Java Programming Tutorial

Java String is Special

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1. A Brief Summary of the `String` Class

A Java `String` contains an immutable sequence of Unicode characters. Unlike C/C++, where string is simply an array of `char`, A Java `String` is an object of the class `java.lang.String`.

Java `String` is, however, special. Unlike an ordinary class:

- `String` is associated with *string literal* in the form of double-quoted texts such as "`hello, world`". You can assign a string literal directly into a `String` variable, instead of calling the constructor to create a `String` instance.
- The `'+'` operator is overloaded to concatenate two `String` operands. `'+'` does not work on any other objects such as `Point` and `Circle`.
- `String` is *immutable*. That is, its content cannot be modified once it is created. For example, the method `toUpperCase()` constructs and returns a new `String` instead of modifying the existing content.

1.1 Method Summary

The commonly-used method in the `String` class are summarized below. Refer to the JDK API for `java.lang.String` a complete listing.

```
// Length
int length()       // returns the length of the String
boolean isEmpty()  // same as str.length() == 0
boolean isBlank()  // contains only white spaces (Unicode aware) (JDK 11)

// Comparison
boolean equals(String another) // CANNOT use '==' or '!=' to compare two Strings in Java
boolean equalsIgnoreCase(String another)
int compareTo(String another)  // return 0 if this string is the same as another;
                               // <0 if lexicographically less than another; or >0
int compareToIgnoreCase(String another)
boolean startsWith(String another)
boolean startsWith(String another, int fromIdx)  // search begins at fromIdx
boolean endsWith(String another)

// Searching: index from 0 to str.length()-1
int indexOf(String key)
int indexOf(String key, int fromIdx)
int indexOf(int char)
int indexOf(int char, int fromIdx)      // search forward starting at fromIdx
int lastIndexOf(String key)
int lastIndexOf(String key, int fromIdx)  // search backward starting at fromIdx
int lastIndexOf(int char)
int lastIndexOf(int char, int fromIdx)

// Extracting a char or substring, include fromIdx but exclude toIdx
char charAt(int idx)
String substring(int fromIdx)
String substring(int fromIdx, int toIdx)

// Creating a new String or char[] from the original - Strings are immutable
String toLowerCase()
String toUpperCase()
String concat(String another)  // same as str+another
String trim()          // creates a new String removing white spaces from front and back
String strip()         // strips the leading and trailing white spaces (Unicode aware) (JDK 11)
String stripLeading()     // (JDK 11)
String stripTrailing()    // (JDK 11)
String repeat(int count)  // (JDK 11)
String indent(int n)  // adjusts the indentation by n (JDK 12)
```

```
char[] toCharArray()                         // create a char[] from this string
void getChars(int srcBegin, int srcEnd, char[] dst, int dstBegin)  // copy into dst char[]

// Working with CharSequence (super-interface of String, StringBuffer, StringBuilder)
boolean contains(CharSequence cs)       // (JDK 5)
boolean contentEquals(CharSequence cs)  // (JDK 5)
boolean contentEquals(StringBuffer sb)  // (JDK 4)
static String join(CharSequence delimiter, CharSequence... elements)  // (JDK 8)
static String join(CharSequence delimiter, Iterable<CharSequence> elements)  // (JDK 8)

// Text Processing and Regular Expression (JDK 4)
boolean matches(String regex)
String replace(char old, char new)
String replace(CharSequence target, CharSequence replacement)  // (JDK 4)
String replaceAll(String regex, String replacement)
String replaceFirst(String regex, String replacement)
String[] split(String regex)  // Split the String using regex as delimiter, return a String array
String[] split(String regex, int count)  // for count times only

/*** static methods ***/
// Converting primitives to String
static String valueOf(type arg)  // type can be primitives or char[]
// Formatting using format specifiers
static String format(String formattingString, Object... args)  // same as printf()

/*** Stream and Functional Programming ***/
Stream<String> lines()  // returns a stream of lines (JDK 11)
IntStream chars()       // returns a IntStream of characters (JDK 9)
IntStream codePoints()
R transform(Function<String, R> f)  // transforms from String to type R (JDK 12)
```

1.2 Examples

static method `String.format()` (JDK 5)

The `static` method `String.format()` (introduced in JDK 5) can be used to produce a formatted `String` using C-like `printf()`'s format specifiers. The `format()` method has the same form as `printf()`. For example,

```
String.format("%.1f", 1.234);   // returns String "1.2"
```

