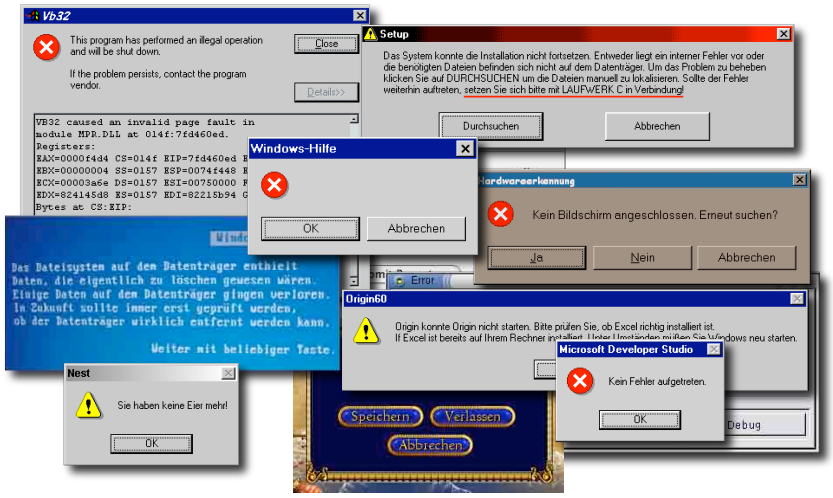
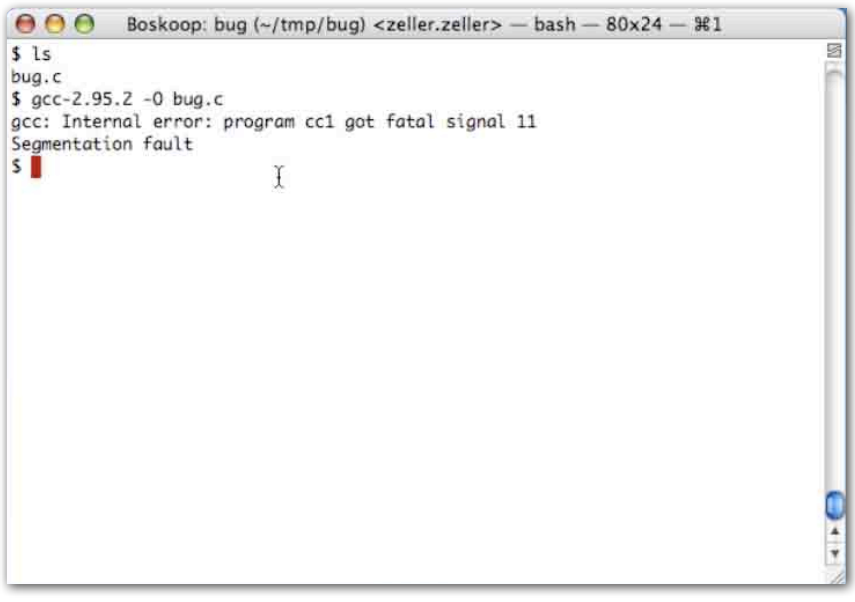
Debugging

Software Engineering

Andreas Zeller • Saarland University

The Problem



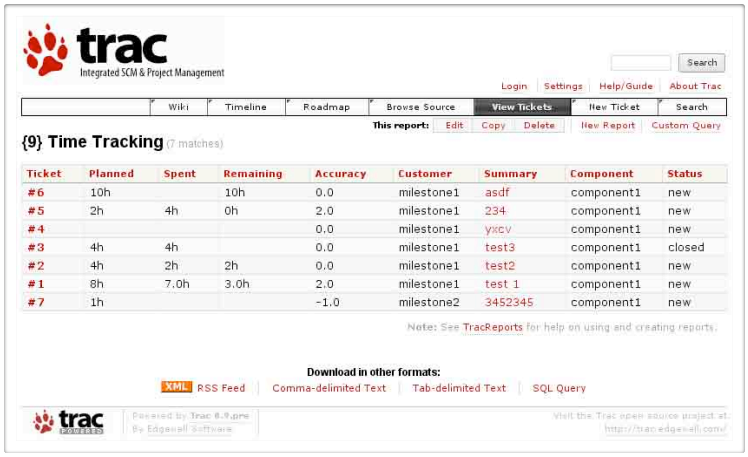


The Process

T rack the problem
R eproduce
A utomate
F ind Origins
F ocus
I solate
C orrect

T
R
A
F
F
I
C

Tracking Problems



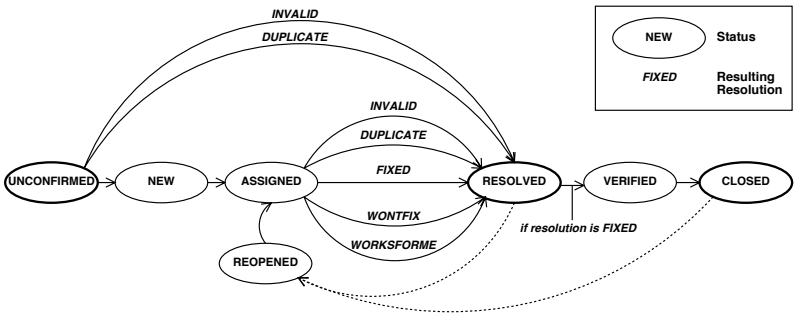
T
R
A
F
F
I
C

Tracking Problems

- Every problem gets entered into a *problem database*
- The *priority* determines which problem is handled next
- The product is ready when all problems are resolved

