CSE 403
Lecture 18

Performance Testing

Reading:

Code Complete, Ch. 25-26 (McConnell)

slides created by Marty Stepp
http://www.cs.washington.edu/403/

Acceptance, performance

- **acceptance testing**: System is shown to the user / client / customer to make sure that it meets their needs.
  - A form of black-box system testing

- Performance is important.
  - Performance is a major aspect of program *acceptance* by users.
  - Your intuition about what's slow is often wrong.

What's wrong with this? (1)

```
public class BuildBigString {
    public final static int REPS = 80000;

    // Builds/returns a big, important string.
    public static String makeString() {
        String str = "";
        for (int n = 0; n < REPS; n++) {
            str += "more";
        }
        return str;
    }

    public static void main(String[] args) {
        System.out.println(makeString());
    }
}
```

What's wrong with this? (2)

```
public class Fibonacci {
    public static void main(String[] args) {
        // print the first 10000 Fibonacci numbers
        for (int i = 1; i <= 10000; i++) {
            System.out.println(fib(i));
        }
    }

    // pre: n >= 1
    public static long fib(int n) {
        if (n <= 2) {
            return 1;
        } else {
            return fib(n - 2) + fib(n - 1);
        }
    }
}
```

What's wrong with this? (3)

```
public class WordDictionary {
    // The set of words in our game.
    List<String> words = new ArrayList<String>();

    public void add(String word) {
        words.add(word.toLowerCase());
    }

    public boolean contains(String word) {
        for (String s : words) {
            if (s.toLowerCase().equals(word)) {
                return true;
            }
        }
        return false;
    }
}
```

What's wrong with this? (4)

```
public class BankManager {
    public static void main(String[] args) {
        Account[] a = Account.getAll();
        for (int i = 0; i < Math.sqrt(895732); i++) {
            a[i].loadTaxData();
            if (a.meetsComplexTaxCode(2020)) {
                a[i].fileTaxes(4 * 4096 * 17);
            }
        }

        Account[] a2 = Account.getAll();
        for (int i = 0; i < Math.sqrt(895732); i++) {
            if (a.meetsComplexTaxCode(2020)) {
                a2[i].setTaxRule(4 * 4096 * 17);
                a2[i].save(new File(a2.getName()));
            }
}   }   }
```

The correct answers

1. Who cares?
2. Who cares?
3. Who cares?
4. Who cares?

- *"We should forget about small efficiencies, say about 97% of the time: **premature optimization is the root of all evil.**"*

  -- Donald Knuth

- "We follow two rules in the matter of optimization:
  1. Don't do it.
  2. (for experts only) Don't do it yet."

  -- M. A. Jackson

Thinking about performance

- The app is only too slow if it doesn't meet your project's stated performance requirements.
  - If it meets them, DON'T optimize it!

- Which is more important, fast code or correct code?

- What are reasonable performance requirements?
  - What are the user's expectations? How slow is "acceptable" for this portion of the application?
  - How long do users wait for a web page to load?
  - Some tasks (admin updates database) can take longer

Optimization myths

- **Myth:** You should optimize your code as you write it.
  - No; makes code ugly, possibly incorrect, and not always faster.
  - Optimize later, only as needed.

- **Myth:** Having a fast program is as important as a correct one.
  - If it doesn't work, it doesn't matter how fast it's running!

- **Myth:** Certain operations are inherently faster than others.
  - `x << 1` is faster to compute than `x * 2` ?
  - This depends on many factors, such as language used.
    Don't write ugly code on the assumption that it will be faster.

- **Myth:** A program with fewer lines of code is faster.

Perceived performance

- "My app feels too slow. What should I do?"
  - possibly *optimize it*
  - And/or improve the app's *perceived performance*

- **perceived performance**:
  User's perception of your app's responsiveness.

