Generic Types, printf, and Miscellaneous Java Utilities

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Topics in This Section

• Supporting generic types in your own code
  – Idea
  – Methods
  – Classes or interfaces
• printf
• varargs
• String vs. StringBuilder
Using Existing Generic Methods and Classes

• **Basic capability**
  – Even beginning Java programmers need to know how to *use* classes that support generics
  – You cannot properly use Lists, Maps, Sets, etc. without this
  – Covered in earlier section

    ```java
    List<Employee> workers = ...;
    workers.add(new Employee(...)); // Type checked @ compile time
    Employee e = workers.get(someIndex); // Return is Employee
    ```

    ```java
    Map<String,Employee> workerTable = ...;
    workerTable.put(someId, someEmployee);
    Employee employeeWithId = workerTable.get(someId);
    ```

Creating Your Own Generic Methods and Classes

• **Intermediate capability**
  – Intermediate Java developers should also to be able to *define* classes or methods that support generics
  – In Java 7 and earlier, being able to do this was mostly reserved for advanced developers, but it is done much more commonly in Java 8
    • Because lambda functions and generic types work together for same goal: to make code more reusable

    ```java
    public interface Map<K,V> { ... }
    public static <T> T lastElement(List<T> elements) { ... }
    ```
Generic Classes and Methods: Syntax Overview

- **Using `<TypeVariable>`**
  - If you put variables in angle brackets in the class or method definition, it tells Java that uses of those variables refer to types, not to values
  - It is conventional to use short names in upper case, such as T, R (input type, result type) or T1, T2 (type1, type2), or E (element type)

- **Examples**
  ```java
  public class ArrayList<E> ... {
    ...
  }
  
  public static <T> T randomElement(T[] array) {
    ...
  }
  ```

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Generic Classes and Methods: Syntax Details

• Declaring methods that support generics

  public static <T> T best(List<T> entries, ...) { ... }

  • This says that the best method takes a List of T's and returns a T. The <T> at the
    beginning means T is not a real type, but a type that Java will figure out from the
    method call.

  • Java will figure out the type of T by looking at parameters to the method call

     List<Person> people = ...;
     Person bestPerson = Utils.best(people, ...);
     List<Car> cars = ...;
     Car bestCar = Utils.best(cars, ...);
public class RandomUtils {
    private static Random r = new Random();

    public static int randomInt(int range) {
        return(r.nextInt(range));
    }

    public static int randomIndex(Object[] array) {
        return(randomInt(array.length));
    }

    public static <T> T randomElement(T[] array) {
        return(array[randomIndex(array)]);
    }
}

Using RandomUtils

• Examples
  String[] names = { "Joe", "John", "Jane" };  
  String name = RandomUtils.randomElement(names);
  Color[] colors = { Color.RED, Color.GREEN, Color.BLUE };  
  Color color = RandomUtils.randomElement(colors);
  Person[] people =
      { new Person("Larry", "Page"), new Person("Larry", "Ellison"),
        new Person("Larry", "Bird"), new Person("Larry", "King") };
  Person person = RandomUtils.randomElement(people);
  Integer[] nums = { 1, 2, 3, 4 };   // Integer[], not int[]
  int num = RandomUtils.randomElement(nums);

• Points
  – No typecast required to convert to String, Color, Person, Integer
  – Autoboxing lets you assign entry from Integer[] to an int, but array passed to randomElement must be Integer[] not int[], since generics work only with Object types, not primitive types
Generic Classes or Interfaces

Generic Classes and Methods: Syntax Details

• Declaring classes or interfaces that support generics
  
  public class SomeClass<T> { ... }

• Methods in the class can now refer to T both for arguments and for return values
  
  public T getValue(int index) { ... }

• Java will figure out the type of T by your declaration
  
  SomeClass<Person> blah = new SomeClass<>();
Example: Generic Class (Simplified)

```java
public class ArrayList<E> {

    public E get(int index) { ... }

    public boolean add(E element) { ... }

    ...  
}
```

This says that `get` returns an `E`. So, if you created `ArrayList<Employee>`, `get` returns an `Employee`. No typecast required in the code that calls `get`.

