Compact Strings: A Memory-Efficient Internal Representation for Strings

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  We encourage questions and discussions

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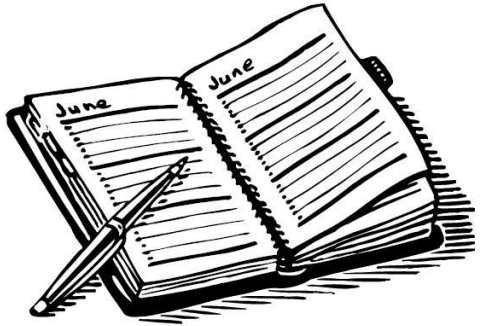
Agenda

- Introduction
- Motivation
- Design
- Performance



JEP 254: Compact Strings

- More space-efficient internal representation for Strings

- Author: Brent Christian
- Owner: Xueming Shen
- Reviewed by: Aleksey Shipilev, Brian Goetz, Charlie Hunt
- Endorsed by: Brian Goetz
- Release: 9
- Issue: 8054307

http://openjdk.java.net/jeps/254
https://bugs.openjdk.java.net/browse/JDK-8054307

Terminology

- Project name: String Density
- Feature name: Compact Strings

String Density Team

- Oracle
  - Charlie Hunt
  - Aleksey Shipilev
  - Sherman Shen
  - Brent Christian
  - Roger Riggs
  - Tobias Hartmann
  - Vladimir Kozlov
  - Guy Delemarter
- Intel
  - Sandhya Viswanathan
  - Vivek Deshpande

Project Goals

Requirements:

- Java supports Unicode (UTF-16) characters which uses 2 byte characters
- Improve the space efficiency of the String and related classes
- Preserve full compatibility for all related Java and native interfaces
- Maintain throughput performance in almost all scenarios
- Replacement for JDK 6's Compressed Strings
- Platforms: X86/X64, SPARC*, ARM* 32/64
- OS: Linux*, Solaris*, Windows* and Mac OS X*

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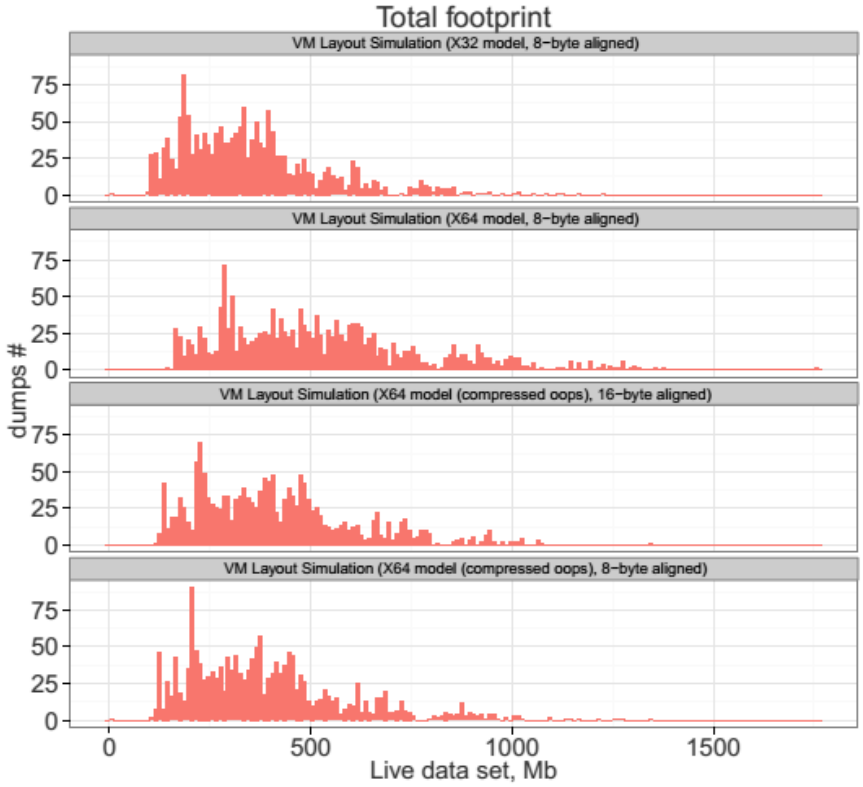
Motivation