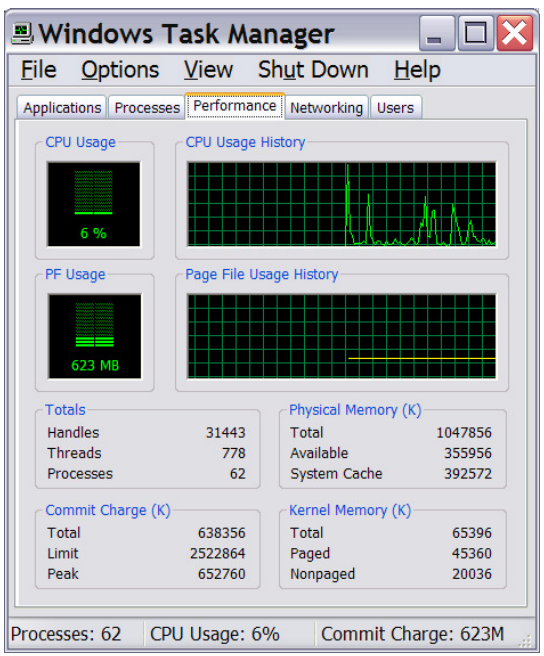
- factors affecting perceived performance:
  - loading screens
  - multi-threaded UIs (GUI doesn't stall while something is happening in the background)

Optimization metrics

- **runtime / CPU usage**
  - what lines of code the program is spending the most time in
  - what call/invocation paths were used to get to these lines
    - naturally represented as tree structures

- **memory usage**
  - what kinds of objects are on the heap
  - where were they allocated
  - who is pointing to them now
  - "memory leaks" (does Java have these?)

- **web page load times, requests/minute, etc.**



Benchmarking, optimization

- **benchmarking**: Measuring the absolute performance of your app on a particular platform (coarse-grained measurement).

- **optimization**: Refactoring and enhancing to speed up code.
  - I/O routines
    - accessing the console (print statements)
    - files, network access, database queries
    - `exec()` / system calls
  - Lazy evaluation saves you from computing/loading
    - don't read / compute things until you need them
  - Hashing, caching save you from reloading resources
    - combine multiple database queries into one query
    - save I/O / query results in memory for later

Optimizing memory access

- Non-contiguous memory access (bad):

```
for (int col = 0; col < NUM_COLS; col++) {
    for (int row = 0; row < NUM_ROWS; row++) {
        table[row][column] = bulkyMethodCall();
    }
}
```

- Contiguous memory access (good):

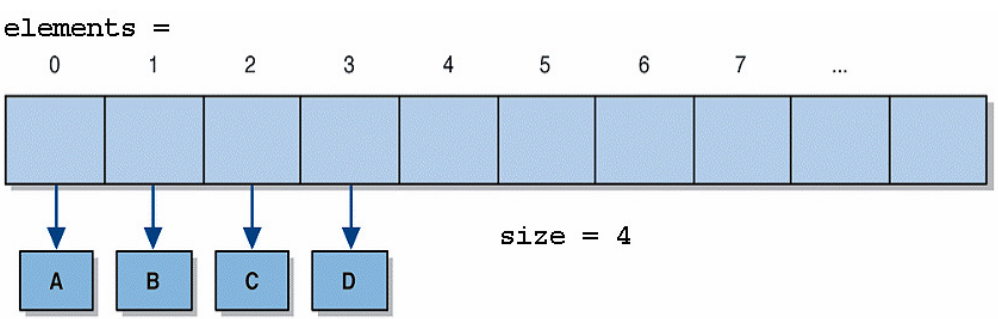
```
for (int row = 0; row < NUM_ROWS; row++) {
    for (int col = 0; col < NUM_COLS; col++) {
        table[row][column] = bulkyMethodCall();
    }
}
```

  - switches rows `NUM_ROWS` times, not `NUM_ROWS * NUM_COLS`

Optimizing data structures

- Take advantage of hash-based data structures
  - searching an ArrayList (contains, indexOf) is O(N)
  - searching a HashMap/HashSet is O(1)

- Getting around limitations of hash data structures
  - need to keep elements in sorted order? Use TreeMap/TreeSet
  - need to keep elements in insertion order? Use LinkedHashSet



