Testing and Debugging

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Source

I. Sommerville, Software Engineering, Addison-Wesley, Sixth Edn., 2000.

svnbook.red-bean.com

www.eclipse.org

Roadmap

1. Testing — definitions and strategies
2. Understanding the run-time stack and heap
3. Debuggers
4. Timing benchmarks
5. Profilers
6. Version control systems

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Testing

Unit testing:	test *individual (stand-alone) components*
Module testing:	test a *collection of related components* (a module)
Sub-system testing:	test *sub-system interface mismatches*
System testing:	(i) test *interactions between sub-systems*, and (ii) test that the complete systems fulfils *functional and non-functional requirements*
Acceptance testing (alpha/beta testing):	test system with *real rather than simulated data*.

Testing is always iterative!

Regression testing

Regression testing means testing that *everything that used to work still works* after changes are made to the system!

tests must be *deterministic and repeatable*

should test “all” functionality

- every interface (black-box testing)
- all boundary situations
- every feature
- every line of code (white-box testing)
- everything that can conceivably go wrong!

Regression testing

It costs extra work to define tests up front, but they more than pay off in debugging & maintenance!

Caveat: Testing and Correctness

"Program testing can be used to show the presence of bugs, but never to show their absence!"

—Edsger Dijkstra, 1970

Testing a Stack

We define a simple regression test that exercises all StackInterface methods and checks the boundary situations:

```
public class LinkStackTest {
   protected StackInterface stack;
   private int size;

   @Before public void setUp() {
      stack = new LinkStack();
   }

   @Test public void empty() {
      assertTrue(stack.isEmpty());
      assertEquals(0, stack.size());
   }
…
```

Build simple test cases

Construct a test case and check the obvious conditions:

```
@Test public void oneElement() {
   stack.push("a");
   assertFalse(stack.isEmpty());
   assertEquals(1, size = stack.size());
   stack.pop();
   assertEquals(size -1, stack.size());
}
```

What other test cases do you need to fully exercise a Stack implementation?

Check that failures are caught

How do we check that an assertion fails when it should?

```
@Test(expected=AssertionError.class)
public void emptyTopFails() {
   stack.top();
}

@Test(expected=AssertionError.class)
public void emptyRemoveFails() {
   stack.pop();
}
```

ArrayStack

We can also implement a (variable) Stack using a (fixed-length) array to store its elements:

```
public class ArrayStack implements StackInterface {
   private Object store [];
   private int capacity;
   private int size;

   public ArrayStack() {
      store = null;     // default value
      capacity = 0;     // available slots
      size = 0;         // used slots
   }
```

What would be a suitable class invariant for ArrayStack?

Handling overflow

Whenever the array runs out of space, the Stack “grows” by allocating a larger array, and copying elements to the new array.

```
public void push(Object item)
{
   if (size == capacity) {
      grow();
   }
   store[++size] = item;     // NB: subtle error!
}
```

How would you implement the grow() method?

Checking pre-conditions

```
public boolean isEmpty() { return size == 0; }
public int size() { return size; }

public Object top() {
   assert(!this.isEmpty());
   return store[size-1];
}
public void pop() {
   assert(!this.isEmpty());
   size--;
}
```

NB: we only check pre-conditions in this version!

Should we also shrink() if the Stack gets too small?

Adapting the test case

We can easily adapt our test case by overriding the **`setUp()`** method in a subclass.

```
public class ArrayStackTest extends LinkStackTest {
   @Before public void setUp() {
      stack = new ArrayStack();
   }
}
```

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Testing ArrayStack

When we test our **`ArrayStack`**, we get a surprise:

```
java.lang.ArrayIndexOutOfBoundsException: 2
   at cc3002.stack.ArrayStack.push(ArrayStack.java:27)
   at cc3002.stack.LinkStackTest.twoElement(LinkStackTest.java:46)
   at ...
```

The stack trace tells us exactly where the exception occurred ...

