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From Java Code to Java Heap

Understanding the Memory Usage of Your Application

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Introduction to the speaker

- 12 years experience developing and deploying Java SDKs

- Recent work focus:
  - Java usability and quality
  - Debugging tools and capabilities
  - Requirements gathering
  - Highly resilient and scalable deployments

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Goals of this talk

- Deliver an insight into the memory usage of Java code:
  - The overhead of Java Objects
  - The cost of delegation
  - The overhead of the common Java Collections

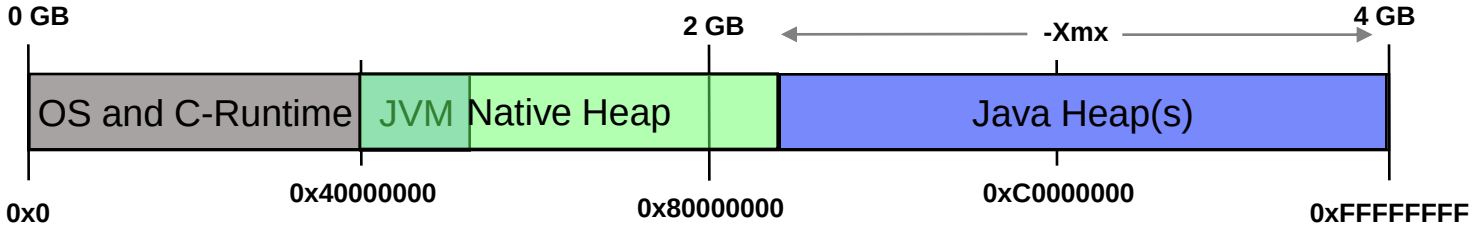
- Provide you with information to:
  - Choose the right collection types
  - Analyze your application for memory inefficiencies

Agenda

- Introduction to Memory Management
- Anatomy of a Java object
- Understanding Java Collections
- Analyzing your application

Understanding Java Memory Management

- Java runs as a Operating System (OS) level process, with the restrictions that the OS imposes:



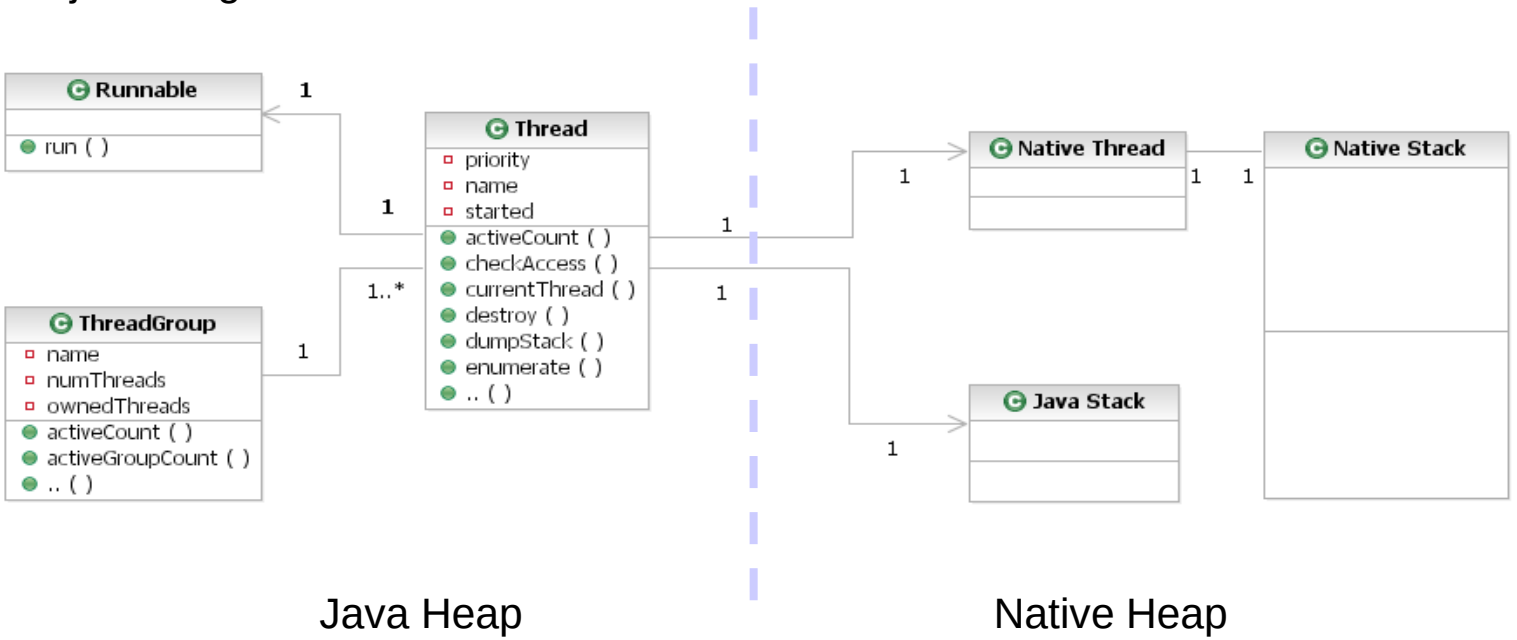
- 32 bit architecture and/or OS gives 4GB of process address space
  - Much, much larger for 64bit
- Some memory is used by the OS and C-language runtime
  - Area left over is termed the “User Space”
- Some memory is used by the Java Virtual Machine (JVM) runtime
- Some of the rest is used for the Java Heap(s)

