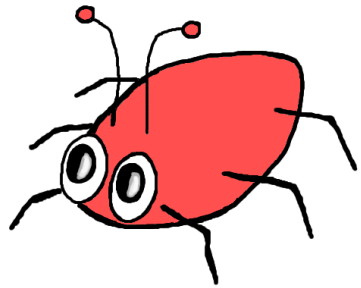
Finding Bugs is Easy

David Hovemeyer and William Pugh



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Bugs in software

- Programmers are smart
- We have good techniques (e.g., unit testing, pair programming, code inspections) for finding bugs early
- So, most bugs remaining in production code must be subtle, and require sophisticated techniques to find
- Right?

- Apache Ant 1.6.2, org.apache.tools.ant.taskdefs.optional.metamata.MAudit

```
if (out == null) {
    try {
        out.close();
    } catch (IOException e) {
    }
}
```

- Eclipse 3.0.1, org.eclipse.update.internal.core.ConfiguredSite

```
if (in == null)
    try {
        in.close();
    } catch (IOException e1) {
    }
```

- JBoss 4.0.0RC1, org.jboss.mq.xml.XElement

```
if ( split[0].equals( null ) ) {
  return this;
}
```

- JBoss 4.0.0RC1, org.jboss.cache.TreeCache

```
int treeNodeSize=fqn.size();
if(fqn == null) return null;
```

- J2SE version 1.5 build 63 (released version), java.lang.annotation.AnnotationTypeMismatchException

```
public String foundType() {
    return this.foundType();
}
```

Software contains bugs

- Lots of obvious bugs find their way into production software
- Testing and code inspections won't find every bug
  - Very hard to get high test coverage for a large system
  - Limits to frequency, completeness of code inspections
- Techniques to find more bugs automatically are valuable

Static analysis

- Let the computer figure out where (some of) the bugs are
- Much work has been done on static analysis to find bugs
  - Lint, PREfix, PREfast, FxCop, MC/Metal, ESC/Java, Cqual
  - Many other tools, papers, techniques
- However, static bug checking not used nearly as widely as testing, code inspections
  - We think it should be!

Static analysis challenges

- Fundamental limits to static analysis
  - Nontrivial properties of programs are undecidable
- Choice: what to do when confronted by a difficult analysis problem
  - Be consistently conservative: could choose to
    - Never miss a real bug (but report some false positives)
    - Never report a false positive (but miss some real bugs)
  - Guess a "likely" behavior
    - *Both* false positives and false negatives are possible
    - But, may be able to get better accuracy overall

Bugs vs. style

- It is important to distinguish *bug checkers* from *style checkers*
  - Style checkers warn about dubious or dangerous coding idioms: however, instances of those idioms may not be particularly likely to be a bug
  - Bug checkers warn about code idioms that *are* likely to be acutal bugs
- Style checkers useful for enforcing consistent coding standards
  - Help *prevent* certain kinds of bugs

Bug-driven bug finding

- When a bug is found, a good developer will:
  - Fix it
  - Add a dynamic check or test case to make sure the bug cannot reoccur
- Why not take this idea a step further?
  - Write a static bug checker to find occurences of similar bugs elsewhere in the program, or in other programs

Bug patterns

- Many bugs share common characteristics
- These common characteristics form *bug patterns*
- Can often be detected using simple analysis techniques
- Consequences of imprecision:
  - May miss some real bugs
  - May report *false warnings*

Genesis of a bug pattern

- Bug arose in intro programming course

```
class WebSpider {
    /** Construct a new WebSpider */
    public WebSpider(boolean isDFS, int limit) {
        WebSpider spider = new WebSpider(isDFS, limit);
    }
```

- Bug is unconditional self-recursive invocation: infinite loop
  - Checked, 4 other students had similar bugs
- Wrote detector to find unconditional self-recursion; ran it on JDK1.5 rt.jar to ensure it wasn't generating false positives
  - Found 3 real bugs!