The Run-time Stack

The *run-time stack* is a fundamental data structure used to record the context of a procedure that will be returned to at a later point in time.

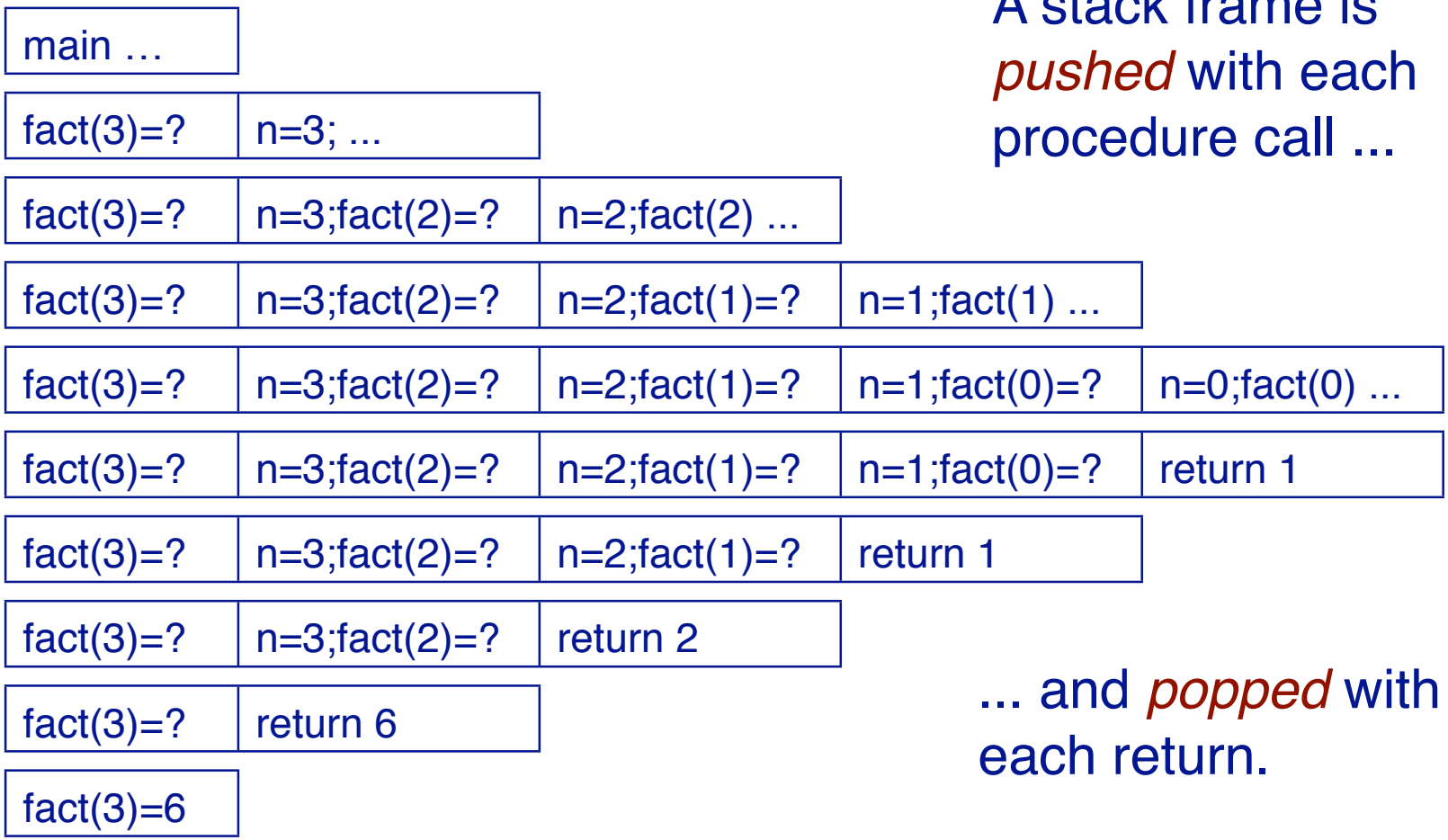
This *context* (AKA "*stack frame*") stores the arguments to the procedure and its local variables.

