OutOfMemoryError: What is the cost of Java objects

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java.lang.Object

Anatomy of java.lang.Object header

Fields	32 bits	64 bits	64 bits CompressedOops
mark word	4 bytes	8 bytes	8 bytes
klass pointer	4 bytes	8 bytes	4 bytes
Total	8 bytes	16 bytes	12 bytes (but 16 with padding/alignment)

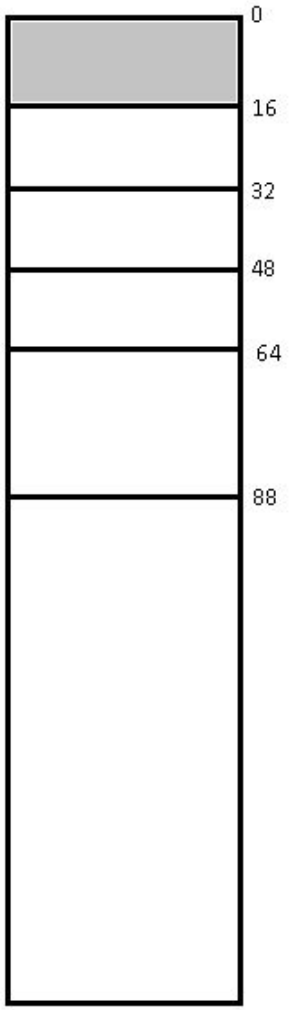
Mark Word

Bitfields			Tag	State
Hashcode	Age	0	01	Unlocked
Lock record address			00	Light-weight locked
Monitor address			10	Heavy-weight locked
Forwarding address, etc.			11	Marked for GC
Thread ID	Age	1	01	Biased / biasable

Compressed Oops

Compressed Oops

- 32 bits pointer can address 4GB
- Memory addresses is aligned (4 or 8)
- Objects reside only on address 8 multiple
- Last 3 bits are not effectively used
- Use this 3 bits to increase addressable space



Example:

Address 88 in binary:
101 1000
will be encoded as (3 bits shift)
1011

Allows to encode 8 times more Object addresses than with raw 32 bits addressing.
=> Maximum addressable is then 32GB.

CompressedOops saves ~20-30% memory

Activated by default on 64bits JVM
JVM Options: -XX:+UseCompressedOops

Padding

Padding

Heap Dump analysis with profilers can give you a good estimation
Real size depends on 32bits/64bits/CompressedOops
A more precise way: Java Object Layout (JOL)

```
java -XX:+UseCompressedOops -jar jol-internals.jar java.lang.Object
Running 64-bit HotSpot VM.
Using compressed references with 3-bit shift.
Objects are 8 bytes aligned.
Field sizes by type: 4, 1, 1, 2, 2, 4, 4, 8, 8 [bytes]
Array element sizes: 4, 1, 1, 2, 2, 4, 4, 8, 8 [bytes]

java.lang.Object object internals:
 OFFSET  SIZE  TYPE DESCRIPTION                    VALUE
      0     4       (object header)                01 00 00 00 (0000 0001 0000 0000 0000 0000 0000
 0000)
      4     4       (object header)                00 00 00 00 (0000 0000 0000 0000 0000 0000 0000
 0000)
      8     4       (object header)                6d 05 88 df (0110 1101 0000 0101 1000 1000 1101
 1111)
     12     4       (loss due to the next object alignment)
Instance size: 16 bytes (estimated, add this JAR via -javaagent: to get accurate result)
Space losses: 0 bytes internal + 4 bytes external = 4 bytes total
```

Padding

With 8 bytes field alignment padding occurs

What is the real size of this class:

```
class Data
{
   long l;
   boolean b;
   int i;
   char c;
   String str;
}
```

Padding

Class Data:

```
java -XX:+UseCompressedOops -classpath .;jol-internals.jar org.openjdk.jol.MainObjectInternals Data
Running 64-bit HotSpot VM.
Using compressed references with 3-bit shift.
Objects are 8 bytes aligned.
Field sizes by type: 4, 1, 1, 2, 2, 4, 4, 8, 8 [bytes]
Array element sizes: 4, 1, 1, 2, 2, 4, 4, 8, 8 [bytes]

Data object internals:
 OFFSET  SIZE    TYPE DESCRIPTION                    VALUE
      0     4         (object header)                01 00 00 00 (0000 0001 0000 0000 0000 0000
 0000 0000)
      4     4         (object header)                00 00 00 00 (0000 0000 0000 0000 0000 0000
 0000 0000)
      8     4         (object header)                b6 8c 91 df (1011 0110 1000 1100 1001 0001
 1101 1111)
     12     4     int Data.i                         0
     16     8    long Data.l                         0
     24     2    char Data.c
     26     1 boolean Data.b                         false
     27     1         (alignment/padding gap)        N/A
     28     4  String Data.str                       null
Instance size: 32 bytes (estimated, add this JAR via -javaagent: to get accurate result)
Space losses: 1 bytes internal + 0 bytes external = 1 bytes total
```

