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NIST -- April 24, 2009

Advances in Coverage-Based Test Suite Reduction

About Me

- Ph.D., University of Maryland, College Park (2008).
  - Research interests include Software Testing, Program Analysis, Software Tools, and Distributed Systems.
- Professional Software Developer
  - Microsoft, Lockheed Martin, Amazon.com, etc.

Agenda

- Background
- Call Stack Coverage for Test Suite Reduction
- Fault Correlation and the Average Probability of Detecting Each Fault
- Other Advances and Future Directions

Motivation for Test Suite Reduction

- Automated Test Case Generation Techniques
  - Code-based (Parasoft, Agitar, etc.)
  - Model-based (GUITAR, etc.)
  - May generate enormous volume of tests
- New Development Methodologies
  - Continuous integration
  - Rapid test cycles

- ➔ *Automated test case generation may result in too many tests to run in a given build/test/deploy process.*

Test Suite Reduction

- Reduce the number of test cases in a test suite, and:
- Maintain as much of the original suite's fault detection effectiveness as possible.
- Most common approaches are based on maintaining coverage relative to some criterion.
  - *Coverage Requirements* are logical or program elements that must be exercised by test cases.
  - Examples: Branches, lines, dynamic program invariants, etc.
- *Traditionally evaluated against conventional, batch-oriented applications, using test suites built using category-partition or similar methods.*

Characteristics of Modern Software

- Object- and aspect-oriented
- Use of reflection
- Use of callbacks
- Multithreading
- Extensive use of libraries and frameworks
- Multi-language development
- Event-reactive paradigm
  - Handler code may be invoked from multiple contexts

- ➔*An effective test coverage technique should account for these factors.*

Dissertation Contributions

- Test suite reduction technique based on the *call stack coverage criterion*.
  - Formal model of call stacks, including notion of *maximum-depth call stack*.
- Empirical studies of test suite reduction in modern versus conventional software applications.
- Development of new metrics for looking at the problem of test suite reduction.
- Guidance for practitioners considering test suite reduction.
- Improvements to the practice of GUI test automation.
- Reusable tools and data.

Call Stacks

- Sequence of active calls associated with each thread of a running program.
- Stack where:
  - Methods are pushed on when they are called.
  - Methods are popped off when they return or throw an exception.

Call Stack - Example

(Ljava/lang/Object;ILjava/lang/Object;II)V Ljava/lang/System;arraycopy
([BII)V Ljava/io/BufferedOutputStream;write
([BII)V Ljava/io/PrintStream;write
()V Lsun/nio/cs/StreamEncoder$CharsetSE;writeBytes
()V Lsun/nio/cs/StreamEncoder$CharsetSE;implFlushBuffer
()V Lsun/nio/cs/StreamEncoder;flushBuffer
()V Ljava/io/OutputStreamWriter;flushBuffer
()V Ljava/io/PrintStream;newLine
(Ljava/lang/String;)V Ljava/io/PrintStream;println
([Ljava/lang/String;)V LHelloWorldApp;main

Full Method Signature (Canonical Representation)

Call Stacks and Test Suite Reduction

- Using call stacks as a coverage criterion addresses challenges posed by modern software applications.
- Call stacks:
  - Are easily collected in a multi-language and/or multi-threaded environment.
  - Automatically identify and resolve reflective and virtual method calls, woven aspects, and callbacks.
  - Capture differences in context when methods are called.
- Note that this application only uses dynamic call stacks.

Capturing Call Stacks

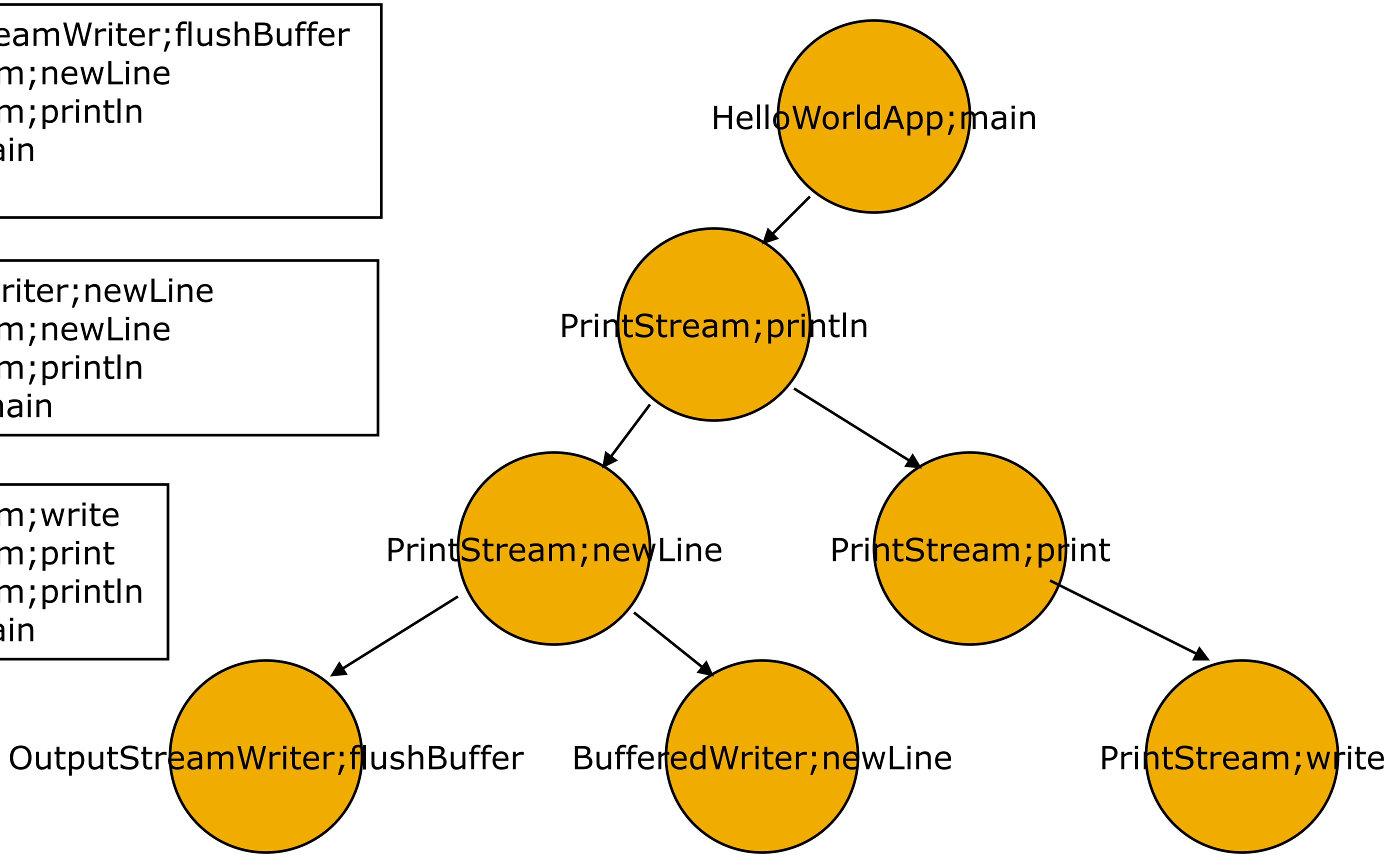
- Efficient data structure is the *calling context tree* (CCT).
  - Nodes are methods and edges are method calls.
  - Traverse all paths to leaves to find maximum-depth call stacks.
  - Multithreaded extension is to maintain one CCT per thread and merge at the end.
- JavaCCTAgent (http://sourceforge.net/projects/javacctagent)
  - Tool for collecting CCTs for Java programs

