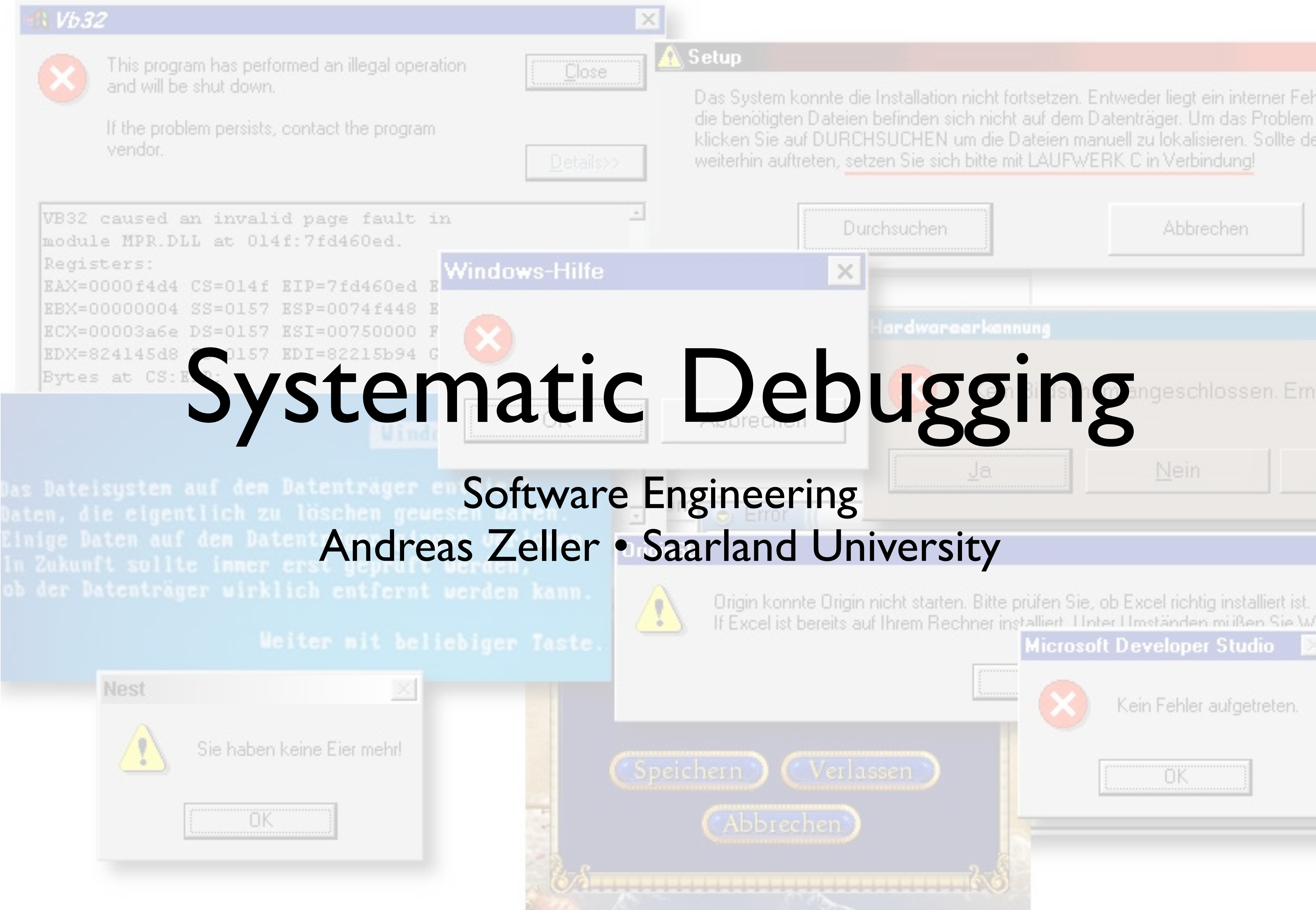