Structure sizes

Arrays

Arrays have additional int for size

header for 64bits + CompressedOops: 16 bytes

```
byte[32]   => header + 1*32 bytes = 48 bytes
short[32]  => header + 2*32 bytes = 80 bytes
char[32]   => header + 2*32 bytes = 80 bytes
int[32]    => header + 4*32 bytes = 144 bytes
long[32]   => header + 8*32 bytes = 272 bytes
double[32] => header + 8*32 bytes = 272 bytes
Object[32] => header + RefSize*32 bytes = 144 bytes
```

String class fields

1.6.0_45 (32 bytes)

- char[] value
- int hash
- int count
- int offset

1.7.0_55 (24 bytes)

- char[] value
- int hash
- int hash32

1.8.0_25 (24 bytes)

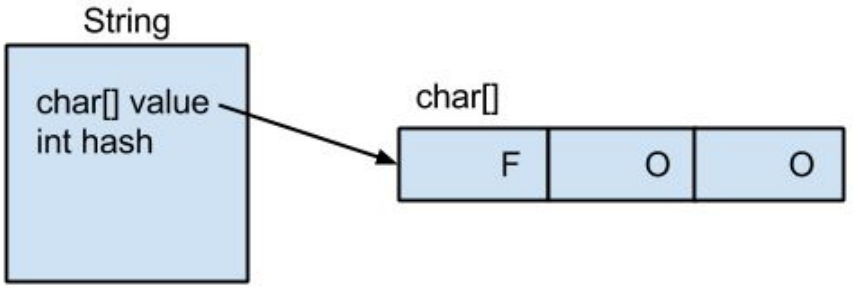
- char[] value
- int hash

11 (24 bytes)

- byte[] value
- int hash
- byte coder

java.lang.String

Class String + char[]



example for string `foo`

```
Class String Size + char array header + 2*3 bytes = 24 + 16 + 6 = 46 bytes
```

overhead = 1433%

for string of 100 characters:

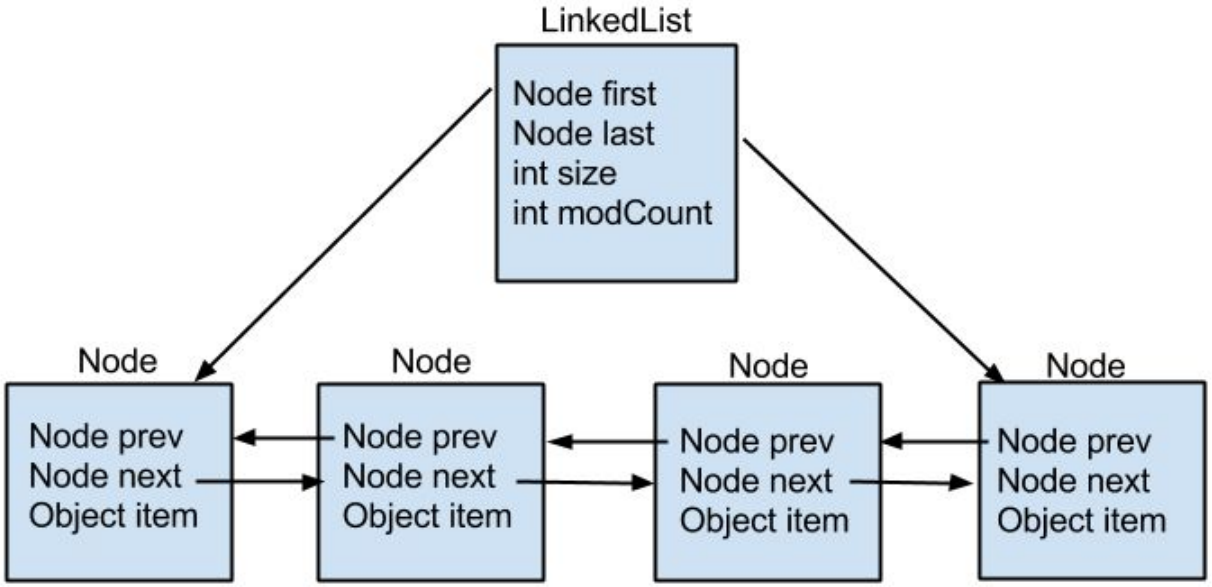
```
Class String Size + char array header + 2*100 bytes = 24 + 16 + 200 = 240 bytes
```

overhead = 140%

String.subString()

- <1.7.0_06 => shared char[]
- >= 1.7.0_06 => make copy of char[]