Calling Context Tree

java/io/OutputStreamWriter;flushBuffer
java/io/PrintStream;newLine
java/io/PrintStream;println
HelloWorldApp;main

java/io/BufferedWriter;newLine
java/io/PrintStream;newLine
java/io/PrintStream;println
LHelloWorldApp;main

java/io/PrintStream;write
java/io/PrintStream;print
java/io/PrintStream;println
HelloWorldApp;main



Traditional Test Suite Reduction Metrics

- % Size Reduction
  - $100 * (1 - Size_{Reduced} / Size_{Full})$
- % Fault Detection Reduction
  - $100 * (1 - FaultsDetected_{Reduced} / FaultsDetected_{Full})$

→ *Test coverage is not explicitly used in these metrics.*

New Test Suite Reduction Metric

- One might expect a correlation between coverage requirements and the faults exposed by test cases that hit them.
- But no existing measure explores this notion.
- Proposal: *Average Probability of Detecting Each Fault*
  - Captures the likelihood that coverage-equivalent reduced test suites will detect the same faults as their original counterparts.
  - Driven by the frequency that coverage requirements get hit by fault-detecting test cases (***fault correlation***).
  - Varies greatly by coverage criterion.
    - Useful for selecting the best coverage criterion for test suite reduction.

Fault Correlation

- Intuition: Certain coverage requirements are more likely to be associated with fault-producing program states.
- From the coverage matrix and fault matrix, we can calculate the *fault correlation.*
- Given:
  1. The set of test cases.
  2. A specific known fault.
  3. A specific coverage requirement.

→ *Fault correlation is the ratio of (test cases that hit the coverage requirement and detect the fault) to (test cases that merely hit the coverage requirement).*

Average Probability of Finding Each Fault

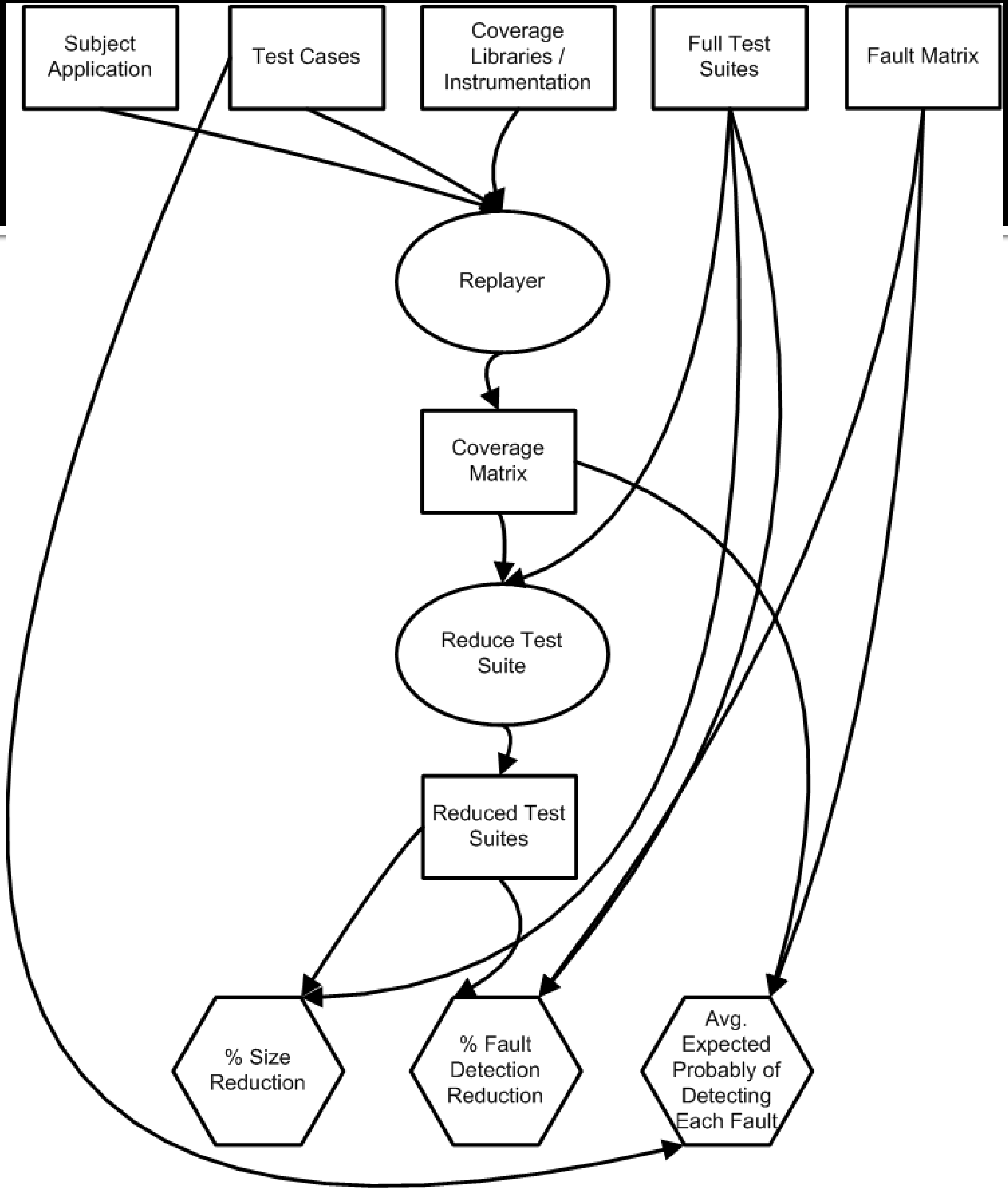
- From fault correlations, we can calculate the…
- *Average the expected probability of finding each fault* across all known faults in an experiment.

