Simplifying Problems

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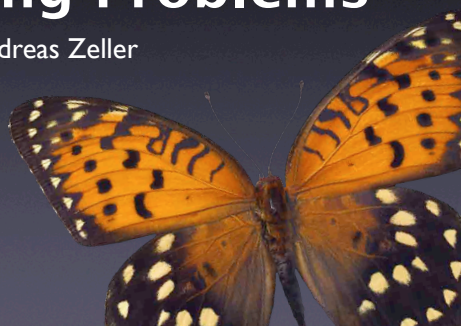
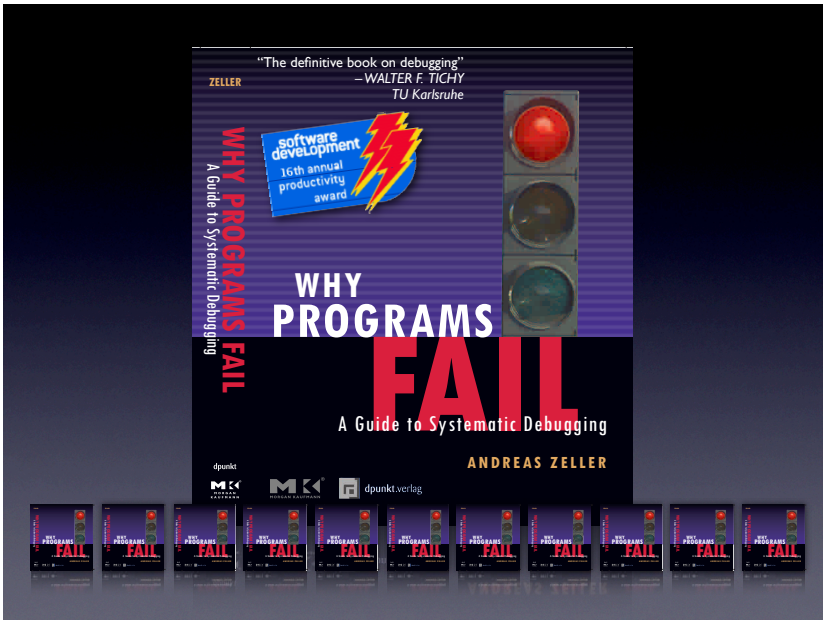


1



And if you need such a toolbox, I have written all these techniques down in a textbook.

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Simplifying

- Once one has tracked and reproduced a problem, one must find out *what's relevant*:
  - Does the problem really depend on 10,000 lines of input?
  - Does the failure really require this exact schedule?
  - Do we need this sequence of calls?

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Why simplify?

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http://www.concordesst.com/accident/accidentindex.html

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Simplifying

- For every circumstance of the problem, check whether it is relevant for the problem to occur.
- If it is not, remove it from the problem report or the test case in question.

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Circumstances

- Any aspect that may influence a problem is a *circumstance:*
  - Aspects of the problem environment
  - Individual steps of the problem history

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Experimentation

- By *experimentation*, one finds out whether a circumstance is relevant or not:
- Omit the circumstance and try to reproduce the problem.
- The circumstance is relevant iff the problem no longer occurs.

Mozilla Bug #24735

Ok the following operations cause mozilla to crash consistently on my machine

-> Start mozilla
-> Go to bugzilla.mozilla.org
-> Select search for bug
-> Print to file setting the bottom and right margins to .50 (I use the file /var/tmp/netscape.ps)
-> Once it's done printing do the exact same thing again on the same file (/var/tmp/netscape.ps)
-> This causes the browser to crash with a segfault