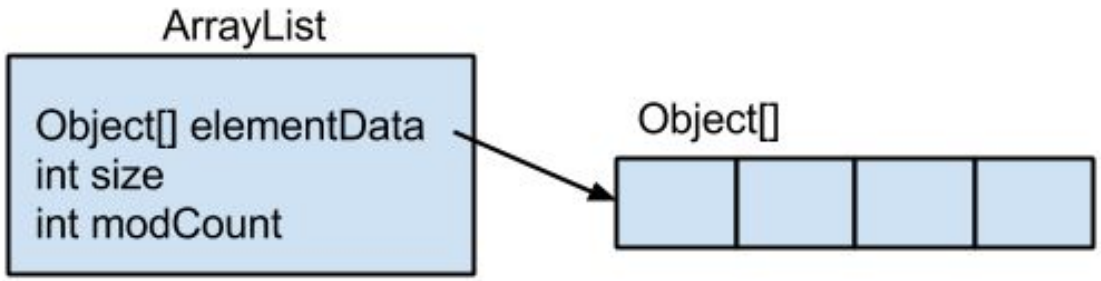
java.util.LinkedList



Class LinkedList: 32 bytes
Class Node: 24 bytes

Example for 100 elements: 32 + 100*24 = 2432 bytes

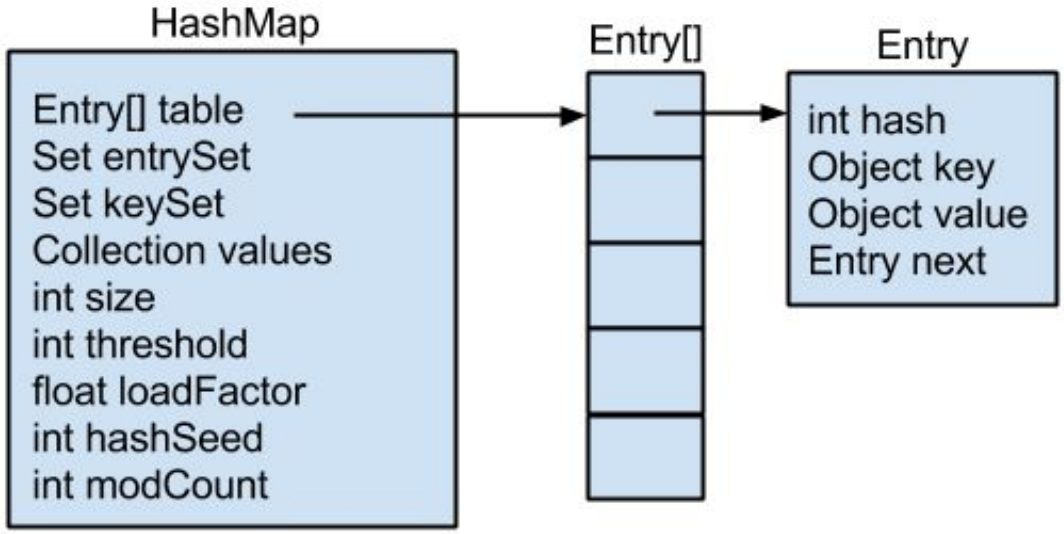
java.util.ArrayList



Class ArrayList: 24 bytes
Object[] : 16 + n*4 bytes

Example for 100 elements: 24 + 16 + 100*4 = 440 bytes

java.util.HashMap



class HashMap: 48 bytes
Entry[]: 16 + n*4 bytes
class Entry: 32 bytes

Example for 100 key/value pairs:
48 + 16 + 256*4 + 100*32 = 4288 bytes

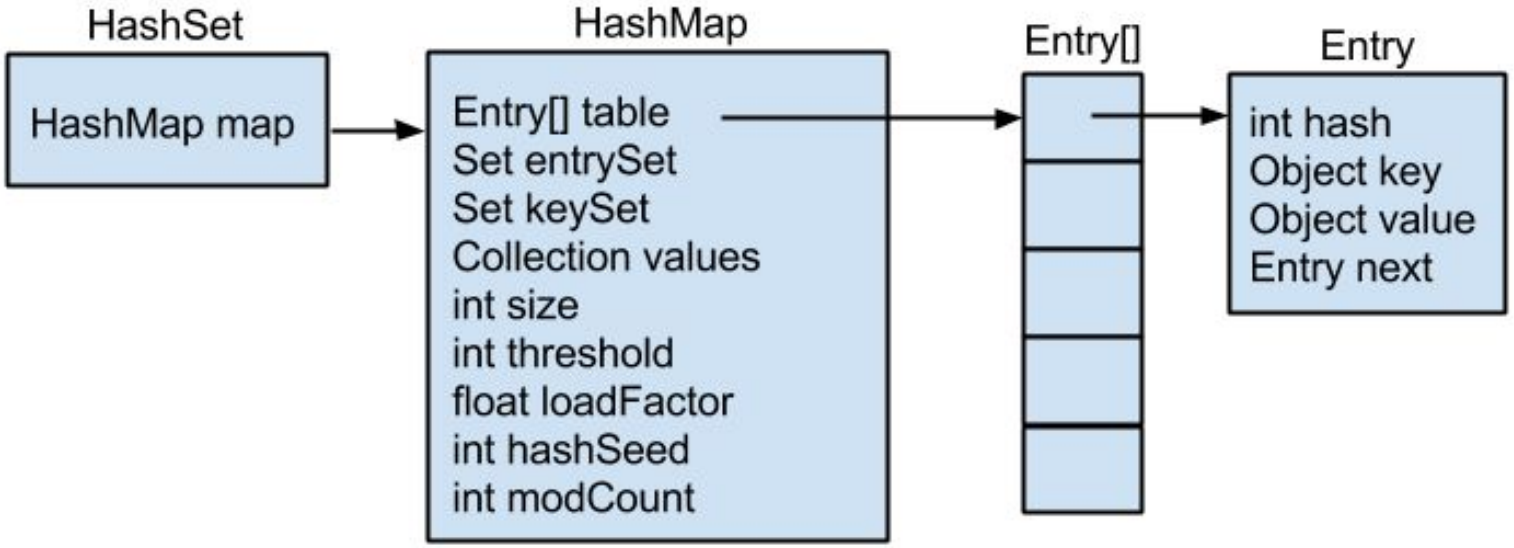
java.util.HashMap

- entrySet() called => add EntrySet instance (16 bytes)
- keySet called => add KeySet instance (16 bytes)
- values() called => add Values instance (16 bytes)