`String.format()` is useful if you need to produce a simple formatted `String` for some purposes (e.g., used in method `toString()`). For complex string, use `StringBuffer`/`StringBuilder` with a `Formatter`. If you simply need to send a simple formatted string to the console, use `System.out.printf()`, e.g.,

```
System.out.printf("%.1f", 1.234);
```

[TODO] More examples

1.3 New Methods

JDK 9 new methods

- `.chars()|.codePoints() -> IntStream`

JDK 9 new methods

- NIL

JDK 11 new methods

- `.repeat(int count) -> String`
- `.strip()|.stripLeading()|.stripTrailing() -> String` and `.isBlank() -> boolean` which are unicode white-space aware.
- `.lines()` to produces a `Stream<String>`. (JDK 9 added `.chars()` and `.codePoints()` to produce an `IntStream`.)

JDK 12 new methods

- `.indent(int n) -> String`
- `.transform(Function<String,R> f) -> R`
- `.describeConstable() -> Optional<String>`
- `.resolveConstantDesc() -> String`

JDK 13 new methods

- NIL

2. String is Really Special!

Strings receive *special treatment* in Java, because they are used frequently in a program. Hence, efficiency (in terms of computation and storage) is crucial.

The designers of Java decided to retain primitive types in an object-oriented language, instead of making everything an object, so as to improve the performance of the language. Primitives are stored in the method stack, which require less storage spaces and are cheaper to manipulate. On the other hand, objects are stored in the program heap, which require complex memory management and more storage spaces.

For performance reason, Java's `String` is designed to be in between a primitive and an object. The special features in `String` include:

- The `'+'` operator, which performs addition on primitives (such as `int` and `double`), is overloaded to operate on `String` objects. `'+'` performs concatenation for two `String` operands.
  Java does not support *operator overloading* for software engineering consideration. In a language that supports operator overloading like C++, you can turn a `'+'` operator to perform a subtraction, resulted in poor codes. The `'+'` operator is the *only* operator that is internally overloaded to support string concatenation in Java. Take note that `'+'` does not work on any two arbitrary objects, such as `Point`s or `Circle`s.
- A `String` can be constructed by either:
  - directly assigning a string *literal* to a `String` reference - *just like a primitive*, or
  - via the "new" operator and constructor, similar to any other classes. However, this is not commonly-used and is not recommended.

  For example,

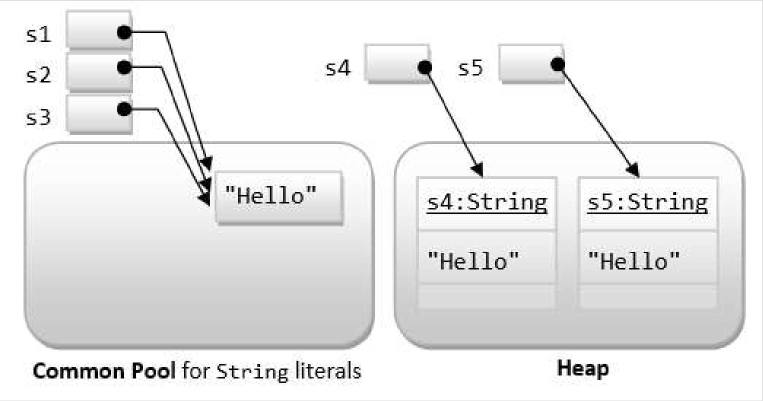
  ```
  String str1 = "Java is Hot";           // Implicit construction via string literal
  String str2 = new String("I'm cool");  // Explicit construction via new
  ```

  In the first statement, `str1` is declared as a `String` reference and initialized with a string literal `"Java is Hot"`. In the second statement, `str2` is declared as a `String` reference and initialized via the `new` operator and constructor to contain `"I'm cool"`.
- `String` literals are stored in *a common pool*. This facilitates *sharing of storage* for strings with the same contents to conserve storage. `String` objects allocated via `new` operator are stored in the heap, and there is no sharing of storage for the same contents.

2.1 String Literal vs. String Object

As mentioned, there are two ways to construct a string: implicit construction by assigning a string literal or explicitly creating a `String` object via the `new` operator and constructor. For example,

```
String s1 = "Hello";              // String literal
String s2 = "Hello";              // String literal
String s3 = s1;                   // same reference
String s4 = new String("Hello");  // String object
String s5 = new String("Hello");  // String object
```



Java has provided a special mechanism for keeping the `String` literals - in a so-called *string common pool*. If two string literals have the same contents, they will share the same storage inside the common pool. This approach is adopted to *conserve storage* for frequently-used strings. On the other hand, `String` objects created via the `new` operator and constructor are kept in the heap. Each `String` object in the heap has its own storage just like any other object. There is no sharing of storage in heap even if two `String` objects have the same contents.