Practically all programming languages use a run-time stack:

The Run-time Stack

```
public static void main(String args[]) {
   System.out.println( "fact(3) = " + fact(3));
}
public static int fact(int n) {
   if (n<=0) { return 1; }
   else { return n*fact(n-1) ; }
}
```

The run-time stack in action ...

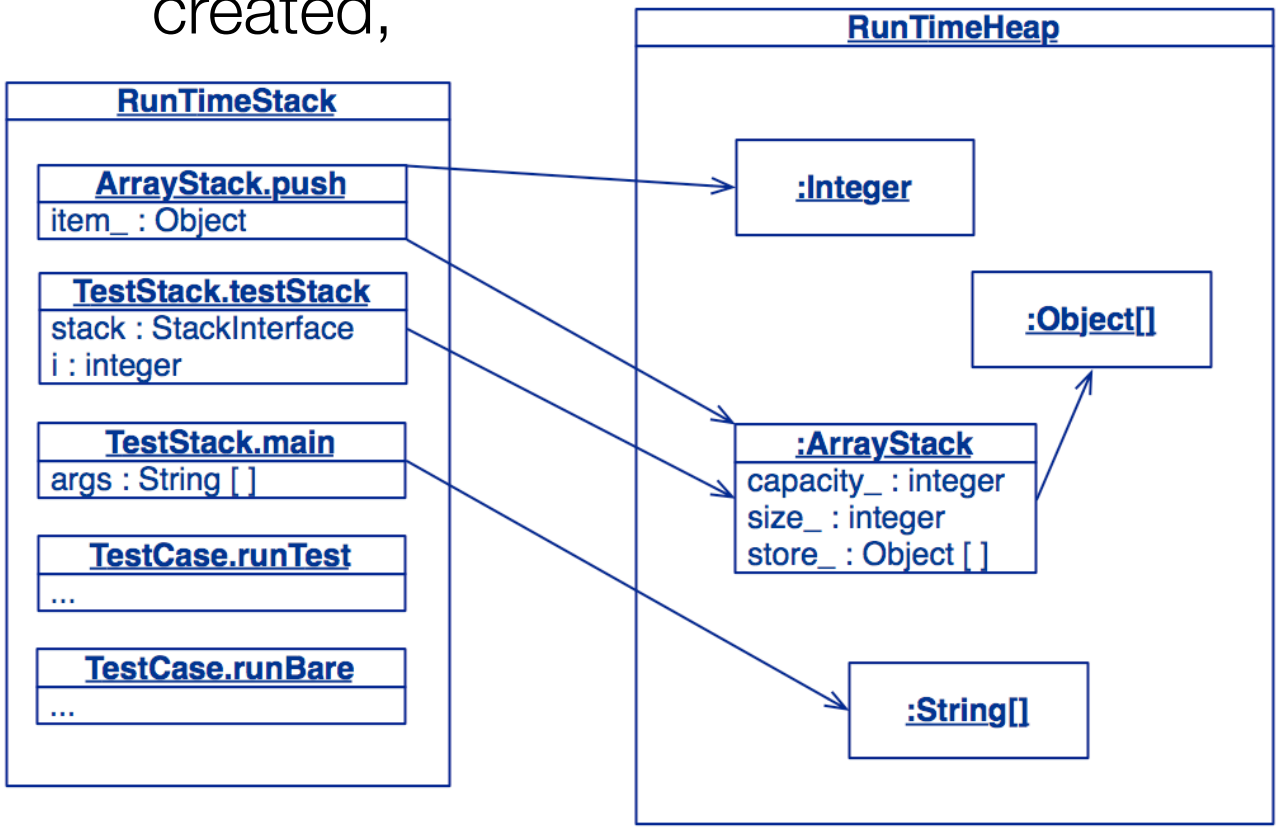


A stack frame is *pushed* with each procedure call ...