For those inner classes this is object header + outer ref

```
java.util.HashMap.Values object internals:
 OFFSET  SIZE    TYPE DESCRIPTION                    VALUE
      0    12         (object header)                N/A
     12     4 HashMap Values.this$0                  N/A
Instance size: 16 bytes (estimated, the sample instance is not available)
Space losses: 0 bytes internal + 0 bytes external = 0 bytes total
```

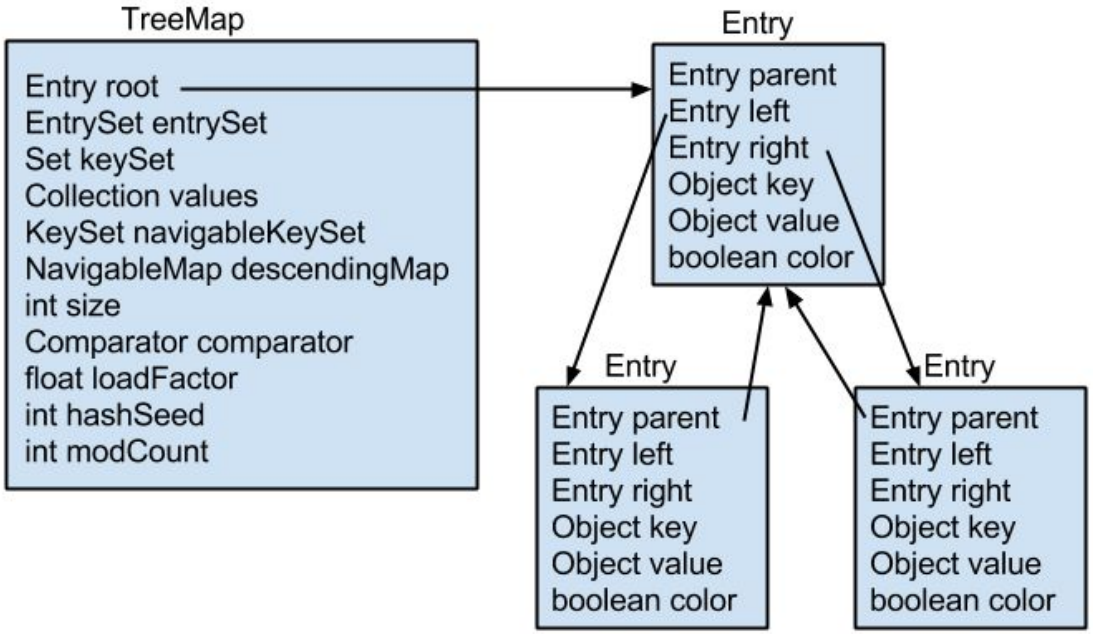
java.util.HashSet



class HashSet: 16 bytes

example for 100 elements: 16 + HashMap cost = 4304 bytes

java.util.TreeMap



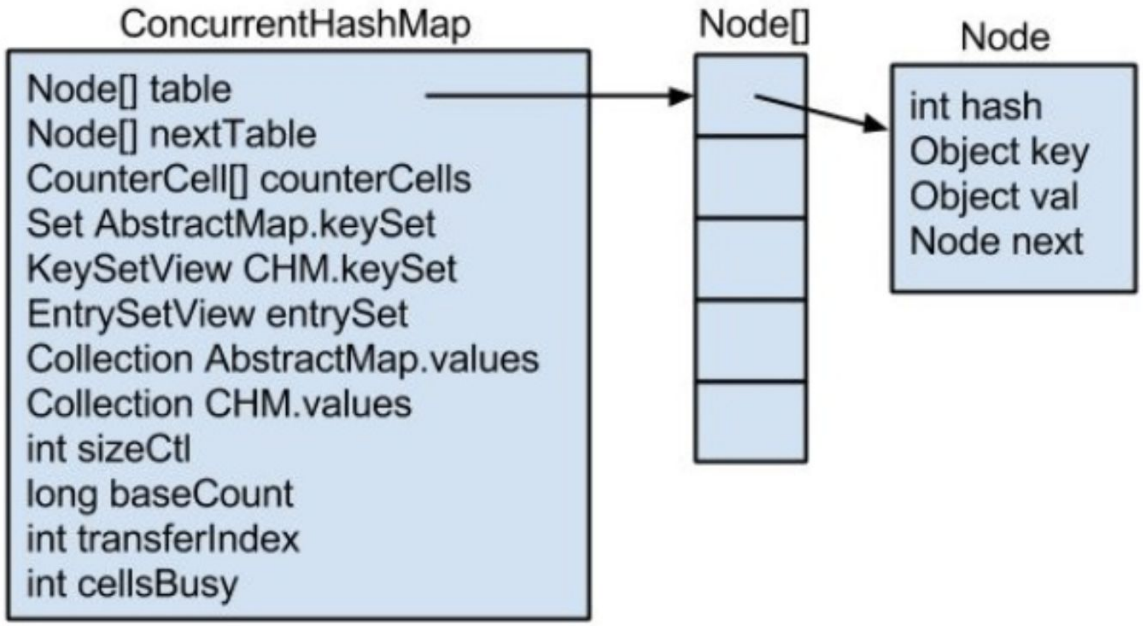
class TreeMap: 48 bytes
class Entry: 40 bytes (double penalty)

