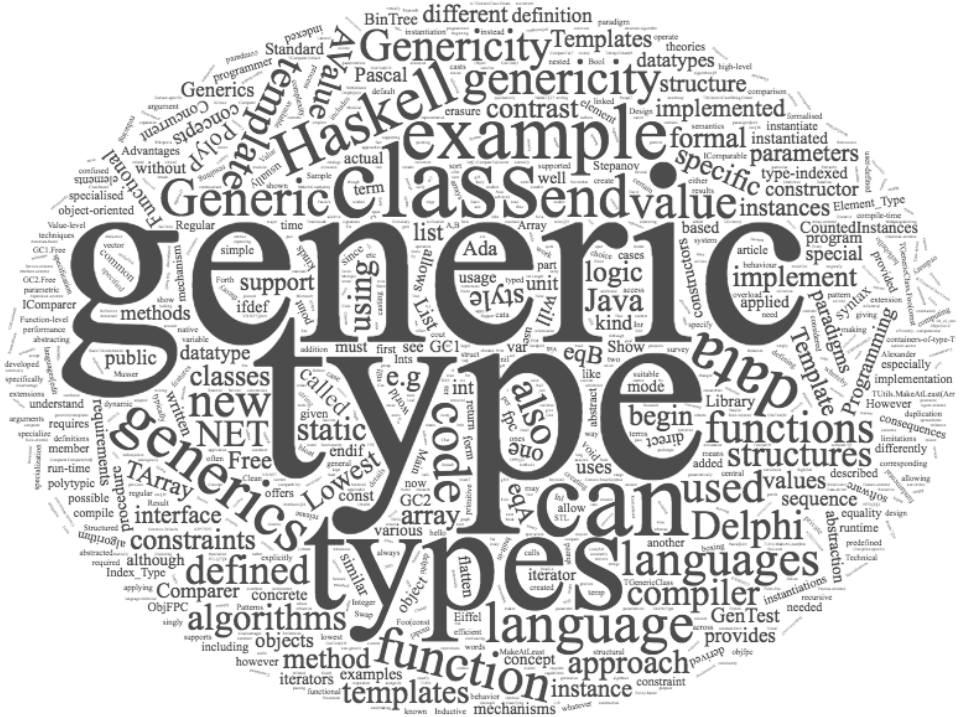
generic programming - java



- **generic programming**
- **java generic programming**
  - methods & generic programming
  - classes & generic programming
- **java with "*generics*"**
  - generic methods
  - generic classes
- **java collections framework**
  - collections framework (pre JDK 5)
  - collections framework with generics
- **references**

- ***definitions*** of generic programming
- generic programming is a ***programming style***
  in which ***algorithms*** are written at the most ***abstract*** possible ***level independent*** of the form of the data
  on which these algorithms will be carried out
- generic programming is a style of computer ***programming***
  in which algorithms are written in terms of ***types to-be-specified-later***
  that are then instantiated when needed
  for specific ***types*** provided as ***parameters***

the roots of generic programming

- David Musser and Alexander Stepanov, in the early 1970s
- the term 'generic programming' is coined in 1989
  - the generic programming approach was pioneered by **ML** in 1973 (?)
  - the generic programming approach was pioneered by **ADA** in 1983 (?)
- different terms (& implementation) → ***similar concept***
  - ***generics***
    - Ada, Eiffel, Java, C#, VisualBasic.NET
  - ***parametric polymorphism***
    - ML, Scala, Haskell
  - ***templates***
    - C++

- ***functions*** (methods) or ***types*** (classes) that ***differ*** only in the set of ***types*** on which they operate
- generic programming is a way to make a language ***more expressive***, while still maintaining ***full static type-safety***
- ***reduce duplication*** of code
- algorithms are written in terms of ***generic types***
- types are passed as ***parameters*** later when needed

- ***generic function***
  - performs the same operation on different data types
- ***generic type (class)***
  - store values and perform operation on different data types
- ***java***
  - generics
- ***c++***
  - templates
  - (concepts)