→ *Evaluated in the subsequent experiments.*

Experiments

1. Compare size and fault detection reduction of call-stack-reduced suites to suites reduced based on other criteria.
2. Compare fault detection of call-stack-reduced suites to suites of the same size created using other approaches.
3. Evaluate the impact of including coverage of third-party library code in test suite reduction.
4. Compare call-stack-based reduction in conventional versus event-driven applications.
5. Test whether certain coverage criteria are more highly associated with faults.

Experimental and Analytical Process



Experimental Infrastructure

- Subject Applications
  - TerpOffice
  - Space
  - nanoxml
- Coverage Tools
  - Java CCTAgent
  - Detours-based library for CCT collection in Win32 applications
  - jcoverage / Cobertura
- JavaGUIReplayer
- Test Suite Reduction Implementation
  - HGS algorithm (implemented in C#)
- Custom test harnesses to tie these tools together

Subject Applications

Application	Source Language	Execution Style	Programming Style	Test Universe Size	# Detectable Faults (Versions)
TerpPaint (TP)	Java	Event-Driven (GUI)	Object-Oriented	1500	43
TerpWord (TW)	Java	Event-Driven (GUI)	Object-Oriented	1000	18
TerpSpreadsheet (TS)	Java	Event-Driven (GUI)	Object-Oriented	1000	101
Space	C	Conventional	Procedural	13585	34
nanoxml	Java	Conventional	Object-Oriented	216	9

Good subjects are hard to find. You need:

- Test cases
- Known faults

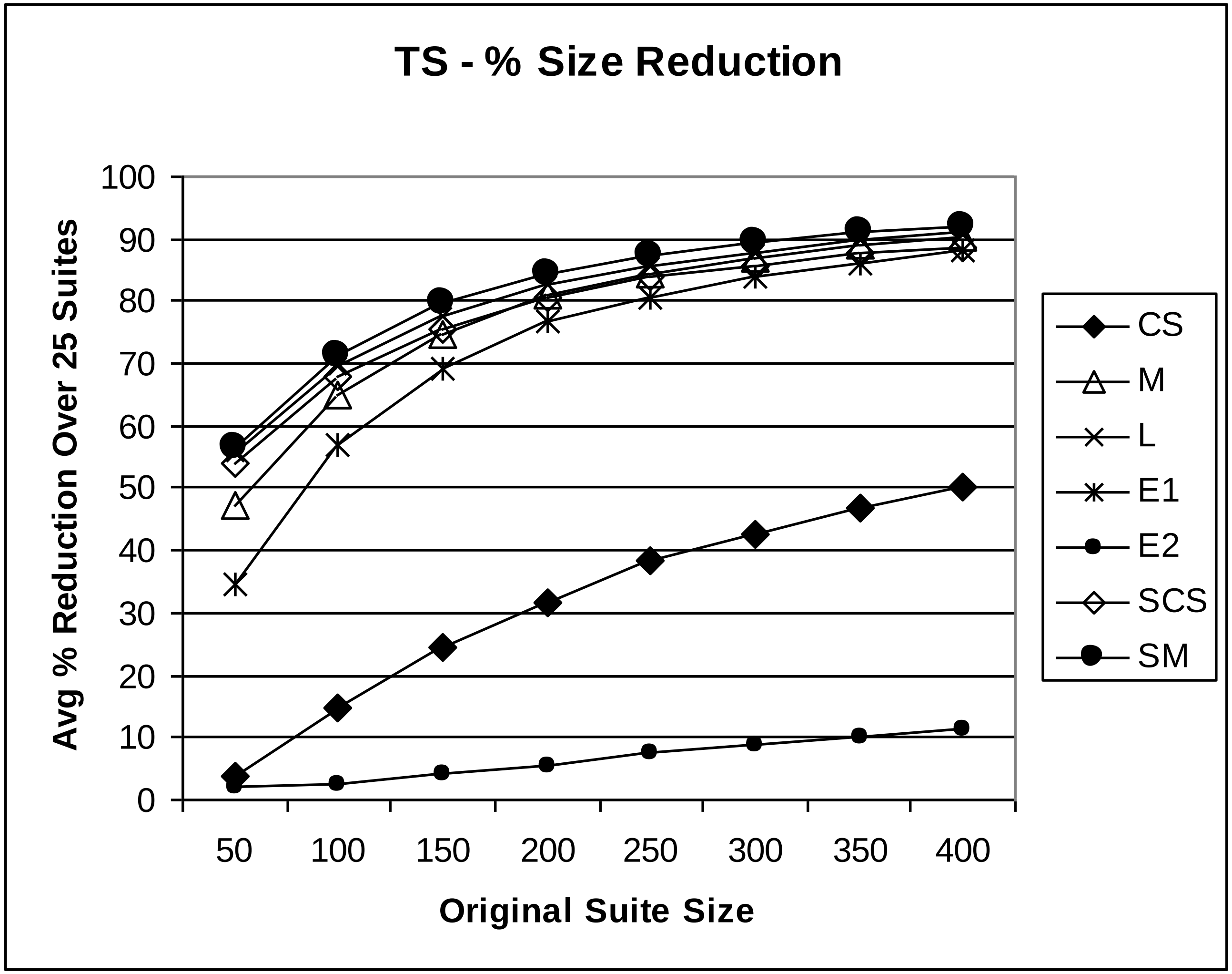
Subject Application Metrics

	Includes Library Data?	TerpPaint (TP)	TerpWord (TW)	TerpSpreadsheet (TS)	Space	Nanoxml
# Call Stacks Observed	Yes	413166	569933	333882	453	6617
# Methods Observed	Yes	12277	12665	11103	143	1126
# Events	N/A	181	219	110	N/A	N/A
# Executable Lines	No	11803	9917	5381	6218	3012
# Classes	No	330	197	135	N/A	25
# Methods	No	1253	1380	746	123	232