example for 100 elements:
48 + 100*48 = 4848 bytes

java.util.TreeMap

- entrySet() called => add EntrySet instance (16 bytes)
- keySet called => add KeySet instance (16 bytes)
- values() called => add Values instance (16 bytes)
- navigableKeySet called => add KeySet instance (16 bytes)
- descendingMap called => add DescendingSubMap instance (56 bytes)

java.util.concurrent.ConcurrentHashMap



class ConcurrentHashMap: 64 bytes
class Node: 32 bytes

example for 100 elements:
64 + 16 + 256*4 + 100*32 = 4304 bytes

Summary

Collections	Overhead for 100
ArrayList	440
LinkedList	2432
TreeMap	4048
HashMap	4288
HashSet	4304
ConcurrentHashMap	4304

Troubleshooting

Class Histogram

jmap -histo <pid>

```
num     #instances         #bytes  class name
----------------------------------------------
   1:         73903        5978960  [C
   2:          4309        4085624  [I
   3:          2790        1730968  [B
   4:         49641        1191384  java.lang.String
   5:         22080         706560  java.util.HashMap$Node
   6:          5420         571328  java.lang.Class
   7:          7408         431080  [Ljava.lang.Object;
   8:          2908         331584  [Ljava.util.HashMap$Node;
   9:          1339         289224  sun.java2d.SunGraphics2D
  10:          2882         253616  java.lang.reflect.Method
  11:          6586         227248  [Ljava.lang.Class;
  12:          1632         223768  [Ljava.lang.String;
  13:          4973         198920  java.security.AccessControlContext
  14:          3880         186240  java.util.HashMap
  15:          4890         156480  java.util.Hashtable$Entry
```

JVM Option: -XX:+PrintClassHistogramBeforeFullGC
Includes class histogram in GC logs

