

Enough `java.lang.String` to Hang Ourselves ...

Dr Heinz M. Kabutz, Dmitry Vyazelenko

Last Updated 2018-10-16



Javaspecialists.eu
java training

Converting `int val` to a `String`?

1. `"" + val`
2. `Integer.toString(val)`
3. `Integer.valueOf(val)`
4. `String.valueOf(val)`
5. `Integer.getInteger(val)`

Which do you think is fastest?

```
String appendBasic(String question, String answer1, String answer2) {  
    return "<h1>" + question + "</h1><ol><li>" + answer1 +  
        "</li><li>" + answer2 + "</li></ol>";  
}  
  
String appendStringBuilder(String question, String answer1, String answer2) {  
    return new StringBuilder().append("<h1>").append(question)  
        .append("</h1><ol><li>").append(answer1)  
        .append("</li><li>").append(answer2)  
        .append("</li></ol>").toString();  
}  
  
String appendStringBuilderSize(String question, String answer1, String answer2) {  
    int len = 36 + question.length() + answer1.length() + answer2.length();  
    return new StringBuilder(len).append("<h1>").append(question)  
        .append("</h1><ol><li>").append(answer1)  
        .append("</li><li>").append(answer2)  
        .append("</li></ol>").toString();  
}
```

When the Dinosaurs Roamed the Earth - Java 1.0

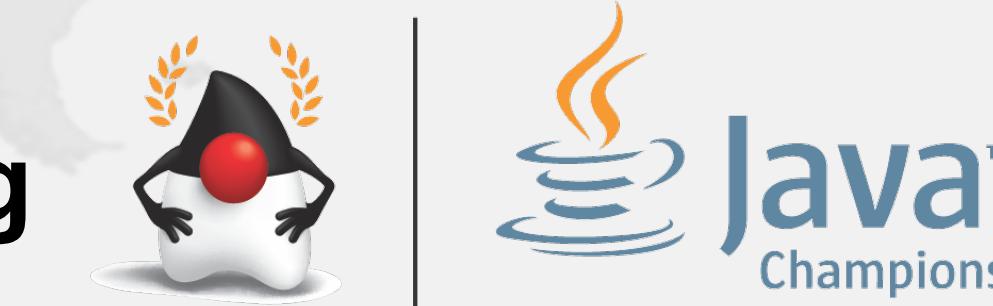
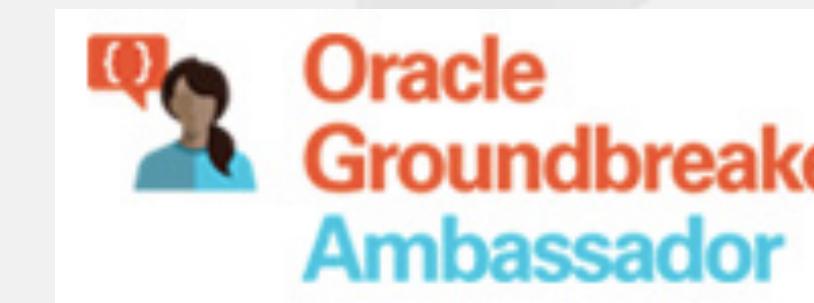
- **Fields:**
 - `private char value[];`
 - `private int offset;`
 - `private int count;`
- **hashCode()** used samples of chars if String was longer than 16
- **equals()** did not check if `obj == this`
- **intern()** used a static Hashtable
 - Memory Leak
- **StringBuffer** a modifiable, thread-safe version
 - `toString()` shared the underlying `char[]` unless it was later modified

hashCode() in String 1.0

```
public int hashCode() {  
    int h = 0;  
    int off = offset;  
    char val[] = value;  
    int len = count;  
  
    if (len < 16) {  
        for (int i = len ; i > 0; i--) {  
            h = (h * 37) + val[off++];  
        }  
    } else {  
        // only sample some characters  
        int skip = len / 8;  
        for (int i = len ; i > 0; i -= skip, off += skip) {  
            h = (h * 39) + val[off];  
        }  
    }  
    return h;  
}
```