<SELECT NAME="op_sys" MULTIPLE SIZE=7>
<OPTION VALUE="All">All<OPTION VALUE="Windows 3.1">Windows 3.1<OPTION
VALUE="Windows 95">Windows 95<OPTION VALUE="Windows 98">Windows
98<OPTION VALUE="Windows ME">Windows ME<OPTION VALUE="Windows
2000">Windows 2000<OPTION VALUE="Windows XP">Windows XP<OPTION
VALUE="Mac System 7">Mac System 7<OPTION VALUE="Mac System 7.5">Mac
System 7.5<OPTION VALUE="Mac System 7.6.1">Mac System 7.6.1<OPTION
VALUE="Mac System 8.0">Mac System 8.0<OPTION VALUE="Mac System
8.5">Mac System 8.5<OPTION VALUE="Mac System 8.6">Mac System
8.6<OPTION VALUE="Mac System 9.x">Mac System 9.x<OPTION VALUE="MacOS
X">MacOS X<OPTION VALUE="Linux">Linux<OPTION VALUE="BSDI">BSDI<OPTION
VALUE="FreeBSD">FreeBSD<OPTION VALUE="NetBSD">NetBSD<OPTION
VALUE="OpenBSD">OpenBSD<OPTION VALUE="AIX">AIX<OPTION
VALUE="BeOS">BeOS<OPTION VALUE="HP-UX">HP-UX<OPTION
VALUE="IRIX">IRIX<OPTION VALUE="Neutrino">Neutrino<OPTION
VALUE="OpenVMS">OpenVMS<OPTION VALUE="OSF/1">OSF/1<OPTION VALUE="OSF/
1">OSF/1<OPTION VALUE="Solaris">Solaris<OPTION
VALUE="SunOS">SunOS<OPTION VALUE="other">other</SELECT>

</td>
<td align=left valign=top>
<SELECT NAME="priority" MULTIPLE SIZE=7>
<OPTION VALUE="--">--<OPTION VALUE="P1">P1<OPTION VALUE="P2">P2<OPTION
VALUE="P3">P3<OPTION VALUE="P4">P4<OPTION VALUE="P5">P5</SELECT>

bugzilla.mozilla.org

What's relevant in here?

Why simplify?

- Ease of communication. A simplified test case is easier to communicate.
- Easier debugging. Smaller test cases result in smaller states and shorter executions.
- Identify duplicates. Simplified test cases *subsume* several duplicates.

The Gecko BugAThon

- Download the Web page to your machine.
- Using a text editor, start removing HTML from the page. Every few minutes, make sure it still reproduces the bug.
- Code not required to reproduce the bug can be safely removed.
- When you've cut away as much as you can, you're done.

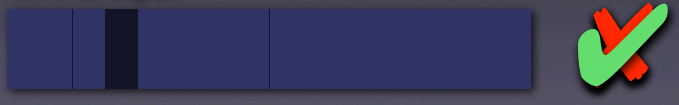
Rewards

5 bugs - invitation to the Gecko launch party
10 bugs - the invitation, plus an attractive Gecko stuffed animal
12 bugs - the invitation, plus an attractive Gecko stuffed animal autographed by Rick Gessner, the Father of Gecko
15 bugs - the invitation, plus a Gecko T-shirt
20 bugs - the invitation, plus a Gecko T-shirt signed by the whole raptor team

Binary Search

- Proceed by binary search. Throw away half the input and see if the output is still wrong.
- If not, go back to the previous state and discard the other half of the input.

HTML input



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Simplified Input

```
<SELECT NAME="priority" MULTIPLE SIZE=7>
```

- Simplified from 896 lines to one single line
- Required 12 tests only

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Benefits

- Ease of communication. All one needs is "Printing <SELECT> crashes".
- Easier debugging. We can directly focus on the piece of code that prints <SELECT>.
- Identify duplicates. Check other test cases whether they're <SELECT>-related, too.

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Why automate?

- Manual simplification is *tedious*.
- Manual simplification is *boring*.
- We have machines for tedious and boring tasks.

Basic Idea

- We set up an *automated test* that checks whether the failure occurs or not (= Mozilla crashes when printing or not)
- We implement a *strategy* that realizes the binary search.

Automated Test

1. Launch Mozilla
2. Replay (previously recorded) steps from problem report
3. Wait to see whether
   - Mozilla crashes (= the test *fails*)
   - Mozilla still runs (= the test *passes*)
4. If neither happens, the test is *unresolved*

Binary Search

<SELECT NAME="priority" MULTIPLE SIZE=7> ✘

What do we do if *both halves* pass?