- generics add a way to specify ***concrete types*** to ***general purpose classes*** and methods that operated on Object before
- Java Specification Request 14 (2004)
  - add generic types to the java programming language
- generics in JDK 5 (originally numbered 1.5) (2005)
- *"This long-awaited enhancement to the type system allows a type or method to operate on objects of various types while providing compile-time type safety. It adds compile-time type safety to the Collections Framework and eliminates the drudgery of casting" [docs.oracle.com]*

generic type

- ***type variable***
  - is an unqualified identifier
- ***generic class***
  - if it declares one or more type variables (type parameters of the class)
- ***generic interface***
  - if it declares one or more type variables (type parameters of the interface)
- ***generic method***
  - if it declares one or more type variables (formal type parameters of the method)

methods & generic programming

- *step back*
  - ***overloading***
  - ***inheritance & polymorphism***
- *step forward*
  - ***generics***

- a first possible solution: ***overloading***
- overloading
  - set of methods all having the ***same name***, but with a ***different*** arguments list (***signature***)
- first example:
  - ***get the central element of array***

```java
/**
 * Generic method - Overloading
 * @author SoWIDE lab
 */
public class ArrayUtil {
    /**
    Get the central element of array
    @param a String array
    @return central element
    */
    public static String getCentral(String[] a) {
        if (a == null || a.length == 0)
            return null;
        return (a[a.length/2]);
    }

    public static Character getCentral(Character[] a) {
        if (a == null || a.length == 0)
            return null;
        return (a[a.length/2]);
    }

    public static Integer getCentral(Integer[] a) {
        if (a == null || a.length == 0)
            return null;
        return (a[a.length/2]);
    }
}
```

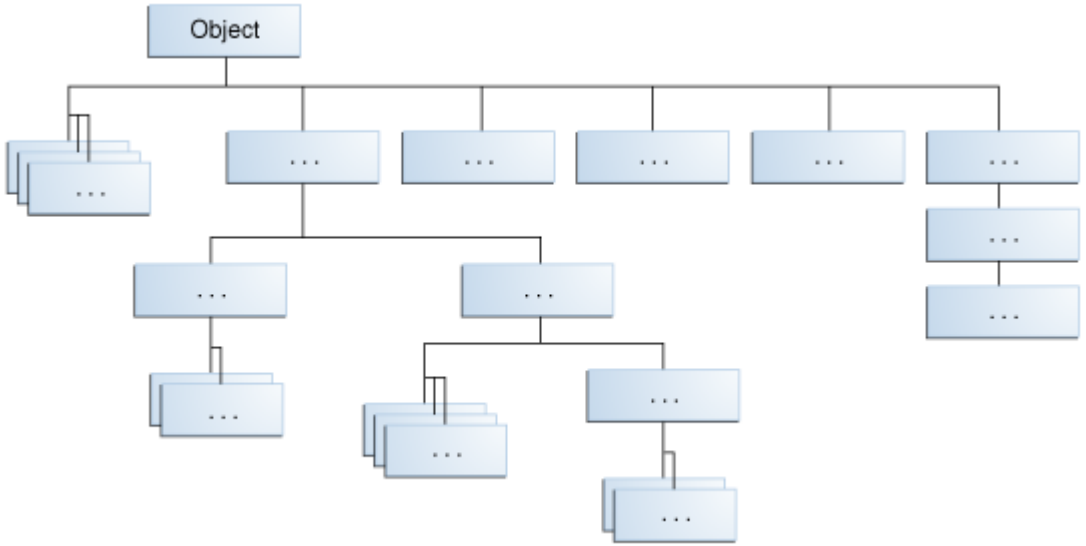
```
public class Main {
    public static void main(String[] args) {

        String[] s = {"alpha","beta","charlie"};
        Character[] c = {'h', 'a', 'l'};              // autoboxing
        Integer[] i = {4 , 8 , 15 , 16 , 23 , 42};

        String sc = ArrayUtil.getCentral(s);
        assert sc.equals("beta");
        Character cc = ArrayUtil.getCentral(c);
        assert cc == 'a';
        int ic = ArrayUtil.getCentral(i);             // unboxing
        assert ic == 16;

        Double[] d = {1.1, 2.3, 5.8, 13.21};
        Double dc = ArrayUtil.getCentral(d);  // compile time error:
                                  // no suitable method found for getCentral(Double[])
        assert dc == 5.8;
    }
}
```