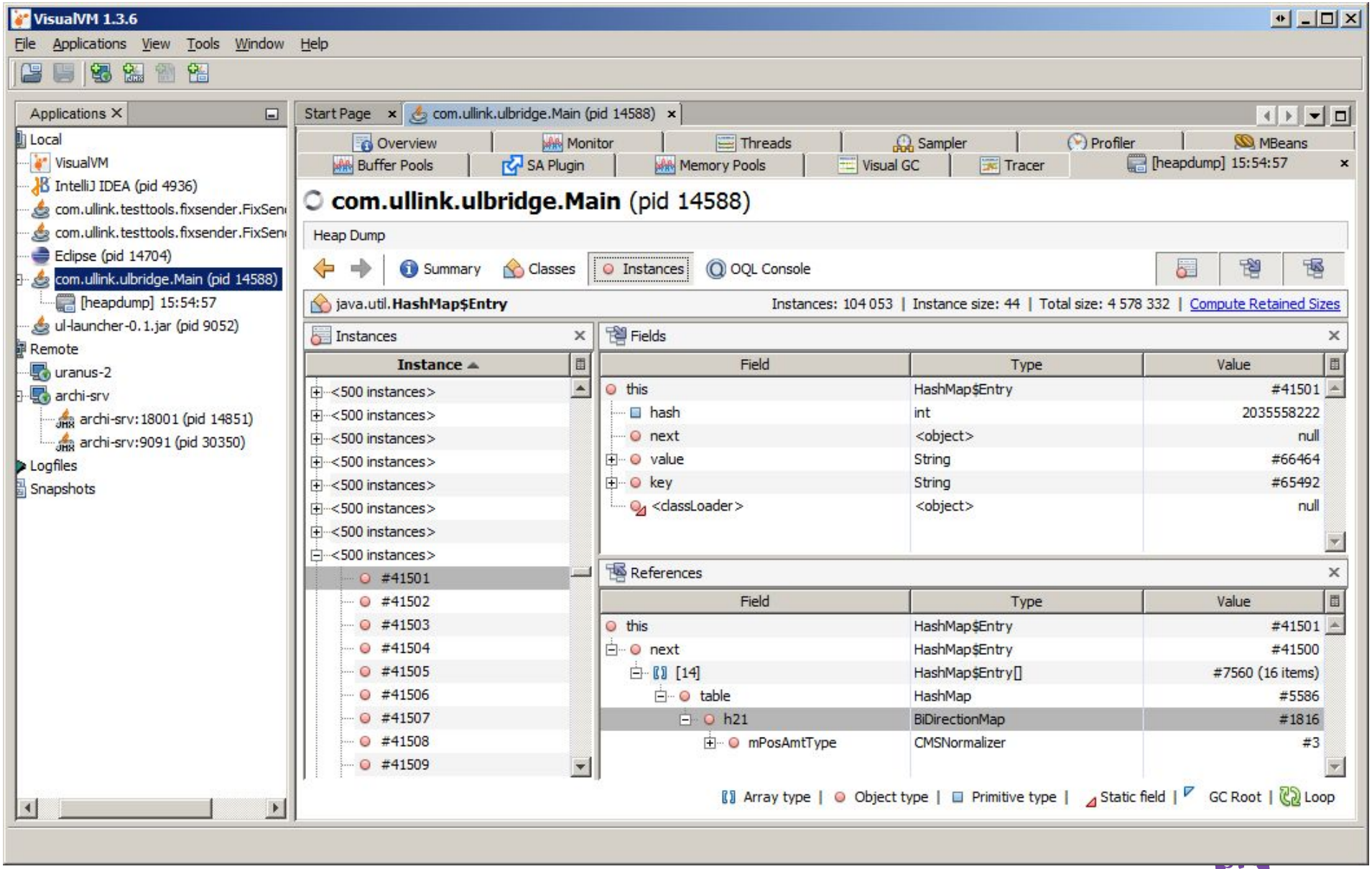
Heap Dump

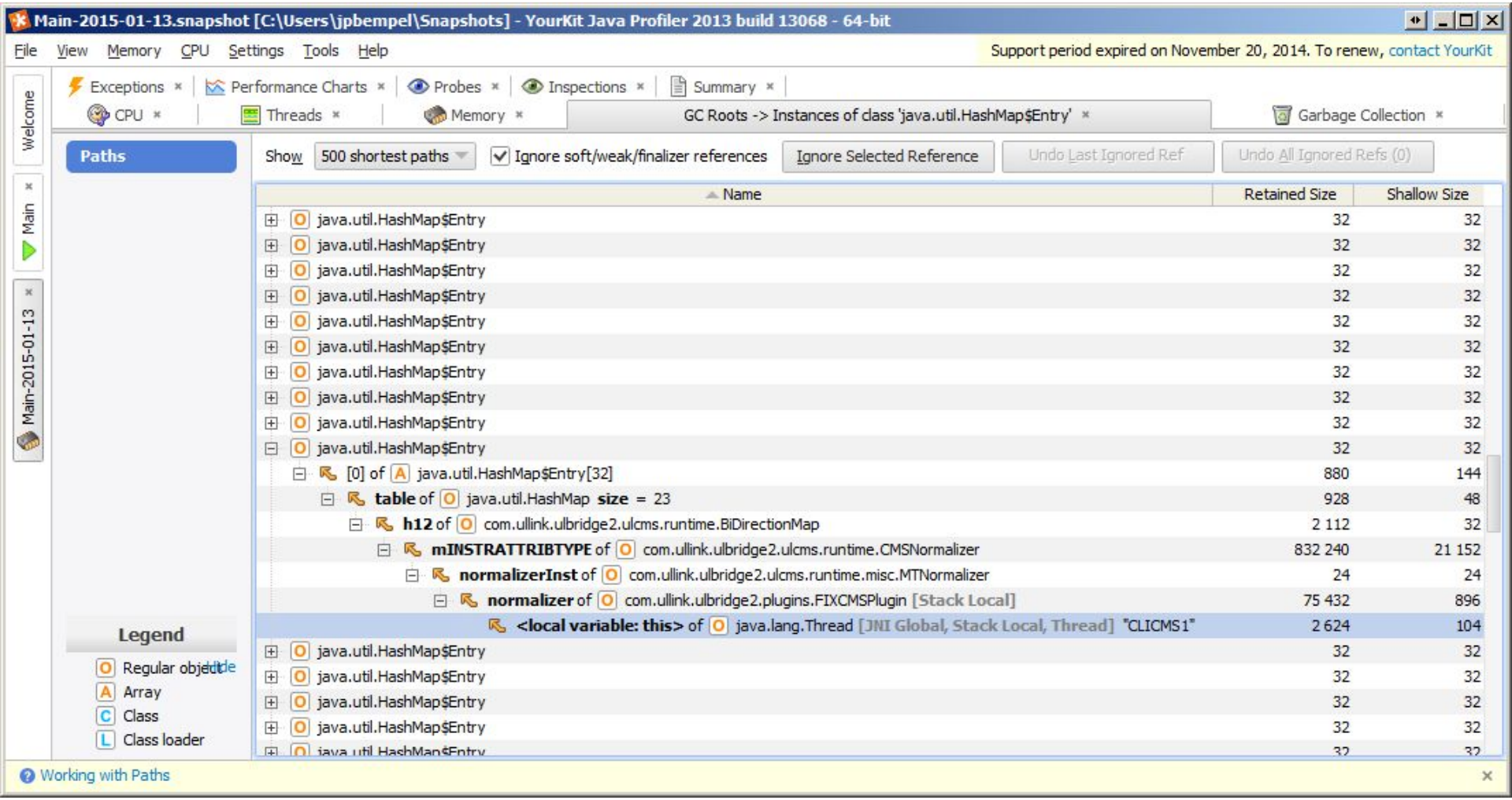
To generate it:

- jmap -dump:live,format=b,file=heap.hprof <pid>
- JVM Options:
  - -XX:+HeapDumpOnOutOfMemoryError
  - -XX:HeapDumpPath=../logs
- JMX: com.sun.management:type=HotSpotDiagnostic.dumpHeap(filename, liveonly)

To exploit heap dump:

- visualVM
- JMC + JOverflow
- YourKit
- Eclipse MAT


VisualVM 1.3.6
File Applications View Tools Window Help
Applications
Local
VisualVM
IntelliJ IDEA (pid 4936)
com.ullink.testtools.fixsender.FixSen
com.ullink.testtools.fixsender.FixSen
Eclipse (pid 14704)
com.ullink.ulbridge.Main (pid 14588)
[heapdump] 15:54:57
ul-launcher-0.1.jar (pid 9052)
Remote
uranus-2
archi-srv
archi-srv:18001 (pid 14851)
archi-srv:9091 (pid 30350)
Logfiles
Snapshots
Start Page
com.ullink.ulbridge.Main (pid 14588)
Overview
Monitor
Threads
Sampler
Profiler
MBeans
Buffer Pools
SA Plugin
Memory Pools
Visual GC
Tracer
[heapdump] 15:54:57
com.ullink.ulbridge.Main (pid 14588)
Heap Dump
Summary
Classes
Instances
OQL Console
java.util.HashMap$Entry
Instances: 104 053 | Instance size: 44 | Total size: 4 578 332 | Compute Retained Sizes
Instances
Instance
<500 instances>
<500 instances>
<500 instances>
<500 instances>
<500 instances>
<500 instances>
<500 instances>
<500 instances>
#41501
#41502
#41503
#41504
#41505
#41506
#41507
#41508
#41509
Fields
Field
Type
Value
this
HashMap$Entry
#41501
hash
int
2035558222
next
<object>
null
value
String
#66464
key
String
#65492
<classLoader>
<object>
null
References
Field
Type
Value
this
HashMap$Entry
#41501
next
HashMap$Entry
#41500
[14]
HashMap$Entry[]
#7560 (16 items)
table
HashMap
#5586
h21
BiDirectionMap
#1816
mPosAmtType
CMSNormalizer
#3
Array type | Object type | Primitive type | Static field | GC Root | Loop


Main-2015-01-13.snapshot [C:\Users\jpbempel\Snapshots] - YourKit Java Profiler 2013 build 13068 - 64-bit
File View Memory CPU Settings Tools Help
Support period expired on November 20, 2014. To renew, contact YourKit
Welcome
Exceptions
Performance Charts
Probes
Inspections
Summary
CPU
Threads
Memory
GC Roots -> Instances of class 'java.util.HashMap$Entry'
Garbage Collection
Main
Main-2015-01-13
Paths
Show 500 shortest paths
Ignore soft/weak/finalizer references
Ignore Selected Reference
Undo Last Ignored Ref
Undo All Ignored Refs (0)
Name
Retained Size
Shallow Size
java.util.HashMap$Entry 32 32
java.util.HashMap$Entry 32 32
java.util.HashMap$Entry 32 32
java.util.HashMap$Entry 32 32
java.util.HashMap$Entry 32 32
java.util.HashMap$Entry 32 32
java.util.HashMap$Entry 32 32
java.util.HashMap$Entry 32 32
java.util.HashMap$Entry 32 32
java.util.HashMap$Entry 32 32
[0] of java.util.HashMap$Entry[32] 880 144
table of java.util.HashMap size = 23 928 48
h12 of com.ullink.ulbridge2.ulcms.runtime.BiDirectionMap 2 112 32
mINSTRATTRIBTYPE of com.ullink.ulbridge2.ulcms.runtime.CMSNormalizer 832 240 21 152
normalizerInst of com.ullink.ulbridge2.ulcms.runtime.misc.MTNormalizer 24 24
normalizer of com.ullink.ulbridge2.plugins.FIXCMSPlugin [Stack Local] 75 432 896
<local variable: this> of java.lang.Thread [JNI Global, Stack Local, Thread] "CLICMS1" 2 624 104
java.util.HashMap$Entry 32 32
java.util.HashMap$Entry 32 32
java.util.HashMap$Entry 32 32
java.util.HashMap$Entry 32 32
Legend
Regular object
Array
Class
Class loader
Working with Paths