Experimental Setup

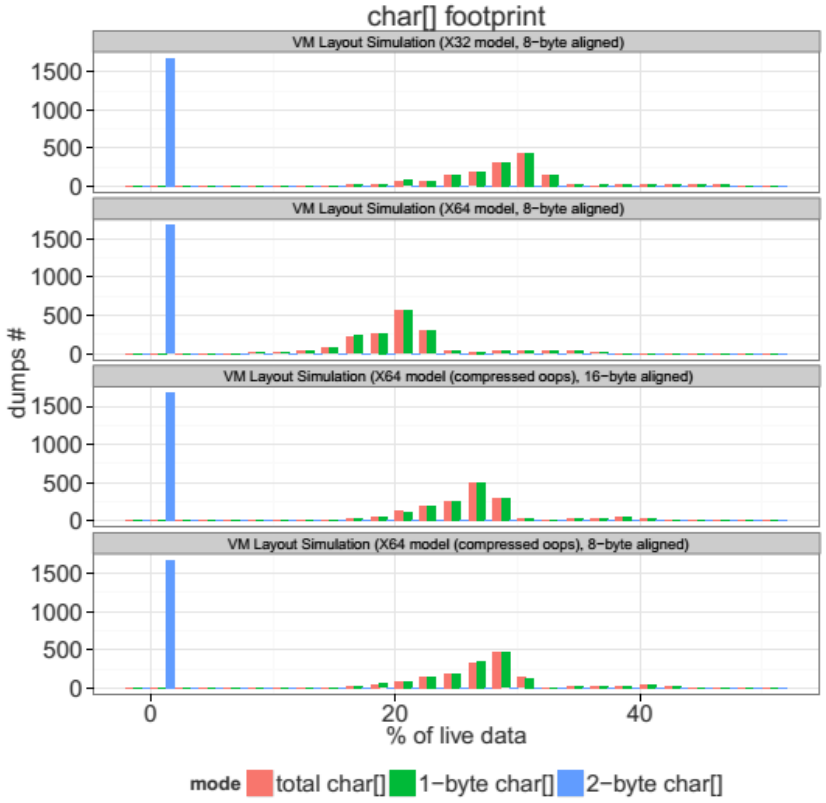
- Collection of 950+ heap dumps from
  - Oracle Fusion Middleware
  - Oracle Fusion Applications
  - Other Oracle Java Applications
- Java Object Layout Tools
- Linux X86_64 running on i7-4790K (1 socket, 4 cores, with HT)
- The following JVM modes emulated:
  - 32 bit data model
  - 64 bit data model, compressed reference disabled
  - 64 bit data model, compressed reference enabled
  - 64 bit data model, compressed reference enabled, 16 byte object alignment