This says that `add` takes an `E` as a parameter. So, if you created `ArrayList<Circle>`, `add` can take only a `Circle`.

In rest of class, `E` does not refer to an existing type. Instead, it refers to whatever type was defined when you created the list. E.g., if you did: `ArrayList<String> words = ...;` then `E` refers to `String`.

This says that get returns an `E`. So, if you created `ArrayList<Employee>`, `get` returns an `Employee`. No typecast required in the code that calls `get`.

This says that `add` takes an `E` as a parameter.

So, if you created `ArrayList<Circle>`, `add` can take only a `Circle`.

In rest of class, `E` does not refer to an existing type. Instead, it refers to whatever type was defined when you created the list. E.g., if you did: `ArrayList<String> words = ...;` then `E` refers to `String`.

This is a highly simplified version of the real Java util `ArrayList` class. That class implements multiple interfaces, and the generic support comes from the interfaces.
printf: Quick Overview

- Values replace %s placeholders (%n means end-of-line)
  ```java
  String name = "Jane";
  double num = 1234.567;
  System.out.printf("%s's number is %.2f%n", name, num);
  ```
  Jane's number is 1234.567.
  Name (8 chars): '     Jane'.
  Num (rounded to 2 places): 1234.57.

- Use %ns to control spacing
  ```java
  System.out.printf("Name (8 chars): '%8s'.%n", name);
  ```

- For numbers, use %f to control decimal places and more
  ```java
  System.out.printf("Num (rounded to 2 places): %.2f.%n", num);
  ```
  Jane's number is 1234.567.
  Name (8 chars): '     Jane'.
  Num (rounded to 2 places): 1234.57.

printf: A Few Details

- Takes a variable number of arguments
  ```java
  System.out.printf("Formatting String", arg1, arg2, ...);
  ```
  – First a string, then one extra arg for each % placeholder (not counting %n)

- The formatting string has % placeholders
  – %s for anything to be treated as string, %f for floating point numbers, %d for whole numbers, %t for times, etc.
    ```java
    System.out.printf("Value1: %s, value2: %s%n", val1, val2);
    ```

- %n means newline
  – Both printouts on same line
    ```java
    System.out.printf("blah");
    System.out.printf("blah");
    ```
  – Two printouts on different lines
    ```java
    System.out.printf("blah%n");
    System.out.printf("blah%n");
    ```
Motivation

• Advantages
  – Lets you insert values into output, without much clumsier String concatenation
  – Lets you control the width of results, so things line up
  – Lets you control the number of digits after the decimal point in numbers, for consistent-looking output
  – Applies to any PrintWriter or PrintStream, not just to System.out
    • In File IO and Networking sections, we will make our own PrintWriter, then use ourWriter.printf

Java printf vs. C++ printf

• They are very similar
  – If you know printf in C/C++, you can probably use Java’s printf immediately without reading any documentation

• Key differences in Java version
  – %s can be used for any type, even numbers. You only need number-specific placeholders like %f and %d when you are doing number-specific formatting like controlling digits after decimal point, inserting commas, etc.
  – You use %n for newlines. You can also use \n as in C++, but %n is slightly better
    • It inserts the newline of the current OS (e.g., LF on Unix, CR/LF pair on Windows)
  – There are a few new options for times and locales
    • But these are not important to learn at the beginning
Simple Example: printf vs. println

- Example
  
  ```java
  public static void printSomeStrings() {
      String firstName = "John";
      String lastName = "Doe";
      int numPets = 7;
      String petType = "chickens";
      System.out.printf("%s %s has %s %s.%n",
                         firstName, lastName, numPets, petType);
      System.out.println(firstName + " " + lastName +
                          " has " + numPets + " " + petType + ").");
  }
  
  - Result:
    John Doe has 7 chickens.
    John Doe has 7 chickens.
  ```