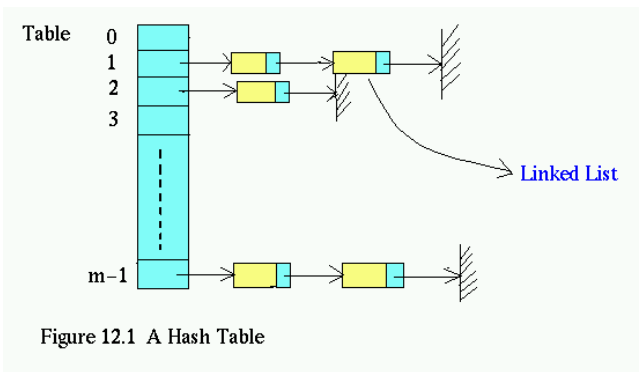


Figure 12.1 A Hash Table

Avoiding computations

- Stop computing when you know the answer:

```
found = false;
for (i = 0; i < reallyBigNumber; i++) {
    if (inputs[i].isTheOneIWant()) {
        found = true;
        break;
    }
}
```

- Hoist expensive loop-invariant code outside the loop:

```
double taxThreshold = reallySlowTaxFunction();
for (i = 0; i < reallyBigNumber; i++) {
    accounts[i].applyTax(taxThreshold);
}
```

Lookup tables

- Figuring out the number of days in a month:

```
if (m == 9 || m == 4 || m == 6 || m == 11) {
    return 30;
} else if (month == 2) {
    return 28;
} else {
    return 31;
}
```

- Days in a month, using a lookup table:

```
DAYS_PER_MONTH = {-1, 31, 28, 31, 30, 31, 30, ..., 31};
...
return DAYS_PER_MONTH[month];
```

  - Probably not worth the speedup with this particular example...

Optimization is deceptive

```
int sum = 0;
for (int row = 0; row < NUM_ROWS; row++) {
    for (int col = 0; col < NUM_COLS; col++) {
        sum += matrix[row][column];
    }
}
```

- Optimized code:

```
int sum = 0;
Cell* p = matrix;
Cell* end = &matrix[NUM_ROWS - 1][NUM_COLS - 1];
while (p != end) {
    sum += *p++;
}
```

- Speed-up observed: NONE.
  - Compiler was already optimizing the original into the second!

Dynamic programming

```
public static boolean isPrime(int n) {
    double sqrt = Math.sqrt(n);
    for (int i = 2; i <= sqrt; i++)
        if (n % i == 0) { return false; }
    return true;
}
```

- **dynamic programming**: Caching previous results.

```
private static Map<Integer, Boolean> PRIME = ...;

public static boolean isPrime2(int n) {
    if (!PRIME.containsKey(n))
        PRIME.put(n, isPrime(n));
    return PRIME.get(n);
}
```

Optimization tips

- **Pareto Principle**, aka the "80-20 Rule"
  - 80% of a program's execution occurs within 20% of its code.
  - You can get 80% results with 20% of the work.

- "The best is the enemy of the good."
  - You don't need to optimize all your app's code.
  - Find the worst bottlenecks and fix them. Leave the rest.

Profiling

- **profiling**: Measuring relative system statistics (fine-grained).
  - Where is the most time being spent? ("classical" profiling)
    - Which method takes the most time?
    - Which method is called the most?
  - How is memory being used?
    - What kind of objects are being created?
    - This in especially applicable in OO, GCed environments.
  - Profiling is *not* the same as benchmarking or optimizing.