<SELECT NAME="priority" MULTIPLE SIZE=7> ✔

<SELECT NAME="priority" MULTIPLE SIZE=7> ✔

<SELECT NAME="priority" MULTIPLE SIZE=7> ✔

<SELECT NAME="priority" MULTIPLE SIZE=7> ✘

<SELECT NAME="priority" MULTIPLE SIZE=7> ✘

<SELECT NAME="priority" MULTIPLE SIZE=7> ✔

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Configuration

Circumstance

$$\delta$$

All circumstances

$$C = \{\delta_1, \delta_2, \ldots\}$$

Configuration $c \subseteq C$

$$c = \{\delta_1, \delta_2, \ldots \delta_n\}$$

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Tests

Testing function

$$test(c) \in \{✔, ✘, ?\}$$

Failure-inducing configuration

$$test(c_✘) = ✘$$

Relevant configuration $c'_✘ \subseteq c_✘$

$$\forall \delta_i \in c'_✘ \cdot test(c'_✘ \setminus \{\delta_i\}) \neq ✘$$

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Binary Strategy

Split input

$$c_{\text{✘}} = c_1 \cup c_2$$

If removing first half fails…

$$test(c_{\text{✘}} \setminus c_1) = \text{✘} \implies c_{\text{✘}}' = c_{\text{✘}} \setminus c_1$$

If removing second half fails…

$$test(c_{\text{✘}} \setminus c_2) = \text{✘} \implies c_{\text{✘}}' = c_{\text{✘}} \setminus c_2$$

Otherwise, increase granularity:

$$c_{\text{✘}} = c_1 \cup c_2 \cup c_3 \cup c_4$$

$$c_{\text{✘}} = c_1 \cup c_2 \cup c_3 \cup c_4 \cup c_5 \cup c_6 \cup c_7 \cup c_8$$

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General Strategy

Split input into *n* parts (initially 2)

$$c_{\text{✘}} = c_1 \cup c_2 \cup \cdots \cup c_n$$

If some removal fails…

$$\exists i \in \{1, \ldots, n\} \cdot test(c_{\text{✘}} \setminus c_i) = \text{✘} \implies \begin{array}{l} c_{\text{✘}}' = c_{\text{✘}} \setminus c_i \\ n' = \max(n-1, 2) \end{array}$$

Otherwise, increase granularity

$$c_{\text{✘}}' = c_{\text{✘}} \quad n' = 2n$$

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ddmin in a Nutshell

$c_{\text{✘}}' = ddmin(c_{\text{✘}})$ is a relevant configuration

$ddmin(c_{\text{✘}}) = ddmin'(c_{\text{✘}}', 2)$ with $ddmin'(c_{\text{✘}}', n) =$

$$\begin{cases} c_{\text{✘}}' & \text{if } |c_{\text{✘}}'| = 1 \\ ddmin'(c_{\text{✘}}' \setminus c_i, \max(n-1, 2)) & \text{else if } \exists i \in \{1..n\} \cdot test(c_{\text{✘}}' \setminus c_i) = \text{✘} \\ & \text{(“some removal fails”)} \\ ddmin'(c_{\text{✘}}', \min(2n, |c_{\text{✘}}'|)) & \text{else if } n < |c_{\text{✘}}'| \text{ (“increase granularity”)} \\ c_{\text{✘}}' & \text{otherwise} \end{cases}$$

where $c_{\text{✘}}' = c_1 \cup c_2 \cup \cdots \cup c_n$

$$\forall c_i, c_j \cdot c_i \cap c_j = \varnothing \wedge |c_i| \approx |c_j|$$

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```
def _ddmin(circumstances, n):
    while len(circumstances) >= 2:
        subsets = split(circumstances, n)

        some_complement_is_failing = 0
        for subset in subsets:
            complement = listminus(circumstances, subset)
            if test(complement) == FAIL:
                circumstances = complement
                n = max(n - 1, 2)
                some_complement_is_failing = 1
                break

        if not some_complement_is_failing:
            if n == len(circumstances):
                break
            n = min(n * 2, len(circumstances))

    return circumstances
```


ddmin at Work

Input: <SELECT NAME="priority" MULTIPLE SIZE=7> ⟨40 characters⟩ ✘
<SELECT NAME="priority" MULTIPLE SIZE=7> ⟨0 characters⟩ ✔