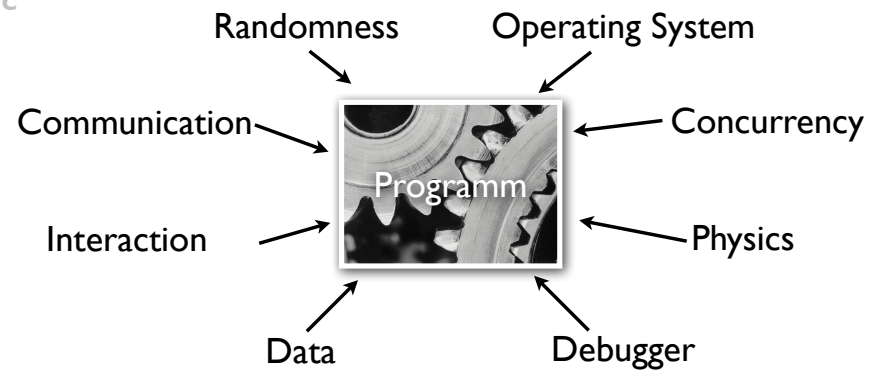
TRAFFIC

Problem Life Cycle



TRAFFIC

Reproduce



TRAFFIC

Automate

```
   // Test for host
   public void testHost() {
int noPort = -1;
     assertEquals(askigor_url.getHost(), "www.askigor.org");
assertEquals(askigor_url.getPort(), noPort);
   }

   // Test for path
   public void testPath() {
assertEquals(askigor_url.getPath(), "/status.php");
   }

   // Test for query part
   public void testQuery() {
assertEquals(askigor_url.getQuery(), "id=sample");
   }
```

TRAFFIC

Automate

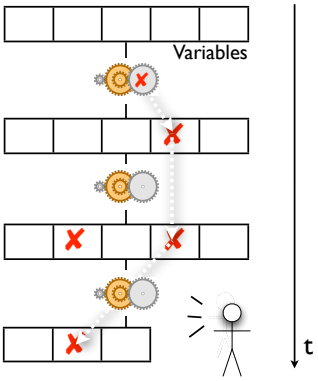
- Every problem should be *reproducible automatically*
- Achieved via appropriate (unit) tests
- After each change, we re-run the tests

TRAFFIC

Finding Origins

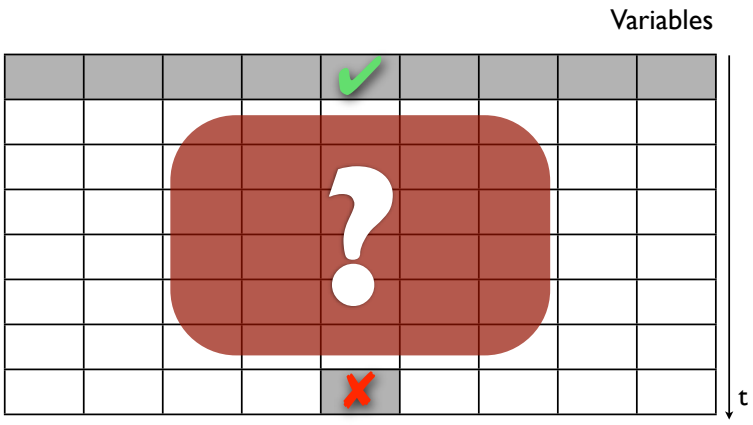
1. The programmer creates a *defect* in the code.
2. When executed, the defect creates an *infection*.
3. The infection *propagates*.
4. The infection causes a *failure*.

This infection chain must be traced back – and broken.