You can use the method `equals()` of the `String` class to compare the contents of two `String`s. You can use the relational equality operator `'=='` to compare the references (or pointers) of two objects. Study the following codes:

```
s1 == s1;         // true, same pointer
s1 == s2;         // true, s1 and s1 share storage in common pool
s1 == s3;         // true, s3 is assigned same pointer as s1
s1.equals(s3);    // true, same contents
s1 == s4;         // false, different pointers
s1.equals(s4);    // true, same contents
s4 == s5;         // false, different pointers in heap
s4.equals(s5);    // true, same contents
```

Important Notes:

- In the above example, I used relational equality operator `'=='` to compare the references of two `String` objects. This is done to demonstrate the differences between string literals sharing storage in the common pool and `String` objects created in the heap. It is a *logical error* to use `(str1 == str2)` in your program to *compare the contents* of two `String`s.
- `String` can be created by directly assigning a `String` literal which is shared in a common pool. It is uncommon and not recommended to use the `new` operator to construct a `String` object in the heap.

2.2 String is Immutable

Since string literals with the same contents share storage in the common pool, Java's `String` is designed to be *immutable*. That is, once a `String` is constructed, its contents cannot be modified. Otherwise, the other `String` references sharing the same storage location will be affected by the change, which can be unpredictable and therefore is undesirable. Methods such as `toUpperCase()` might appear to modify the contents of a `String` object. In fact, a completely new `String` object is created and returned to the caller. The original `String` object will be deallocated, once there is no more references, and subsequently garbage-collected.

Because `String` is immutable, it is not efficient to use `String` if you need to modify your string frequently (that would create many new `String`s occupying new storage areas). For example,

```
// inefficient codes
String str = "Hello";
for (int i = 1; i < 1000; ++i) {
   str = str + i;
}
```

If the contents of a `String` have to be modified frequently, use the `StringBuffer` or `StringBuilder` class instead.

2.3 `String.intern()`

[TODO]

3. `StringBuffer` & `StringBuilder`

As explained earlier, `String`s are *immutable* because `String` literals with same content share the same storage in the string common pool. Modifying the content of one `String` directly may cause adverse side-effects to other `String`s sharing the same storage.

JDK provides two classes to support *mutable* strings: `StringBuffer` and `StringBuilder` (in core package `java.lang`). A `StringBuffer` or `StringBuilder` object is just like any ordinary object, which are stored in the heap and not shared, and therefore, can be modified without causing adverse side-effect to other objects.

`StringBuilder` class was introduced in JDK 5. It is the same as `StringBuffer` class, except that `StringBuilder` is *not synchronized* for multi-thread operations. However, for single-thread program, `StringBuilder`, without the synchronization overhead, is more efficient.

3.1 `java.lang.StringBuffer`

Read the JDK API specification for `java.lang.StringBuffer`.

```
// Constructors
StringBuffer()             // an initially-empty StringBuffer
StringBuffer(int size)     // with the specified initial size
StringBuffer(String s)     // with the specified initial content

// Length
int length()

// Methods for building up the content
StringBuffer append(type arg)  // type could be primitives, char[], String, StringBuffer, etc
StringBuffer insert(int offset, arg)

// Methods for manipulating the content
StringBuffer delete(int fromIdx, int toIdx)
StringBuffer deleteCharAt(int idx)
void setLength(int newSize)
void setCharAt(int idx, char newChar)
StringBuffer replace(int fromIdx, int toIdx, String s)
StringBuffer reverse()

// Methods for extracting whole/part of the content
char charAt(int idx)
String substring(int fromIdx)
String substring(int fromIdx, int toIdx)
String toString()

// Indexing
int indexOf(String key)
int indexOf(String key, int fromIdx)
int lastIndexOf(String key)
int lastIndexOf(String key, int fromIdx)
```

Take note that `StringBuffer` is an ordinary object. You need to use a constructor to create a `StringBuffer` (instead of assigning to a `String` literal). Furthermore, `'+'` operator does not apply to objects, including the `StringBuffer`. You need to use a proper method such as `append()` or `insert()` to manipulating a `StringBuffer`.