... and *popped* with each return.

The Stack and the Heap

The Heap grows with each new Object created,



and shrinks when Objects are garbage-collected.

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Debuggers

A *debugger* is a tool that allows you to examine the state of a running program:

- *step* through the program instruction by instruction
- *view* the source code of the executing program
- *inspect* (and *modify*) *values* of variables in various formats
- *set* and *unset breakpoints* anywhere in your program
- *execute* up to a specified breakpoint
- *examine* the state of an aborted program (in a “core file”)

Using Debuggers

Interactive debuggers are available for most mature programming languages and integrated in IDEs.

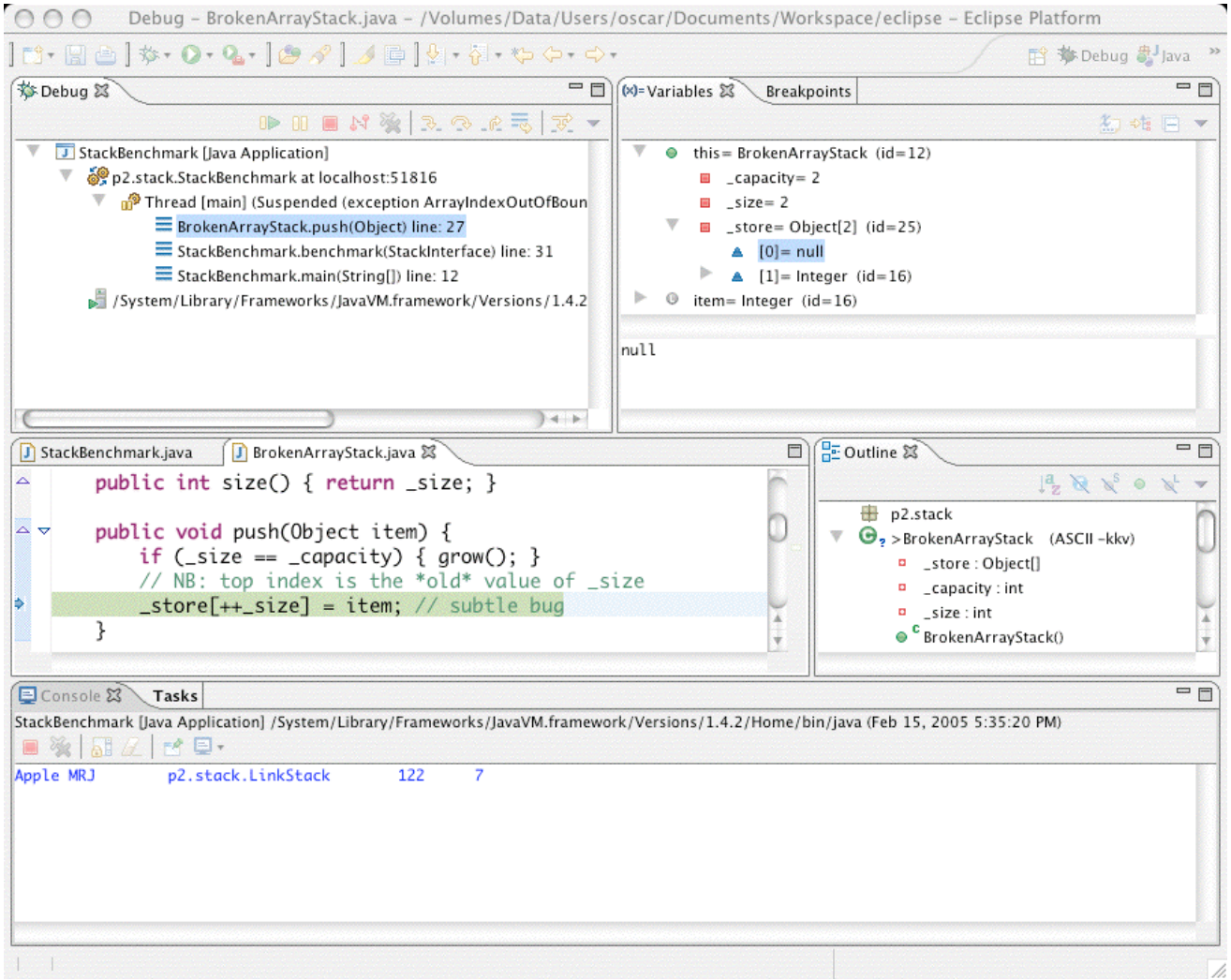
Classical debuggers are line-oriented (e.g., jdb); most modern ones are graphical.