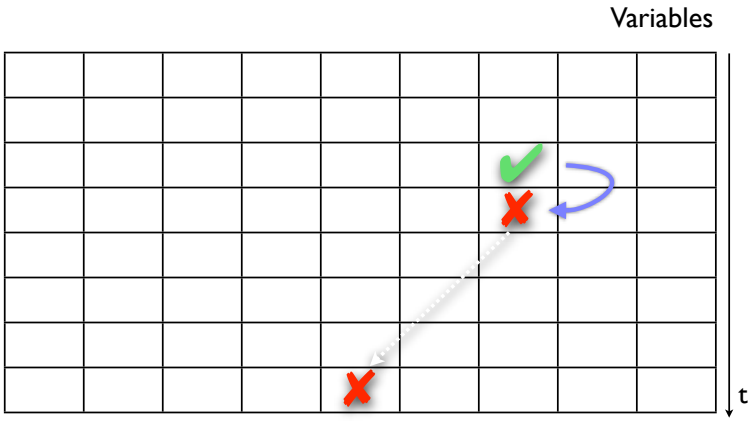
TRAFFIC

Finding Origins



TRAFFIC

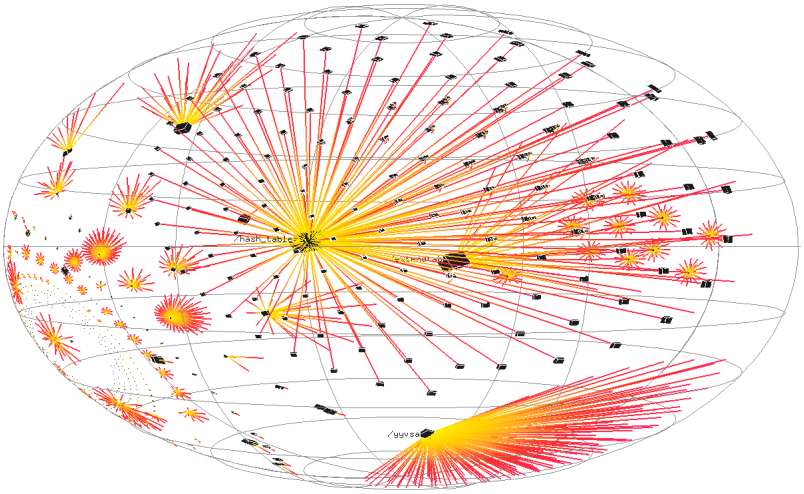
The Defect



13

TRAFFIC

A Program State



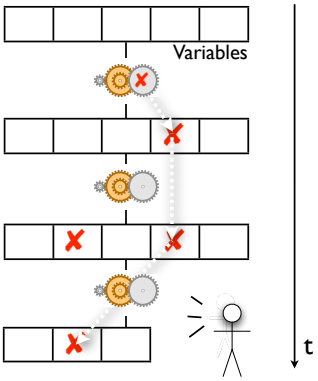
14

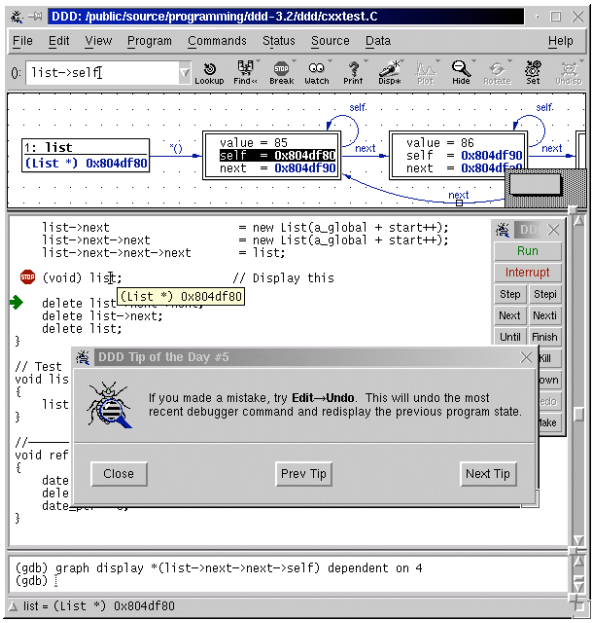
TRAFFIC

15

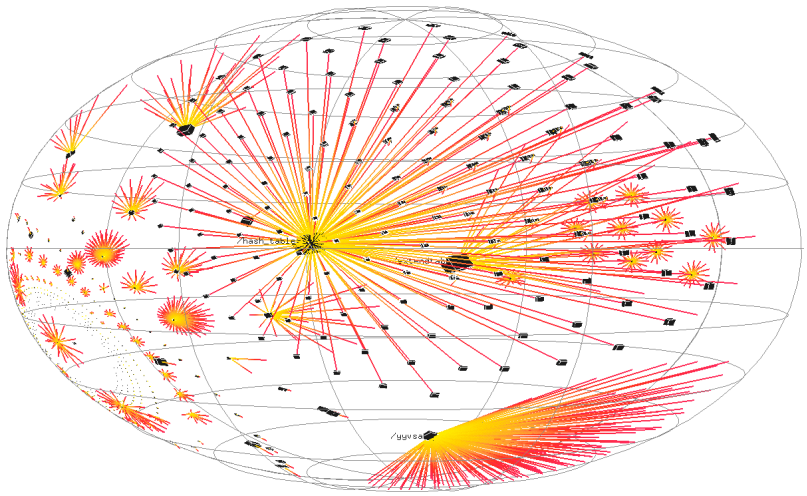
Finding Origins

1. We start with a *known infection* (say, at the failure)
2. We search the infection in the *previous state*



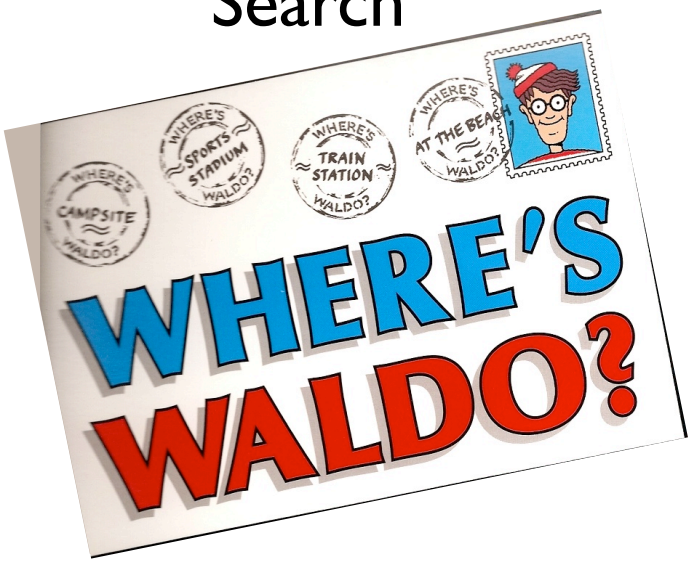


A Program State



TRAFFIC

Search



19

20

TRAFFIC

Focus

During our search for infection, we focus upon locations that

- *are possibly wrong*
  (e.g., because they were buggy before)
- *are explicitly wrong*
  (e.g., because they violate an *assertion*)

Assertions are the best way to find infections!

21

TRAFFIC

Finding Infections

```
class Time {
public:
    int hour();     // 0..23
    int minutes();  // 0..59
    int seconds();  // 0..60 (incl. leap seconds)

    void set_hour(int h);
    …
}
```

Every time between 00:00:00 and 23:59:60 is valid

TRAFFIC

Finding Origins

```
bool Time::sane()
{
    return (0 <= hour() && hour() <= 23) &&
           (0 <= minutes() && minutes() <= 59) &&
           (0 <= seconds() && seconds() <= 60);
}

void Time::set_hour(int h)
{
    assert (sane());  // Precondition
    …
    assert (sane());  // Postcondition
}
```


TRAFFIC

Finding Origins

```
bool Time::sane()
{
    return (0 <= hour() && hour() <= 23) &&
           (0 <= minutes() && minutes() <= 59) &&
           (0 <= seconds() && seconds() <= 60);
}
```

sane() is the *invariant* of a Time object:

- valid *before* every public method
- valid *after* every public method

TRAFFIC

Finding Origins

- Precondition fails = Infection *before* method
- Postcondition fails = Infection *after* method
- All assertions pass = no infection

```
void Time::set_hour(int h)
{
    assert (sane());  // Precondition
    …
    assert (sane());  // Postcondition
}
```


TRAFFIC

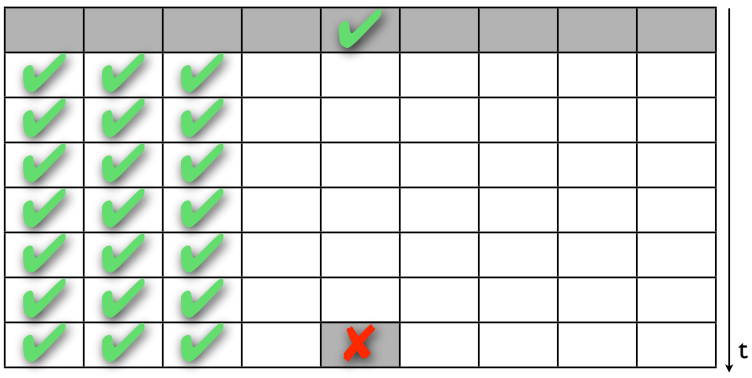
Complex Invariants

```
class RedBlackTree {
  …
  boolean sane() {
      assert (rootHasNoParent());
      assert (rootIsBlack());
      assert (redNodesHaveOnlyBlackChildren());
      assert (equalNumberOfBlackNodesOnSubtrees());
      assert (treeIsAcyclic());
      assert (parentsAreConsistent());

      return true;
  }
}
```