Total Memory Footprint



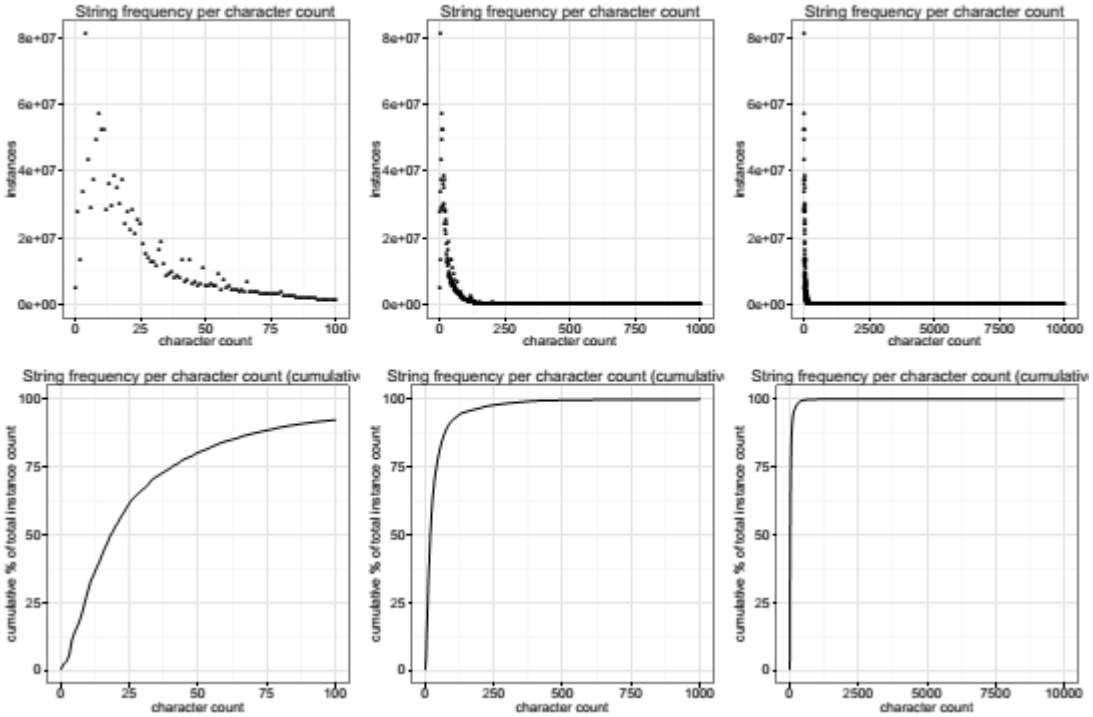
- 950+ Heap Dumps processed with Java Object Layout Tool
- Live Data Set size distribution shown
- Similar distribution in all models
- X64 dumps without compressed reference have larger footprints (2nd graph)

char[] Footprint



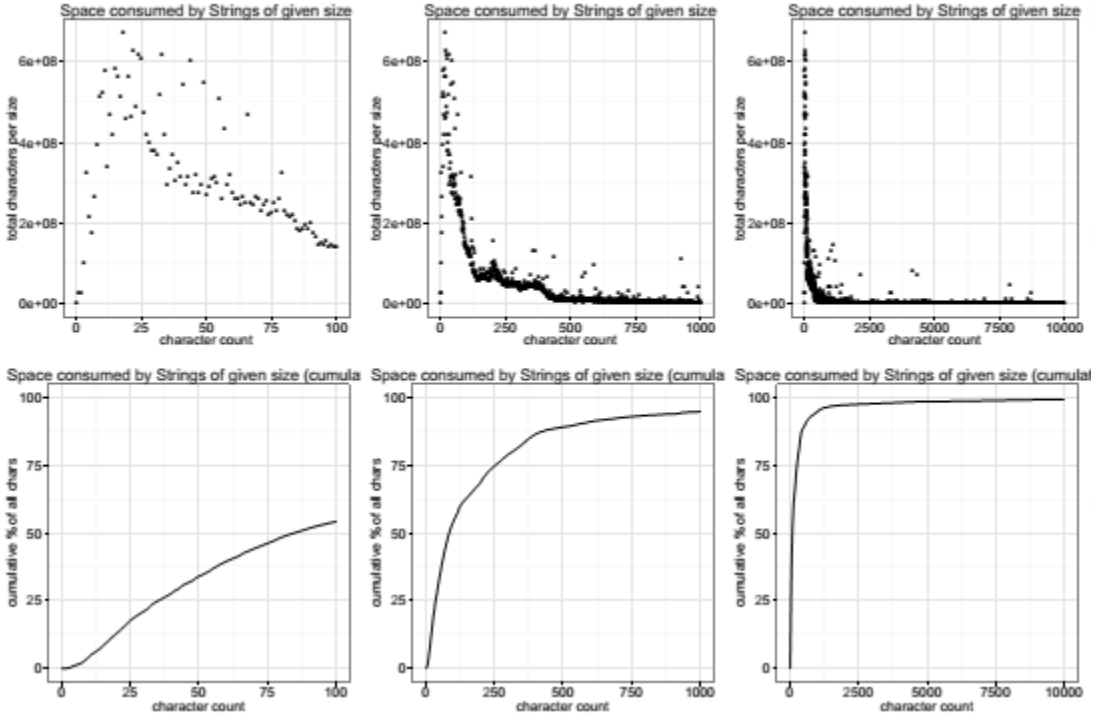
- char[] footprint as a % of LDS
- Consumes 10% to 45% of LDS
- X64 mode without compressed reference has lower % due to larger object header size
- Mostly 1 byte char[]