Controlling Formatting

- Different flags
  - %s for strings, %f for floats/doubles, %t for dates, etc.
    - Unlike in C/C++, you can use %s for any type (even numbers)

- Various extra entries can be inserted
  - To control width, number of digits, commas, justification, type of date format, and more

- Details
  - printf uses mini-language
    - Complete coverage would take an entire lecture
    - However, basic usage is straightforward
  - For complete coverage, see
    [http://docs.oracle.com/javase/8/docs/api/java/util/Formatter.html#syntax](http://docs.oracle.com/javase/8/docs/api/java/util/Formatter.html#syntax)
printf Formatting Options

<table>
<thead>
<tr>
<th>Stands For</th>
<th>Options</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>%s</td>
<td>String, Can output any data type. If arg is Object, toString is called.</td>
<td>printf(&quot;%8s&quot;, &quot;Hi&quot;) outputs &quot;      Hi&quot;</td>
</tr>
<tr>
<td>%d</td>
<td>Decimal. Outputs whole number in base 10. Also %x and %o for hex and octal.</td>
<td>printf(&quot;%9d&quot;, 1234) outputs &quot;    1,234&quot;</td>
</tr>
<tr>
<td>%f</td>
<td>Floating point. Lets you line up decimal point and control precision.</td>
<td>printf(&quot;%6.2f&quot;, Math.PI) outputs &quot;  3.14&quot;</td>
</tr>
<tr>
<td>%t</td>
<td>Time (or date). %tA for day name, %td for day number, %tB for month, %tY for year, and many more.</td>
<td>Date now = new Date(); System.out.printf(&quot;%tA, %tB %td, %tY&quot;, now, now, now, now); outputs &quot;Tuesday, April 12, 2016&quot;</td>
</tr>
<tr>
<td>%n</td>
<td>OS-specific end of line (linefeed on Linux, CR/LF pair on Windows)</td>
<td></td>
</tr>
</tbody>
</table>

Most Common Flag: %s

- **Overview**
  - Treat entry as a String
  - Any type is legal, not just Strings

- **Usage and options**
  - %s – prints the same way as System.out.print would: for doubles prints all the digits, and for objects prints the exact result of toString
    - System.out.printf("%s", valueOfAnyType);
  - %ns – prints the value the same as above, but if the output is less than n characters long, pads with spaces on the left so that total output is exactly n characters
    - System.out.printf("%15f", valueOfAnyType);

- **Reminder: printf does not add carriage return automatically**
  - Use %n to add carriage return
    - System.out.printf("%s", valueOfAnyType); // Same as print
    - System.out.printf("%s%n", valueOfAnyType); // Same as println
**Second Most Common Flag: %f**

- **Overview**
  - For printing floating point numbers. Lets you control number of decimal points, total spacing, and commas in the main part of the number.
  - Often used to line up rows of numbers on the decimal point

- **Usage and options**
  - `%f` – prints all digits and with 0 at the end
    - `System.out.printf("%f", someDouble);`
  - `%d.f` – prints exactly `d` digits after the decimal point; the final digit is rounded
    - `System.out.printf("%.2f", someDouble);`
  - `%n.d.f` – prints exactly `d` digits after the decimal point as above, and if the total output is less than `n` characters, pads with spaces on the left
    - `System.out.printf("%7.2f", someDouble);`
  - `%n.d.f` – Same as above, but adds commas every 3 digits in main part of number
    - `System.out.printf("%,7.2f", someDouble);`