When should you use a debugger?

When you are unsure why (or where) your program is not working

Debugging in Eclipse

When unexpected exceptions arise, you can use the debugger to inspect the program state …



Debugging Strategy...

Develop tests as you program

Apply *Design by Contract* to decorate classes with invariants and pre- and post-conditions

Develop *unit tests* to exercise all paths through your program

use *assertions* (not print statements) to probe the program state

print the state only when an assertion fails

After every modification, do regression testing!

Debugging Strategy

If errors arise during testing or usage

Use the test results to track down and fix the bug

If you can't tell where the bug is, *then use a debugger* to identify the faulty code

- fix the bug

- identify and *add any missing tests*!

All software bugs are a matter of *false assumptions*. If you make your assumptions explicit, you will find and stamp out your bugs!

Fixing our mistake

We erroneously used the incremented size as an index into the store, instead of the new size of the stack - 1:

```
public void push(Object item) ... {
   if (size == capacity) { grow(); }
   store[size++] = item;
   assert(this.top() == item);
   assert(invariant());
}
```

NB: perhaps it would be clearer to write:

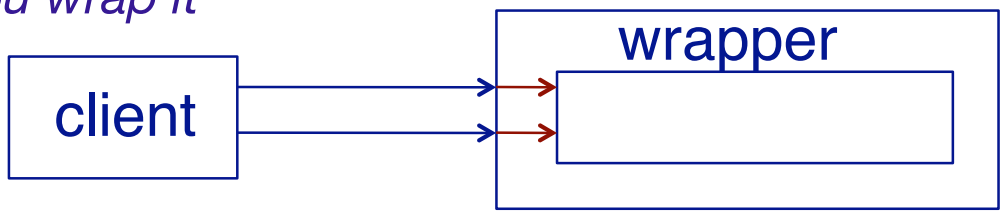
```
store[this.topIndex()] = item;
```

Wrapping Objects

Wrapping is a fundamental programming technique for systems integration.

What do you do with an object whose interface doesn't fit your expectations?

You wrap it



What are possible disadvantages of wrapping?

java.util.Stack

Java also provides a Stack implementation,
but it is not compatible with our interface:

```
public class Stack extends Vector {
   public Stack();
   public Object push(Object item);
   public synchronized Object pop();
   public synchronized Object peek();
   public boolean empty();
   public synchronized int search(Object o);
}
```

If we change our programs to work with the Java Stack,
we won't be able to work with our own Stack implementations ...

A Wrapped Stack

A wrapper class implements a required interface, by *delegating requests* to an instance of the wrapped class:

```
public class SimpleWrappedStack implements StackInterface {
   Stack stack;
   public SimpleWrappedStack() { stack = new Stack(); }
   public boolean isEmpty() { return stack.empty(); }
   public int size() { return stack.size(); }
   public void push(Object item) { stack.push(item); }
   public Object top() { return stack.peek(); }
   public void pop() { stack.pop(); }
}
```

Do you see any flaws with our wrapper class?

A contract mismatch

But running the test case yields:

```
java.lang.Exception: Unexpected exception,
expected<java.lang.AssertionError> but
was<java.util.EmptyStackException>
   ...
Caused by: java.util.EmptyStackException
   at java.util.Stack.peek(Stack.java:79)
   at cc3002.stack.SimpleWrappedStack.top(SimpleWrappedStack.java:32)
   at cc3002.stack.LinkStackTest.emptyTopFails(LinkStackTest.java:28)
   ...
```

What went wrong?