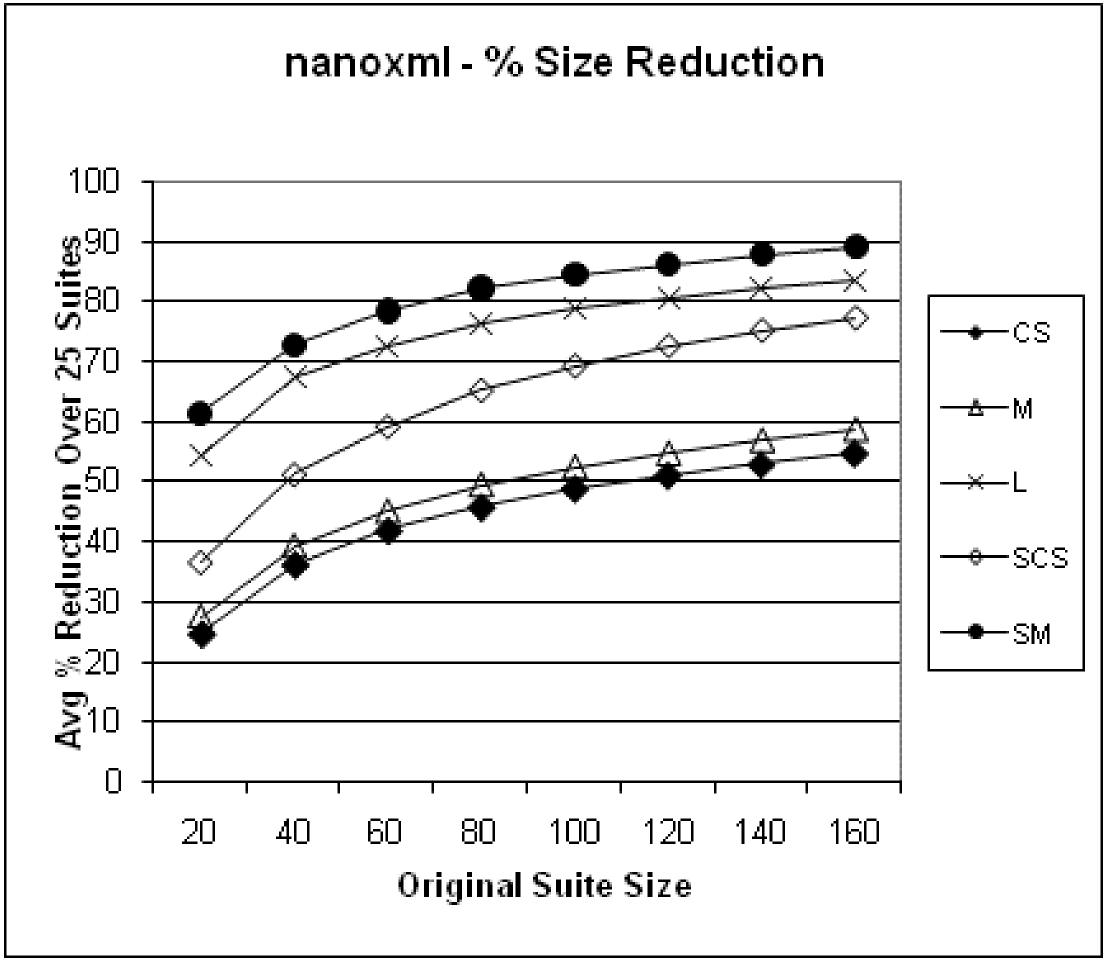
Reduction Techniques

- Standard Approaches
  - Call Stack (CS)
  - Line (L)
  - Method (M)
  - Random (RAND)
  - Event (E1)
  - Event-Interaction (E2)
- "Additional" Approaches (adds random cases to match CS size)
  - Line-Additional (LA)
  - Method-Additional (MA)
  - Event-Additional (E1A)
- "Short" Approaches (excludes library methods)
  - Short Call Stack (SCS)
  - Short Method (SM)

Size Reduction (GUI Application)