assertion – autoboxing - unboxing

- ***assertion***
  - an assertion is a statement in the Java programming language that enables you to ***test*** you're assumptions about your program
- ***autoboxing***
  - autoboxing is the automatic ***conversion*** that the Java compiler makes between the ***primitive types*** and their corresponding object ***wrapper classes***
- ***unboxing***
  - unboxing is the conversion of an object of a ***wrapper*** type to its ***corresponding primitive*** value
  - the Java compiler applies unboxing when an object of a wrapper class is:
    - passed as a parameter to a method that expects a value of the corresponding primitive type
    - assigned to a variable of the corresponding primitive type

generic method inheritance & polymorphism

- we can ***write*** a method that takes a ***base class*** (or interface) as an argument, and then ***use*** that method with any ***class derived*** from that base class
- this method is more general and can be used in more places



```java
/**
 * Generic method - Inheritance
 * @author SoWIDE lab
 */
public class ArrayUtil {
    /**
    Get the central element of the array
    @param a Object array
    @return central element
    */
    public static Object getCentral(Object[] a)
    {
        if (a == null || a.length == 0)
            return null;
        return (a[a.length/2]);
    }
}
```

```java
public class Main {
 public static void main(String[] args) {

   String[] s = {"alpha","beta","charlie"};
   Character[] c = {'h', 'a', 'l'};
   Integer[] i = {4 , 8 , 15 , 16 , 23 , 42};

   String sc = (String) ArrayUtil.getCentral(s);   //downcast from Objet to String
   assert sc.equals("beta");
   Character cc = (Character) ArrayUtil.getCentral(c);
   assert cc == 'a';
   int ic = (int) ArrayUtil.getCentral(i); //downcast & unboxing
   assert ic == 16;
   Double[] d = {1.1, 2.3, 5.8, 13.21};
   Double dc = (Double) ArrayUtil.getCentral(d);
   assert dc == 5.8;

   Integer iVar = (Integer) ArrayUtil.getCentral(c); // no compile-time error
        // run-time exception
        // Exception in thread ... java.lang.ClassCastException: java.lang.Character
        //cannot be cast to java.lang.Integer ...
 }
}
```

type safety

- ***type safety***
  - the compiler will validate types while compiling
  - throw an error if you try to assign the wrong type to a variable
- ***downcasting*** from base class can generate ***no type-safe*** code
  - run-time exception occurs in wrong cast operations

java generic methods (generics)

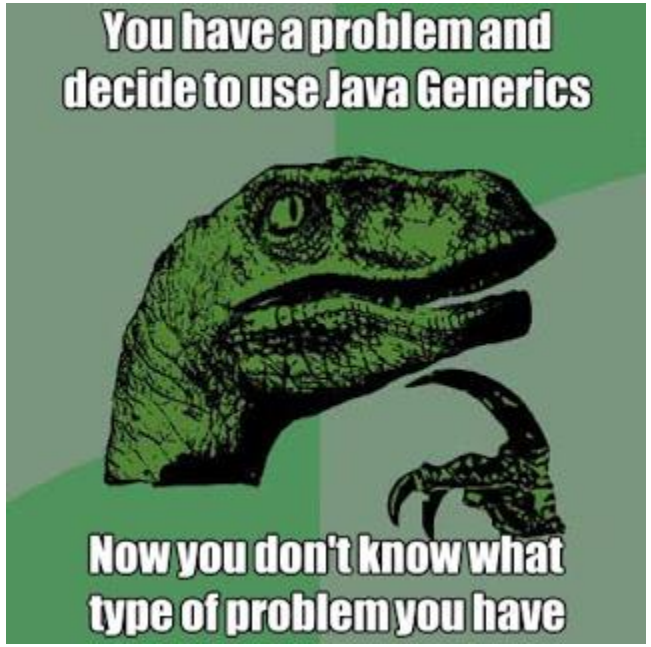
- a generic method (***with generics***) is a method with a ***type parameter***
- you can think of it as a ***template*** for a ***set of methods*** that differ only by one or more types
- when you call the generic method, you need ***not specify*** which ***type*** to use for the type parameter
- you call the method with appropriate parameters, and the ***compiler*** will match up the type parameters with the parameter types
- *as with generic classes, you cannot replace type parameters with primitive types*

```
modifier <TypeVariable1, TypeVariable2 ...> returnType methodName(parameters) {
    body
}
```