  …and some is left over: the “native” heap
- Native heap is usually measured including the JVM memory usage

Java objects with “native” resources

- A number of Java objects are underpinned by OS level resources
  - Therefore have associated “native” heap memory

- Example: java.lang.Thread



Anatomy of a Java Object

- A Java Object consists of:
  - Object data (fields)
    - boolean, byte, char, short, int, float, long, double and object references
  - Object metadata
    - describes the Object data

- Question: What is the size ratio of a *Integer* object, to an *int* value?
  (for a 32bit platform)

  (a) 1 : 1

  (b) 1.5 : 1

  (c) 2 : 1

  (d) 3: 1

- **Answer is option (e) 4 : 1 !!**

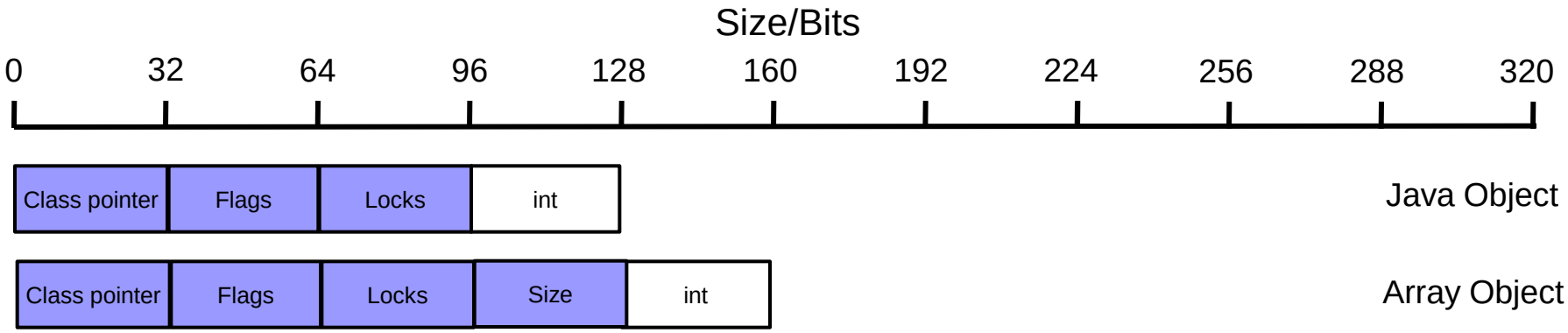
Object Field Sizes

Field Type	Field size/bits			
	32bit Process		64bit Process	
	Object	Array	Object	Array
boolean	32	8	32	8
byte	32	8	32	8
char	32	16	32	16
short	32	16	32	16
int	32	32	32	32
float	32	32	32	32
long	64	64	64	64
double	64	64	64	64
Objects	32	32	64*	64

