

Strings in Java: Verstrickt nochmal!

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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();
}

String appendFormat(String question, String answer1, String answer2) {
    return String.format("<h1>%s</h1><ol><li>%s</li><li>%s</li></ol>",
        question, answer1, answer2);
}
```

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



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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**

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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

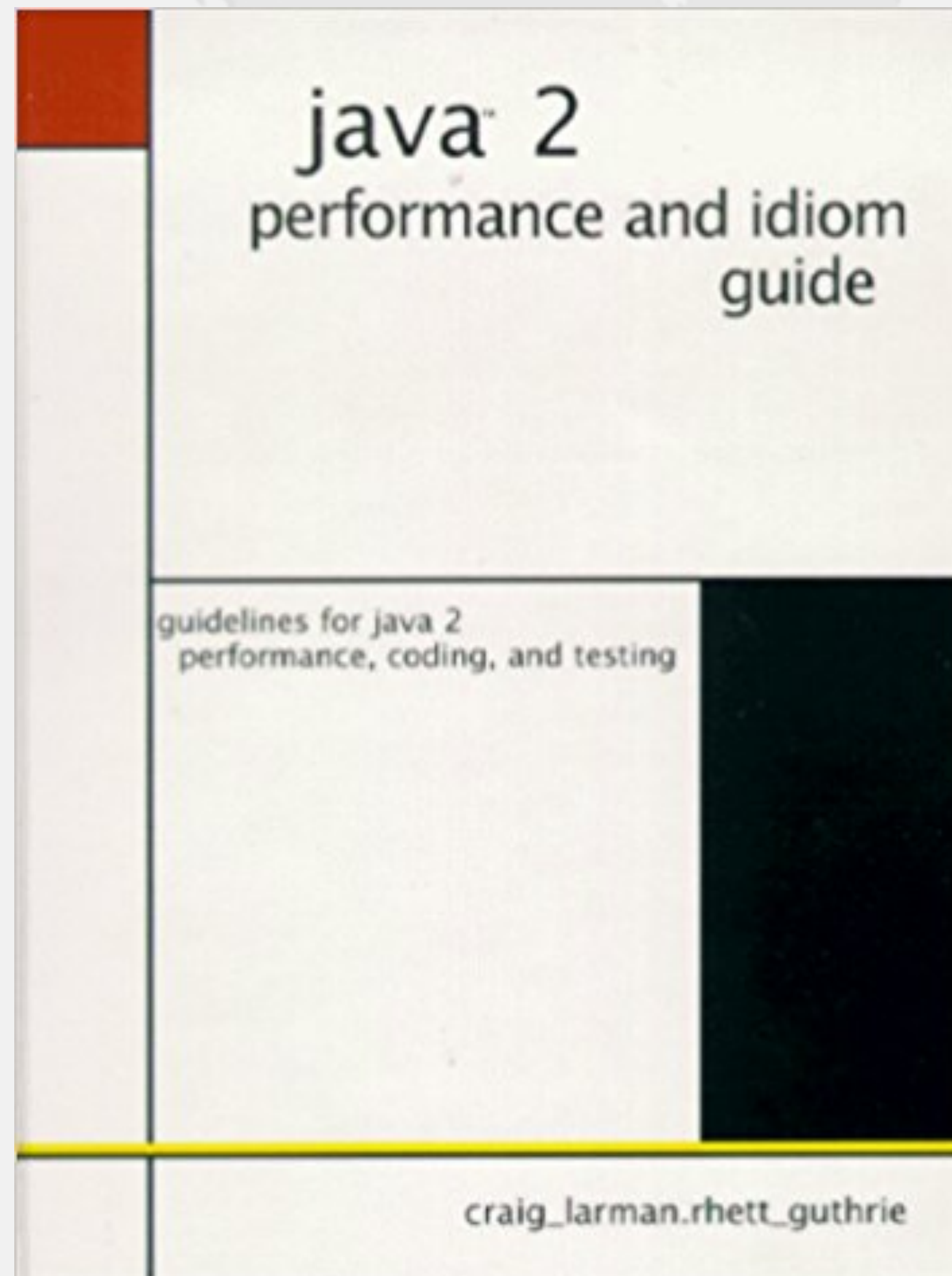
- **Java 1.0 and 1.1 calculation was $O(1)$ - constant time**
- **Java 1.2 calculation is $O(n)$ - linear time**



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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", "ARbzIWW",
 "ARcZguv", "ARcZgvW", "ARcZhVv", "ARcZhWW", "ASCyguv", "ASCygvW", "ASCyhVv", "ASCyhWW",
 "ASCzHuv", "ASCzHvW", "ASCzIVv", "ASCzIWW", "ASDZguv", "ASDZgvW", "ASDZhVv", "ASDZhWW",
 "bmgkAEs", "bmgkAFT", "bmhLAEs", "bmhLAFT", "bnHkAEs", "bnHkAFT", "bnILAEs", "bnILAFT",
 "cNgkAEs", "cNgkAFT", "cNhLAEs", "cNhLAFT", "c0HkAEs", "c0HkAFT", "c0ILAEs", "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",
 "Obdwdac", "ObdwdbD", "ObdweBc", "ObdweCD", "ObdxEac", "ObdxEbD", "ObdxFBc", "ObdxFCD",
 "ObeXdac", "ObeXdbD", "ObeXeBc", "ObeXeCD", "ObeYEac", "ObeYEbD", "ObeYFBc", "ObeYFCD",
 "OcEwdac", "OcEwdbD", "OcEweBc", "OcEweCD", "OcExEac", "OcExEbD", "OcExFBc", "OcExFCD",
 "OcFXdac", "OcFXdbD", "OcFXeBc", "OcFXeCD", "OcFYEac", "OcFYEbD", "OcFYFBc", "OcFYFCD",
 "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",
 "zsjpgah", "zsjpgbI", "zsjpgyBh", "zsjpgyCI", "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?**
- **github.com/kabutz/string-performance**
 - `eu.javaspecialists.playground.hasher.StringDOS`

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; -Djdk.map.althashing.threshold=512
- private transient int hash32 = 0; // used to avoid DOS attacks on HashMap

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

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

- **String.substring() now created new char[]s**

- SubbableString alternative
- 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 8 64-bit compressed OOPS**
 - String: 12 (header) + 4 (value) + 4 (hash) \approx 24 bytes
 - char[]: 12 (header) + 24 (12 characters) + 4 (length) = 40 bytes
 - Total: 64 bytes
- **Deduplication saves 40 bytes automatically**
- **intern() saves 64 bytes, but at high cost**
 - Until Java 10, intern table did not grow
 - jcmd in Java 9+ can show details with VM.stringtable
- **Own ConcurrentHashMap with putIfAbsent(s, s) saves 64 bytes**