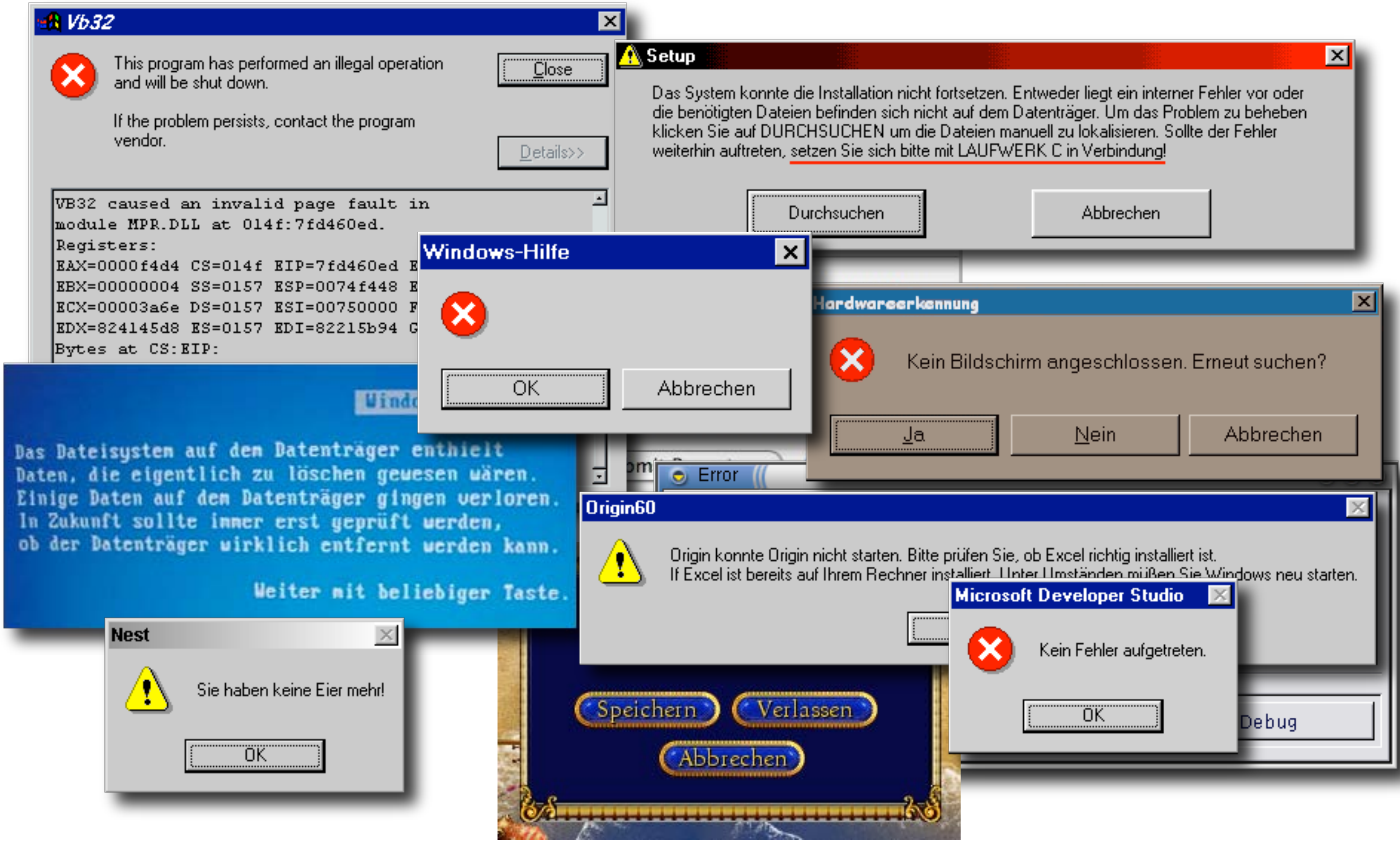
# Systematic Debugging