***32bits if Compressed References / Compressed Oops enabled**

Anatomy of a Java Object

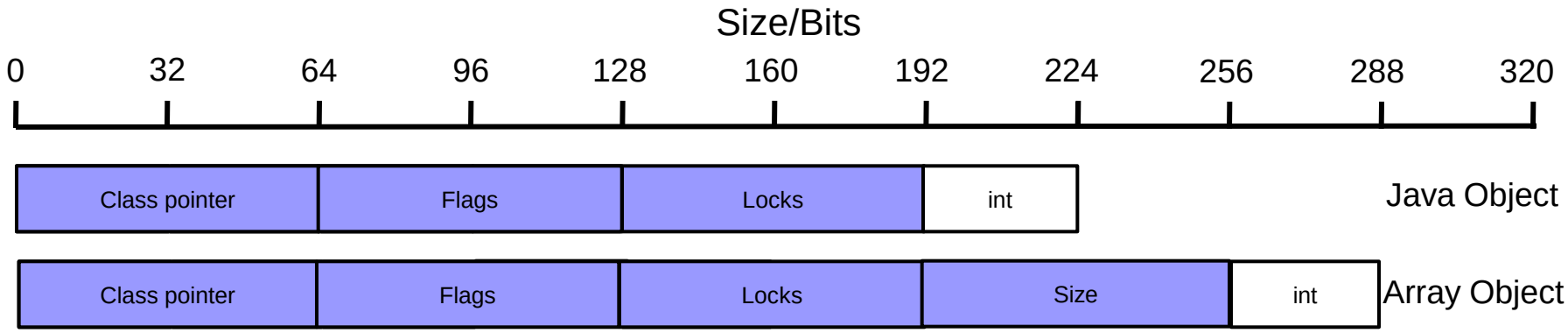
- Object Metadata: 3 slots of data (4 for arrays)
  - Class: pointer to class information
  - Flags: shape, hash code, etc
  - Lock: flatlock or pointer to inflated monitor
  - Size: the length of the array *(arrays only)*



- Additionally, all Objects are 8 byte aligned (16 byte for CompressedOops with large heaps)

Anatomy of a 64bit Java Object

- Object Metadata: 3 slots of data (4 for arrays)
  - Class: pointer to class information
  - Flags: shape, hash code, etc
  - Lock: flatlock or pointer to inflated monitor
  - Size: the length of the array *(arrays only)*



- Size ratio of an *Integer* object to an *int* value becomes 9:1 !!

Compressed References and CompressedOOPs

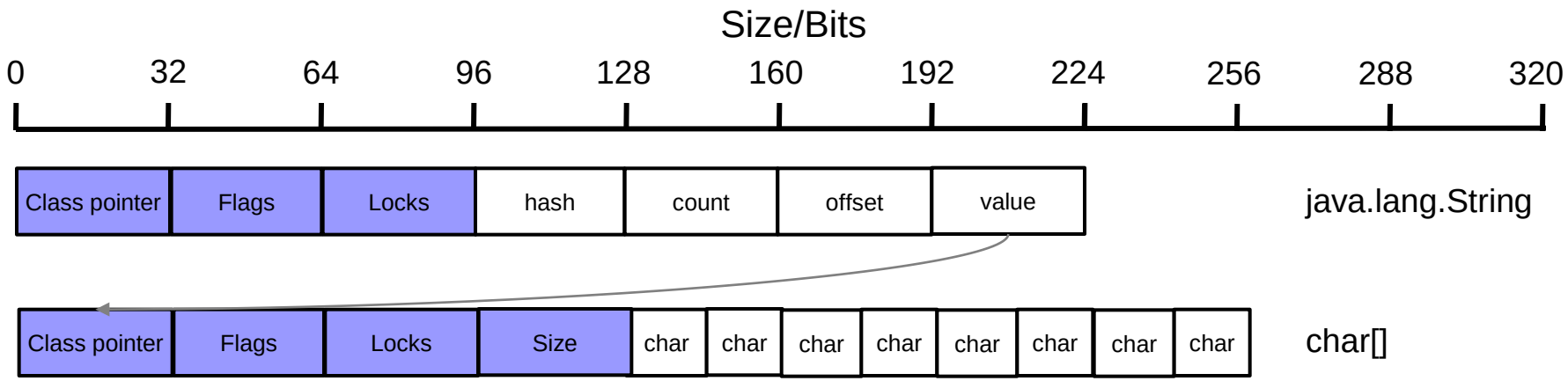
- Migrating an application from 32bit to 64bit Java increases memory usage:
  - Java heap usage increases by ~70%
  - “Native” heap usage increases by ~90%