String Size Distribution (i)



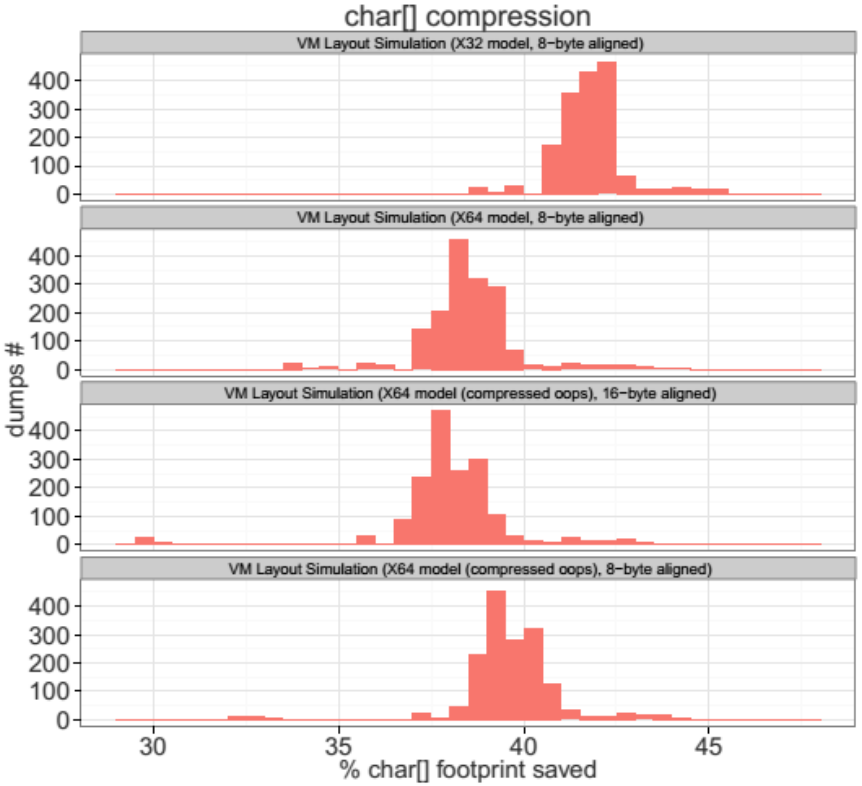
- Strings of a particular size (String instance count)
- Majority of Strings are small
- > 75% of strings are of size smaller than 35 characters

String Size Distribution (ii)