java generic methods (generics)

```
public static <T>  T getCentral(T[] a) {
    if (a == null || a.length == 0)
        return null;
    return (a[a.length/2]);
}
...
String[] s = { "alpha", "beta", "charlie" };
String sc = ArrayUtil.getCentral(s); // implicit type(String)parameter
```

```
public class Main {
 public static void main(String[] args) {

   String[] s = { "alpha", "beta", "charlie" };
   Character[] c = { 'h', 'a', 'l' };
   Integer[] i = { 4, 8, 15, 16, 23, 42 };
   Double[] d = { 1.1, 2.3, 5.8, 13.21 };

   String sc = ArrayUtil.getCentral(s); // implicit type (String) parameter
   assert sc.equals("beta");
   Character cc = ArrayUtil.<Character> getCentral(c); // esplicit type parameter
   assert cc == 'a';
   int ic = ArrayUtil.getCentral(i); // implicit type parameter & unboxing
   assert ic == 16;
   Double dc = ArrayUtil.getCentral(d);
   assert dc == 5.8;

   Integer iVar = ArrayUtil.getCentral(c);  // compile-time error: incompatible types
 }
}
```


You have a problem and
decide to use Java Generics
Now you don't know what
type of problem you have

generic class

- a class that hold elements of various type
- for example a simple generic class Pair that stores pairs of objects, each of which can have an arbitrary type

```java
public class Pair {
    private Object first;
    private Object second;
    /**
     * Constructs a pair containing two given elements
     * @param firstElement the first element
     * @param secondElement the second element
     */
    public Pair(Object firstElement, Object secondElement) {
        first = firstElement;
        second = secondElement;
    }
    /**
     * Gets the first element of this pair
     * @return the first element
     */
    public Object getFirst() {
        return first;
    }
    /**
     * Gets the second element of this pair
     * @return the second element
     */
    public Object getSecond() {
        return second;
    }
    public String toString() {
        return "(" + first + ", " + second + ")";
    }
}
```

test Pair

```
public class Main {

  public static void main(String[] args) {
    Pair p1 = new Pair("alpha", 1);
    // String & Integer (autoboxing) - Implicit upcasting to Object
    String name = (String) p1.getFirst();
    // esplicit downcasting from Object to String
    Integer value = (Integer) p1.getSecond();
    System.out.println("Name: "+name+" Value: "+value);
    Pair p2 = new Pair(3.2,5.5);          // Double & Double (autoboxing)
    Double x = (Double) p2.getFirst();
    double y = (double) p2.getSecond();          // unboxing
    System.out.println("x: "+x+" y: "+y);
    x = (Double) p1.getFirst();                  // run-time error
       // Exception in thread "main" java.lang.ClassCastException: java.lang.String
       // cannot be cast to java.lang.Double
    }
}
```

generic class - syntax

```
accessSpecifier class GenericClassName <TypeVariable1 , TypeVariable2 , ...> {
    instance variables
    constructors
    methods
}
```

Pair - generic class

```
public class Pair<T, S> {
    private T first;
    private S second;

    public Pair(T firstElement, S secondElement) {
        first = firstElement;
        second = secondElement;
    }

    public T getFirst() {
        return first;
    }

    public S getSecond() {
        return second;
    }

    public String toString() {
        return "(" + first + ", " + second + ")";
    }
}
```