```
 1 <SELECT NAME="priority" MULTIPLE SIZE=7> (20) ✔
 2 <SELECT NAME="priority" MULTIPLE SIZE=7> (20) ✔
 3 <SELECT NAME="priority" MULTIPLE SIZE=7> (30) ✔
 4 <SELECT NAME="priority" MULTIPLE SIZE=7> (30) ✘
 5 <SELECT NAME="priority" MULTIPLE SIZE=7> (20) ✔
 6 <SELECT NAME="priority" MULTIPLE SIZE=7> (20) ✘
 7 <SELECT NAME="priority" MULTIPLE SIZE=7> (10) ✔
 8 <SELECT NAME="priority" MULTIPLE SIZE=7> (10) ✔
 9 <SELECT NAME="priority" MULTIPLE SIZE=7> (15) ✔
10 <SELECT NAME="priority" MULTIPLE SIZE=7> (15) ✔
11 <SELECT NAME="priority" MULTIPLE SIZE=7> (15) ✘
12 <SELECT NAME="priority" MULTIPLE SIZE=7> (10) ✔
13 <SELECT NAME="priority" MULTIPLE SIZE=7> (10) ✔
14 <SELECT NAME="priority" MULTIPLE SIZE=7> (10) ✔
15 <SELECT NAME="priority" MULTIPLE SIZE=7> (12) ✔
16 <SELECT NAME="priority" MULTIPLE SIZE=7> (13) ✔
17 <SELECT NAME="priority" MULTIPLE SIZE=7> (12) ✔
18 <SELECT NAME="priority" MULTIPLE SIZE=7> (13) ✘
19 <SELECT NAME="priority" MULTIPLE SIZE=7> (10) ✔
20 <SELECT NAME="priority" MULTIPLE SIZE=7> (10) ✔
21 <SELECT NAME="priority" MULTIPLE SIZE=7> (11) ✔
22 <SELECT NAME="priority" MULTIPLE SIZE=7> (10) ✘
23 <SELECT NAME="priority" MULTIPLE SIZE=7>  (7) ✔
24 <SELECT NAME="priority" MULTIPLE SIZE=7>  (8) ✔
25 <SELECT NAME="priority" MULTIPLE SIZE=7> (7) ✔
26 <SELECT NAME="priority" MULTIPLE SIZE=7> (8) ✔
27 <SELECT NAME="priority" MULTIPLE SIZE=7> (9) ✔
28 <SELECT NAME="priority" MULTIPLE SIZE=7> (9) ✔
29 <SELECT NAME="priority" MULTIPLE SIZE=7> (9) ✔
30 <SELECT NAME="priority" MULTIPLE SIZE=7> (9) ✔
31 <SELECT NAME="priority" MULTIPLE SIZE=7> (8) ✔
32 <SELECT NAME="priority" MULTIPLE SIZE=7> (9) ✔
33 <SELECT NAME="priority" MULTIPLE SIZE=7> (8) ✘
34 <SELECT NAME="priority" MULTIPLE SIZE=7> (7) ✔
35 <SELECT NAME="priority" MULTIPLE SIZE=7> (7) ✔
36 <SELECT NAME="priority" MULTIPLE SIZE=7> (7) ✔
37 <SELECT NAME="priority" MULTIPLE SIZE=7> (7) ✔
38 <SELECT NAME="priority" MULTIPLE SIZE=7> (7) ✔
39 <SELECT NAME="priority" MULTIPLE SIZE=7> (6) ✔
40 <SELECT NAME="priority" MULTIPLE SIZE=7> (7) ✔
41 <SELECT NAME="priority" MULTIPLE SIZE=7> (7) ✔
42 <SELECT NAME="priority" MULTIPLE SIZE=7> (7) ✔
43 <SELECT NAME="priority" MULTIPLE SIZE=7> (7) ✔