TRAFFIC

Assertions



TRAFFIC

Focusing

- All possible influences must be checked
- Focusing on most likely candidates
- Assertions help in finding infections fast

TRAFFIC

Isolation

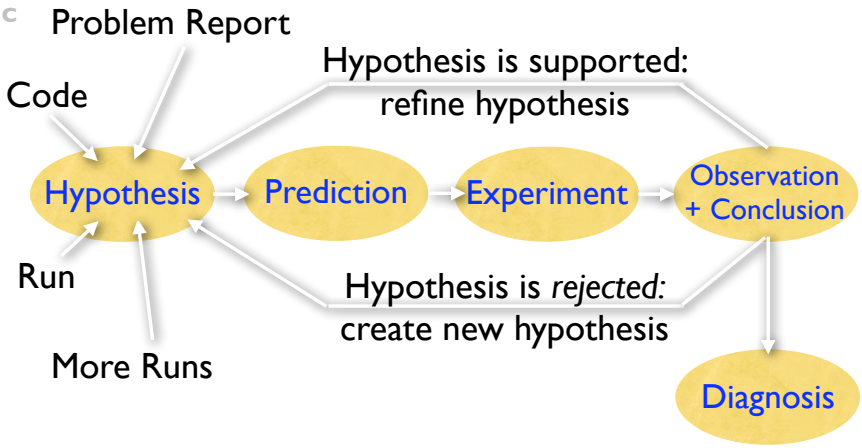
- Failure causes should be *narrowed down systematically*
- Use *observation* and *experiments*

TRAFFIC

Scientific Method

1. Observe some aspect of the universe.
2. Invent a *hypothesis* that is consistent with the observation.
3. Use the hypothesis to make *predictions*.
4. Tests the predictions by experiments or observations and modify the hypothesis.
5. Repeat 3 and 4 to refine the hypothesis.

Scientific Method



Explicit Hypotheses

Hypothesis	The execu…auses a[0] = 0
Prediction	At L…hould hold.
Experiment	…Line 37.
Observati…	…olds as predicted.
Conclusion	…hesis is confirmed.

Keeping everything in memory is like playing mastermind blind!

TRAFFIC

Explicit Hypotheses

TRAFFIC

Isolate

- We repeat the search for infection origins until we found the defect
- We proceed *systematically* along the scientific method
- *Explicit steps* guide the search – and make it repeatable at any time

TRAFFIC

Correction

Before correcting the defect, we must check whether the defect

- actually is an *error* and
- *causes* the failure

Only when we understood both, can we correct the defect

TRAFFIC

The Devil's Guide to Debugging

Find the defect by guessing:

- Scatter debugging statements everywhere
- Try changing code until something works
- Don't back up old versions of the code
- Don't bother understanding what the program should do

TRAFFIC

The Devil's Guide to Debugging

Don't waste time understanding the problem.

- Most problems are trivial, anyway.

TRAFFIC

The Devil's Guide to Debugging

Use the most obvious fix.

- Just fix what you see:

```
x = compute(y)
// compute(17) is wrong – fix it
if (y == 17)
    x = 25.15
```

Why bother going into compute()?

T
R
A
F
F
I
C

Successful Correction

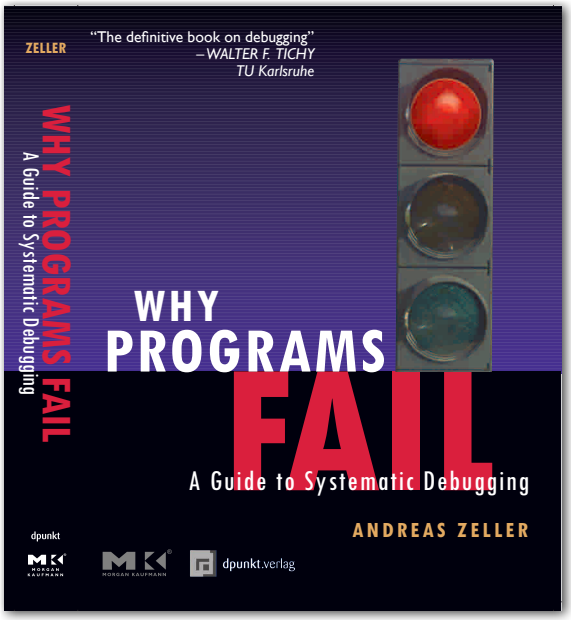
T
R
A
F
F
I
C

Homework

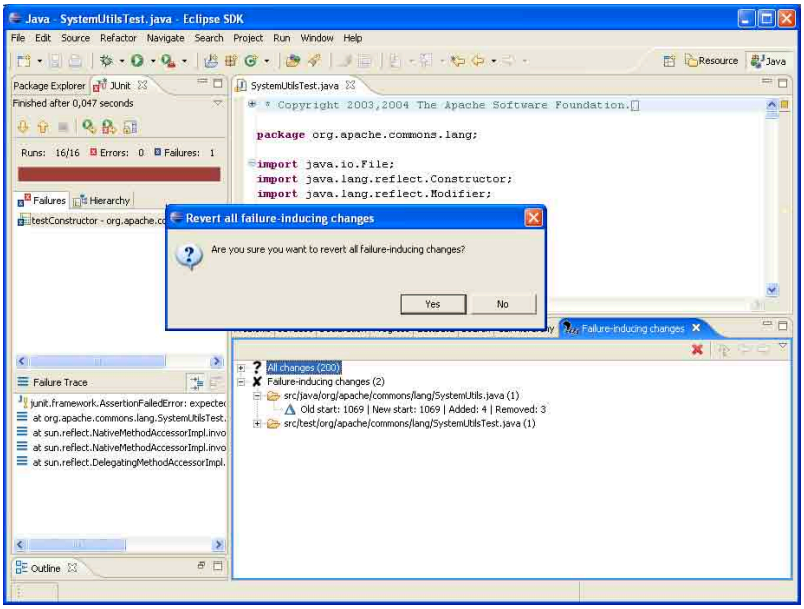
- Does the failure no longer occur?
  (If it does still occur, this should come as a big surprise)
- Did the correction introduce new problems?
- Was the same mistake made elsewhere?
- Did I commit the change to version control and problem tracking?