Fixing the problem

Our tester *expects* an empty Stack to throw an exception when it is popped, but java.util.Stack doesn't do this — so *our wrapper should check its preconditions*!

```
public class WrappedStack implements StackInterface {
   public Object top() {
      assert !this.isEmpty();
      return super.top();
   }
   public void pop() {
      assert !this.isEmpty();
      super.pop();
      assert invariant();
   }
   …
}
```

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Timing benchmarks

Which of the Stack implementations performs better?

```
timer.reset();
for (int i=0; i<iterations; i++) {
   stack.push(item);
}
elapsed = timer.timeElapsed();
System.out.println(elapsed + " milliseconds for "
     + iterations + " pushes");
...
```

Complexity aside, how can you tell which implementation strategy will perform best?

Run a benchmark

Timer

```
import java.util.Date;
public class Timer {                    // Abstract from the
   protected Date startTime;            // details of timing
   public Timer() {
      this.reset();
   }
   public void reset() {
      startTime = new Date();
   }
   public long timeElapsed() {
      return new Date().getTime() - startTime.getTime();
   }
}
```

Sample benchmarks (milliseconds)

Stack Implementation	***100K pushes***	***100K pops***
p2.stack.LinkStack	126	6
p2.stack.ArrayStack	138	3
p2.stack.**WrappedStack**	104	154

Can you explain these results? Are they what you expected?