Who's Who

- **Dmitry Vyazelenko @DVyazelenko**
 - Software engineer, JCrete Chief Disorganizer
- **Heinz Kabutz @heinzkabutz**
 - JCrete Unfounder
 - Java Specialists Newsletter
 - www.javaspecialists.eu
 - Oracle Groundbreaker Ambassador
 - developer.oracle.com/devo/ambassadors
 - Java Champion
 - www.javachampions.org



www.jcrete.org



Early Hunter Gatherer - Java 1.1

- Fields stayed the same
- `hashCode()` still sampling
- `intern()` moved to native code
 - Not necessarily better than Java
- `toUpperCase()` added some weird edge cases such as ß → SS

Discovering Fire - Java 1.2

- Fields still the same
- `hashCode()` changed to

```
public int hashCode() {  
    int h = 0;  
    int off = offset;  
    char val[] = value;  
    int len = count;  
  
    for (int i = 0; i < len; i++)  
        h = 31*h + val[off++];  
  
    return h;  
}
```

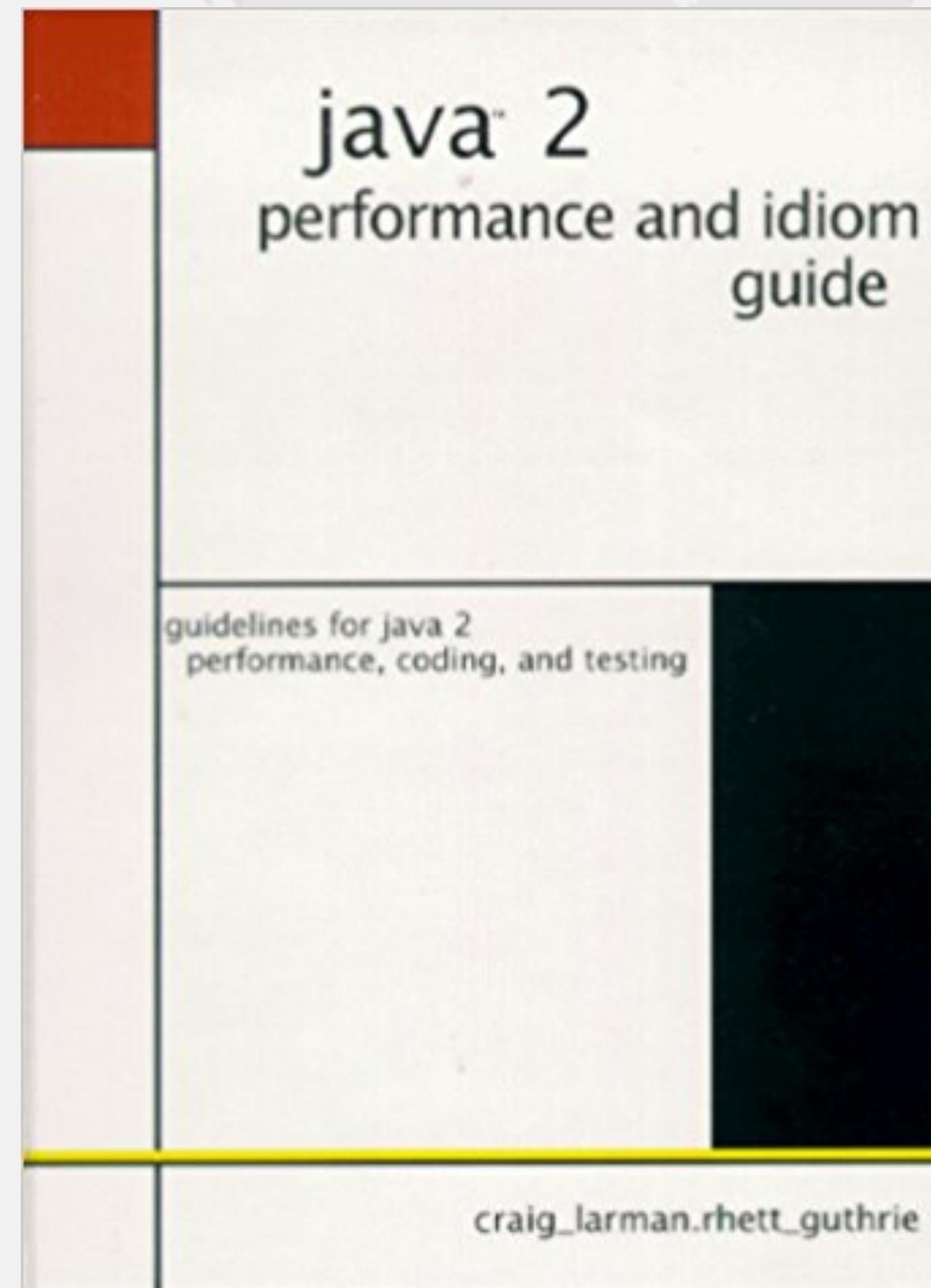
- Broke a bunch of code
- Introduced the Comparable interface