- Compressed References / Compressed Ordinary Object Pointers
  - Use bit shifted, relative addressing for 64bit Java heaps
  - Object metadata and Objects references become 32bits

- Using compressed technologies ***does*** remove **Java heap** usage increase
- Using compressed technologies ***does not*** remove **“native” heap** usage increase

Allocating (slightly) more complex objects

- Good object orientated design encourages encapsulation and delegation
- Simple example: java.lang.String containing “MyString”:



- 128 bits of char data, stored in 480 bits of memory, size ratio of 3.75 : 1
  - Maximum overhead would be 24:1 for a single character!

HashSet

- Implementation of the Set interface
  - *"A collection that contains no duplicate elements. More formally, sets contain no pair of elements e1 and e2 such that e1.equals(e2), and at most one null element. As implied by its name, this interface models the mathematical set abstraction. "*
    - *Java Platform SE 6 API doc*

- Implementation is a wrapper around a HashMap:

Class Name	Shallow Heap	Retained Heap
<Regex>	<Numeric>	<Numeric>
java.util.HashSet @ 0x10a6d908	16	144
java.util.HashMap @ 0x10a6d918	48	128

- Default capacity for HashSet is 16
- Empty size is 144 bytes
- Additional 16 bytes / 128 bits overhead for wrappering over HashMap

HashMap

- Implementation of the Map interface:
  - *"An object that maps keys to values. A map cannot contain duplicate keys; each key can map to at most one value."*
    - *Java Platform SE 6 API doc*

- Implementation is an array of HashMap$Entry objects:

Class Name	Shallow Heap	Retained Heap
<Regex>	<Numeric>	<Numeric>
java.util.HashMap @ 0x10a6d918	48	128
java.util.HashMap$Entry[16] @ 0x10a6d948	80	80

- Default capacity is 16 entries
- Empty size is 128 bytes
- Overhead is 48 bytes for HashMap, plus (16 + (entries * 4bytes)) for array
  - Plus overhead of HashMap$Entry objects

HashMap$Entry

- Each HashMap$Entry contains:
  - int KeyHash
  - Object next
  - Object key
  - Object value
- Additional 32bytes per key ↔ value entry
- Overhead of HashMap is therefore:
  - 48 bytes, plus 36 bytes per entry
- For a 10,000 entry HashMap, the overhead is ~360K

Hashtable

- Implementation of the Map interface:
  - *"This class implements a hashtable, which maps keys to values. Any non-null object can be used as a key or as a value."*
    - *Java Platform SE 6 API doc*

- Implementation is an array of Hashtable$Entry objects:

Class Name	Shallow Heap	Retained Heap
<Regex>	<Numeric>	<Numeric>
java.util.Hashtable @ 0x1bae9290	40	104
java.util.Hashtable$Entry[11] @ 0x1bae92b8	64	64

- Default capacity is 11 entries
- Empty size is 104 bytes
- Overhead is 40 bytes for Hashtable, plus (16 + (entries * 4bytes)) for array
  - Plus overhead of Hashtable$Entry objects

Hashtable$Entry

- Each Hashtable$Entry contains:
  - int KeyHash
  - Object next
  - Object key
  - Object value
- Additional 32bytes per key ↔ value entry
- Overhead of Hashtable is therefore:
  - 40 bytes, plus 36 bytes per entry
- For a 10,000 entry Hashtable, the overhead is ~360K

LinkedList

- Linked list implementation of the List interface:
  - *"An ordered collection (also known as a sequence). The user of this interface has precise control over where in the list each element is inserted. The user can access elements by their integer index (position in the list), and search for elements in the list.*
  - *Unlike sets, lists typically allow duplicate elements. "*
    - *Java Platform SE 6 API doc*