The Process

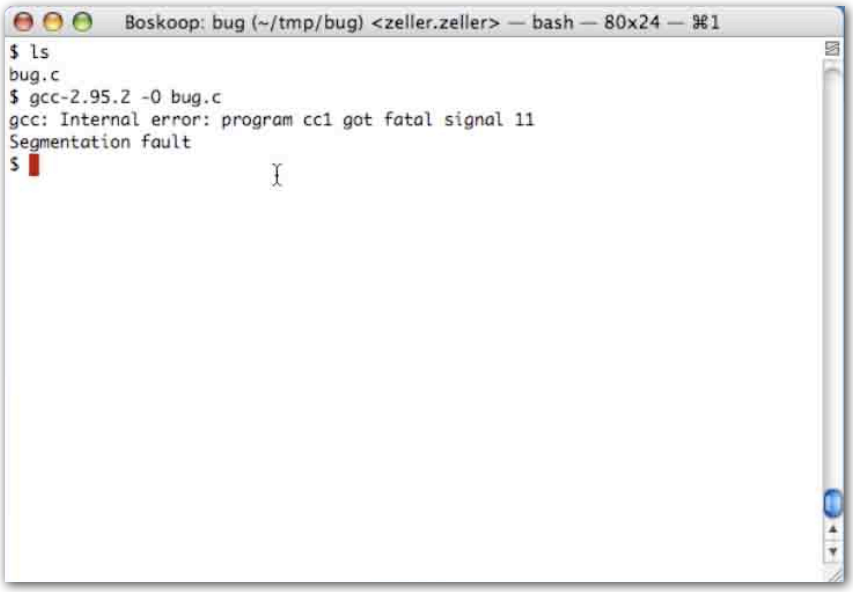
T rack the problem
R eproduce
A utomate
F ind Origins
F ocus
I solate
C orrect


ZELLER
"The definitive book on debugging"
– WALTER F. TICHY
TU Karlsruhe
WHY PROGRAMS FAIL
A Guide to Systematic Debugging
WHY
PROGRAMS
FAIL
A Guide to Systematic Debugging
ANDREAS ZELLER
dpunkt
dpunkt.verlag

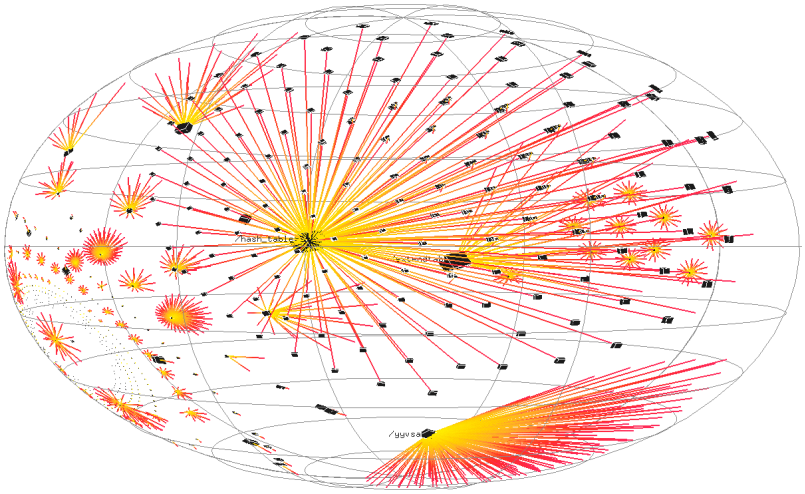
43


Java - SystemUtilsTest.java - Eclipse SDK
File Edit Source Refactor Navigate Search Project Run Window Help
Package Explorer JUnit
Finished after 0,047 seconds
Runs: 16/16 Errors: 0 Failures: 1
Failures Hierarchy
SystemUtilsTest.java
* Copyright 2003,2004 The Apache Software Foundation.
package org.apache.commons.lang;
import java.io.File;
import java.lang.reflect.Constructor;
import java.lang.reflect.Modifier;
Revert all failure-inducing changes
Are you sure you want to revert all failure-inducing changes?
Yes
No
Failure-inducing changes
All changes (200)
Failure-inducing changes (2)
src/java/org/apache/commons/lang/SystemUtils.java (1)
Old start: 1069 | New start: 1069 | Added: 4 | Removed: 3
src/test/org/apache/commons/lang/SystemUtilsTest.java (1)
Failure Trace
Outline

44

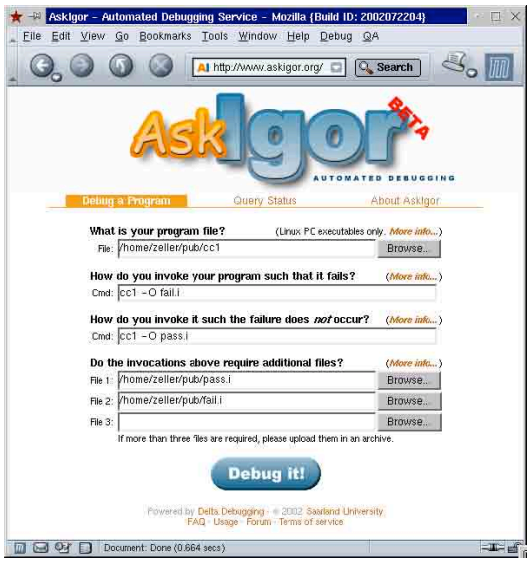

Boskoop: bug (~/tmp/bug) <zeller.zeller> — bash — 80x24 — ⌘1
$ ls
bug.c
$ gcc-2.95.2 -O bug.c
gcc: Internal error: program cc1 got fatal signal 11
Segmentation fault
$