Software Engineering

Andreas Zeller • Saarland University



# The Problem


Vb32
This program has performed an illegal operation and will be shut down.
If the problem persists, contact the program vendor.
Close
Details>>
VB32 caused an invalid page fault in module MPR.DLL at 014f:7fd460ed.
Registers:
EAX=0000f4d4 CS=014f EIP=7fd460ed
EBX=00000004 SS=0157 ESP=0074f448
ECX=00003a6e DS=0157 ESI=00750000
EDX=824145d8 ES=0157 EDI=82215b94
Bytes at CS:EIP:
Setup
Das System konnte die Installation nicht fortsetzen. Entweder liegt ein interner Fehler vor oder die benötigten Dateien befinden sich nicht auf dem Datenträger. Um das Problem zu beheben klicken Sie auf DURCHSUCHEN um die Dateien manuell zu lokalisieren. Sollte der Fehler weiterhin auftreten, setzen Sie sich bitte mit LAUFWERK C in Verbindung!
Durchsuchen
Abbrechen
Windows-Hilfe
OK
Abbrechen
Hardwareerkennung
Kein Bildschirm angeschlossen. Erneut suchen?
Ja
Nein
Abbrechen
Das Dateisystem auf dem Datenträger enthielt Daten, die eigentlich zu löschen gewesen wären. Einige Daten auf dem Datenträger gingen verloren. In Zukunft sollte immer erst geprüft werden, ob der Datenträger wirklich entfernt werden kann.
Weiter mit beliebiger Taste.
Error
Origin60
Origin konnte Origin nicht starten. Bitte prüfen Sie, ob Excel richtig installiert ist.
Microsoft Developer Studio
Kein Fehler aufgetreten.
OK
Debug
Nest
Sie haben keine Eier mehr!
OK
Speichern
Verlassen
Abbrechen

# Facts on Debugging

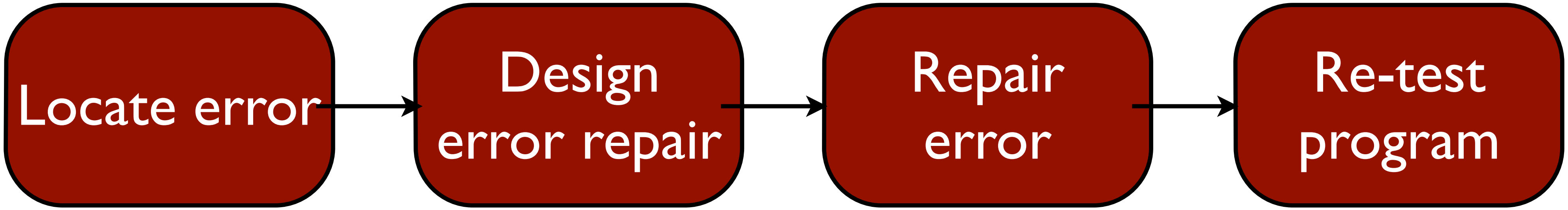
- Software bugs cost ~60 bln US$/yr in US
- Improvements could reduce cost by 30%
- Validation (including debugging) can easily take up to 50-75% of the development time
- When debugging, some people are *three times* as efficient than others