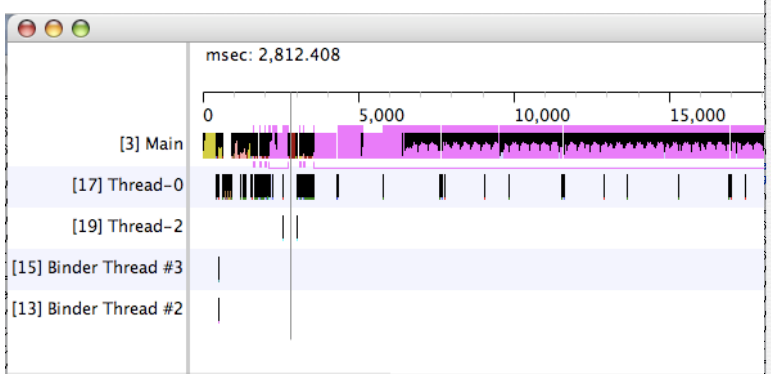
Types of profiling

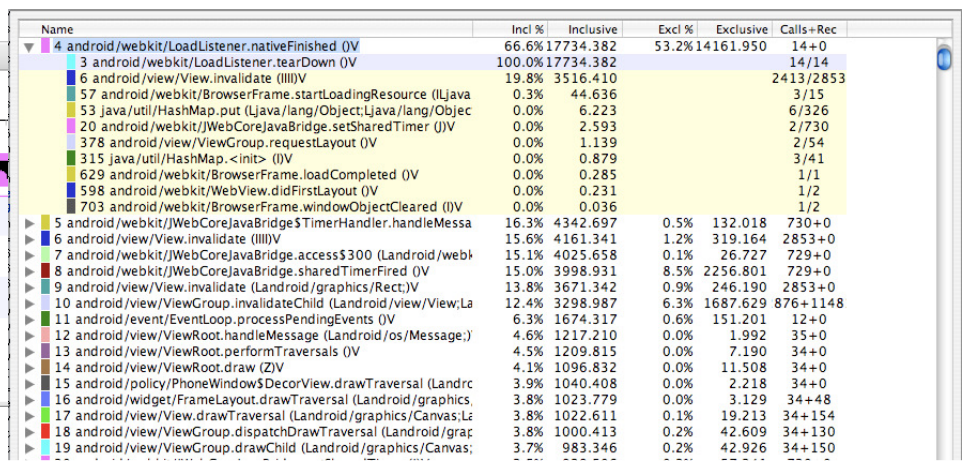
- **insertion**: placing special profiling code into your program (manually or automatically)
  - *pros*: can be used across a variety of platforms; accurate
  - *cons*: requires recompiling; profiling code may affect performance

- **sampling**: monitoring CPU or VM at regular intervals and saving a snapshot of CPU and/or memory state
  - *pros*: no modification of app is necessary
  - *cons*: less accurate; varying sample interval leads to a time/accuracy trade-off; small methods may be missed; cannot easily monitor memory usage

Android Traceview

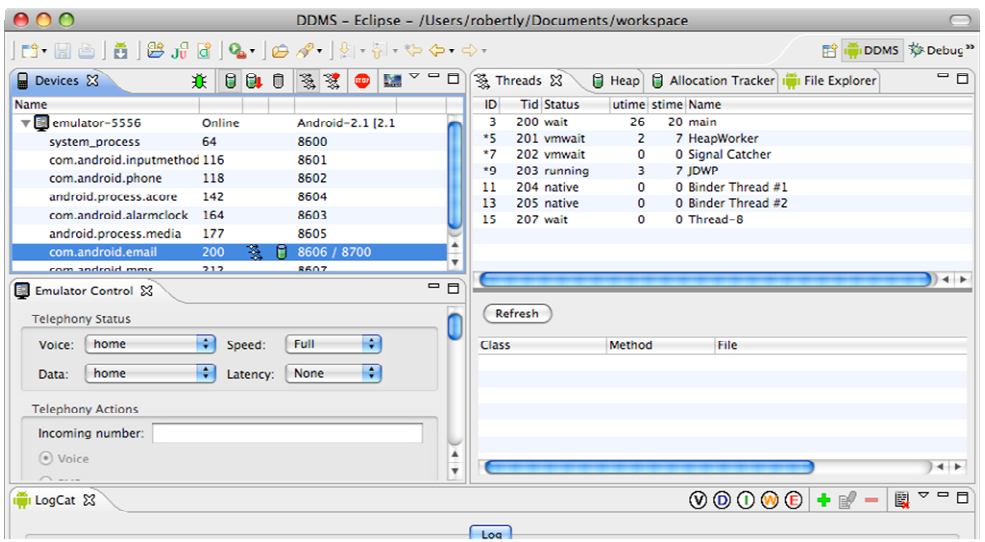
- Traceview:
  - http://developer.android.com/tools/debugging/debugging-tracing.html
  - `Debug` class generates *.trace files to be viewed
    - Debug.startMethodTracing(); ... Debug.stopMethodTracing();
  - *timeline panel:* describes when each thread/method start/stops
  - *profile panel:* summary of what happened inside a method