Pair - test class

```
// explicit actual type paramethers
Pair<String, Integer> p1 = new Pair<String, Integer>("alpha", 1);
String name = p1.getFirst();
Integer value = p1.getSecond();
System.out.println("Name: "+name+" Value: "+value);

// implicit actual type paramethers
Pair<Double, Double> p2 = new Pair(3.2,5.5);
Double x = p2.getFirst();
double y = p2.getSecond();
System.out.println("x: "+x+" y: "+y);

x = p1.getFirst();
// Compile-time error: Type mismatch: cannot convert from String to Double
```

conventions

- type variable meaning
  - **E** Element type in a collection
  - **K** Key type in a map
  - **V** Value type in a map
  - **T** General type
  - **S , U** Additional general types

bounds

- type parameters can be ***constrained*** with ***bounds***
- it is often necessary to specify what types ***can be used*** in a generic class or method

wildcard types

- it is often necessary to formulate ***constraints*** of type parameters
- there are three kinds of wildcard types:

name	**syntax**	**meaning**
wildcard with **upper** bound	**? extends B**	any ***subtype*** of B
wildcard with **lower** bound	**? super B**	any *supertype* of B
unbounded	**?**	***any type***

upper bounded wildcards

- *example*: if you want to write a method that works on **`List<Integer>`**, **`List<Double>`**, and **`List<Number>`** you can achieve this by using an upper bounded wildcard
- to write the method that works on lists of Number and the subtypes of Number, such as Integer, Double, and Float, you would specify **`List<? extends Number>`**
- *the term* **`List<Number>`** *is more restrictive than* **`List<? extends Number>`**
  - *the former matches a list of type Number* ***only***
  - *the latter matches a list of type Number or any of its* ***subclasses***

collections & generic

```
public static double sumOfList(List<? extends Number> list) {
    double s = 0.0;
    for (Number n : list)
        s += n.doubleValue();
    return s;
}

public static double productOfList(List<? extends Number> list) {
    double p = 1.0;
    for (Number n : list)
        p *= n.doubleValue();
    return p;
}
```

collections & generic

```
public static void main(String[] args) {
    List<Integer> li = Arrays.asList(1, 2, 3);
    System.out.println("sum = " + sumOfList(li));          // output sum = 6
    System.out.println("product = " + productOfList(li));

    List<String> sli =Arrays.asList("alpha","beta","charlie");
    System.out.println("sum = " + sumOfList(sli));
    // Compile time error: The method sumOfList(List<? extends Number>) …
    // is not applicable for the arguments (List<String>) …

    List gli = Arrays.asList("alpha","beta","charlie");;
    System.out.println("sum = " + sumOfList(gli));
    // Exception in thread "main" java.lang.ClassCastException:
    // java.lang.String cannot be cast to java.lang.Number
}
```

unbounded wildcards

- the ***unbounded wildcard*** type is specified using the wildcard character (?), for example, **`List<?>`**. this is called a list of unknown type
- there are two scenarios where an unbounded wildcard is a useful approach:
  - if you are writing a method that can be implemented using functionality provided in the ***Object*** class
  - when the code is using methods in the generic class that ***don't depend on the type*** parameter

under the hood

- generics in Java provide ***compile-time safety*** for type-correctness
  - *but is partially considered as a run-time feature and it is somewhat similar to inheritance-polymorphism in practice*
- there is a process called ***type erasure***
  - ***type*** information is ***removed*** during ***compilation*** and there is no way to tell what was the type of a generic when it was instantiated during run-time
- any algorithm that requires to know the original type cannot be implemented through generics

source code

```
public static <T> T getCentral(T[] a)
{
  if (a == null || a.length == 0)
    return null;
  return (a[a.length/2]);
}
```

code after erasure

```
public static Object getCentral(Object[] a
{
  if (a == null || a.length == 0)
    return null;
  return a[a.length / 2];
}
```