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
$
```

# How to Debug

(Sommerville 2004)



# The Process

**T** rack the problem

**R** eproduce

**A** utomate

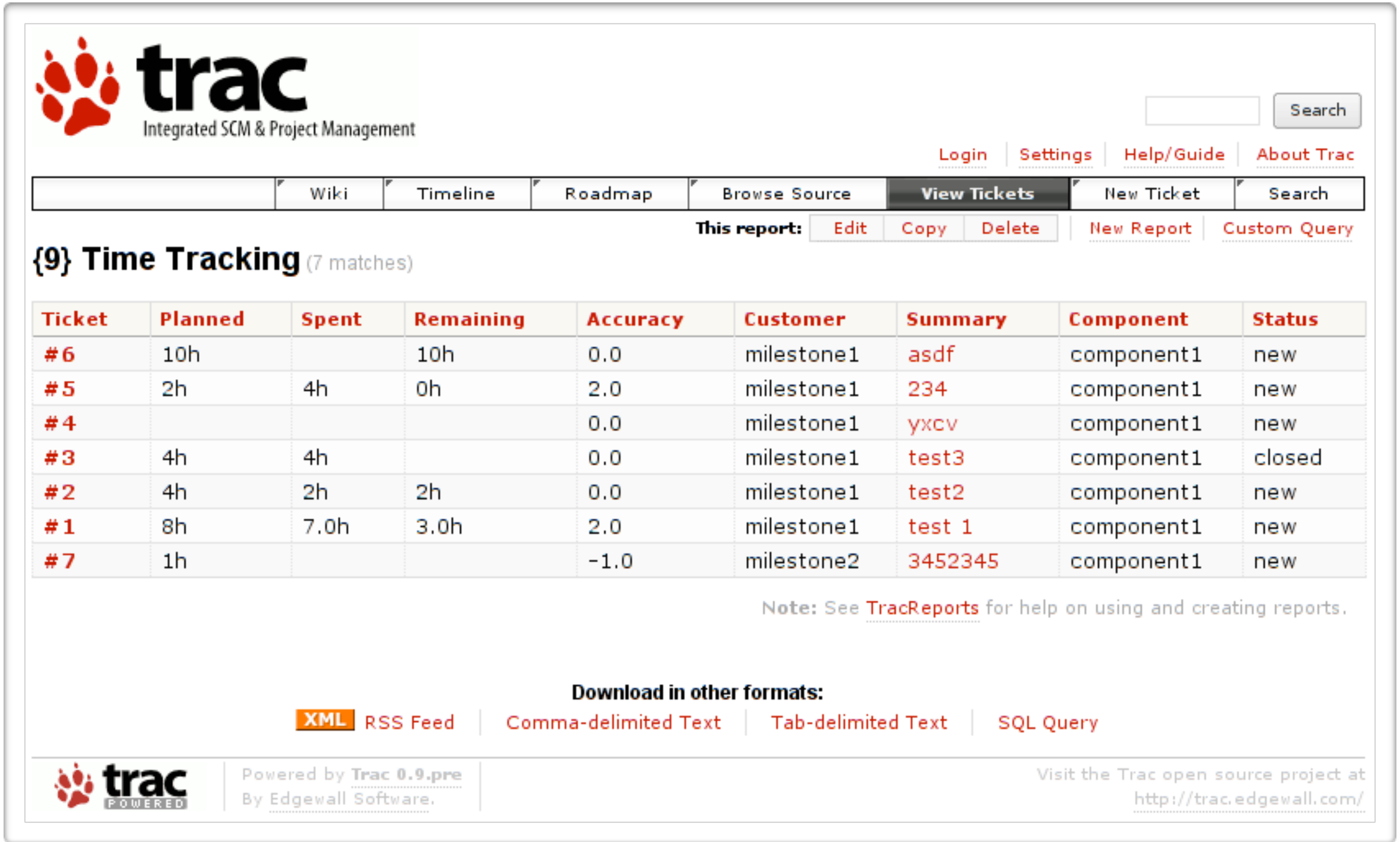
**F** ind Origins

**F** ocus

**I** solate

**C** orrect

# Tracking Problems



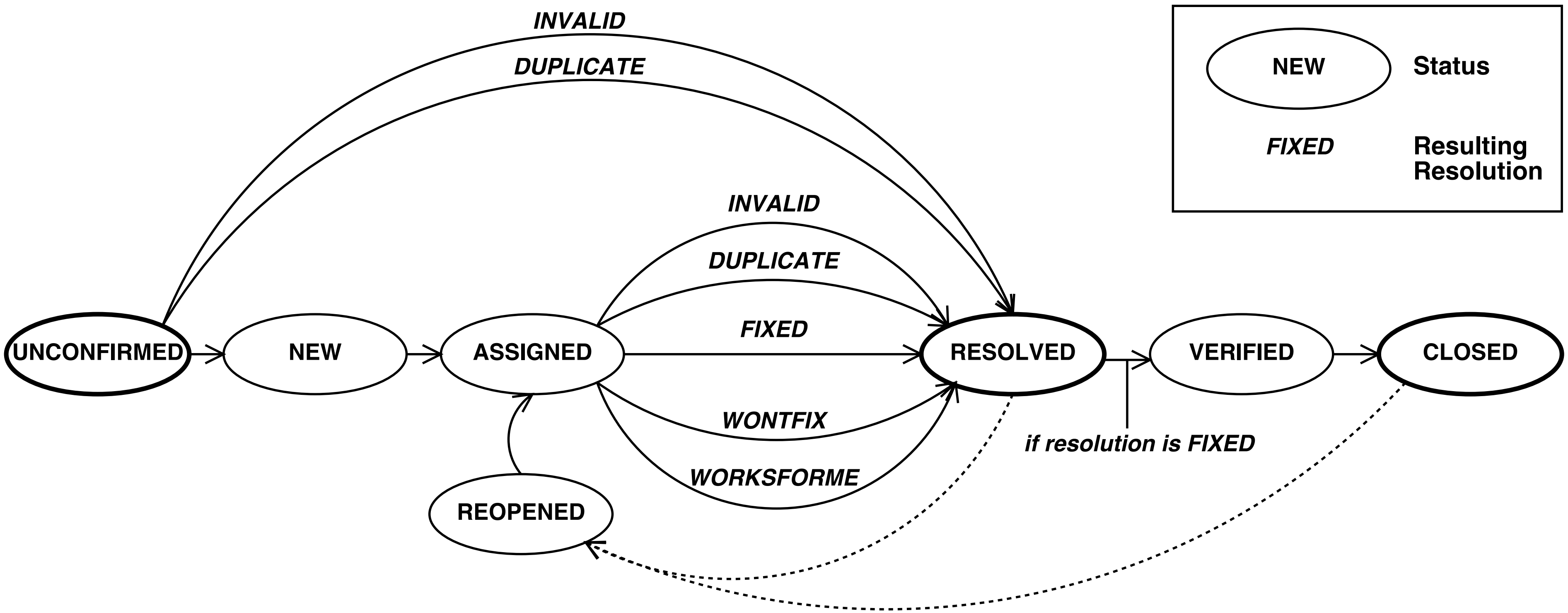

| Ticket | Planned | Spent | Remaining | Accuracy | Customer | Summary | Component | Status |
|---|---|---|---|---|---|---|---|---|
| #6 | 10h | | 10h | 0.0 | milestone1 | asdf | component1 | new |
| #5 | 2h | 4h | 0h | 2.0 | milestone1 | 234 | component1 | new |
| #4 | | | | 0.0 | milestone1 | yxcv | component1 | new |
| #3 | 4h | 4h | | 0.0 | milestone1 | test3 | component1 | closed |