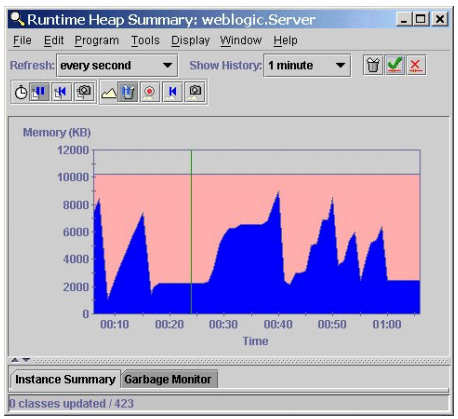
Android profiling DDMS

- Dalvik Debug Monitor Server (DDMS):
  - http://developer.android.com/tools/debugging/ddms.html
    - Eclipse: Window → Open Perspective → Other... → DDMS
    - console: run `ddms` from `tools/` directory
  - On Devices tab, select process that you want to profile
    - Click **Start Method Profiling**
    - Interact with application to run and profile its code.

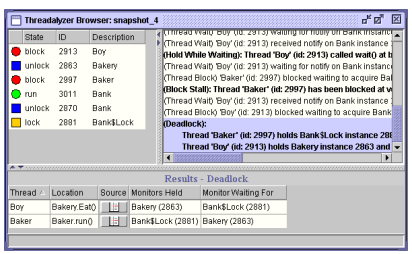


Java profiling tools

- Many free Java profiling/optimization tools available:
  - TPTP profiler extension for Eclipse
  - Extensible Java Profiler (EJP) - open source, CPU tracing only
  - Eclipse Profiler plugin
  - Java Memory Profiler (JMP)
  - Mike's Java Profiler (MJP)
  - JProbe Profiler - uses an instrumented VM



- hprof (`java -Xrunhprof`)
  - comes with JDK from Sun, free
  - good enough for anything I've ever needed



Using hprof

```
usage: java -Xrunhprof:[help]|[<option>=<value>, ...]

Option Name and Value  Description                    Default
---------------------  -----------                    -------
heap=dump|sites|all    heap profiling                 all
cpu=samples|times|old  CPU usage                      off
monitor=y|n            monitor contention             n
format=a|b             text(txt) or binary output     a
file=<file>            write data to file             off
depth=<size>           stack trace depth              4
interval=<ms>          sample interval in ms          10
cutoff=<value>         output cutoff point            0.0001
lineno=y|n             line number in traces?         Y
thread=y|n             thread in traces?              N
doe=y|n                dump on exit?                  Y
msa=y|n                Solaris micro state accounting n
force=y|n              force output to <file>         y
verbose=y|n            print messages about dumps     y
```

Sample hprof usage

```
java -Xrunhprof:cpu=samples,depth=6,heap=sites
```

or

```
java -Xrunhprof:cpu=old,thread=y,depth=10,cutoff=0,format=a
  ClassName
```

- Takes samples of CPU execution
- Record call traces that include the last 6/10 levels on the stack
- Only record "sites" used on heap (to keep output file small)

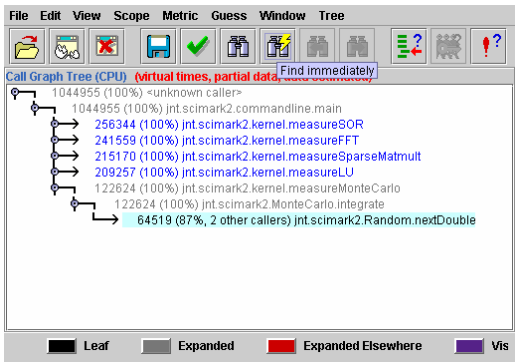
```
java -Xrunhprof ClassName
```

- Takes samples of memory/object usage

- After execution, open the text file `java.hprof.txt` in the current directory with a text editor