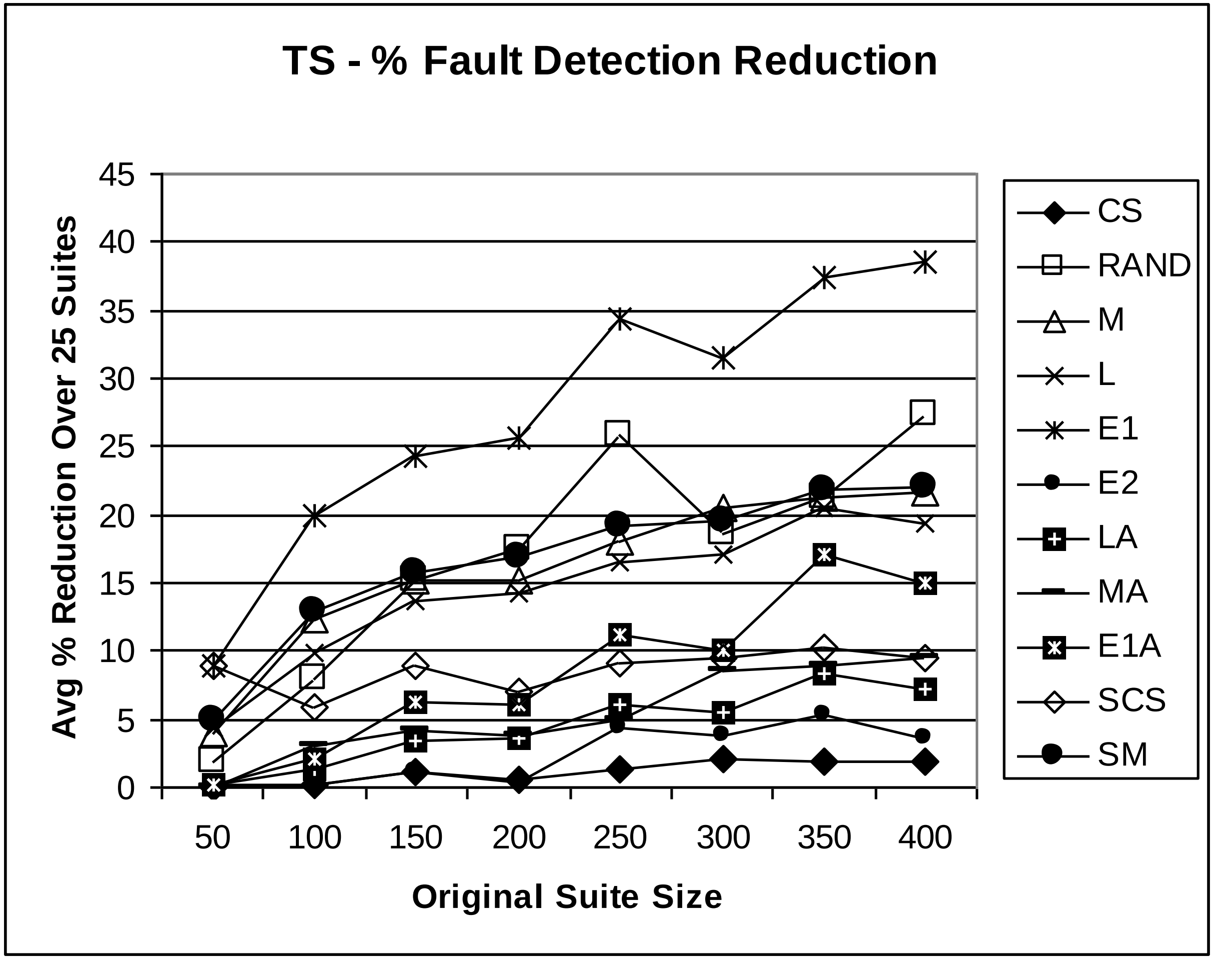
Size Reduction (Conventional Application)



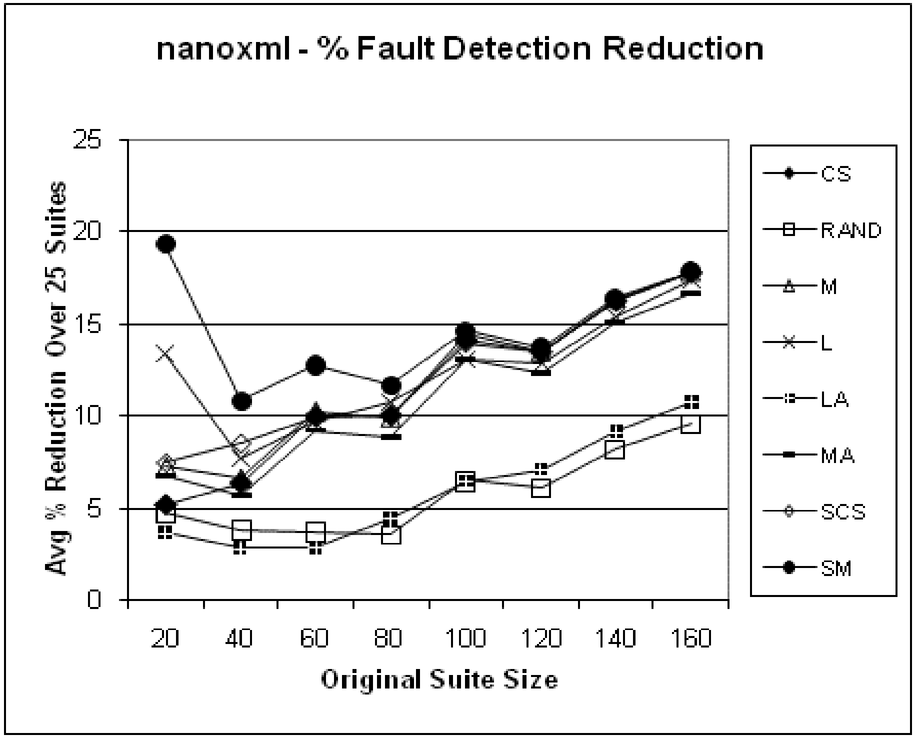
Size Reduction -- Conclusions

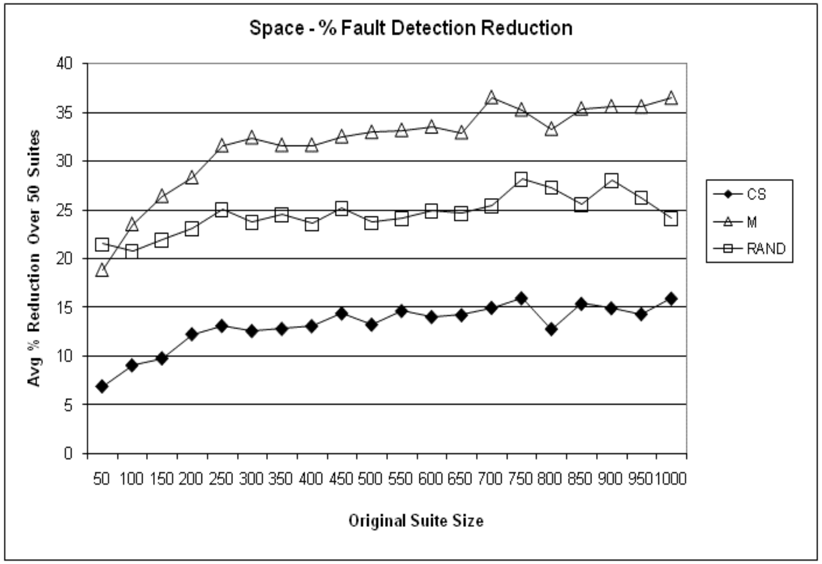
- GUI Applications
  - E2 displays very little size reduction (expected because test case generation was E2-based).
  - Other non-CS techniques perform similarly.
  - CS strikes a middle ground (38-50% reduction for largest suite size).
- Conventional Applications
  - CS still yields less reduction than comparison techniques.
  - But closer than in the GUI subjects.