Old Hash vs New Hash Calculation Performance

- Java 1.0 and 1.1 calculation was $O(1)$ - constant time
- Java 1.2 calculation is $O(n)$ - linear time

Java 2 Performance and Idiom Guide

- Proposed wrapping `String` with own object and caching hash code



Why Caching Hash Codes Seldom Helps

- How long to `put()` 30x?
- How long to `get()` 30x?
 - If you are going to keep keys for maps around, why not just keep the values?

```
public class Key {  
    private final int id;  
  
    public Key(int id) { this.id = id; }  
  
    public int hashCode() {  
        try {  
            Thread.sleep(100); // now THIS is slow  
        } catch (InterruptedException e) {  
            Thread.currentThread().interrupt();  
        }  
        return id;  
    }  
  
    public boolean equals(Object obj) {  
        if (!(obj instanceof Key)) return false;  
        return id == ((Key)obj).id;  
    }  
}
```

Stone Age - Java 1.3

- **Fields:**

- **private char value[];**
- **private int offset;**
- **private int count;**
- **private int hash; ←**

- **So is String really immutable?**

```
public int hashCode() {  
    int h = hash;  
    if (h == 0) {  
        int off = offset;  
        char val[] = value;  
        int len = count;  
  
        for (int i = 0; i < len; i++)  
            h = 31*h + val[off++];  
        hash = h;  
    }  
    return h;  
}
```

What Do These Strings Have in Common?