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Profilers

A profiler tells you where a terminated program *has spent its time*

1 - your program must first be instrumented by

I - setting a compiler (or interpreter) option, or

II - adding instrumentation code to your source program

2 - the program is run, generating a profile data file

3 - the profiler is executed with the profile data as input

The profiler can then display the call graph in various formats

Caveat: the technical details vary from compiler to compiler

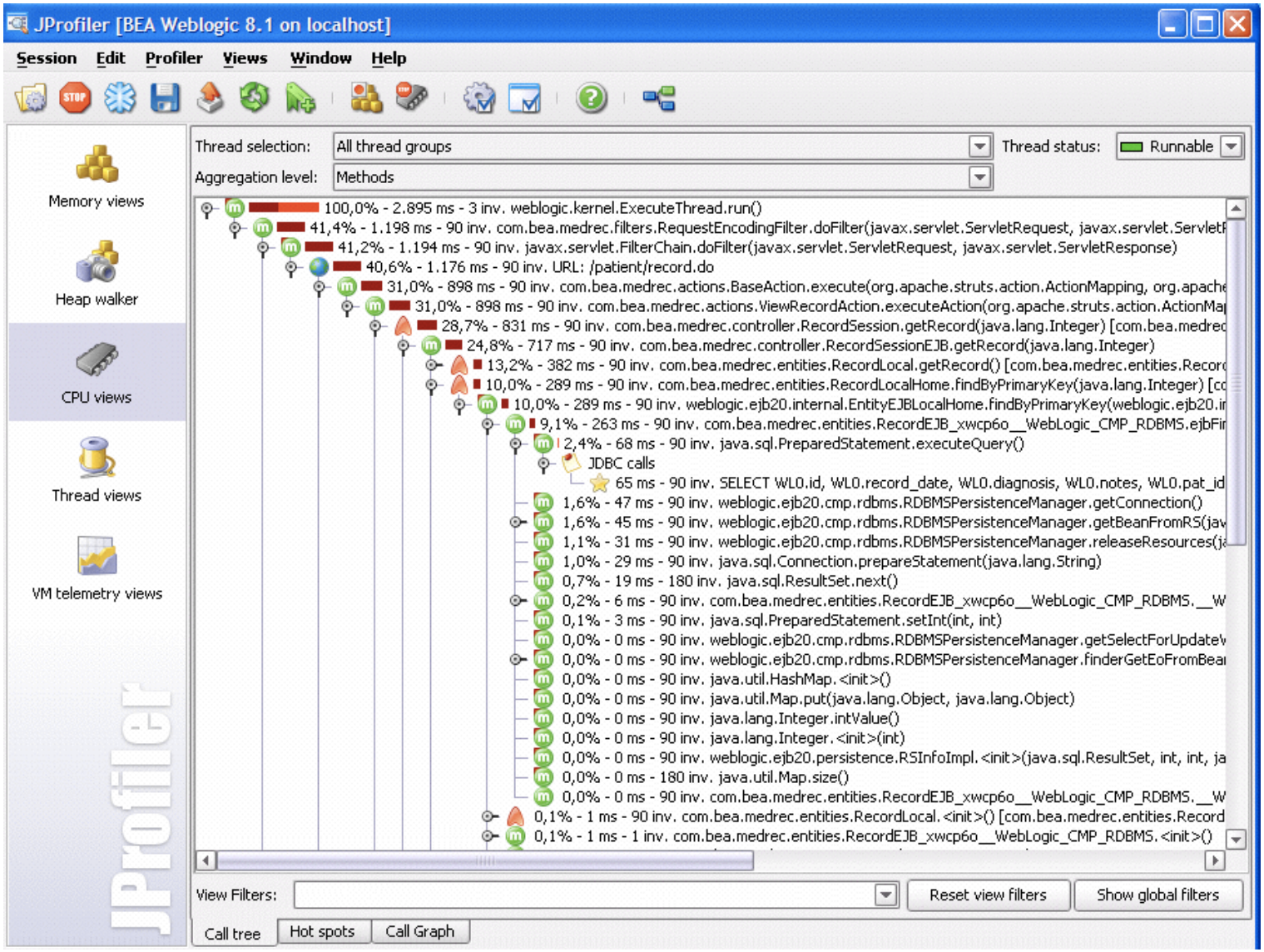
Using java -Xprof

```
Flat profile of 0.61 secs (29 total ticks): main

  Interpreted + native   Method
 20.7%     0  +     6    java.io.FileOutputStream.writeBytes
  3.4%     0  +     1    sun.misc.URLClassPath$FileLoader.<init>
  3.4%     0  +     1    p2.stack.LinkStack.push
  3.4%     0  +     1    p2.stack.WrappedStack.push
  3.4%     0  +     1    java.io.FileInputStream.open
  3.4%     1  +     0    sun.misc.URLClassPath$JarLoader.getResource
  3.4%     0  +     1    java.util.zip.Inflater.init
  3.4%     0  +     1    p2.stack.ArrayStack.grow
 44.8%     1  +    12    Total interpreted

…
```

Example of Profiler Features



Using Profilers

When should you use a profiler?

Always run a profiler before attempting to tune performance.

How early should you start worrying about performance?

Only after you have a clean, running program with poor performance.

NB: The call graph also tells you which parts of the program have (not) been tested!

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Version Control Systems

A version control system keeps track of multiple file revisions:

- *check-in* and *check-out* of files
- *logging changes* (who, where, when)
- *merge* and *comparison* of versions
- *retrieval* of arbitrary versions
- "*freezing*" of versions as releases
- reduces storage space (manages sources files + multiple "deltas")

Version control

Version control enables you to make radical changes to a software system, with the assurance that *you can always go back* to the last working version.

When should you use a version control system?

> Use it whenever you have one available, for even the smallest project!

Version control is as important as testing in iterative development!