Static analysis philosophy

Two approaches to devising a static analysis to find bugs:

1. Given an analysis technique, figure out what bugs it could find
2. Given a bug, figure out an analysis that could be used to find occurrences of similar bugs

The FindBugs tool

- We have implemented automatic detectors for about 50 bug patterns in a tool called FindBugs
  - Open source
  - http://findbugs.sourceforge.net
- Analyzes Java bytecode using Apache BCEL library
  - Bytecode is easy to analyze
  - Tool continues to work in the face of language changes (e.g., new Java 1.5 language features)

Implementing a bug pattern detector

- Implementation steps:
  1. Think of the simplest technique that would find occurrences of the bug
  2. Implement it
  3. Apply it to real software
     - Hopefully find some real bugs
     - Will probably produce some false warnings
  4. Add heuristics to reduce percentage of false warnings
- Our experience: new detectors can usually be implemented quickly (somewhere between a few minutes and a few days)
- Often, detectors find more bugs than you would expect

Implementation techniques

- We use various kinds of analysis in implementing detectors:
  - Examination of method names, signatures, class hierarchy
  - Linear scan of bytecode instructions using a state machine
  - Method control flow graphs, dataflow anlysis
- No interprocedural flow analysis or sophisticated heap analysis

Categories

- Categories of bug patterns
  - Correctness
    - Multithreaded correctness
  - Malicious code vulnerability
  - Efficiency and design
- Will we describe a few of the patterns and show some examples of bugs found
  - See paper, website for more bug patterns

Correctness bugs

Hashcode/Equals

- Equal objects must have equal hash codes
  - Programmers sometimes override equals() but not hashCode()
    - Or, override hashCode() but not equals()
  - Objects violating the contract won't work in hash tables, maps, sets
- Example (JDK 1.5 build 59):
  - javax.management.Attribute
- Warnings: 55 in rt.jar 1.5-b59, 170 in eclipse-3.0

Covariant Equals

- equals() method must have parameter of type Object
- Programmers sometimes define with the type of the class
  - Doesn't actually override Object.equals()
  - The right equals() won't get used in Collections
- Examples (JDK 1.5 build 59)
  - java.awt.geom.Area
  - sun.security.krb5.Realm
- Warnings: 9 in rt.jar 1.5-b59, 3 in eclipse-3.0

Null Pointer Dereference

- Often, these happen because of trivial mistakes (e.g., using && instead of ||, or vice versa)
- Sometimes, code is modified incorrectly during maintenance
- Bugs: 37 in rt.jar 1.5-b59, 55 in eclipse-3.0

Null pointer examples

- Eclipse 3.0.1, org.eclipse.team.internal.ccvs.core.CVSSyncInfo

```
if (local != null || local.getType() == IResource.FILE) {
```

- Eclipse 3.0.1, org.eclipse.debug.internal.ui.sourcelookup.AddSourceContainerDialog

```
if(browser == null) {
    super.okPressed();
}
ISourceContainer results =
    browser.addSourceContainers(getShell(), fDirector);
```

Null pointer examples

- JBoss 4.0.0RC1, javax.xml.soap.SOAPPart, getContentId()

```
if( header != null || header.length > 0 )
   id = header[0];
```

- JBoss 4.0.0RC1, javax.xml.soap.SOAPPart, getContentLocation()

```
if( header != null || header.length > 0 )
   location = header[0];
```

Return value ignored

- Many API methods can only be used correctly if return value is checked
  - E.g., methods that perform an operation on an immutable object such as a String
  - Programmers might think operation actually modifies object
- Bugs: 5 in rt.jar 1.5-b59, 7 in eclipse-3.0

Return value ignored examples

- Eclipse 3.0.1, org.eclipse.ui.externaltools.internal.model.BuilderUtils

```
String name= workingCopy.getName();
name.replace('/', '.');
if (name.charAt(0) == ('.')) {
```

Return value ignored examples

- Eclipse 3.0.1, org.eclipse.update.internal.ui.security.UpdateManagerAuthenticator

```
String hostString = host;
if (hostString == null && address != null) {
    address.getHostName();     Meant to assign to hostString?
}
if (hostString == null) {
    hostString = ""; //$NON-NLS-1$
}
```

Multithreaded correctness bugs

Inconsistent synchronization

- Detecting data races: NP hard in general case
  - Many complicated analyses have been developed to find data races
  - What if we try looking for very obvious data races?
- Common idiom for thread safe classes is to synchronize on the receiver object ("this")
- Examine all field accesses and synchronized regions
  - Find fields where lock on "this" object is sometimes, but not always, held
  - Unsynchronized accesses, if reachable by multiple threads, constitute a potential data race
- Bugs: 52 in rt.jar 1.5-b59, 39 in eclipse-3.0