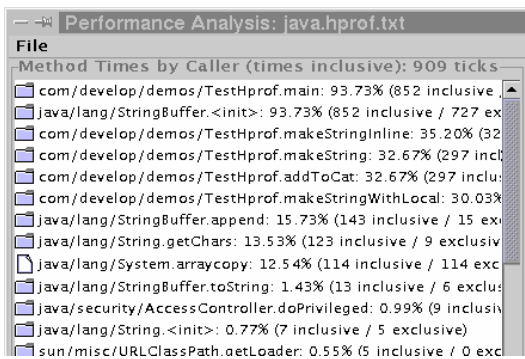
hprof visualization tools

- CPU samples
  - critical to see traces to modify code
  - hard to read - far from the traces in the file
  - **HPjmeter** analyzes java.hprof.txt visually
    - http://software.hp.com/portal/swdepot/displayProductInfo.do?productNumber=HPJMETER



  - another good tool called **PerfAnal** builds and navigates the invocation tree
  - download `PerfAnal.jar`, and:

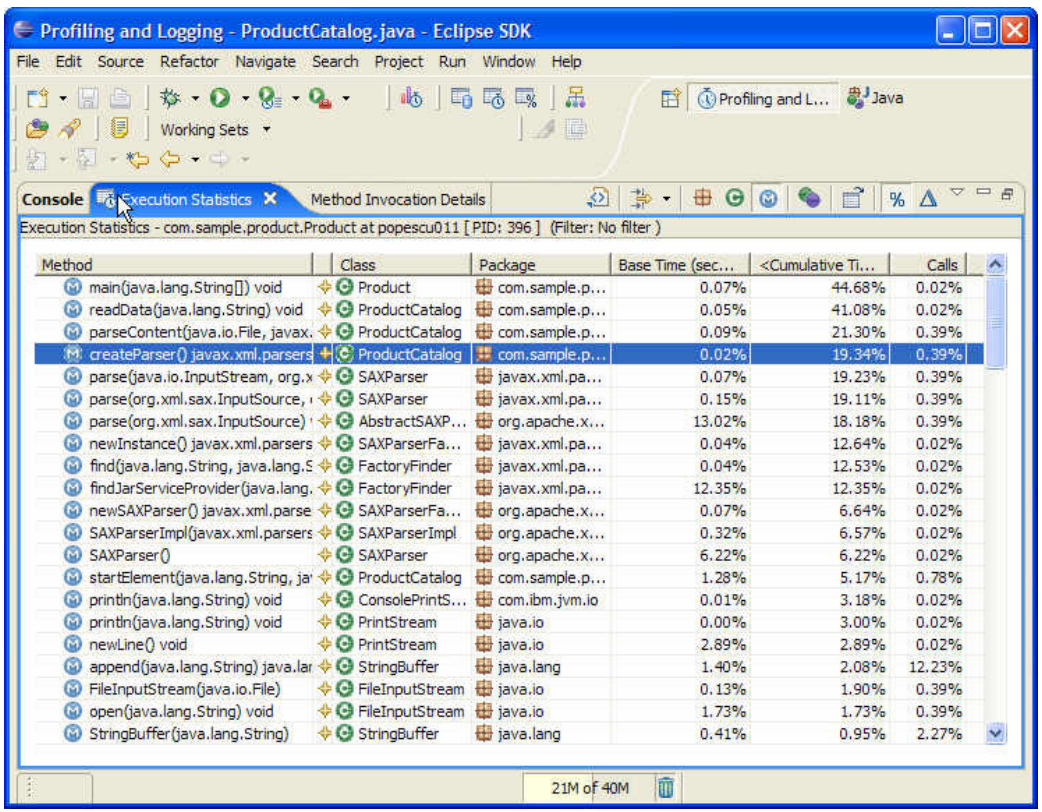
```
java -jar PerfAnal.jar ./java.hprof.txt
```



- Heap dump
  - critical to see what objects are there, and who points to them
  - HPjmeter or **HAT**: https://hat.dev.java.net/

TPTP

- a free extension to Eclipse for Java profiling
  - easier to interpret than raw hprof results
  - has add-ons for profiling web applications (J2EE)