45



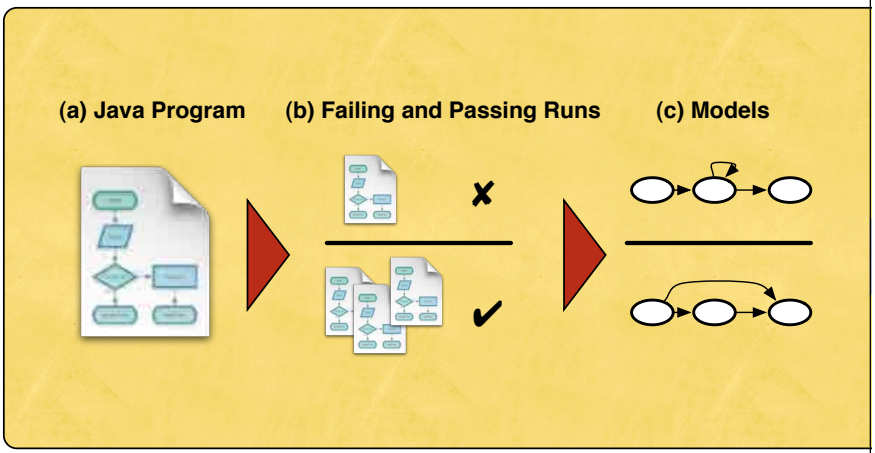
Failure Causes in GCC

Location	Failure Cause
<Start>	argv[3]
toplev.c:4755	name
toplev.c:2909	dump_base_name
c-lex.c:187	finput→_IO_buf_base
c-lex.c:1213	nextchar
c-lex.c:1213	yyssa[41]
c-typeck.c:3615	yyssa[42]
c-lex.c:1213	last_insn→fld[1].rtx→…→fld[1].rtx.code
c-decl.c:1213	sequence_result[2]→…→fld[1].rtx.code
combine.c:4271	x→fld[0].rtx→fld[0].rtx

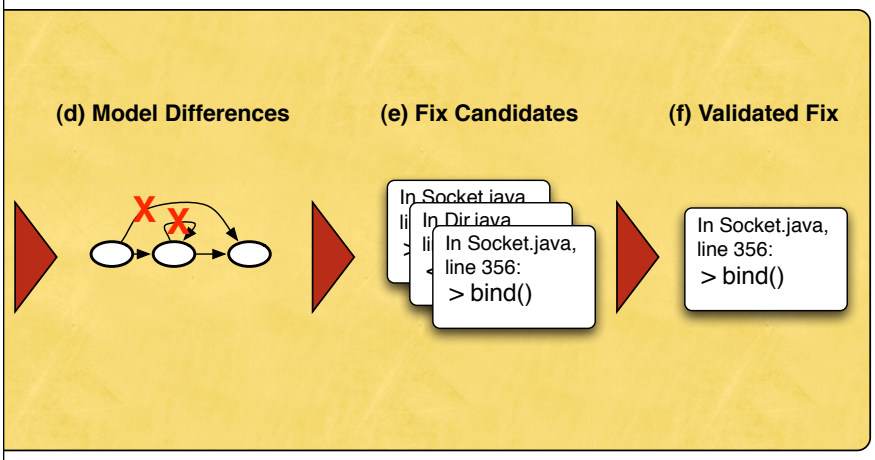


Automatic Fixes!

Automatic Fixes



Automatic Fixes



Mining Object Behavior

Mutators
change state

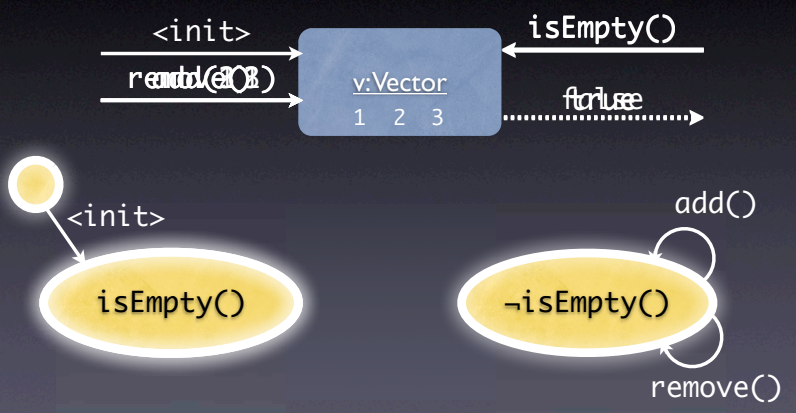
Inspectors
return state

Use static analysis to differentiate

Building Models

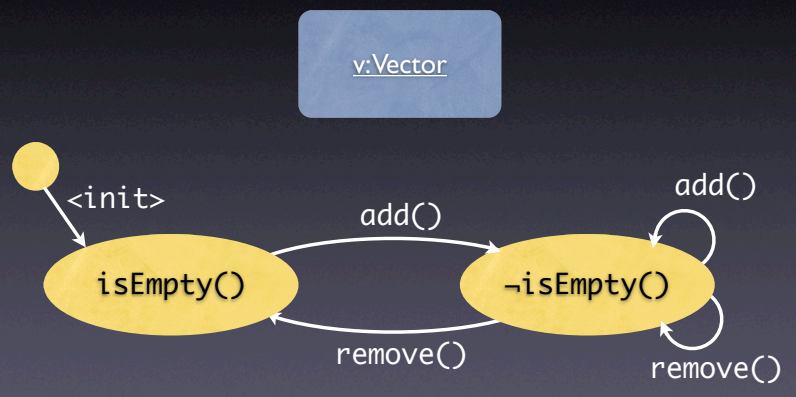
- After each mutator call, we extract attributes and invoke the inspectors
- Extracted states form finite state machine