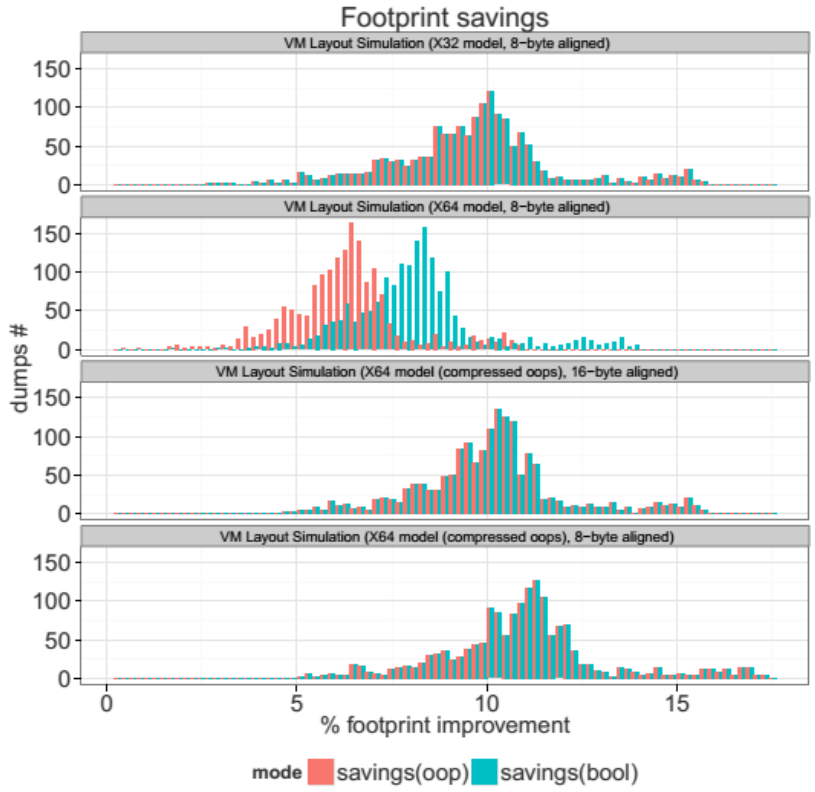
- Total character count for strings of particular size
- Skew the footprint towards the tail
- 75% of all the chars are residing in strings of size < 250

char[] Compression



- Projected char[] footprint improvements
- 35% to 40% reduction
- Less than 50% theoretical max due to dominance of small strings

Total Footprint Saving



- 5% - 15% reduction in total footprint due to:
  - Compressed underlying storage for characters in the string
  - Increased String object size

Design

New String Class Design

- Preserves full compatibility for all related Java and native interfaces
- Changes the internal representation of String class
- Characters of String encoded as either UTF-16 or ISO-8859-1/Latin-1
  - Stripped off the leading zero byte of a two byte UTF-16 character
- Uses byte array instead of char array to store characters
  - 1 byte per char for ISO-8859-1/Latin-1
  - 2 bytes per char for UTF-16
- An encoding byte field to indicate which encoding is used
  - Ability to extend to support additional character encoding(s)
- Reduces memory footprint
- Maintains throughput performance

String Encoding

- String with **any** leading byte in incoming chars as non 0
  - Cannot be compressed in our scheme
  - Stored as 2 byte chars using UTF-16 encoding
- Strings with leading byte in **all** the incoming chars as 0
  - Candidates for compression
  - Leading 0 bytes are stripped off and only the trailing byte is stored
  - This maps to the Latin-1 encoding
- Why not UTF-8?
  - UTF-8 supports variable width characters
  - Many String API implementations use random access into sequence of chars
  - Good encoding for transmission but not for performant String operations

String Class Old versus New

- Old String Class (JDK 8)

```
{
   private final char value[];
   private int hash;
   ...
}
```

- New String Class (JDK 9)

```
{
   private final byte[] value;
   private final byte coder;
   private int hash;
   ...
}
```

JDK 6 Compressed Strings

- JDK 6 String Class

```
{
    private final char value[];
    private final int offset;
    private final int count;
    private int hash;
    …
}
```

- JDK 6 Compressed String Class

```
{
    private final object value;
    private final int offset;
    private final int count;
    private int hash;
    …
}
```