To create a string from parts, It is more efficient to use `StringBuffer` (multi-thread) or `StringBuilder` (single-thread) instead of via `String` concatenation. For example,

```
// Create a string of YYYY-MM-DD HH:MM:SS
int year = 2010, month = 10, day = 10;
int hour = 10, minute = 10, second = 10;
String dateStr = new StringBuilder()
      .append(year).append("-").append(month).append("-").append(day).append(" ")
      .append(hour).append(":").append(minute).append(":").append(second).toString();
System.out.println(dateStr);

// StringBuilder is more efficient than String concatenation
String anotherDataStr = year + "-" + month + "-" + day + " " + hour + ":" + minute + ":" + second;
System.out.println(anotherDataStr);
```

JDK compiler, in fact, uses both `String` and `StringBuffer` to handle string concatenation via the `'+'` operator. For examples,

```
String msg = "a" + "b" + "c";
```

will be compiled into the following codes for better efficiency:

```
String msg = new StringBuffer().append("a").append("b").append("c").toString();
```

Two objects are created during the process, an intermediate `StringBuffer` object and the returned `String` object.

Rule of Thumb: `String`s are more efficient if they are not modified (because they are shared in the string common pool). However, if you have to modify the content of a string frequently (such as a status message), you should use the `StringBuffer` class (or the `StringBuilder` described below) instead.

3.2 `java.lang.StringBuilder` (JDK 5)

JDK 5 introduced a new `StringBuilder` class (in package `java.lang`), which is almost identical to the `StringBuffer` class, except that it is *not synchronized*. In other words, if multiple threads are accessing a `StringBuilder` instance at the same time, its integrity cannot be guaranteed. However, for a single-thread program (most commonly), doing away with the overhead of synchronization makes the `StringBuilder` faster.

`StringBuilder` is API-compatible with the `StringBuffer` class, i.e., having the same set of constructors and methods, but with no guarantee of synchronization. It can be a drop-in replacement for `StringBuffer` under a *single-thread* environment.

3.3 Benchmarking `String/StringBuffer/StringBuilder`

The following program compare the times taken to reverse a long string via a `String` object and a `StringBuffer`.

```
// Reversing a long String via a String vs. a StringBuffer
public class StringsBenchMark {
   public static void main(String[] args) {
      long beginTime, elapsedTime;

      // Build a long string
      String str = "";
      int size = 16536;
      char ch = 'a';
      beginTime = System.nanoTime();   // Reference time in nanoseconds
      for (int count = 0; count < size; ++count) {
         str += ch;
         ++ch;
         if (ch > 'z') {
            ch = 'a';
         }
      }
      elapsedTime = System.nanoTime() - beginTime;
      System.out.println("Elapsed Time is " + elapsedTime/1000 + " usec (Build String)");

      // Reverse a String by building another String character-by-character in the reverse order
      String strReverse = "";
      beginTime = System.nanoTime();
      for (int pos = str.length() - 1; pos >= 0 ; pos--) {
         strReverse += str.charAt(pos);   // Concatenate
      }
      elapsedTime = System.nanoTime() - beginTime;
      System.out.println("Elapsed Time is " + elapsedTime/1000 + " usec (Using String to reverse)");

      // Reverse a String via an empty StringBuffer by appending characters in the reverse order
      beginTime = System.nanoTime();
      StringBuffer sBufferReverse = new StringBuffer(size);
      for (int pos = str.length() - 1; pos >= 0 ; pos--) {
         sBufferReverse.append(str.charAt(pos));      // append
      }
      elapsedTime = System.nanoTime() - beginTime;
      System.out.println("Elapsed Time is " + elapsedTime/1000 + " usec (Using StringBuffer to reverse)");

      // Reverse a String by creating a StringBuffer with the given String and invoke its reverse()
      beginTime = System.nanoTime();
      StringBuffer sBufferReverseMethod = new StringBuffer(str);
      sBufferReverseMethod.reverse();     // use reverse() method
      elapsedTime = System.nanoTime() - beginTime;
      System.out.println("Elapsed Time is " + elapsedTime/1000 + " usec (Using StringBuffer's reverse() method)");

      // Reverse a String via an empty StringBuilder by appending characters in the reverse order
      beginTime = System.nanoTime();
      StringBuilder sBuilderReverse = new StringBuilder(size);
      for (int pos = str.length() - 1; pos >= 0 ; pos--) {
         sBuilderReverse.append(str.charAt(pos));
      }
      elapsedTime = System.nanoTime() - beginTime;
      System.out.println("Elapsed Time is " + elapsedTime/1000 + " usec (Using StringBuilder to reverse)");

      // Reverse a String by creating a StringBuilder with the given String and invoke its reverse()
      beginTime = System.nanoTime();
      StringBuffer sBuilderReverseMethod = new StringBuffer(str);
      sBuilderReverseMethod.reverse();
      elapsedTime = System.nanoTime() - beginTime;
      System.out.println("Elapsed Time is " + elapsedTime/1000 + " usec (Using StringBuidler's reverse() method)");
   }
}
```

```
Elapsed Time is 332100 usec (Build String)
Elapsed Time is 346639 usec (Using String to reverse)
Elapsed Time is 2028 usec   (Using StringBuffer to reverse)
Elapsed Time is 847 usec    (Using StringBuffer's reverse() method)
Elapsed Time is 1092 usec   (Using StringBuilder to reverse)
Elapsed Time is 836 usec    (Using StringBuidler's reverse() method)
```