Inconsistent synchronization example

- GNU Classpath 0.08, java.util.Vector

```
public int lastIndexOf(Object elem)
{
  return lastIndexOf(elem, elementCount - 1);
}

public synchronized int lastIndexOf(Object e, int index)
{
  ...
```

Unconditional wait

- Before waiting on a monitor, the condition waited for should be checked
  - Waiting unconditionally upon entering a synchronized block usually a bug
  - If condition checked without lock held, could miss notification
- Bugs: 3 in rt.jar 1.5-b59, 2 in eclipse-3.0

Unconditional wait example

- JBoss 4.0.0RC1, org.jboss.deployment.scanner.AbstractDeploymentScanner

```
// If we are not enabled, then wait
if (!enabled) {                    Condition checked without lock held!
   try {                                  Notification could occur here!
      log.debug("Disabled, waiting for notification");
      synchronized (lock) {
         lock.wait();                              Could wait forever
      }
```

Malicious code vulnerabilities

Mutable static

- Can static fields (or the objects they refer to) be modified by untrusted code?
  - Public, non-final static fields
  - Public static fields pointing to an array
- Warnings: 254 in rt.jar 1.5-b59, 967 in eclipse-3.0

Mutable static example

- J2SE 1.5 build 63 (released version), javax.swing.plaf.metal.MetalSliderUI

```
protected static Color thumbColor;
protected static Color highlightColor;
protected static Color darkShadowColor;
protected static int trackWidth;
protected static int tickLength;
protected static Icon horizThumbIcon;
protected static Icon vertThumbIcon;
```

Returning a reference to an internal array

- Method returns a reference to an array which is still part of the internal representation of the class
- Caller can
  - see changes to the array
  - make their own changes to the array
- Warnings: 407 in rt.jar 1.5-b59, 755 in eclipse-3.0

Who would do such a thing?

- J2SE 1.4.1, java.util.jar.JarEntry

```
public class JarEntry extends ZipEntry {
    Certificate[] certs;
    public Certificate[] getCertificates() {
      return certs;
    }
}
```

- This is the exact same design flaw as the JDK1.1 code signing flaw
  - That flaw was easily exploitable

Accuracy goal

- Our goal is that at least 50% of high and medium priority warnings should be real bugs
  - We manually classified warnings produced by tool for several real applications and libraries
- In general, we came close to achieving our goal
  - Some detectors more accurate than others
  - Detectors work better on some applications than others
    - Different development teams use different idioms
- Lower accuracy is tolerable if detector produces a small number of warnings, and real instances are especially serious

Detectors that produce false positives

- For high and medium priority warnings, selected detectors:

Application	Warnings	Serious
classpath-0.08	93	66%
rt.jar 1.5 build 59	349	68%
eclipse-3.0.0	420	65%
drjava-stable-20040326	13	77%
jboss-4.0.0RC1	118	47%
jedit-4.2pre15	22	50%

Detectors that are generally accurate

- These warnings may not be relevant for every application

Application	Eq	HE	MS
classpath-0.08	2	14	39
rt.jar 1.5.0 build 59	9	55	259
eclipse-3.0	3	170	1,000
drjava-stable-20040326		9	45
jboss-4.0.0RC1	1	18	227
jedit-4.2pre15		6	53

Bugs vs. style

- Total warnings counts for FindBugs and PMD
  - Using recommended rules for PMD

Application	KLOC	FindBugs	PMD
rt.jar 1.5.0 build 59	1,183	3,314	17,133
eclipse-3.0	2,237	4,227	25,227

- Style checkers tend to produce a large number of warnings
  - They are most useful to *enforce* consistent standards
- Bug checkers can be used productively on any software

Why do bugs occur?

- Everybody makes dumb mistakes
  - *Everybody*
- Java (and similar languages) have very large standard libraries
  - Many possibilities for confusion and misuse
- Many possibilities for latent bugs (e.g., hashcode/equals)
- Programmers play fast and loose with threads

Conclusions

- All software contains bugs
  - Including *your* software
  - Some of them are blatant, obvious, and undiscovered
  - Very simple techniques suffice to find them
- Imprecise analysis can be very accurate
- Writing bug detectors is surprisingly easy
  - You should try it!
  - FindBugs is open source
  - We welcome contributions

Future work

- Find, implement detectors for new bug patterns
- Better integration into continuous development
  - False warning suppression
  - Automatic ranking of new warnings based on previously classified warnings
- Bug patterns for beginning programmers
- User-specified patterns
  - Learn new patterns from examples?

Questions?