Fault Detection Reduction (GUI Applications)



Fault Detection Reduction (Conventional Applications)





Fault Detection Reduction -- Conclusions

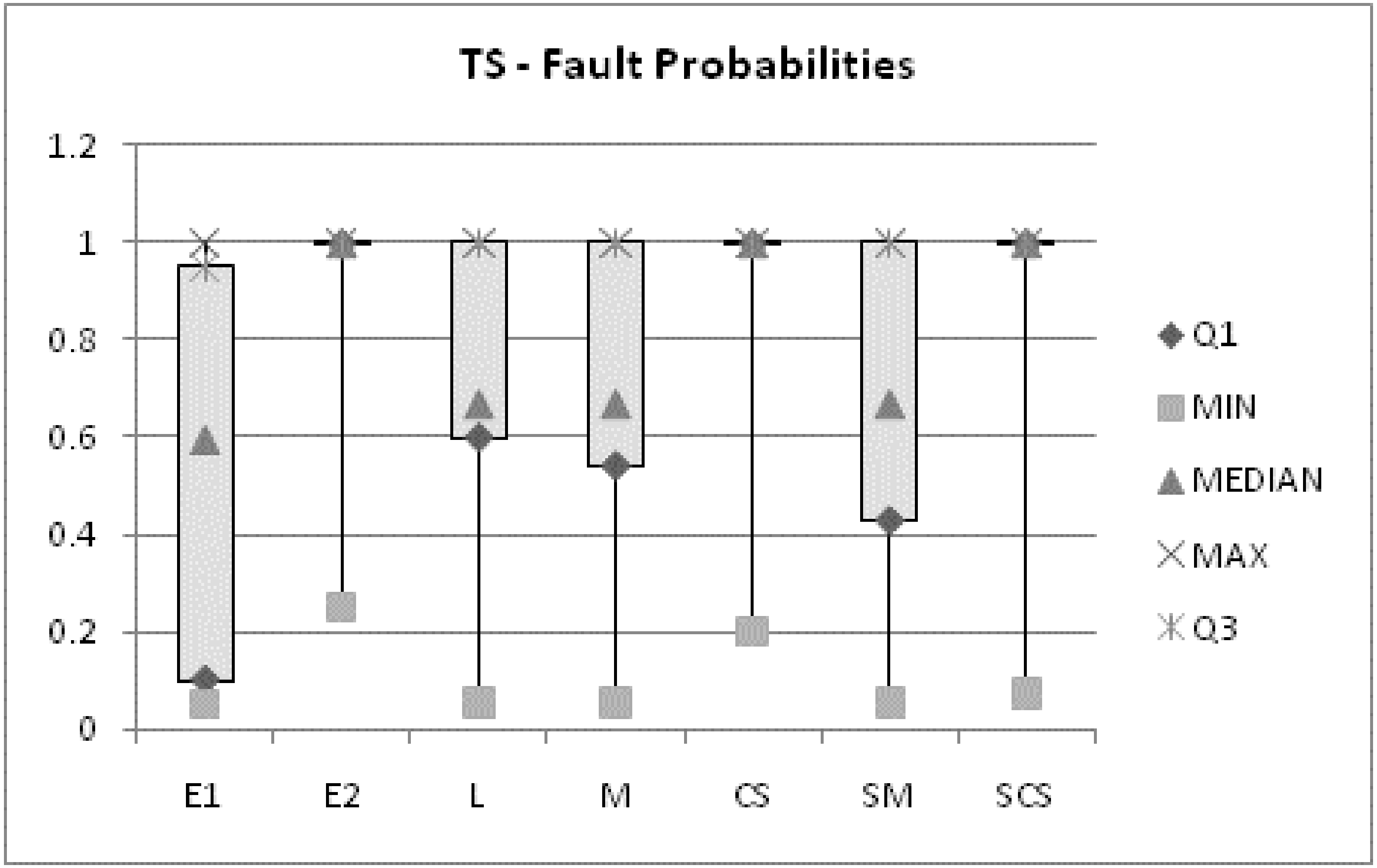
- GUI Applications
  - Call-Stack-based reduction (CS) loses only 0-5% of detectable faults.
    - Comparable to E2, even though E2 displays almost no *size* reduction.
  - Other techniques perform comparably to one another.
- Conventional Applications
  - CS performs well for space, not for Nanoxml.
    - Nanoxml has only 9 faults, and 7 are very easy to find (allowing techniques with random selection to perform well).

Coverage Requirements and Fault-Revealing Test Cases

- Which coverage criterion's requirements are best correlated with fault-revealing test cases?
- Use the *average probability of detecting each fault* metric against the full universe of test cases.

	TP	*TS*	*TW*	*nanoxml*
E1	0.51	0.52	0.47	--
E2	0.92	0.88	0.96	--
L	0.84	0.69	0.77	1.00
M	0.80	0.69	0.72	0.81
CS	1.00	0.97	0.97	0.997
SM	0.70	0.68	0.61	0.81
SCS	0.73	0.85	0.77	0.94

Individual Fault Probabilities



Dissertation Bibliography

1. S. McMaster and A. Memon. Call Stack Coverage for GUI Test-Suite Reduction, IEEE Transactions on Software Engineering (**TSE 2008**), January 2008.
2. S. McMaster and A. Memon. Fault detection probability analysis for coverage-based test suite reduction. *IEEE International Conference on Software Maintenance (**ICSM 2007**)*, Paris, France, 2007.
3. S. McMaster and A. Memon, Call Stack Coverage for GUI Test-Suite Reduction, *Proceedings of the 17th IEEE International Symposium on Software Reliability Engineering (**ISSRE 2006**)*, Raleigh, NC, USA, Nov. 6-10 2006.
4. S. McMaster and A. Memon. Call stack coverage for test suite reduction. *IEEE International Conference on Software Maintenance (**ICSM 2005**)*, pages 539-548, Budapest, Hungary, 2005.