---

**Printf Example: Using %s and %f**

```java
double num = 1234.56722;
System.out.printf("num is 's' (using %s)%n", num);
System.out.printf("num is '%12s' (using %12s)%n", num);
System.out.printf("num is '%f' (using %f)%n", num);
System.out.printf("num is '%.2f' (using %.2f)%n", num);
System.out.printf("num is '%4.2f' (using %4.2f)%n", num);
System.out.printf("num is '%6.2f' (using %6.2f)%n", num);
System.out.printf("num is '%10.3f' (using %10.3f)%n", num);
System.out.printf("num is '%,10.3f' (using %,10.3f)%n", num);
```

```
num is '1234.56722' (using %s)
num is '  1234.56722' (using %12s)
num is '1234.56722' (using %f)
num is '1234.57' (using %.2f)
num is ' 1234.57' (using %8.2f)
num is '1234.57' (using %6.2f)
num is ' 1234.567' (using %10.3f)
num is ' 1,234.567' (using %,10.3f)
```
Printf Example: Controlling Width and Precision

CEO[] softwareCEOs = { new CEO("Steve Jobs", 3.1234),
                         new CEO("Scott McNealy", 45.5678),
                         new CEO("Jeff Bezos", 567.982323),
                         new CEO("Larry Ellison", 6789.0),
                         new CEO("Bill Gates", 78901234567890.12) };

System.out.println("SALARIES: ");
for(CEO ceo: softwareCEOs) {
    System.out.printf("%15s: $%,8.2f\n", ceo.getName(), ceo.getSalary());
}

SALARIES:
Steve Jobs: $  3.12
Scott McNealy: $  45.57
Jeff Bezos: $  567.98
Larry Ellison: $6,789.00
Bill Gates: $78,901,234,567,890.12

Printf never throws away significant digits, so the salary of Bill Gates is not lined up properly. Conclusion: you must know something about the range of possible values if you want to line things up on the decimal points.

Printf Example: Controlling Width and Precision

public class CEO {
    private String name;
    private double salary; // In billions

    public CEO(String name, double salary) {
        this.name = name;
        this.salary = salary;
    }

    public String getName() { return(name); }

    public double getSalary() { return(salary); }
}
printf vs. String.format

- printf
  - Outputs a formatted String

- String.format
  - Returns a formatted String

- Equivalent code
  ```java
  System.out.printf("Blah %s", 7);
  
  String s = String.format("Blah %s", 7);
  System.out.print(s);
  ```

- Note
  - For consistency with String.format, System.out.format is synonymous with System.out.printf

Common printf Errors

- Forgetting %s can be used for any type
  - In Java, %s can be used for strings, objects, numbers, etc.
    - You only need number-specific placeholders like %f and %d when you are doing number-specific formatting like controlling decimal points, inserting commas, etc.
  - In C++, %s can be used only for strings

- Using + instead of , between arguments
  - printf uses varargs
  - println uses a single String

- Forgetting to use %n
  - printf does not add a newline automatically
  - println does

- Forgetting how to insert a literal %
  - You use %%
  - You do not use \%
### Variable-Length Arguments

- **printf takes any number of arguments**
  - You could use overloading to define a few versions of printf with different argument lengths, but printf takes *any* number of arguments

- **To do this yourself, use "type... variable"**
  - variable becomes an array of given type
  - Only legal for *final* argument of method
  - Examples
    ```java
    public void printf(String format, Object... arguments)
    public int max(int... numbers)
    ```
    - Can call `max(1, 2, 3, 4, 5, 6)` or `max(someArrayOfInts)`

- **Use sparingly**
  - You usually know how many arguments are possible
Varargs: Example

```java
public class MathUtils {
    public static int min(int... numbers) {
        int minimum = Integer.MAX_VALUE;
        for (int number : numbers) {
            if (number < minimum) {
                minimum = number;
            }
        }
        return (minimum);
    }

    public static void main(String[] args) {
        System.out.printf("Min of 2 nums: %d.%n", min(2, 1));
        System.out.printf("Min of 7 nums: %d.%n", min(2, 4, 6, 8, 1, 2, 3));
    }
}
```

Rare But Tricky Problem: Primitive Arrays with Varargs

**Problem**
- If you pass ints one at a time to a method that uses Object..., each one is converted to Integer, and things work as you expect
- If you group the same numbers into an Integer[], you get the same result, as expected
- But, if you pass an array of primitives to the same method, the entire array is considered a single element