| #2 | 4h | 2h | 2h | 0.0 | milestone1 | test2 | component1 | new |
| #1 | 8h | 7.0h | 3.0h | 2.0 | milestone1 | test 1 | component1 | new |
| #7 | 1h | | | -1.0 | milestone2 | 3452345 | component1 | new |

# Tracking Problems

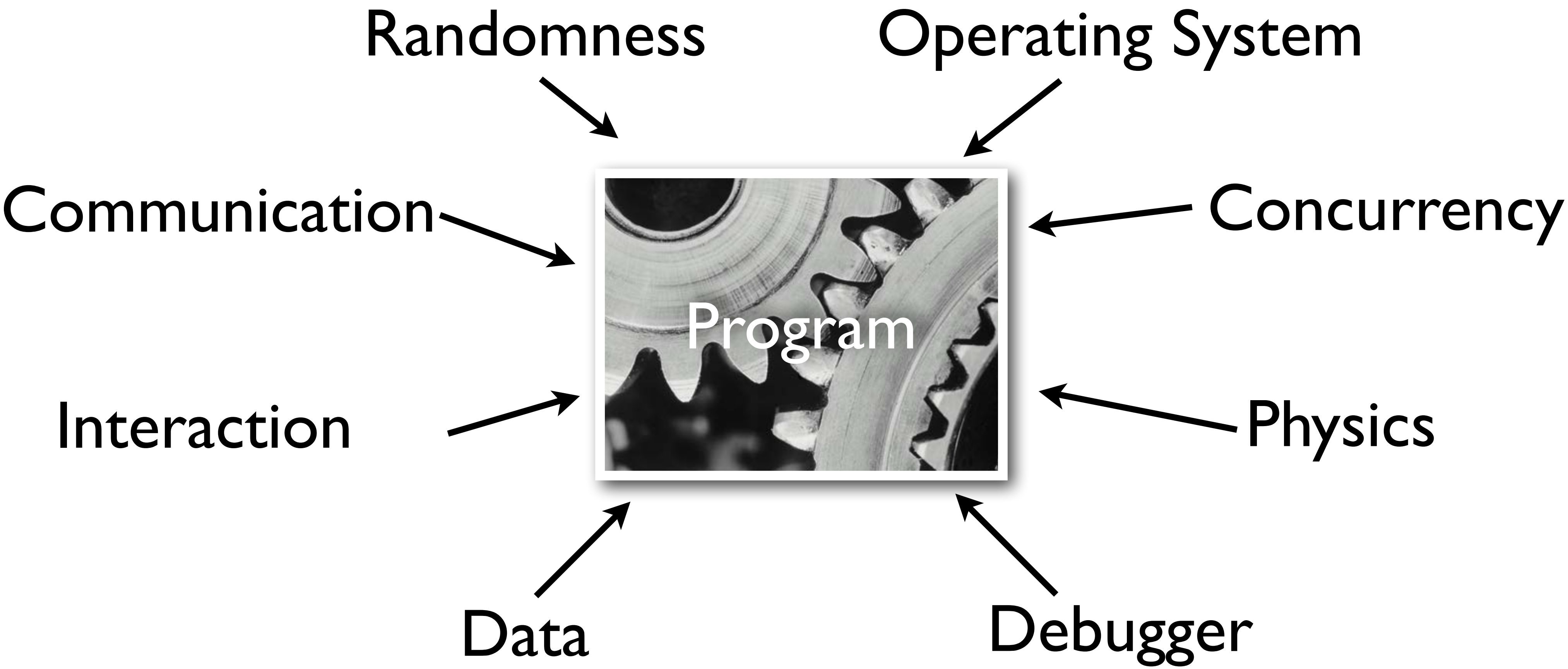
- Every problem gets entered into a *problem database*
- The *priority* determines which problem is handled next
- The product is ready when all problems are resolved

T
R
A
F
F
I
C

# Problem Life Cycle



# Reproduce


Randomness
Operating System
Communication
Concurrency
Program
Interaction
Physics
Data
Debugger

T
R
A
F
F
I
C

# 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");
}
```