Profiler results

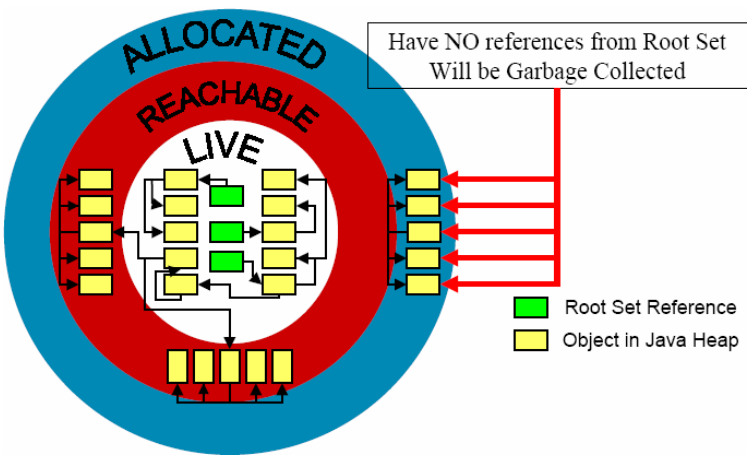
- What to do with profiler results:
  - observe which methods are being called the most
    - These may not necessarily be the "slowest" methods!
  - observe which methods are taking most time relative to others

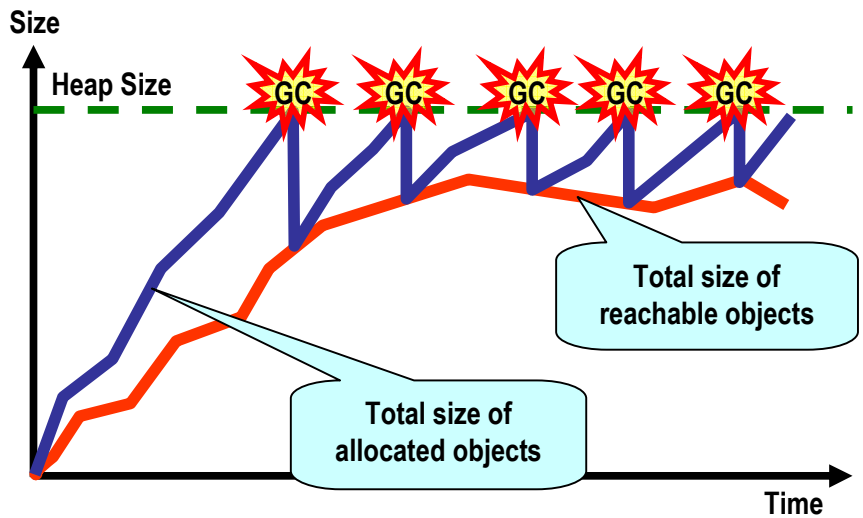
- Warnings
  - CPU profiling slows down your code (a lot)
    - design your profiling tests to be very short
  - CPU samples don't measure everything
    - doesn't record object creation and garbage collection time
  - Output files are very large, esp. if there is a heap dump

Garbage collection

- **garbage collector**: A memory manager that reclaims objects that are not reachable from a root-set

- **root set**: all objects with an immediate reference
  - all reference variables in each frame of every thread's stack
  - all static reference fields in all loaded classes





Profiling Web languages

- HTML/CSS
  - YSlow: http://developer.yahoo.com/yslow/
- JavaScript
  - Firebug: http://getfirebug.com/
- Ruby on Rails
  - ruby-prof: http://ruby-prof.rubyforge.org/
  - ruby-prof --printer=graph_html --file=myoutput.html myscript.rb
- JSP
  - x.Link: http://sourceforge.net/projects/xlink/
- PHP
  - Xdebug: http://xdebug.org/

JavaScript optimization

- JavaScript is ~1000x slower than C code.
- Modifying a page using the DOM can be expensive.

```
var ul = document.getElementById("myUL");
for (var i = 0; i < 2000; i++) {
    ul.appendChild(document.createElement("li"));
}
```

  - Faster code that modifies DOM objects "offline":

```
var ul = document.getElementById("myUL");
var li = document.createElement("li");
var parent = ul.parentNode;
parent.removeChild(ul);
for (var i = 0; i < 2000; i++) {
    ul.appendChild(li.cloneNode(true));
}
parent.appendChild(ul);
```