- Implementation is a linked list of LinkedList$Entry objects (or LinkedList$Link):

Class Name	Shallow Heap	Retained Heap
<Regex>	<Numeric>	<Numeric>
java.util.LinkedList @ 0x11624d50 Thread	24	48
java.util.LinkedList$Link @ 0x11624d68	24	24

- Default capacity is 1 entry
- Empty size is 48 bytes
- Overhead is 24 bytes for LinkedList, plus overhead of LinkedList$Entry/Link objects

LinkedList$Entry / Link

- Each LinkedList$Entry contains:
  - Object previous
  - Object next
  - Object entry
- Additional 24bytes per entry
- Overhead of LinkedList is therefore:
  - 24 bytes, plus 24 bytes per entry
- For a 10,000 entry LinkedList, the overhead is ~240K

ArrayList

- A resizeable array instance of the List interface:
  - *"An ordered collection (also known as a sequence). The user of this interface has precise control over where in the list each element is inserted. The user can access elements by their integer index (position in the list), and search for elements in the list.*
  - *Unlike sets, lists typically allow duplicate elements. "*
    - *Java Platform SE 6 API doc*

- Implementation is an array of Object:

Class Name	Shallow Heap	Retained Heap
<Regex>	<Numeric>	<Numeric>
java.util.ArrayList @ 0x1fc279e0	32	88
java.lang.Object[10] @ 0x1fc27a00	56	56

- Default capacity is 10 entries
- Empty size is 88 bytes
- Overhead is 32bytes for ArrayList, plus (16 + (entries * 4bytes)) for array
- For a 10,000 entry ArrayList, the overhead is ~40K

Other types of “Collections”

- StringBuffers can be considered to be a type of collection
  - *“A thread-safe, mutable sequence of characters...*
    ....
  - *Every string buffer has a capacity. As long as the length of the character sequence contained in the string buffer does not exceed the capacity, it is not necessary to allocate a new internal buffer array. If the internal buffer overflows, it is automatically made larger.”*
    - *Java Platform SE 6 API doc*

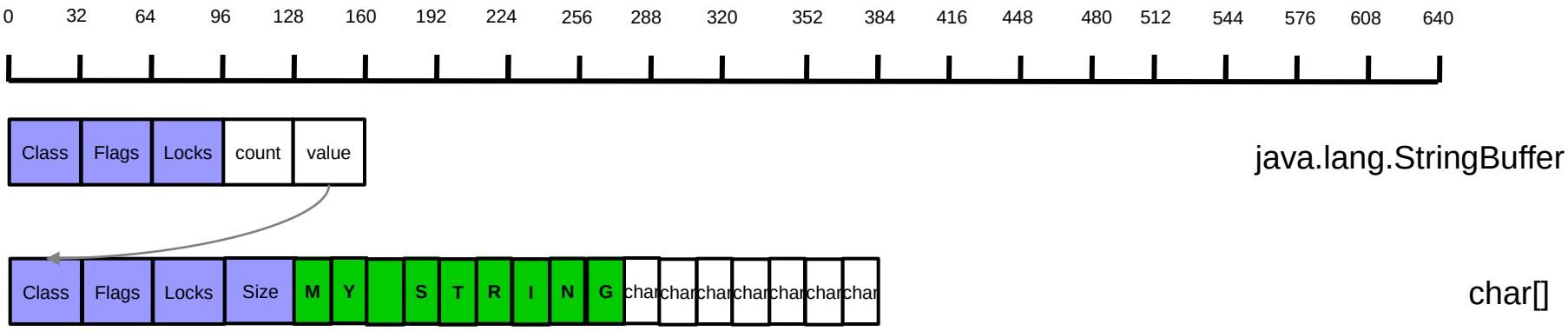
- Implementation is an array of char

Class Name	Shallow Heap	Retained Heap
<Regex>	<Numeric>	<Numeric>
java.lang.StringBuffer @ 0x2898eb0 buffer text	24	72
char[16] @ 0x2898ec8 buffer text\u0000\u0000\u0000\u0000\u0000	48	48

- Default capacity is 16 characters
- Empty size is 72 bytes
- Overhead is just 24bytes for StringBuffer