War stories

Overhead structures example

```
251614.001: [GC 251614.001: [ParNew (promotion failed): 943744K->940573K(943744K), 0.9248570
secs]251614.926: [Class Histogram:
 num     #instances         #bytes  class name
----------------------------------------------
   1:     421751083    20244051984  java.util.concurrent.ConcurrentHashMap$HashEntry
   2:      23327688    12130397760  com.ullink.ulmonitoring.api.model.SimpleBMOrder
   3:      23428922     6694953456  [Ljava.util.concurrent.ConcurrentHashMap$HashEntry;
   4:      11574497     5007170576  [C
   5:        178973     2246627208  [B
   6:      23357783     1681760376  java.util.concurrent.ConcurrentHashMap
   7:      26115162     1253527776  java.util.HashMap$Entry
   8:      23386843     1122568464  java.util.concurrent.locks.ReentrantLock$NonfairSync
   9:      23381591     1122316368  java.util.concurrent.ConcurrentHashMap$Segment
  10:      27363594     1094543760  java.lang.String
  11:      22350856      894034240  com.ullink.ulmonitoring.api.model.IndentedHelper
  12:      22350849      894033960  com.ullink.ulmonitoring.api.model.OrderLine
  13:      23357784      747639528  [Ljava.util.concurrent.ConcurrentHashMap$Segment;
  14:      22350792      715225344  com.ullink.ulmonitoring.extension.view.HierarchicalOrderLine
  15:      23356168      560548032  com.ullink.ulmonitoring.api.model.property.PropertyHolderImpl
...
817:            40           4480
com.ullink.ulmonitoring.extension.view.HierarchicalViewDataContainer
```

Client class (104 bytes)

```
com.ullink.oms.model.Client object internals:
 OFFSET  SIZE                 TYPE DESCRIPTION                    VALUE
      0     4                      (object header)                01 00 00 00 (0000 0001 0000 0000 0000 0000
0000 0000)
      4     4                      (object header)                00 00 00 00 (0000 0000 0000 0000 0000 0000
0000 0000)
      8     4                      (object header)                3b de 91 df (0011 1011 1101 1110 1001 0001
1101 1111)
     12     4               String OdisysObject.id                null
     16     4               String Client.type                    null
     20     4             Capacity Client.capacity                null
     24     4               String Client.description             null
     28     4               String Client.currency                null
     32     4               String Client.parentClientId          null
     36     4           Collection Client.contact                 null
     40     4               String Client.data                    null
     44     4              Contact Client.office                  null
     48     4               String Client.originCountry           null
     52     4              Boolean Client.allowUnknownAccount     null
     56     4               String Client.connectionDetails       null
     60     4               String Client.backoffice              null
     64     4               Policy Client.policy                  null
     68     4 ConfirmationSchedule Client.confirmationSchedule    null
     72     4           Collection Client.stampExemptCountries    null
     76     4                  Map Client.customProperties        null
     80     4             Delivery Client.delivery                null
     84     4          Warehousing Client.warehousing             null
     88     4                  Map Client.externalIds             null
     92     4               String Client.feeId                   null
     96     4              Boolean Client.active                  null
    100     4                      (loss due to the next object alignment)
Instance size: 104 bytes (estimated, add this JAR via -javaagent: to get accurate result)
Space losses: 0 bytes internal + 4 bytes external = 4 bytes total
```

Event user.update

```
 num     #instances         #bytes  class name
----------------------------------------------
   1:     116925840    18595529736  [C
   2:     100508918    10452927472  com.ullink.oms.model.Client
   3:     116908590     2805806160  java.lang.String
   4:         39690      773638968  [B
   5:         77391      596989120  [Ljava.lang.Object;
   6:       6116590      195730880  java.util.HashMap$Entry
   7:       2370792      149697448  [Ljava.util.HashMap$Entry;
   8:       2406042      115490016  java.util.HashMap
   9:        149661       20530168  <constMethodKlass>
  10:        149661       19166816  <methodKlass>
```

Event user.update
1 user with 32 560 Clients
action with User with 32 560 Clients
3796 events = 245M Client instances => 25GB + Strings

Instrument class

- 62 ref fields
- String, BigDecimal, Boolean, Double, Collection, Custom Classes (AlternateId (56B), Time (80B), Enums (24B)...)

Size: 264 bytes

Instrument Referential: 3M

Only Instrument instances: 792MB
Add 8 chars for instrumentId: +168MB (56*3M)
Add 4 chars for symbol: + 312MB (48*3M + 56*3M)
Add settlement date: + 408MB (56*3M + 80*3M)
Add 3 chars for currency: + 138MB (46*3M)
  Total 1818MB

Market Data Representation:
for each instrument : Map<String, MDRecord>
MDStringRecord: str + converted String (24B)

Solutions

Solutions

- Flyweight/internalizers
- ArrayList vs LinkedList
- HashMap => OpenAddressingHashMap

Measure, don’t guess!

Kirk Pepperdine & Jack Shirazi

Measure, don’t premature!

References

Java Object Layout

What Heap Dumps Are Lying To You About

From Java code to Java heap

Building Memory-efficient Java Applications: Practices and Challenges

Thank you!

@jpbempel