44 <SELECT NAME="priority" MULTIPLE SIZE=7> (7) ✔
45 <SELECT NAME="priority" MULTIPLE SIZE=7> (7) ✔
46 <SELECT NAME="priority" MULTIPLE SIZE=7> (7) ✔
47 <SELECT NAME="priority" MULTIPLE SIZE=7> (7) ✔
48 <SELECT NAME="priority" MULTIPLE SIZE=7> (7) ✔
```

Result: <SELECT>

Complexity

- The maximal number of *ddmin* tests is

$$\frac{(|c_✘|^2 + 7|c_✘|)}{2}$$

Worst Case Details

First phase: every test is unresolved

$$t = 2 + 4 + 8 + \cdots + 2|c_x|$$
$$= 2|c_x| + |c_x| + \frac{|c_x|}{2} + \frac{|c_x|}{4} + \cdots = 4|c_x|$$

Second phase: testing *last* set always fails

$$t' = (|c_x| - 1) + (|c_x| - 2) + \cdots + 1$$
$$= 1 + 2 + 3 + \cdots + (|c_x| - 1)$$
$$= \frac{|c_x|(|c_x| - 1)}{2} = \frac{|c_x|^2 - |c_x|}{2}$$

Binary Search

If

- there is only one failure-inducing circumstance, and
- all configurations that include this circumstance fail,

the number of tests is $t \leq \log_2(|c_x|)$

More Simplification

Simplified failure-inducing *fuzz* input:

- FLEX crashes on 2,121 or more non-newline characters
- NROFF crashes on "\D^J%0F" or "\302\n"
- CRTPLOT crashes on "t"

Minimal Interaction

Ok the following operations cause mozilla to crash consistently on my machine

-> Start mozilla
-> Go to bugzilla.mozilla.org
-> Select search for bug
-> Print to file setting the bottom and right margins to .50 (I use the file /var/tmp/netscape.ps)
-> Once it's done printing do the exact same thing again on the same file (/var/tmp/netscape.ps)
-> This causes the browser to crash with a segfault

Minimal Interaction

Basic idea:
Apply *ddmin* to recorded user interaction

- To reproduce the Mozilla printing crash:
  - Press *P* while holding *Alt*
  - Press *mouse button 1*
  - Release *mouse button 1*

Optimization

- Caching
- Stop Early
- Syntactic Simplification
- Isolate Differences, not Circumstances

Caching

- Basic idea: store the results of earlier test()
- Saves 8 out of 48 tests in <SELECT> example

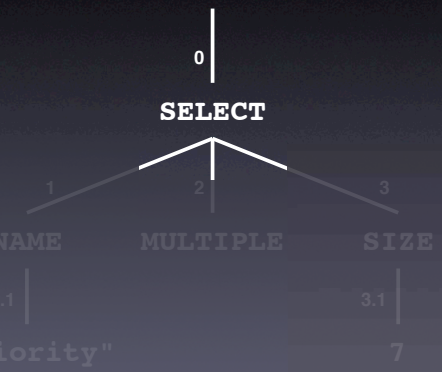
Stop Early

One may stop simplification when

- a certain *granularity* has been reached
- no *progress* has been made
- a certain *amount of time* has elapsed

Syntactic Simplification