**This comes up later with Streams**
- Passing ints one at a time to Stream.of results in a Stream<Integer> containing each number separately
- Passing an Integer[] to Stream.of also results in a Stream<Integer> containing each number separately
- Passing an int[] to Stream.of results in a one-element stream, where the one element is the int[]
public class PrintUtilities {
    public static void printAll(Object... entries) {
        for(Object o: entries) {
            System.out.println(o);
        }
    }
}

public class VarArgsTest {
    public static void main(String[] args) {
        PrintUtilities.printAll(1, 2, 3);
        Integer[] nums1 = { 1, 2, 3 };
        PrintUtilities.printAll(nums1);
        int[] nums2 = { 1, 2, 3 };
        PrintUtilities.printAll(nums2);
    }
}
StringBuilder

Overview

- **Strings are immutable**
  - Once a String object is allocated, it cannot be modified.
  - However, a variable that refers to a String can be changed to refer to a new String that was derived from old one

- **String concatenation**
  - Results in copying the String that is before the “+”

- **Performance implications**
  - For a few fixed concatenations: no problem
  - For repeated concatenation in a loop: could be a problem

- **StringBuilder**
  - Alternative that can be directly modified
  - Also supports useful reverse method
Strings are Mutable?

```java
public class StringsAppearMutable {
    public static void main(String[] args) {
        String s = "Hello";
        s = s + ", World";
        System.out.println(s);
    }
}
```

The string was modified here, right? You actually cannot tell from this test. Maybe the original String object was changed, or maybe a new String object was created, and the original one was copied. You need a better test.

```
Hello, World
```

Strings are Immutable

```java
public class StringsAreImmutable {
    public static void main(String[] args) {
        String s1 = "Hello";
        String s2 = s1;
        s1 = s1 + ", World";
        System.out.println(s1);
        System.out.println(s2);
    }
}
```

Since s2 is still "Hello", this shows that the line that did concatenation really copied s1, allocated a new String object, and assigned that new object to s1.

```
Hello, World
Hello
```
String vs. StringBuilder

- **Strings are immutable (unmodifiable)**
  - Thus what appears to be String concatenation really involves copying the string on the left (oldString below)
    ```java
    String newString = oldString + "some extra stuff";
    ```
  - Never do String concatenation inside a loop that could be very long (i.e., more than about 100)

- **StringBuilder is mutable**
  - Build a StringBuilder from a String by passing the String to the constructor
    ```java
    StringBuilder b = new StringBuilder(someString);
    ```
  - Call append to append data to the end
    ```java
    b.append("more");
    ```
  - Call toString to turn back into a string
    ```java
    String s = b.toString();
    ```
  - Other methods: insert, replace, substring, indexOf, reverse

Performance Comparison: Using String

- **Code**
  ```java
  public static String padChars1(int n, String orig) {
      String result = "";
      for(int i=0; i<n; i++) {
          result = result + orig;
      }
      return(result);
  }
  ```

- **Usage**
  - padChars(5, "x") returns "xxxxx" for this, and also for the upcoming StringBuilder version

- **Performance**
  - O(N²). Why?
Performance Comparison: Using StringBuilder

• Code

    public static String padChars2(int n, String orig) {
        StringBuilder result = new StringBuilder(" ");
        for(int i=0; i<n; i++) {
            result = result.append(orig);
        }
        return(result.toString());
    }

• Performance

    – O(N)
Summary

• **Generic types in your code**
  - public class MyClass<E> { ... }
  - public interface MyInterface<E1,E2> { ... }
  - public static <T> T someMethod(T[] entries) { ... }

• **printf**
  System.out.printf("%s, %s, and %s.n", v1, v2, v3);

• **Varargs**
  public static int min(int... nums) { ... }
  - You can call min(int1, int2, int3) or min(intArray)
  - nums above is int[]

• **StringBuilder**
  - Better performance than String if many repeated concatenations
  - Some convenient methods like reverse and insert