Other Advances and Future Directions

- Automated GUI Test Case Maintenance
- Using Annotations in GUI Testing
  - Test Oracles
  - Test Case Generation

Automated GUI Test Case Maintenance

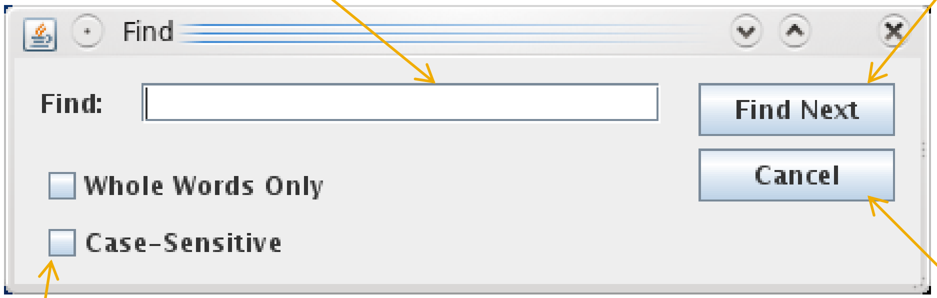
- Test case replayers need to find the right elements to act upon when GUIs are modified.
- Automated approach is based on *heuristics* (same-label, same-position, etc.).

→ *S. McMaster and A. Memon. An Extensible Heuristic-Based Framework for GUI Test Case Maintenance. First International Workshop on Testing Techniques & Experimentation Benchmarks for Event-Driven Software (**TESTBEDS 2009**), Denver, CO, April 4, 2009.*

Example GUI Test Case

1. {FindTextBox, setText('GUI')}

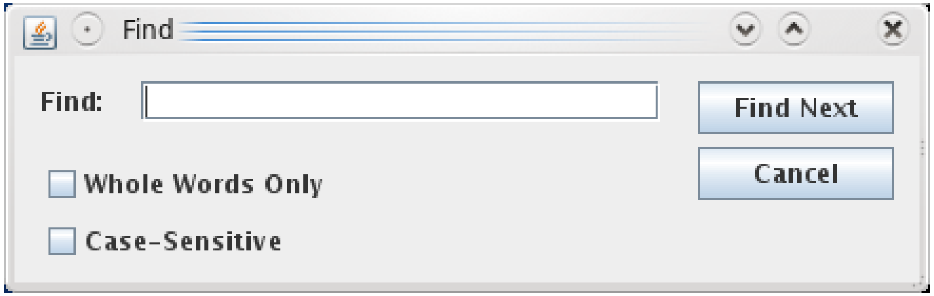
3. {FindButton, click}



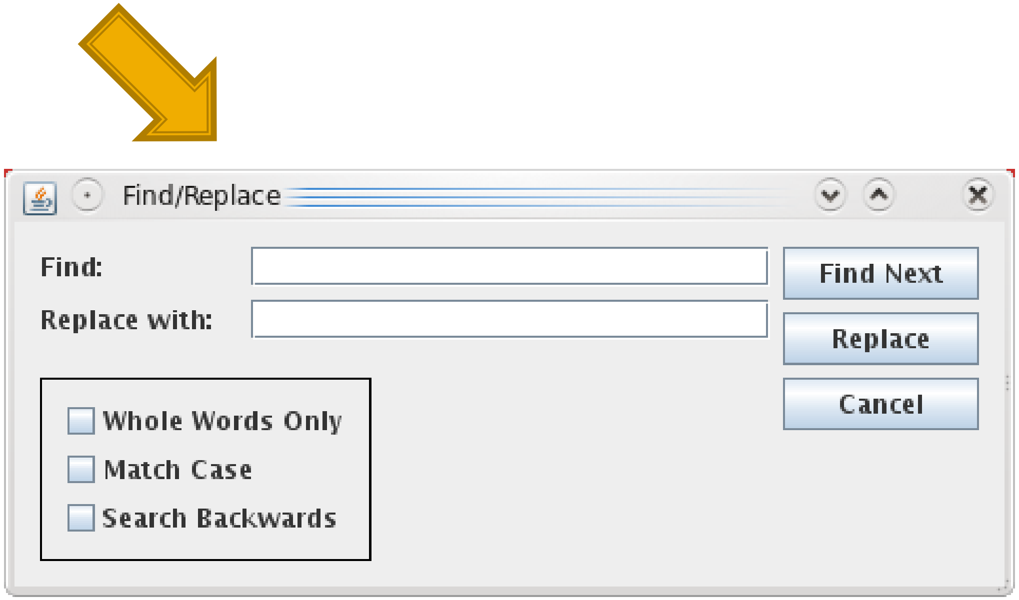
2. {CaseSensitiveCheckBox, click}

4. {CancelButton, click}

GUI Modification



Version 1

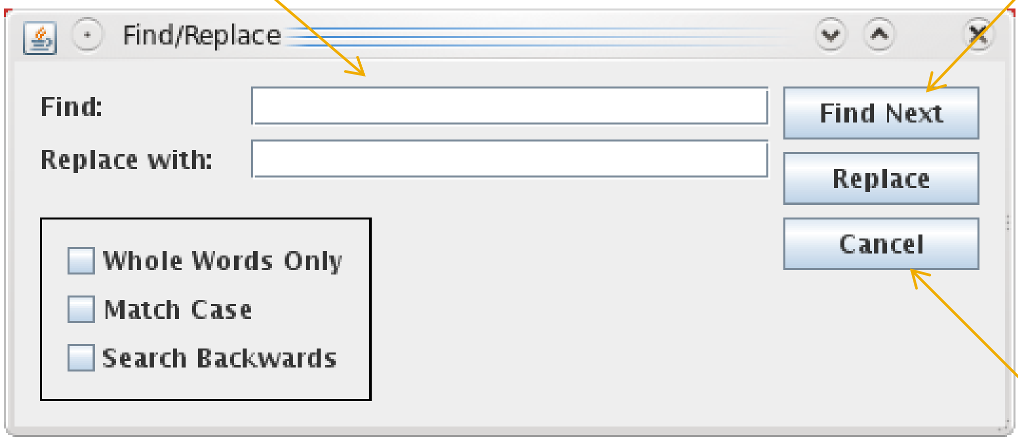


Version 2

What About the Test Case?