```
<SELECT NAME="priority" MULTIPLE SIZE=7>
```



Differences

```
<SELECT NAME="priority" MULTIPLE SIZE=7>
```

The extra "<" is failure-inducing!

```
<SELECT NAME="priority" MULTIPLE SIZE=7>
```

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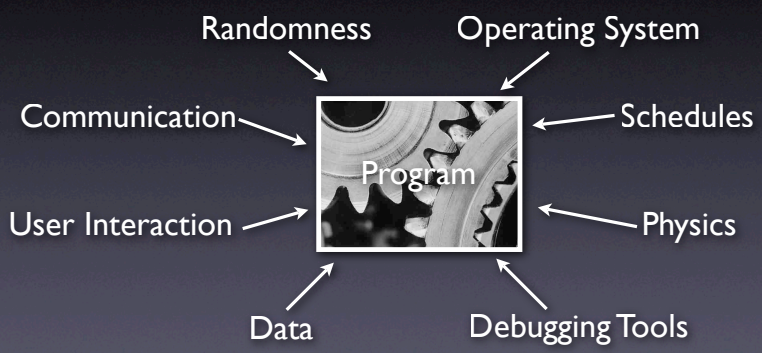
More Circumstances



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More Automation

- Failure-Inducing Input
- Failure-Inducing Code Changes
- Failure-Inducing Schedules
- Failure-Inducing Program States
- Failure-Inducing Method Calls

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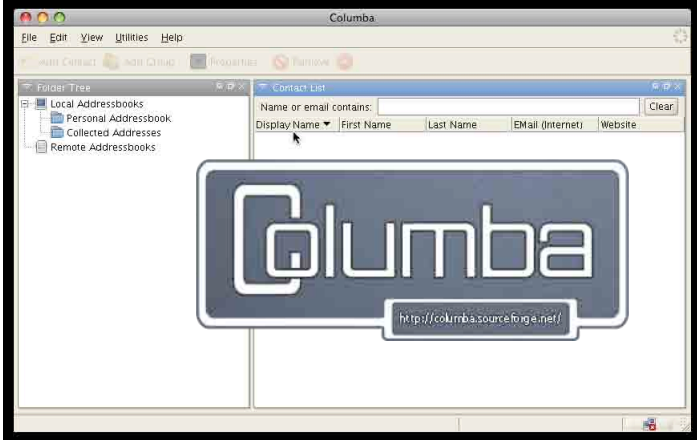

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Failure Cause

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Now, the idea is that we can easily automate the whole process.

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Problem:
Simulating user interaction is cumbersome.

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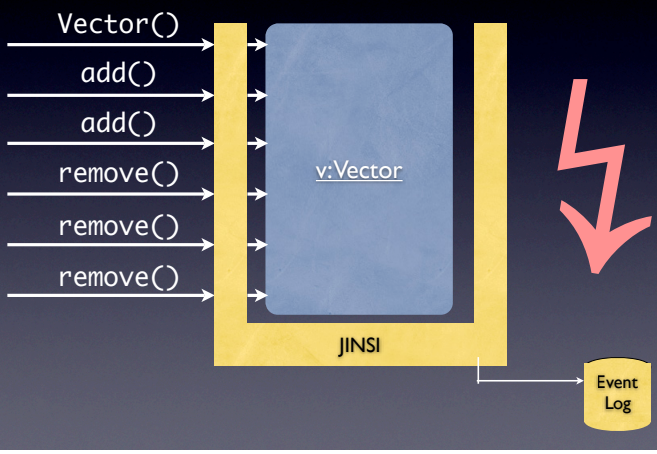
Isolating Relevant Calls

Step 1: Record



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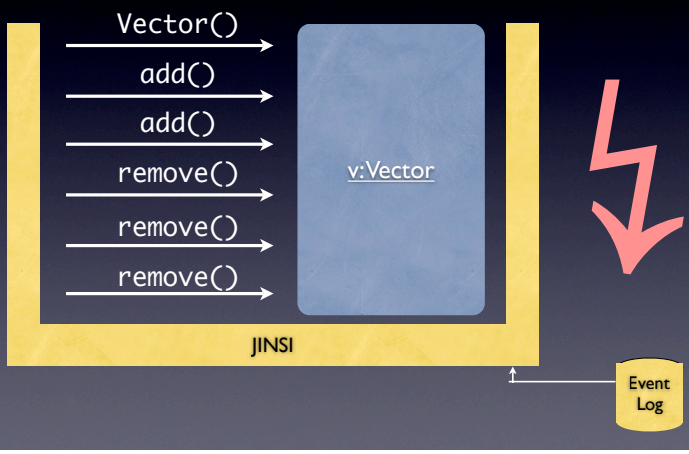
Isolating Relevant Calls

Step 2: Replay



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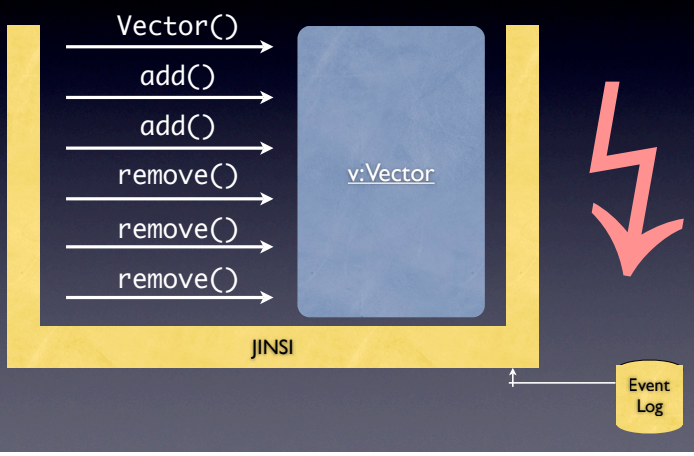
Isolating Relevant Calls

Step 3: Simplify



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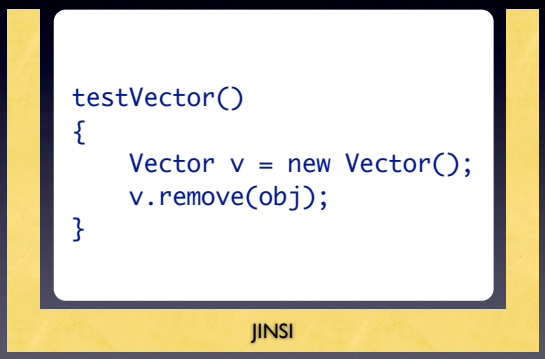
Isolating Relevant Calls

Step 4: Create Unit Test