- the Java compiler ***erases*** type parameters, replacing them with their ***bounds*** or ***Objects***
- because the Java compiler erases all type parameters in generic code, you ***cannot verify*** which parameterized type for a generic type is being used at ***runtime***
- the process ***erases type*** parameters but ***adds casts***
- knowing about type erasure helps you understand limitations of Java generics
  - for example, you cannot construct new objects of a generic type

```
public static <E> void fillWithDefaults(E[] a){
    private E[] elements;
    elements = new E[10]; // error
    for (int i = 0; i < a.length; i++)
        a[i] = new E(); // error
}
```

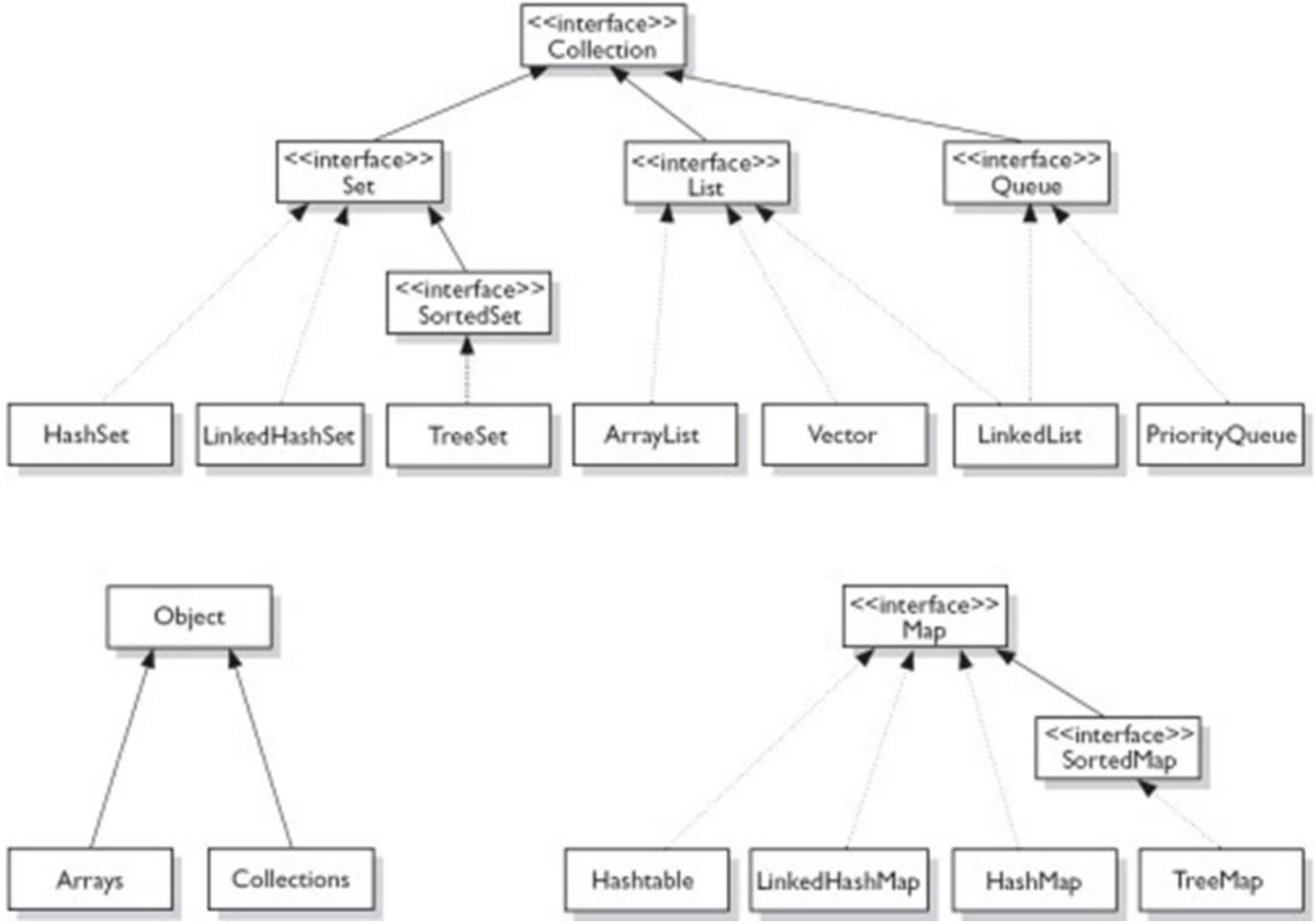
Main (after erasure)

```
public static void main(String args[]) {
 String s[] = { "alpha", "beta", "charlie" };
 Character c[] = { Character.valueOf('h'), Character.valueOf('a'), …};
 Integer i[] = { Integer.valueOf(4), Integer.valueOf(8),…};
 Double d[] = { Double.valueOf(1.100000000000001D),…};
 String sc = (String) ArrayUtil.getCentral(s);
 if (!$assertionsDisabled && !sc.equals("beta"))
    throw new AssertionError();
 Character cc = (Character) ArrayUtil.getCentral(c);
 if (!$assertionsDisabled && cc.charValue() != 'a')
    throw new AssertionError();
 int ic = ((Integer) ArrayUtil.getCentral(i)).intValue();
 if (!$assertionsDisabled && ic != 16)
    throw new AssertionError();
 Double dc = (Double) ArrayUtil.getCentral(d);
 if (!$assertionsDisabled && dc.doubleValue() != 5.799999999999998D)
    throw new AssertionError();
 else
    return;
}
```