Observe `StringBuilder` is 2x faster than `StringBuffer`, and 300x faster than `String`. The `reverse()` method is the fastest, which take about the same time for `StringBuilder` and `StringBuffer`.

4. `java.util.StringTokenizer` (Obsoleted by regex)

Very often, you need to break a line of texts into tokens delimited by white spaces. The `java.util.StringTokenizer` class supports this.

For example, the following program reverses the words in a String.

```
import java.util.StringTokenizer;
/**
 * Reverse the words in a String using StringTokenizer
 */
public class StringTokenizerTest {
   public static void main(String[] args) {
      String str = "Monday Tuesday Wednesday Thursday Friday Saturday Sunday";
      String strReverse;
      StringBuilder sb = new StringBuilder();
      StringTokenizer st = new StringTokenizer(str);

      while (st.hasMoreTokens()) {
         sb.insert(0, st.nextToken());
         if (st.hasMoreTokens()) {
            sb.insert(0, " ");
         }
      }
      strReverse = sb.toString();
      System.out.println(strReverse);
   }
}
```

```
// Constructors
StringTokenizer(String s)  // Constructs a StringTokenizer for the given string,
                           // using the default delimiter set of " \t\n\r\f"
                           // (i.e., blank, tab, newline, carriage-return, and form-feed).
                           // Delimiter characters themselves will not be treated as tokens.
StrintTokenizer(String s, String delimiterChars)  // Use characters in delimiterSet as delimiters.

// Methods
boolean hasNextToken()     // Returns true if next token available
String nextToken()         // Returns the next token
```

For example,

```
// Code Sample
StringTokenizer tokenizer = new StringTokenizer(aString);
while (tokenizer.hasNextToken()) {
   String token = tokenizer.nextToken();
   .....
}
```

The JDK documentation stated that "`StringTokenizer` is a legacy class that is retained for compatibility reasons although its use is discouraged in new code. It is recommended that anyone seeking this functionality use the `split()` method of `String` or the `java.util.regex` package instead."

For example, the following program uses the `split()` method of the `String` class to reverse the words of a `String`.

```
/**
 * Reverse the words in a String using split() method of the String class
 */
public class StringSplitTest {
   public static void main(String[] args) {
      String str = "Monday Tuesday Wednesday Thursday Friday Saturday Sunday";
      String[] tokens = str.split("\\s");  // white space '\s' as delimiter
      StringBuilder sb = new StringBuilder();
      for (int i = 0; i < tokens.length; ++i) {
         sb.insert(0, tokens[i]);
         if (i < tokens.length - 1) {
            sb.insert(0, " ");
         }
      }
      String strReverse = sb.toString();
      System.out.println(strReverse);
   }
}
```

5. Regular Expression (Regex), Patterns & Matches (JDK 4)

Read "Regular Expression in Java".

6. Super-Interface `CharSequence` for `String`, `StringBuffer` and `StringBuilder` (since JDK 4)

The interface `java.lang.CharSequence` is implemented by classes `String`, `StringBuffer`, `StringBuilder`, `CharBuffer` and `Segment`.

It defines the common behavior via these `abstract` methods:

```
// java.lang.CharSequence
abstract charAt(int index) -> char
abstract length() -> int
abstract subSequence(int fromIdx, int toIdx) -> CharSequence
abstract toString() -> String
```

JDK 8 added two `default` methods into the interface:

```
// java.lang.CharSequence (JDK 8)
default chars() -> IntStream
default codePoints() -> IntStream
```

JDK 11 added one `static` methods into the interface:

```
// java.lang.CharSequence (JDK 11)
static compare(CharSequence cs1, CharSequence cs2) -> int
```

LINK TO JAVA REFERENCES & RESOURCES

Latest version tested: JDK 1.13.1
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Feedback, comments, corrections, and errata can be sent to Chua Hock-Chuan (ehchua@ntu.edu.sg) | HOME