 - But potential memory leak as unused Strings never deleted

Brief History Lesson of String - Java 9 / 10 / 11 / 12

● **Fields:**

- **private final byte[] value;**
- **private final byte coder;**
- **private int hash;**

Indify String Concatenation Java 9+

- **+ is no longer compiled to StringBuilder**
 - **StringConcatFactory**
 - **Demo and look at benchmarks: <https://github.com/kabutz/string-performance>**

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
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

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
MH_INLINE_SIZED_EXACT	127 ns/op, 152 B/op
BC_SB_SIZED_EXACT	157 ns/op, 208 B/op
MH_SB_SIZED	251 ns/op, 328 B/op
BC_SB_SIZED	255 ns/op, 328 B/op
MH_SB_SIZED_EXACT	290 ns/op, 408 B/op
BC_SB	301 ns/op, 512 B/op

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 +/- CompactStrings

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

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

<code>_compareTo</code>	<code>int String.compareTo(String)</code>
<code>_indexOf</code>	<code>int String.indexOf(String)</code>
<code>_equals</code>	<code>boolean String.equals(Object)</code>
<code>_String_String</code>	<code>String(String)</code>
<code>_StringBuilder_void</code>	<code>StringBuilder()</code>
<code>_StringBuilder_int</code>	<code>StringBuilder(int)</code>
<code>_StringBuilder_String</code>	<code>StringBuilder(String)</code>
<code>_StringBuilder_append_char</code>	<code>StringBuilder StringBuilder.append(char)</code>
<code>_StringBuilder_append_int</code>	<code>StringBuilder StringBuilder.append(int)</code>
<code>_StringBuilder_append_String</code>	<code>StringBuilder StringBuilder.append(String)</code>
<code>_StringBuilder_toString</code>	<code>String StringBuilder.toString()</code>

// similarly for StringBuffer

Intrinsics in Java 11

```

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

@HotSpotIntrinsicCandidate

```
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;  
}
```

Using Arrays.mismatch()

```
// Probably how it is implemented in the intrinsic  
private static boolean equals(byte[] value, byte[] other) {  
    if (value.length == other.length) {  
        return Arrays.mismatch(value, other) == -1;  
    }  
    return false;  
}
```

Note: Deduplication not taken into account with String.equals

	length=4	length=16	length=64	length=256
string_equals	7 ns/op	9 ns/op	8 ns/op	15 ns/op
mismatch_equals	8 ns/op	9 ns/op	11 ns/op	19 ns/op
hand_rolled	7 ns/op	14 ns/op	29 ns/op	97 ns/op

Lessons from Today

- **Use + instead of StringBuilder where possible**
 - Recompile classes for Java 9+
- **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
- **github.com/kabutz/string-performance**

Please vote



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