"ARbyguv", "ARbygvW", "ARbyhVv", "ARbyhWW", "ARbzHuv", "ARbzHvW", "ARbzIVv", "ARbzIW",
"ARcZgув", "ARcZgvW", "ARcZhVv", "ARcZhWW", "ASCyгуv", "ASCygvW", "ASCyhVv", "ASCyhWW",
"ASCzHuv", "ASCzHvW", "ASCzIVv", "ASCzIW", "ASDZгуv", "ASDZgvW", "ASDZhVv", "ASDZhWW",
"bmгkAEs", "bmгkAFT", "bmhLAEs", "bmhLAFT", "bnHkAEs", "bnHkAFT", "bnILAЕs", "bnILAFT",
"cNгkAEs", "cNгkAFT", "cNhLAEs", "cNhLAFT", "c0HkAEs", "c0HkAFT", "c0ILAЕs", "c0ILAFT",
"Elcnfnz", "Elcng0z", "ElcoGnz", "ElcoH0z", "Eld0fnz", "Eld0g0z", "EldPGnz", "EldPH0z",
"EmDnfnz", "EmDng0z", "EmDoGnz", "EmDoH0z", "EmE0fnz", "EmE0g0z", "EmEPGnz", "EmEPH0z",
"FMcnfnz", "FMcng0z", "FMcoGnz", "FMcoH0z", "FMd0fnz", "FMd0g0z", "FMdPGnz", "FMdPH0z",
"FNDnfnz", "FNDng0z", "FNDoGnz", "FNDoH0z", "FNE0fnz", "FNE0g0z", "FNEPGnz", "FNEPH0z",
"Obdwdaс", "ObdwdbD", "ObdweBc", "ObdweCD", "ObdxEac", "ObdxEbD", "ObdxFBc", "ObdxFCD",
"ObеXdaс", "ObеXdbD", "ObеXeBc", "ObеXeCD", "ObеYEac", "ObеYEbD", "ObеYFBc", "ObеYFCD",
"0cEwdac", "0cEwdbD", "0cEweBc", "0cEweCD", "0cExEac", "0cExEbD", "0cExFBc", "0cExFCD",
"0cFXdac", "0cFXdbD", "0cFXeBc", "0cFXeCD", "0cFYEac", "0cFYEbD", "0cFYFBc", "0cFYFCD",
"PCdwdac", "PCdwdbD", "PCdweBc", "PCdweCD", "PCdxEac", "PCdxEbD", "PCdxFBc", "PCdxFCD",
"PCeXdac", "PCeXdbD", "PCeXeBc", "PCeXeCD", "PCeYEac", "PCeYEbD", "PCeYFBc", "PCeYFCD",
"PDEwdac", "PDEwdbD", "PDEweBc", "PDEweCD", "PDExEac", "PDExEbD", "PDExFBc", "PDExFCD",
"PDFXdac", "PDFXdbD", "PDFXeBc", "PDFXeCD", "PDFYEac", "PDFYEbD", "PDFYFBc", "PDFYFCD",
"Xwfaark", "XwfaasL", "XwfabSk", "XwfabTL", "XwfbBrk", "XwfbBsL", "XwfbCSk", "XwfbCTL",
"XwgBark", "XwgBasL", "XwgBbSk", "XwgBbTL", "XwgCBrk", "XwgCBSL", "XwgCCSk", "XwgCCTL",
"XxGaark", "XxGaasL", "XxGabSk", "XxGabTL", "XxGbBrk", "XxGbBsL", "XxGbCSk", "XxGbCTL",
"XxHBark", "XxHBasL", "XxHBbSk", "XxHBbTL", "XxHCBrk", "XxHCBsL", "XxHCCSk", "XxHCCTL",
"zsjpxah", "zsjpxbI", "zsjpyBh", "zsjpyCI", "zsjqYah", "zsjqYbI", "zsjqZBh", "zsjqZCI",

All Those Strings Have `hashCode() == 0`

- Plus any combination of these Strings also have `hashCode` of 0
 - Thus we can produce an endless sequence of such Strings
 - `"zsjpyClcOHkAEsObeXeCDASCzIVv".hashCode() == 0`
- Why is this so bad?

Bucket Collisions

- Can attack server by sending lots of Strings with same hashCode
 - Very easy to do when == 0
- Both `put()` and `get()` become linear

Brief History Lesson of String - Java 1.4

- Fields same as 1.3
- Introduced CharSequence interface
- Regular expressions
 - Methods like `matches()`, `split()`, etc.

Before we go on ...

- Adding Strings together

```
public class Hello {  
    public static void main(String[] args) {  
        System.out.println("Hello " + args[0]);  
    }  
}
```

- Became (Java 1.0 - 1.4)

```
public class Hello {  
    public static void main(String[] args) {  
        System.out.println(new StringBuffer().append("Hello ")  
            .append(args[0]).toString());  
    }  
}
```

- `new StringBuffer()` would create an array of 16 characters

Brief History Lesson of String - Java 1.5

- Fields same as 1.3, but marked final (except for hash)
- Code points introduced
 - 32-bit characters
- `StringBuilder` as unsynchronized `StringBuffer`
 - `char[]` no longer shared with created `Strings`
- Needed to recompile all code
 - And hand-crafted `StringBuffer` code would now typically be slower than +

Brief History Lesson of String - Java 1.6

- Not much changed since 1.5
- **-XX:+UseCompressedStrings**
 - `byte[]` when 7-bit ASCII
 - otherwise `char[]`
- **-XX:+OptimizeStringConcat**
 - `char[]` could in some cases be shared between `StringBuilder/Buffer` and `String`

Quiz 2: StringAppenderBenchmark.append Strings

	1.6.0_113	1.7.0_191	1.8.0_172	11
appendBasic	61 ns/op 208 B/op	56 ns/op 200 B/op	58 ns/op 200 B/op	75 ns/op 120 B/op
appendString Builder	61 ns/op 208 B/op	56 ns/op 200 B/op	58 ns/op 200 B/op	75 ns/op 120 B/op
appendString BuilderSize	57 ns/op 208 B/op	57 ns/op 200 B/op	58 ns/op 200 B/op	75 ns/op 120 B/op

