integer>.

Problem: Implement a Pair Of *Things* in Java

You are to code the class `GenericPair`, such that it passes the tests written in `JUnit_GenericPairTest` (which can be downloaded from the module web site). It is a good idea to put this generic class in a package reserved for generic behaviour - eg a `templates` package. I have provided JUnit tests for this class.

templates.GenericPair<T>

A 2-tuple (pair) of *things*

For teaching advanced OO concepts in Java - genericity

Parameters:

<T> is the type/class of the pair

Version:

1

Author:

J Paul Gibson

tests.JUnit_GenericPairTest

A test for a 2-tuple (pair) of *things*

For teaching advanced OO concepts in Java - genericity

Uses **JUnit** to test template class `GenericPair`

Version:

1

Author:

J Paul Gibson

Problem: Implement a Pair Of *Things* in Java

Field Summary

(package private) GenericPair<java.lang.Character>	**poc** A pair of characters
(package private) GenericPair<java.lang.Character>	**poc_copy** A copy of the pair of Characters poc
(package private) GenericPair<java.lang.Integer>	**poi** A pair of integers
(package private) GenericPair<java.lang.Integer>	**poi_copy** A copy of the pair of Integers poi
(package private) GenericPair<GenericPair<?>>	**pop** A generic pair of pairs
(package private) GenericPair<GenericPair<java.lang.Character>>	**popoc** A pair of a pair of Characters
(package private) GenericPair<GenericPair<java.lang.Integer>>	**popoi** A pair of a pair of Integers

The test variables

void tests.JUnit_GenericPairTest.setUp()

@Before

Initialise the test variables

- poi and poi_copy as pair of Integers (0,0)
- poc and poc_copy as a pair of Characters ('a', 'b')
- popoi as ((1,2) , (3,4)
- popoc as (('a','b') , ('c','d'))
- pop as ((1,2) , ('c','d'))

The variable initialisation: setup

Problem: Implement a Pair Of *Things* in Java

The tests:

`testToString`
Tests method `GenericPair.toString()`

`testSwap_static`
Tests method `GenericPair.swap(GenericPair)`

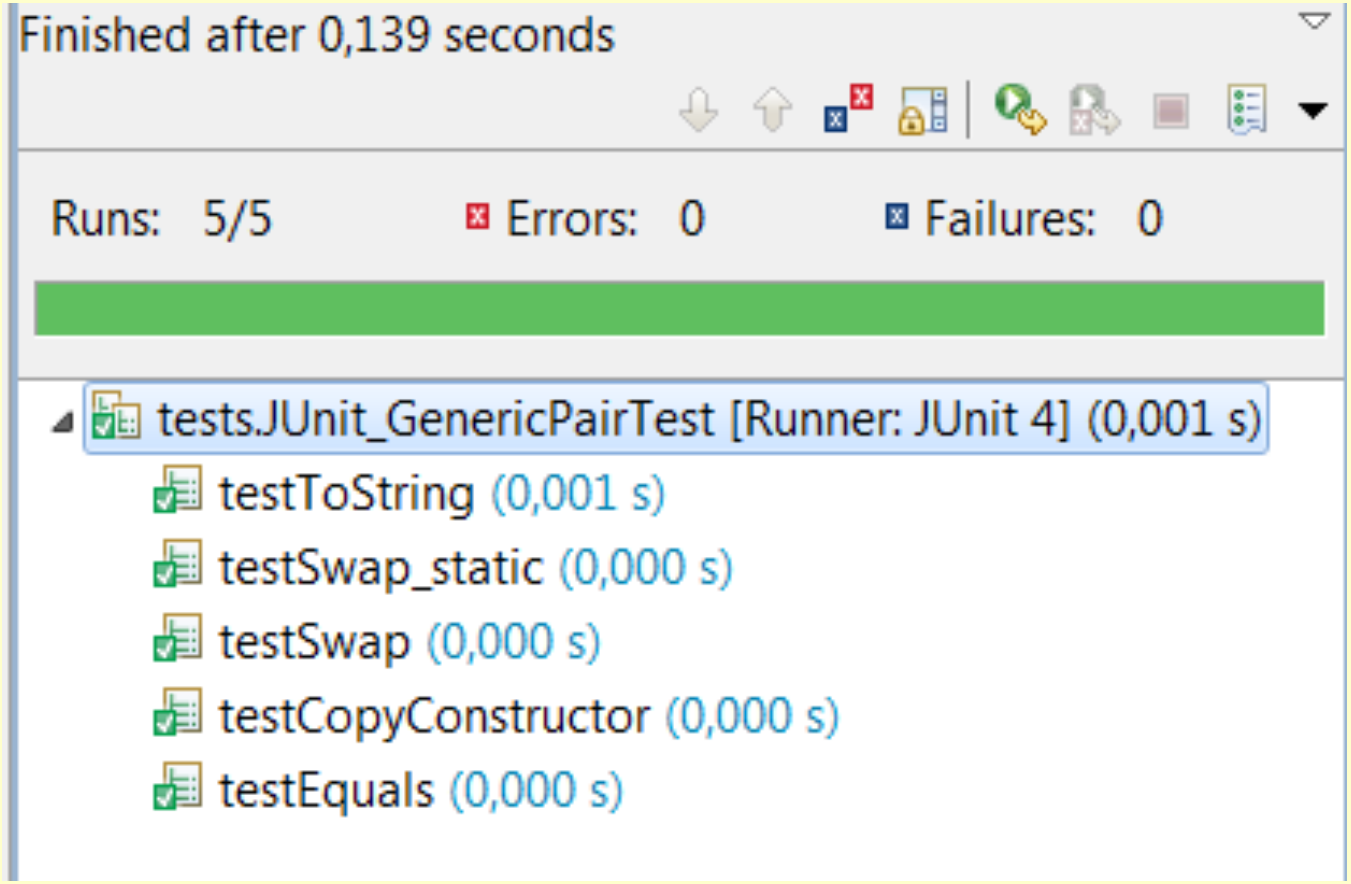
`testSwap`
Tests method `GenericPair.swap()`

`testCopyConstructor`
Tests method `GenericPair.GenericPair(GenericPair)`

`testEquals`
Tests method `GenericPair.equals(java.lang.Object)`

Problem: Implement a Pair Of *Things* in Java

TO DO: Write the `GenericPair` so that the tests are successful



Problem: Implement a Pair Of *Things* in Java

TO DO: Write the `GenericPair` so that the tests are successful

You should consider the test code to specify the requirements.

For example, you can deduce that you need constructors:

templates.GenericPair.GenericPair(T first, T second)

Explicit constructor

Parameters:

first is the initial value of the first element
second is the initial value of the second element

templates.GenericPair.GenericPair(GenericPair<T> pair)

Shallow copy constructor, where first and second values are copied by reference

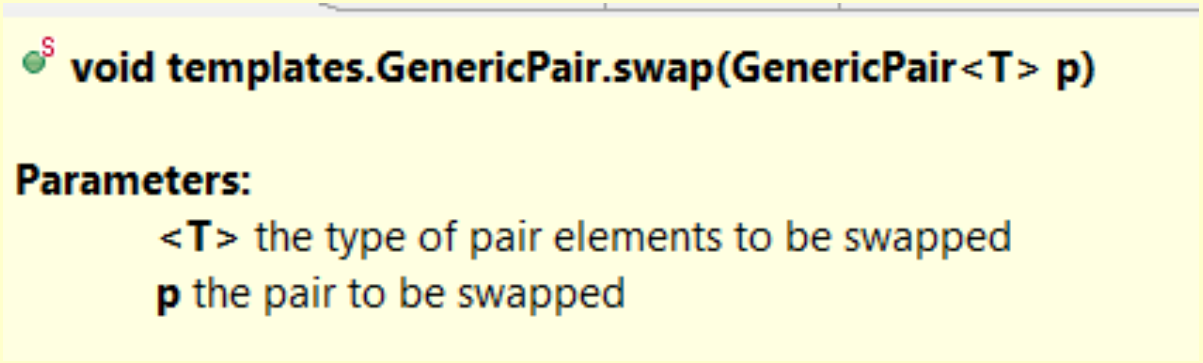
Parameters:

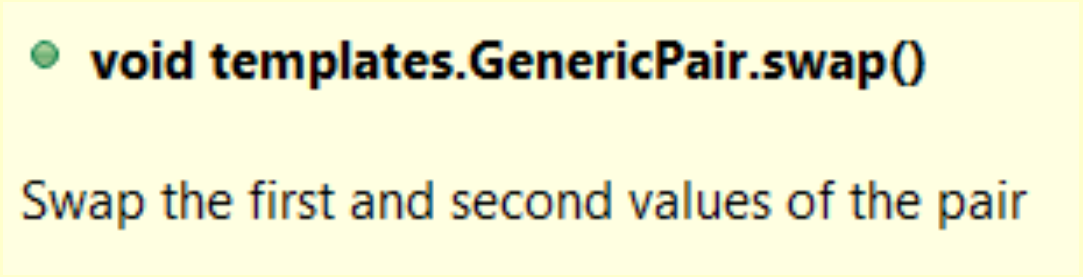
pair is the pair to be copied

Problem: Implement a Pair Of *Things* in Java (using generics)

TO DO: Write the `GenericPair` so that the tests are successful

For example, you can also deduce that you need 2 swap methods:

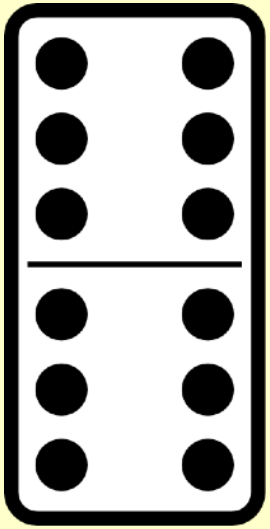




QUESTION: What other methods do you need?

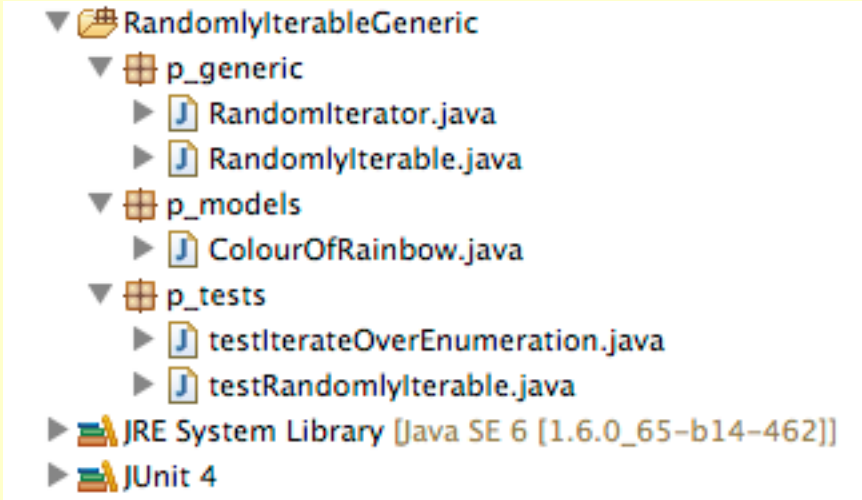
Dominoes Revisited

Would it be a good idea to implement a domino as a pair of integers, re-using our generic pair behaviour?



TO DO: Implement a pair of integers, and its Unit tests, as an instantiation of our generic pair.

Problem : Implement a generic randomly iterable class




```
Iterate over elements in colours of rainbow enumeration
colour = Red
colour = Orange
colour = Yellow
colour = Green
colour = Blue
colour = Indigo
colour = Violet
```

```
Iterate randomly over elements in string_data
 three
 one
 four
 two
 five

Iterate randomly over elements in int_data
 2
 3
 1
 4
 5
```