Empty space in collections

- Collections that contain empty space introduce additional overhead
  - Low “Fill Ratio”
- Default collection size may not be appropriate for the amount of data being held

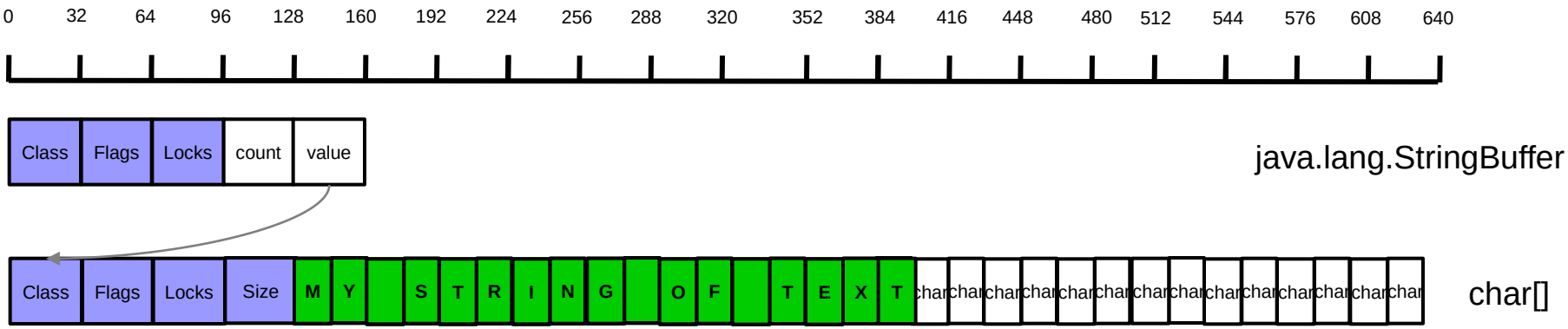


- StringBuffer default of 16 is inappropriate to hold a 9 character string
  - 7 additional entries in char[]
  - 112 byte additional overhead

Expansion of collections

- When collections hit the limit of their capacity, they expand
  - Greatly increases capacity
  - Greatly reduces “fill ratio”

- Introduces additional collection overhead:



- Additional 16 char[] entries to hold single extra character
  - 240 byte additional overhead

Collections Summary

Collection	Default Capacity	Empty Size	10K Entry Overhead	Expansion Algorithm
HashSet	16	144	360K	double size
HashMap	16	128	360K	double size
Hashtable	11	104	360K	double size + 1
LinkedList	1	48	240K	single entries
ArrayList	10	88	40K	size + 50%
StringBuffer	16	72	24	double size