Building Models



55

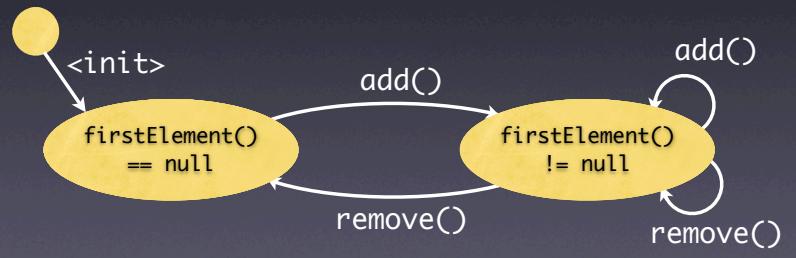
Building Models



56

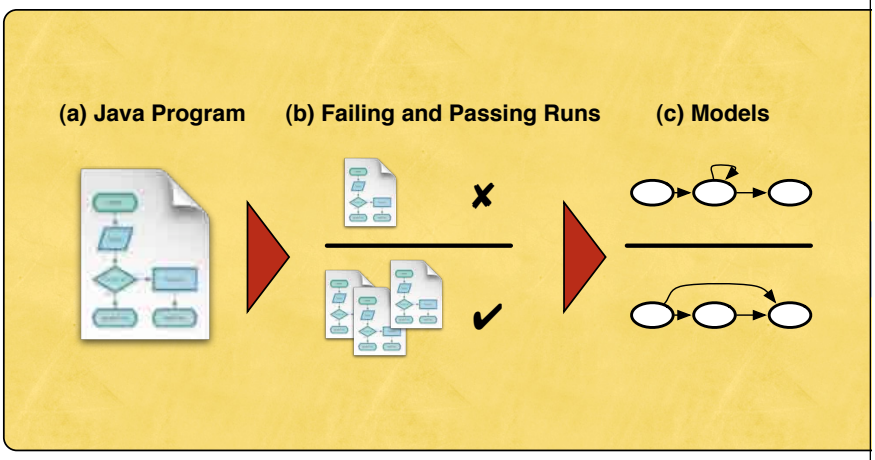
Equivalence Classes

Inspector type	boolean	numeric	object
States	true | false	< 0 | = 0 | > 0	null | class

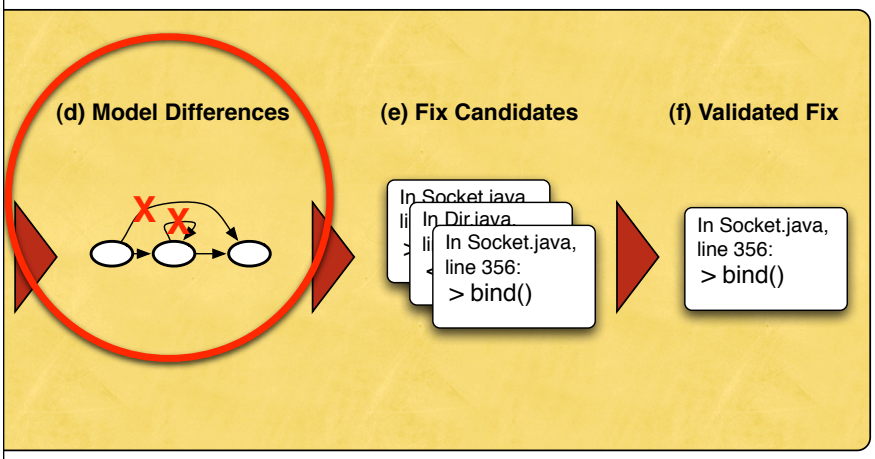


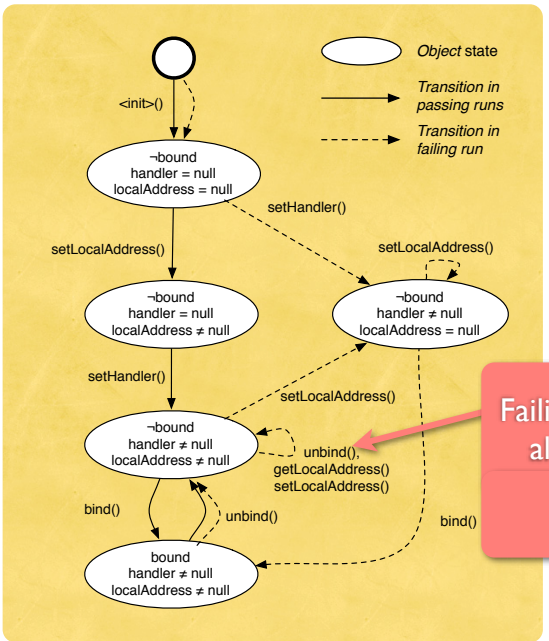
57

Automatic Fixes



Automatic Fixes





Mina

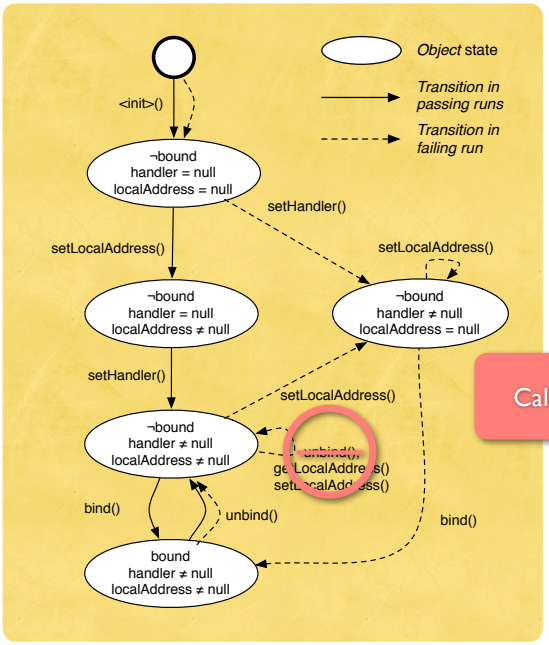
- Multipurpose Infrastructure for Network Applications

Failing run calls unbind() although not bound

Can we fix it?

Deleting Calls

- The first option to create fixes is to *delete calls:*
- Make calls dependent on precondition
- Or, make callees return when precondition does not hold



Fix it!