syntactic sugar?

- are Java Generics just syntactic sugar?

java collections framework



- is a unified architecture for representing and manipulating collections, enabling ***collections*** to be manipulated ***independently*** of ***implementation*** details
- **pre-JDK5** collections are not type-safe
  - the ***upcasting*** to java.lang.Object is done implicitly by the compiler
  - the programmer has to ***explicitly downcast*** the Object retrieved back to their original class
  - the ***compiler*** is ***not able*** to check whether the downcasting is valid at compile-time
  - incorrect downcasting will show up only at runtime, as a ***ClassCastException***
- ***post-JDK5***
  - the **compiler** can perform all the ***necessary type-check*** during compilation to ensure ***type-safety at runtime***

java collections framework (pre JDK 5)

```
import java.util.ArrayList;
import java.util.Iterator;

public class ArrayListPreJDK5Test {
   public static void main(String[] args) {
      ArrayList lst = new ArrayList();  // ArrayList contains instances of Object
      lst.add("alpha"); // add() takes Object. String upcast to Object implicitly
      lst.add("beta");
      lst.add("charlie");
      lst.add(new Integer(10));      //Integer upcast to Object implicitly
      System.out.println(lst);       // [alpha, beta, charlie, 10]

      Iterator iter = lst.iterator();
      while (iter.hasNext()) {
        //explicitly downcast from Object to String
         String str = (String)iter.next();  // ERROR
         System.out.println(str);
      }
   }
}
```

java collections framework (post JDK 5)

```
public class ArrayListPostJDK15Test {
   public static void main(String[] args) {
      ArrayList<String> lst = new ArrayList<String>();  //Inform compiler about type
      lst.add("alpha");          // compiler checks if argument's type is String
      …
      Iterator<String> iter = lst.iterator();   // Iterator of Strings
      while (iter.hasNext()) {
         String str = iter.next();  // compiler inserts downcast operator
         System.out.println(str);
      }
      lst.add(new Integer(1234));  // ERROR: compiler can detect wrong type
                                   // error: no suitable method found for add(Integer)
      Integer intObj = lst.get(0); // ERROR: compiler can detect wrong type
                  // error: incompatible types: String cannot be converted to Integer

      // Enhanced for-loop (JDK 1.5)
      for (String str : lst) {
         System.out.println(str);
      }
   }
}
```

references

- Musser, D.A. and Stepanov, A.A., Generic Programming, Proceeding of International Symposium on Symbolic and Algebraic Computation, vol. 358: Lecture Notes in Computer Science, Rome, Italy, 1988, pp. 13–25
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- Jaime Niño. 2007. The cost of erasure in Java generics type system. J. Comput. Sci. Coll. 22, 5 (May 2007), 2-11