Collections Summary

- Collections exist in large numbers in many Java applications

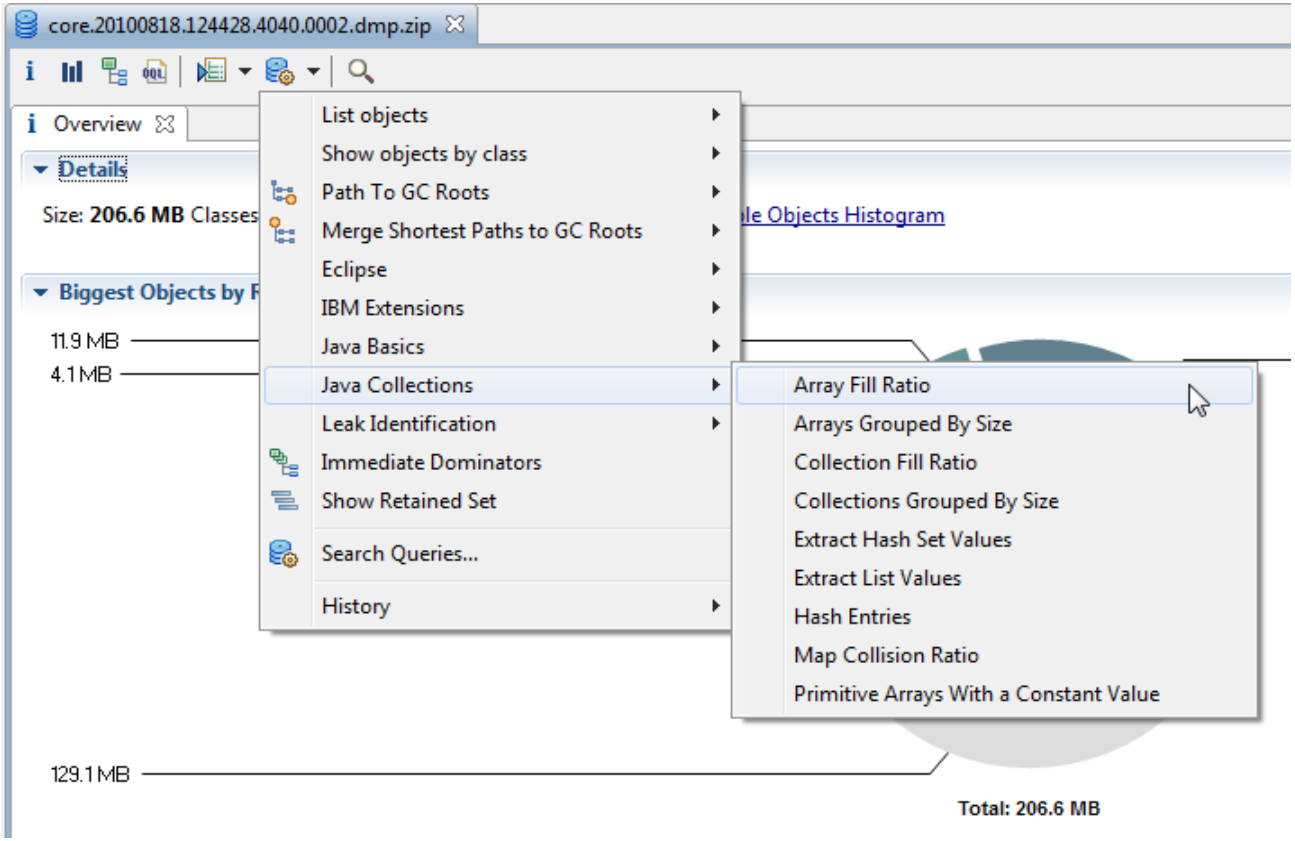
- Example: IBM WebSphere Application Server running PlantsByWebSphere
  - When running a 5 user test load, and using 206MB of Java heap:

HashTable	262,234 instances,	26.5MB of Java heap	
WeakHashMap	19,562 instances	2.6MB of Java heap	
HashMap	10,600 instances	2.3MB of Java heap	
ArrayList	9,530 instances	0.3MB of Java heap	
HashSet	1,551 instances	1.0MB of Java heap	
Vector	1,271 instances	0.04MB of Java heap	
LinkedList	1,148 instances	0.1MB of Java heap	
TreeMap	299 instances	0.03MB of Java heap	
306,195	**32.9MB**		

- 16% of the Java heap used just for the collection objects !!