Brief History Lesson of String - Java 1.7

Fields:

- private final char value[];
 - private int hash;
 - private transient int hash32 = 0; // used to avoid DOS attacks on HashMap

-Djdk.map.althashing.threshold=

- new constructor `String(char[], boolean unshared)`

- `SharedSecrets.getJavaLangAccess().newStringUnsafe(char[])`
 - Demo
 - Moved out of harm's way since Java 9

- `String.substring()` now creates new `char[]`s

- **SubbableString** alternative - demo
 - Newsletter 230 - <https://www.javaspecialists.eu/archive/Issue230.html>

Brief History Lesson of String - Java 1.8

- **Fields:**
 - `private final char value[];`
 - `private int hash;`
- **static methods for joining several Strings**
- **Deduplication of `char[]`s**
- **Hash Maps use trees in case of too many bucket collisions**

String Deduplication

- Java 1.8.0_20 can replace `char[]`s of duplicate strings
 - Only works for the G1 collector `-XX:+UseStringDeduplication`
 - Threshold when deduplicated `-XX:StringDeduplicationAgeThreshold`

```
public class DeduplicationDemo {  
    public static void main(String... args) throws Exception {  
        char[] heinz = {'h', 'e', 'i', 'n', 'z'};  
        String[] s = {new String(heinz), new String(heinz),};  
        Field value = String.class.getDeclaredField("value");  
        value.setAccessible(true);  
        System.out.println("Before GC");  
        System.out.println(value.get(s[0]));  
        System.out.println(value.get(s[1]));  
        System.gc(); Thread.sleep(100);  
        System.out.println("After GC");  
        System.out.println(value.get(s[0]));  
        System.out.println(value.get(s[1]));  
    }  
}
```

Before GC
[C@76ed5528
[C@2c7b84de
After GC
[C@2c7b84de
[C@2c7b84de

Deduplication vs `intern()` vs Roll Own

- **`new String("Hello World!")` in Java 11 64-bit compressed OOPS**
 - `String`: 12 (header) + 4 (value) + 4 (hash) + 1 (coder) \approx 24 bytes
 - `byte[]`: 12 (header) + 12 (bytes) + 4 (length) \approx 32 bytes
 - **Total: 56 bytes**
- **Deduplication saves 32 bytes automagically**
- **`intern()` saves 56 bytes, but at high cost**
 - Intern table does not grow and slower than `ConcurrentHashMap`
- **Own `ConcurrentHashMap` with `putIfAbsent(s, s)` saves 56 bytes**
 - But potential memory leak as unused `Strings` never deleted
 - In theory could use `WeakReference`, but that causes other performance issues

Brief History Lesson of String - Java 9 / 10 / 11

- **Fields:**
 - `private final byte[] value;`
 - `private final byte coder;`
 - `private int hash;`
- **Latin1 are one byte per character, everything else two bytes**
 - Most methods are a lot more complicated
- **`chars()` returns an `IntStream` of contents of `String`**
- **`+` is no longer compiled to `StringBuilder`**
 - `StringConcatFactory`
 - Demo and look at benchmarks: <https://github.com/kabutz/string-performance>

JEP 254: Compact Strings

- **char[] replaced with byte[]**
- **Saves space if characters fit into a byte (i.e. Latin1)**
- **kill switch -XX:-CompactStrings**
- **Max String length is now half of what it was**
 - Whether compact Strings disabled or not Latin1 String

StringAppenderBenchmark Mixed Parameters

	1.6.0_113	1.7.0_191	1.8.0_172	11
plus	319 ns/op 896 B/op	317 ns/op 864 B/op	333 ns/op 864 B/op	127 ns/op 152 B/op
sb_sized	220 ns/op 536 B/op	230 ns/op 504 B/op	245 ns/op 504 B/op	259 ns/op 280 B/op
sb	320 ns/op 896 B/op	316 ns/op 864 B/op	332 ns/op 864 B/op	303 ns/op 488 B/op
concat	644 ns/op 2024 B/op	576 ns/op 1712 B/op	590 ns/op 1664 B/op	368 ns/op 960 B/op
message_format	980 ns/op 1600 B/op	1036 ns/op 1744 B/op	1013 ns/op 1744 B/op	1026 ns/op 984 B/op
format	4088 ns/op 3560 B/op	3541 ns/op 3504 B/op	3208 ns/op 3304 B/op	3855 ns/op 1896 B/op