Where value would point to char[] or byte[] based on String contents

JDK 6 vs JEP 254

- JDK 6 Compressed Strings
  - Two underlying implementations of String Class
  - Two sets of libraries: difficult to maintain
  - instanceof check, overhead for chars as byte[] or char[]
  - Limited support in the JRE
    - Resulted in frequent string inflation to UTF-16
- JEP 254
  - One underlying implementation of String Class using byte[]
  - Add an encoding (byte) field
  - Expanded support for compressed strings in JRE

String Class Layout

```
***** 32-bit VM: ************************************************************
java.lang.String object internals:
 OFFSET  SIZE   TYPE DESCRIPTION                    VALUE
      0     8        (object header)                N/A
      8     4 char[] String.value                   N/A
     12     4    int String.hash                    N/A
Instance size: 16 bytes (estimated, the sample instance is not available)
Space losses: 0 bytes internal + 0 bytes external = 0 bytes total

***** 64-bit VM: ************************************************************
java.lang.String object internals:
 OFFSET  SIZE   TYPE DESCRIPTION                    VALUE
      0    16        (object header)                N/A
     16     8 char[] String.value                   N/A
     24     4    int String.hash                    N/A
     28     4        (loss due to the next object alignment)
Instance size: 32 bytes (estimated, the sample instance is not available)
Space losses: 0 bytes internal + 4 bytes external = 4 bytes total
```

String Class Layout Contd

```
***** 64-bit VM, compressed references enabled: ***************************
java.lang.String object internals:
 OFFSET  SIZE   TYPE DESCRIPTION                    VALUE
      0    12        (object header)                N/A
     12     4 char[] String.value                   N/A
     16     4    int String.hash                    N/A
     20     4        (loss due to the next object alignment)
Instance size: 24 bytes (estimated, the sample instance is not available)
Space losses: 0 bytes internal + 4 bytes external = 4 bytes total

***** 64-bit VM, compressed references enabled, 16-byte align: ************
java.lang.String object internals:
 OFFSET  SIZE   TYPE DESCRIPTION                    VALUE
      0    12        (object header)                N/A
     12     4 char[] String.value                   N/A
     16     4    int String.hash                    N/A
     20    12        (loss due to the next object alignment)
Instance size: 32 bytes (estimated, the sample instance is not available)
Space losses: 0 bytes internal + 12 bytes external = 12 bytes total
```

- In 32 bit VM addition of encoding field inflates String object size
- No increase in String object size for 64 bit VM

Performance

JMH Micro-Benchmarks

- JMH based extensive throughput Micro-Benchmarks for
  - String, StringBuilder, StringBuffer APIs
  - String encoding and decoding operations
- Performance:
  http://cr.openjdk.java.net/~thartmann/compact_strings/microbenchmark/
- String methods are highly optimized using SIMD instructions where possible
- With CompactString ability to do twice the operation per iteration, e.g.:

Benchmark	BASE ns/op	SD ns/op	BASE/SD
compareto.CompareToBench.cmp1_cmp1	201.05	124.61	1.61
concat.ConcatCharBench.test_char1_cmp1	1072.21	581.13	1.85
encoding.From.ascii (ISO-8859-1)	2649.99	585.63	4.53
encoding.To.ascii (ISO-8859-1)	897.48	584.10	1.54
equals.EqualsBench.cmp1_cmp1	195.77	95.20	2.06
indexof.IndexOfChar.base1_img1__img1	906.86	752.44	1.21
indexof.IndexOfString.base1_img1__img1	1164.63	588.95	1.98

BASE: Base repo without Compact Strings

SD: With Compact Strings

Platform: Intel® Xeon ™ CPU E5-2697v3 @ 2.60GHz, 64 GB RAM with Linux 64-bit.