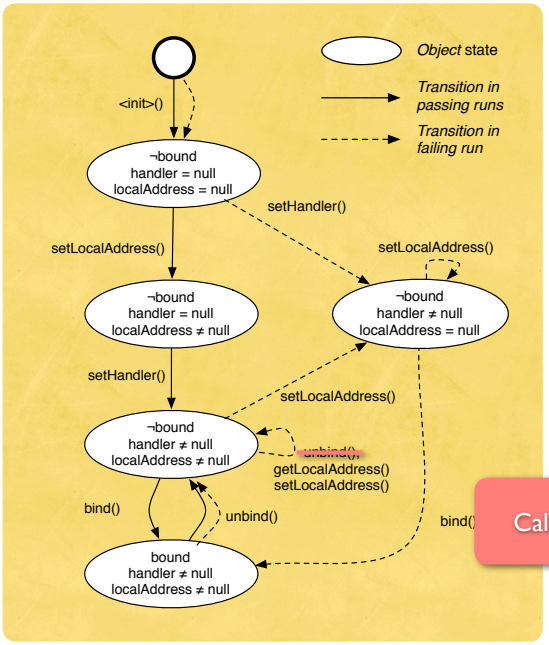
Deleting Calls

- The first option to create fixes is to *delete calls:*
- Make calls dependent on precondition
- Or, make callees return when precondition does not hold

Call unbind() only if bound

Inserting Calls

- The second fix option is to *insert calls:*
- For a violated precondition, insert calls to reach that state
- May need to traverse model for that



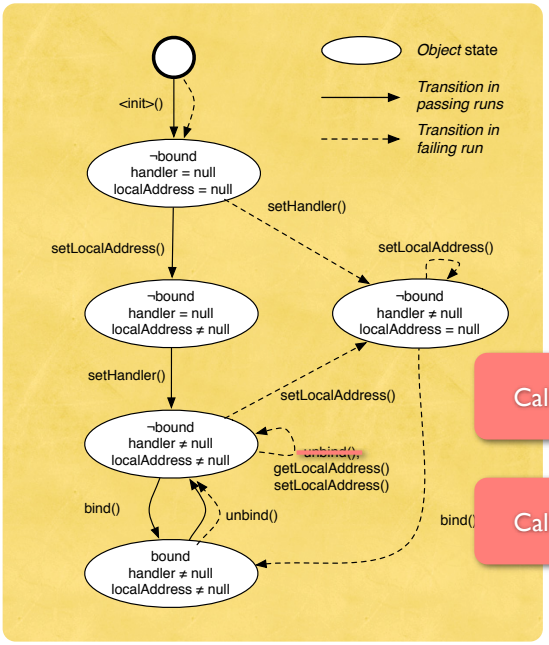
Fix it!

Inserting Calls

- The second fix option is to *insert calls:*
- For a violated precondition, insert calls to reach that state
- May need to traverse model for that

Call bind() before unbind()

64



Fix it!

Call unbind() only if bound

Call bind() before unbind()

65

Validating Fixes

All fix options must be *validated:*

We validate fix candidates

1. On failing test
2. On entire test suite

Only validated fixes remain

Call unbind() only if bound ✔

Call bind() before unbind() ✔

66

Pachika

Suaheli for "fix", "insert"

- Tool for automatic fixing of Java programs
- Takes a failing run and a test suite
- Produces either a validated fix – or nothing
- Available for download

	Candidate Fixes		Potential	Validated
Bug	Insert	Delete	Fixes	Fixes
34858	420	50	0	0
43033	219	65	0	0
51322	**112**	**190**	**56**	**1**
67774	0	72	0	0
70619	6	1	0	0
75129	0	0	0	0
87376	20	218	0	0
107858	405	235	0	0
109614	0	0	0	0
120474	0	0	0	0
121616	**123**	**0**	**38**	**1**
125475	72	122	7	0
128237	283	4	123	0
131933	0	50	0	0
152631	0	783	0	0
158412	2895	310	0	0
158624	0	0	0	0
173602	**17**	**13**	**7**	**1**

AspectJ

- Compiler for AOP programs
- Great source of bugs

Bug 173602

```
   public void resolve(ClassScope upperScope) {
>     // Fix from source repository
>     if (binding == null)
>        ignoreFurtherInvestigation = true;
>     // Fix generated by PACHIKA
>     if (binding == null)
>          return;
      if (munger == null)
           ignoreFurtherInvestigation = true;
      if (ignoreFurtherInvestigation) return;
          ...
      }
  }
```

Bug 121616

```
  public boolean visit(MethodDeclaration md,
                       ClassScope scope) {
>   // Fix generated by PACHIKA
>   // (same as in the source repository)
>   if (methodDeclaration.hasErrors())
>       return false;
    ContextToken tok = ...
    ...
  }
```


Bug 51322

```
public EclipseTypeMunger build(ClassScope cs)
{
    ...
       binding = classScope.referenceContext.
                    binding.resolveTypesFor(binding);
>      // Fix generated by PACHIKA
>      binding.constantPoolDeclaringClass().
>              addDefaultAbstractMethods();
>      binding.constantPoolDeclaringClass().methods();
>      // Fix from source repository
>      if (binding == null)
>          throw new AbortCompilation();
       ResolvedMember sig = new ResolvedMember(...);
       ...
}
```


Automatic Fixing

- Adaptive fix generation
- Assessing the impact of fixes
- Leveraging contracts
- Programs that fix themselves

http://www.st.cs.uni-saarland.de/models/

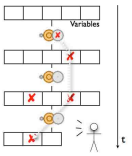
The Process

T rack the problem
R eproduce
A utomate
F ind Origins
F ocus
I solate
C orrect

Finding Origins

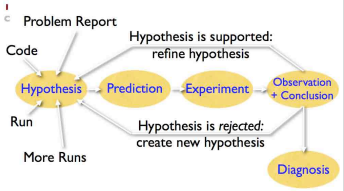
1. The programmer creates a *defect* in the code.
2. When executed, the defect creates an *infection*.
3. The infection *propagates*.
4. The infection causes a *failure*.

This infection chain must be traced back – and broken.



Summary

Scientific Method



Automatic Fixing

- Adaptive fix generation
- Assessing the impact of fixes
- Leveraging contracts
- Programs that fix themselves

http://www.st.cs.uni-saarland.de/models/