NumberToStringBenchmark +/- CompactStrings

	+CompactStrings (default)	-CompactStrings
int_plus	33 ns/op 56 B/op	26 ns/op 64 B/op
int_toString	34 ns/op 56 B/op	29 ns/op 64 B/op
long_plus	53 ns/op 64 B/op	56 ns/op 80 B/op
long_toString	53 ns/op 64 B/op	58 ns/op 80 B/op

StringAppenderBenchmark +/- CompactStrings

	+CompactStrings	-CompactStrings
<code>plus</code>	127 ns/op, 152 B/op	135 ns/op, 264 B/op
<code>sb_sized</code>	259 ns/op, 304 B/op	247 ns/op, 528 B/op
<code>sb</code>	302 ns/op, 512 B/op	316 ns/op, 888 B/op
<code>concat</code>	369 ns/op, 1224 B/op	408 ns/op, 1928 B/op
<code>message_format</code>	1026 ns/op, 984 B/op	948 ns/op, 1408 B/op
<code>format</code>	3855 ns/op, 1872 B/op	3647 ns/op, 2296 B/op

JEP 280: Indify String Concatenation

- **Uses invokedynamic for String concatenation**
- **Bytecode generator**
 - `BC_SB` - like old Java 5 + concatenation
 - `BC_SB_SIZED`
 - `BC_SB_SIZED_EXACT`
- **MethodHandles**
 - `MH_SB_SIZED`
 - `MH_SB_SIZED_EXACT`
 - `MH_INLINE_SIZED_EXACT` (default)
 - Converts non-primitives, float and double to String using `StringifierMost`
 - Uses `StringConcatHelper#mixLen` to compute exact sizes for other primitives

StringAppenderBenchmark.plus

- `-Djava.lang.invoke.stringConcat=...`

	plus with mixed values
<code>MH_INLINE_SIZED_EXACT</code>	127 ns/op, 152 B/op
<code>BC_SB_SIZED_EXACT</code>	157 ns/op, 208 B/op
<code>MH_SB_SIZED</code>	251 ns/op, 328 B/op
<code>BC_SB_SIZED</code>	255 ns/op, 328 B/op
<code>MH_SB_SIZED_EXACT</code>	290 ns/op, 408 B/op
<code>BC_SB</code>	301 ns/op, 512 B/op

Intrinsics in Java 8 (<https://github.com/apangin>)

```
_compareTo  
_indexOf  
_equals  
_String_String  
_StringBuilder_void  
_StringBuilder_int  
_StringBuilder_String  
_StringBuilder_append_char  
_StringBuilder_append_int  
_StringBuilder_append_String  
_StringBuilder_toString
```

// similarly for `StringBuffer`

```
int String.compareTo(String)  
int String.indexOf(String)  
boolean String.equals(Object)  
String(String)  
StringBuilder()  
StringBuilder(int)  
StringBuilder(String)  
StringBuilder StringBuilder.append(char)  
StringBuilder StringBuilder.append(int)  
StringBuilder StringBuilder.append(String)  
String StringBuilder.toString()
```