SPECjbb2005*

	BASE	SD	SD/BASE
Peak Throughput			1.05
Avg secs between GC (s)	3.898	4.937	1.27
Avg GC length (s)	0.018	0.019	1.06
Time Spent in GC (%)	0.459	0.384	0.84
Avg Resident Memory (K)	96139	75528	0.79

With CompactStrings

- Avg Resident Memory reduced by 21%
- Throughput increased by 5%

Comparing optimized JEP-254 String Density branch versus un-optimized JDK 9 Sandbox running on Intel® Core™ i7-4770 CPU @ 3.40GHz, 32 GB RAM with Linux 64-bit. JAVAOPTIONS="-server -showversion -Xmx12g -Xms12g -Xmn10g -XX:-UseAdaptiveSizePolicy -XX:MaxTenuringThreshold=15 -XX:InitialTenuringThreshold=15 -XX:+UseParallelOldGC -XX:ParallelGCThreads=4 -XX:+UseLargePages -verbose:gc -XX:+PrintGCDetails -XX:+PrintGCTimeStamps -XX:+PrintFlagsFinal"

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See http://www.spec.org for more information.

SPECjbb2005 Heap Dump

	#instances		#bytes	
class	BASE	SD	BASE	SD
[C	1027729	1427	74592544	398096
java.lang.String	1069949	1069607	25678776	25670568
[Ljava.lang.String;	80486	80486	4510512	4510512
[B	1037	1027175	509536	49374184
...	...	...	...	...
Total	2677131	2676155	124671480	99312552

- Total # instances similar between the baseline & String Density.
- Total # bytes allocated is 21% less with String Density

*BASE: Base repo without Compact Strings

*SD: With Compact Strings

SPECjbb2015*

	BASE	SD	SD/BASE
max-jOPS			1.03
critical-jOPS			1.11
Avg secs between GC (s)	16.20	16.61	1.03
Avg GC length (s)	0.29	0.27	0.96
Time Spent in GC (%)	1.74	1.63	0.93
Avg Resident Memory (K)	1959521	1823907	0.93

With CompactStrings

- Avg Resident Memory reduced by 7%
- MultiJVM critical-jOPS increased by 11%

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JAVAOPTIONS="-server -XX:+AlwaysPreTouch -XX:+UseParallelOldGC -XX:-UseAdaptiveSizePolicy -XX:MaxTenuringThreshold=15 -XX:-UseBiasedLocking -XX:+AggressiveOpts -XX:LargePageSizeInBytes=2m -XX:SurvivorRatio=28 -XX:TargetSurvivorRatio=95 -Xms19g -Xmx19g -Xmn17g -XX:+UseLargePages -XX:ParallelGCThreads=4 -XX:+PrintGCDetails -XX:+PrintGCTimeStamps -XX:+PrintTenuringDistribution"

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Call for Action

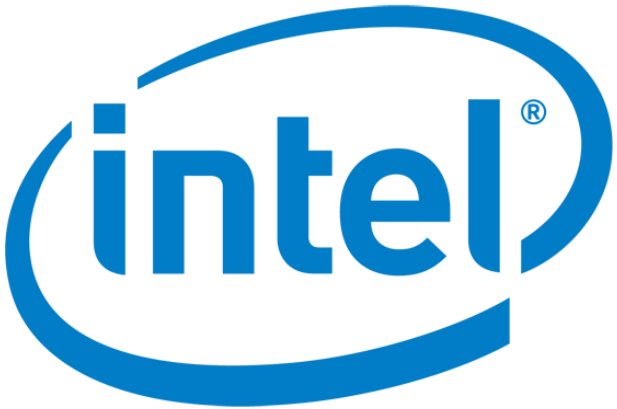
- Intrigued or Interested?
  Try CompactStrings feature on your workload and give us feedback

- Implementation:
  Repository: http://hg.openjdk.java.net/jdk9/sandbox/
  Branch: JDK-8054307-branch

- Steps:

```
$ hg clone http://hg.openjdk.java.net/jdk9/sandbox/
$ cd sandbox
$ sh ./get_source.sh
$ sh ./common/bin/hgforest.sh up -r JDK-8054307-branch
$ make configure
$ make images
```

- The option to enable/disable CompactStrings: -XX:+CompactStrings/-XX:-CompactStrings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