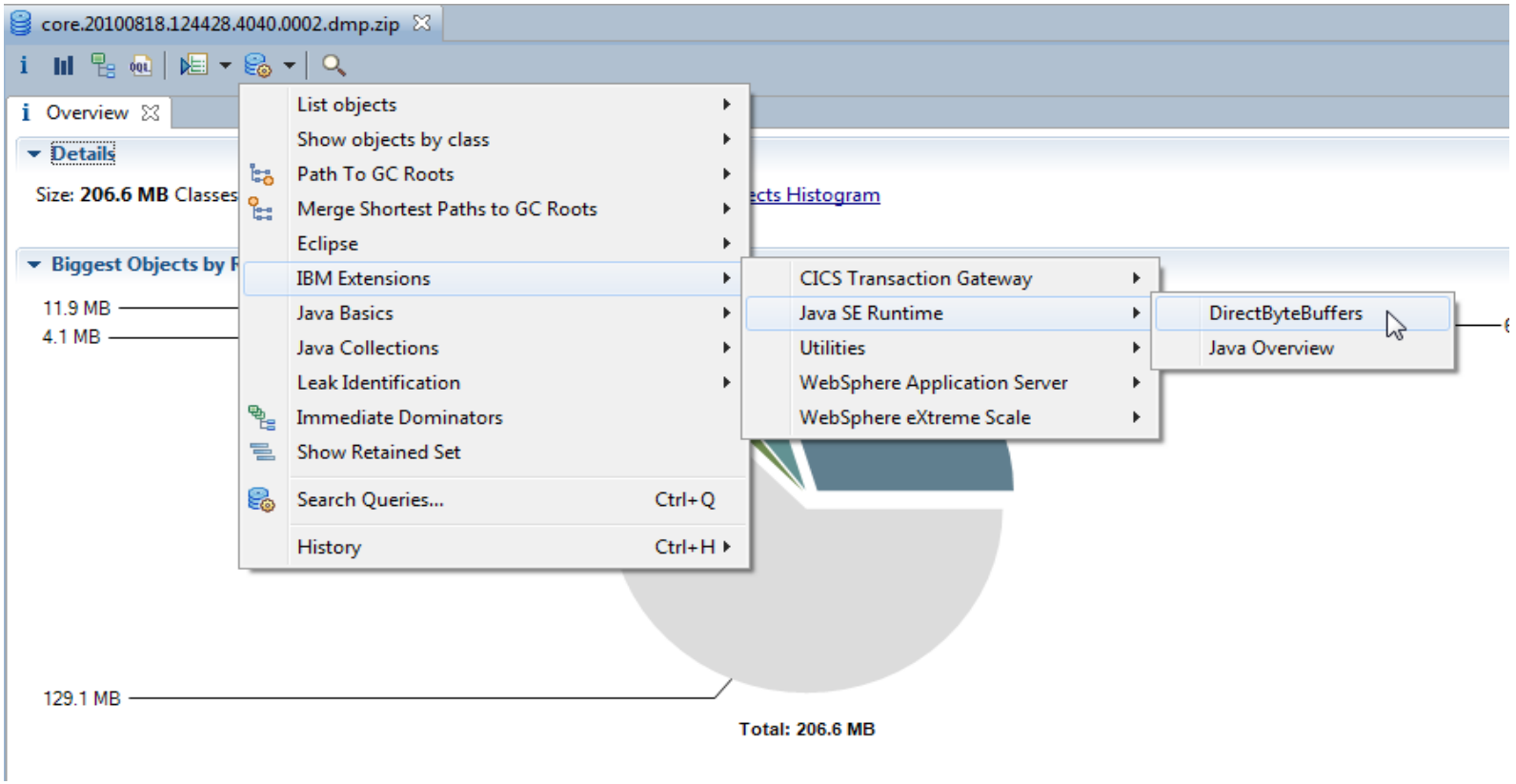
Analyzing your Collections

- Eclipse Memory Analyzer Tool (MAT) provides Collection analysis:



Analyzing your DirectByteBuffers

- IBM Extensions for Memory Analyzer (IEMA) provides DirectByteBuffer analysis:



Demo

Summary

- There is significant overhead to your data!
  - Some of which is on the “native” heap
- Applications often have:
  - The wrong collection types in use
  - Empty or sparsely populated collections
- Careful use of:
  - Data structure layout
  - Collection type selection
  - Collection type default sizing

  Can improve your memory efficiency
- Eclipse Memory Analyzer Tool can identify inefficiencies in your application
  - As well as show you the wider memory usage for code

Read the Article:

From Java Code to Java Heap on IBM developerWorks:

http://www.ibm.com/developerworks/java/library/j-codetoheap/index.html

References

- **Get Products and Technologies:**
  - IBM Monitoring and Diagnostic Tools for Java:
    - https://www.ibm.com/developerworks/java/jdk/tools/
  - Eclipse Memory Analyzer Tool:
    - http://eclipse.org/mat/downloads.php

- **Learn:**
  - Debugging from Dumps:
    - http://www.ibm.com/developerworks/java/library/j-memoryanalyzer/index.html
  - Why the Memory Analyzer (with IBM Extensions) isn't just for memory leaks anymore:
    - http://www.ibm.com/developerworks/websphere/techjournal/1103_supauth/1103_supauth.html

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