Intrinsics in Java 9

```
_compressStringC
_compressStringB
_inflateStringC
_inflateStringB
_toBytesStringU
_getCharsStringU
_getCharStringU
_putCharStringU
_COMPARE_TO_L
_COMPARE_TO_U
_COMPARE_TO_L_U
_COMPARE_TO_U_L
_indexOfL
_indexOfU
_indexOfUL
_indexOfIL
_indexOfIU
_indexOfIUL
_indexOfU_char
_equalsL
_equalsU
_String_String
_hasNegatives
_encodeByteISOArray
_StringBuilder_void
_StringBuilder_int
_StringBuilder_String
_StringBuilder_append_char
_StringBuilder_append_int
_StringBuilder_append_String
_StringBuilder_toString
StringUTF16.compress([CI[BII])I
StringUTF16.compress([BI[BII])I
StringLatin1.inflate([BI[CII])V
StringLatin1.inflate([BI[BII))V
StringUTF16.toBytes([CII)[B
StringUTF16.getChars([BII[CI)V
StringUTF16.getChar([BI)C
StringUTF16.putChar([BII)V
StringLatin1.compareTo([B[B))I
StringUTF16.compareTo([B[B))I
StringLatin1.compareToUTF16([B[B))I
StringUTF16.compareToLatin1([B[B))I
StringLatin1.indexOf([B[B))I
StringUTF16.indexOf([B[B))I
StringUTF16.indexOfLatin1([B[B))I
StringLatin1.indexOf([BI[BII))I
StringUTF16.indexOf([BI[BII))I
StringUTF16.indexOfLatin1([BI[BII))I
StringUTF16.indexOfChar([BIII))I
StringLatin1.equals([B[B))Z
StringUTF16.equals([B[B))Z
String.<init>(LString;)V
StringCoding.hasNegatives([BII))Z
StringCoding.implEncodeISOArray([BI[BII))I
StringBuilder.<init>()V
StringBuilder.<init>(I)V
StringBuilder.<init>(LString;)V
StringBuilder.append(C)LStringBuilder;
StringBuilder.append(I)LStringBuilder;
StringBuilder.append(LString;)LStringBuilder;
StringBuilder.toString()LString;
```

`java.lang.String#equals`

```
public boolean equals(Object anObject) {  
    if (this == anObject) {  
        return true;  
    }  
    if (anObject instanceof String) {  
        String aString = (String)anObject;  
        if (coder() == aString.coder()) {  
            return isLatin1() ? StringLatin1.equals(value, aString.value)  
                            : StringUTF16.equals(value, aString.value);  
        }  
    }  
    return false;  
}
```

`java.lang.StringLatin1#equals`

```
public static boolean equals(byte[] value, byte[] other) {  
    if (value.length == other.length) {  
        for (int i = 0; i < value.length; i++) {  
            if (value[i] != other[i]) {  
                return false;  
            }  
        }  
        return true;  
    }  
    return false;  
}
```

Note: Deduplication not taken into account

`StringIntrinsicsBenchmark`

	length=10	length=1 000	length=100 000
<code>hand_rolled</code>	11 ns/op	350 ns/op	33415 ns/op
<code>string_equals</code>	8 ns/op	34 ns/op	3944 ns/op

`intern()`

- Constant Strings in different classes point to same object
 - We can use the same constant table with `intern()`
- Debugging intern table
 - View events with `-XX:+PrintStringTableStatistics`
 - Extend table with `-XX:StringTableSize=n`
 - 1009 up until Java 6, 60013
 - `jcmd` in Java 9 can show details with `VM.stringtable`

Lessons from Today

- **Use + instead of `StringBuilder` where possible**
 - += still needs the `StringBuilder`
- **Avoid `intern()` in your code**
 - use String Deduplication or own cache instead
- **Hashing on Strings can be particularly expensive**
 - Especially dangerous if the hash resolves to 0
- **Strings since Java 9 use `byte[]`**
 - Might use less memory. Shorter maximum String if not Latin1

Questions?

Enough `java.lang.String` to Hang Ourselves ...



Javaspecialists.eu
java training

Quiz 1: NumberToStringBenchmark

	1.6.0_113	1.7.0_191	1.8.0_172	11
int_plus	45 ns/op 72 B/op	50 ns/op 64 B/op	53 ns/op 64 B/op	33 ns/op 56 B/op
int_toString	61 ns/op 72 B/op	60 ns/op 64 B/op	59 ns/op 64 B/op	34 ns/op 56 B/op
long_plus	122 ns/op 248 B/op	118 ns/op 216 B/op	127 ns/op 216 B/op	53 ns/op 64 B/op
long_toString	85 ns/op 88 B/op	63 ns/op 80 B/op	65 ns/op 80 B/op	53 ns/op 64 B/op