1. {FindTextBox, setText('GUI')}

3. {FindButton, click}



2. {CaseSensitiveCheckBox, click}

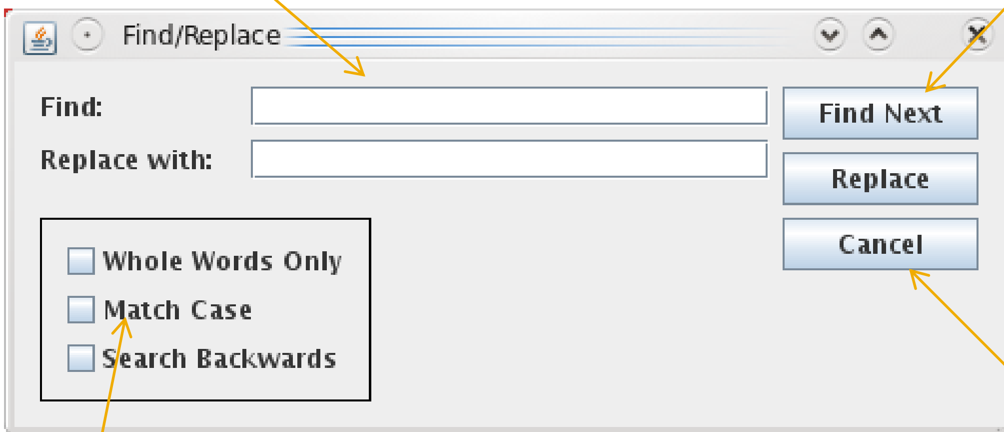
4. {CancelButton, click}

=> Test Case is BROKEN!!!

The Fix

1. {FindTextBox, setText('GUI')}

3. {FindButton, click}



2. {MatchCaseCheckBox, click}

4. {CancelButton, click}

Can the fix be automated?

GUI Element Identification

- Classify each GUI element into one of three sets:
  1. **Created** - elements which are new in the new version of the GUI.
  2. **Deleted** - elements from the old version of the GUI which do not appear in the new version.
  3. **Maintained** – elements which have been kept and possibly modified between versions.
- Calculating these sets requires heuristic approaches.
  - Cannot work on arbitrary GUI modifications.
  - Focus is on building an accurate *Maintained* set for relatively small modifications.

GUIAnalyzer

- Automated framework for GUI element identification.
- Builds *GUI models* from windows/dialogs in Java Swing applications.
- Performs GUI element identification using customizable, extensible *heuristic sets*.
  - Heuristics are applied in order of definition.
  - Multiple passes are made until the process converges.

Model Reconciliation Example

```
Applying heuristics, pass 1
javax.swing.JLabel:Find: identified by SameTextHeuristic as javax.swing.JLabel:Find:
javax.swing.JCheckBox:Whole Words Only identified by SameTextHeuristic as
javax.swing.JCheckBox:Whole Words Only
javax.swing.JButton:Find Next identified by SameTextHeuristic as javax.swing.JButton:Find Next
javax.swing.JButton:Cancel identified by SameTextHeuristic as javax.swing.JButton:Cancel
javax.swing.JTextField:null identified by SamePreviousSiblingHeuristic as
javax.swing.JTextField:null
javax.swing.JCheckBox:Match Case identified by SamePreviousSiblingHeuristic as
javax.swing.JCheckBox:Case-Sensitive
Applying heuristics, pass 2
Done
```

1. “Whole Words Only” checkbox is identified by its label.
2. “Case-Sensitive” checkbox is presumed to be the same as the old “Match Case” checkbox by its position in the element hierarchy.
3. Heuristics identify no further elements → termination.

Research Agenda for Automated GUI Test Case Maintenance

- Evaluate the effectiveness of different heuristics, heuristic sets and priorities.
  - Metrics
    1. False Positives (misidentified elements from original version).
    2. False Negatives (unidentified elements from original version).
- Empirical studies using a variety of GUI windows/dialogs with multiple versions and different-sized modifications.
- New techniques
  - Evaluate test case executability with a proposed *Maintained* set.
  - Apply multiple heuristic sets simultaneously.

Annotations for GUI Oracles

- Oracles for GUI testing have been rather limited.
  - "Crash-testing"
- Researchers and practitioners are leveraging *annotations* (source-code-based metadata) for program analysis and bug detection.
  - JSR 305, JSR 308
  - @Nonnull, @NullFeasible, @NonNegative, etc.
- →Idea: Define annotations for GUI state invariants, and a framework that test case replayers can use to verify them.

GUI Oracle Annotation Example

- CrosswordSage
  - Open-source application.
  - Has several menu items that should be disabled but aren't (leads to unhandled exceptions).

MainScreen.java (annotated)

```
private CrosswordCompiler cc;

@Enabled("cc != null")
JMenuItem mFile_Print = new JMenuItem();

@Enabled("cc != null")
JMenuItem mAction_Publish = new JMenuItem();
```

Checking GUI Invariants

JUnit/Jemmy test case that checks CrosswordSage MainScreen:

```
private JFrameOperator mainFrame;

@Before
public void setUp() throws Exception {
    new ClassReference("crosswordsage.MainScreen").startApplication();
    mainFrame = new JFrameOperator("Crossword Sage");
}

private void checkGUI() throws Exception {
    GUIAnnotationChecker checker = new GUIAnnotationChecker();
    List<GUIInvariantViolation> result = checker.check(mainFrame.getSource());
    for( GUIInvariantViolation violation : result ) {
        System.err.println(violation);
    }
    assertTrue("Got GUI invariant violations", result.isEmpty());     // FAILS
}
```

Prints:

```
mFile_Print was enabled but shouldn't be
mAction_Publish was enabled but shouldn't be
```

Annotations for GUI Test Case Generation

- → Idea: If we have GUI element invariants defined in annotations, we should be able to use them to generate test cases that cover the invariant conditions.

Questions

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