Subversion (SVN)

SVN is a standard versioning system for Mac, Windows and UNIX platforms (see subversion.tigris.org)

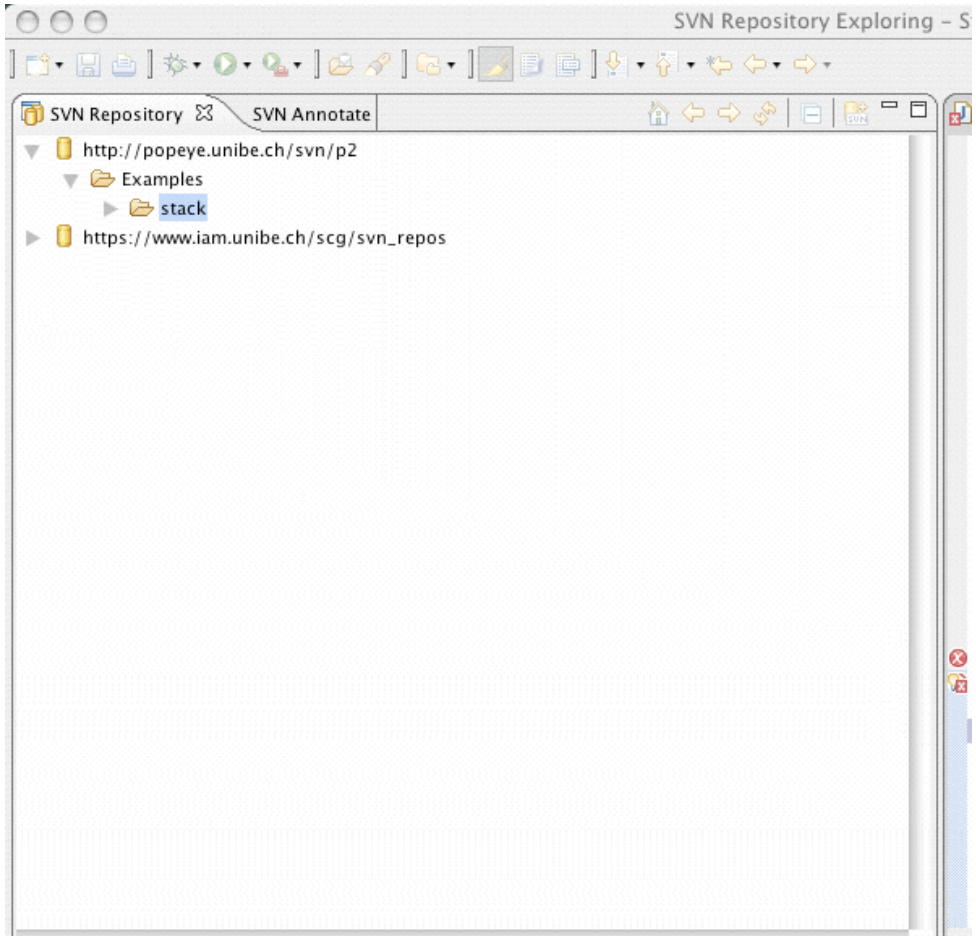
- *Shared repository* for teamwork
  - Manages hierarchies of files
  - Manages parallel development branches
- Uses *optimistic version control*
  - no locking
  - merging on conflict
- Offers *network-based* repositories
- Integrated in Eclipse!

Using SVN

```
svn import ${svnrepo}/MyProject
cd MyProject                    make a svn directory
cd somewhere                    checkout a svn project
svn co ${svnrepo}/MyProject
cd MyProject
...                                modify and add files (text or binary)
svn add ArrayStack.java
svn commit                      commit changes (with comments)
...                                time passes ...
svn update                      update working copy (if necessary)
svn log                         list recent changes
```

SVN and Eclipse

Eclipse offers a simple GUI for interacting with svn repositories



What you should know!

What is a *regression test*? Why is it important?

What *strategies* should you apply to design a test?

What are the *run-time* stack and *heap*?

How can you adapt client/supplier interfaces that don't match?

When are *benchmarks* useful?

Can you answer these questions?

Why can't you use tests to demonstrate absence of defects?

How would you implement ArrayStack.grow()?

Why doesn't Java allocate objects on the run-time stack?

What are the advantages and disadvantages of wrapping?

What is a suitable class invariant for WrappedStack?

How can we learn where each Stack implementation is spending its time?

How much can the same benchmarks differ if you run them several times?

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