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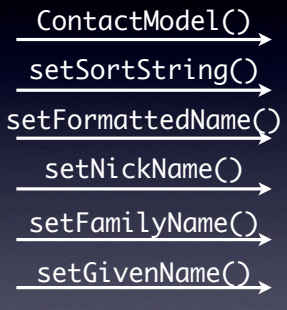
Columba ContactModel



and 18732 more…

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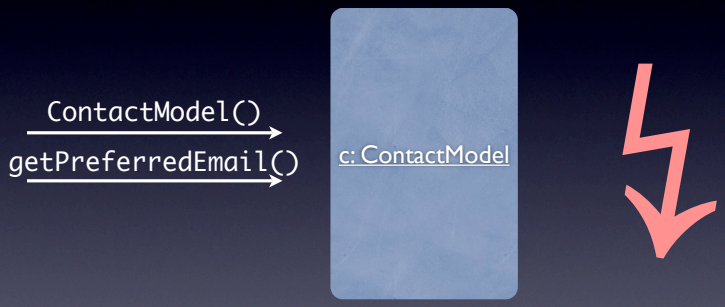
Columba ContactModel



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Unit Test

```
testContactModel()
{
    ContactModel c = new ContactModel();
    String s = c.getPreferredEmail();
}
```

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getPreferredEmail

```
public String getPreferredEmail() {
   Iterator it = getEmailIterator();

   // get first item
   IEmailModel model = (IEmailModel) it.next();

   // backwards compatiblity
   // -> its not possible anymore to create a
   // contact model without email address
   if (model == null)
      return null;

   return model.getAddress();
}
```

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Concepts

- The aim of simplification is to create a simple *test case* from a problem report.
- Simplified test cases…
  - are easier to communicate
  - facilitate debugging
  - identify duplicate problem reports

Concepts (2)

- To simplify a test case, remove all irrelevant circumstances.
- A circumstance is irrelevant if the problem occurs regardless of whether the circumstance is present or not.

Concepts (3)

- To automate simplification, set up
  - an *automated test*
  - a *strategy* to determine the relevant circumstances
- One such strategy is the *ddmin* delta debugging algorithm

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