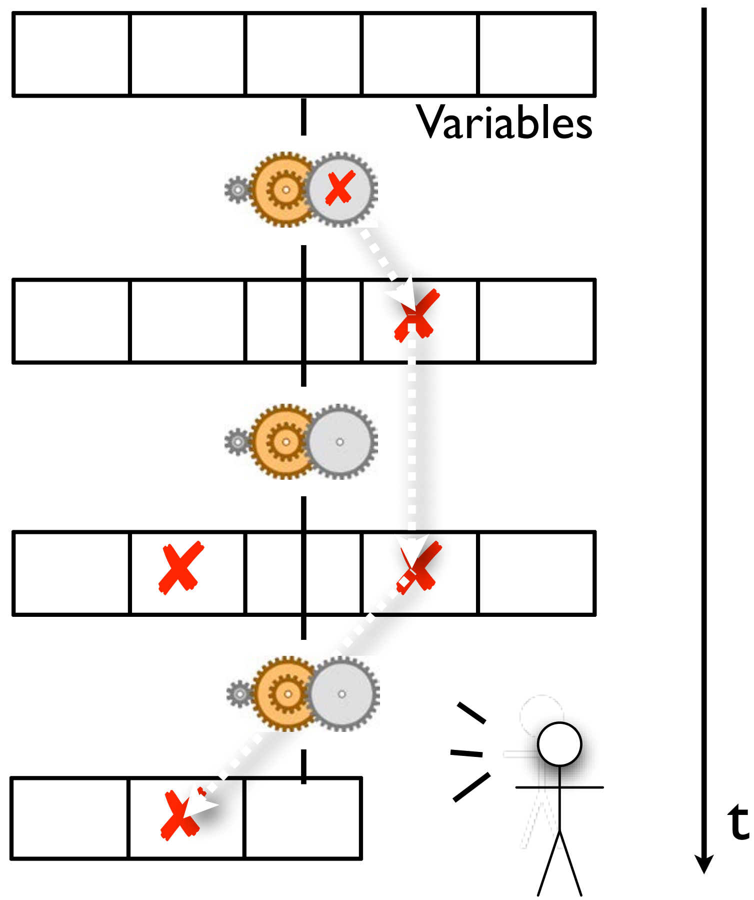
# Automate

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

T
R
A
F
F
I
C

# Finding Origins

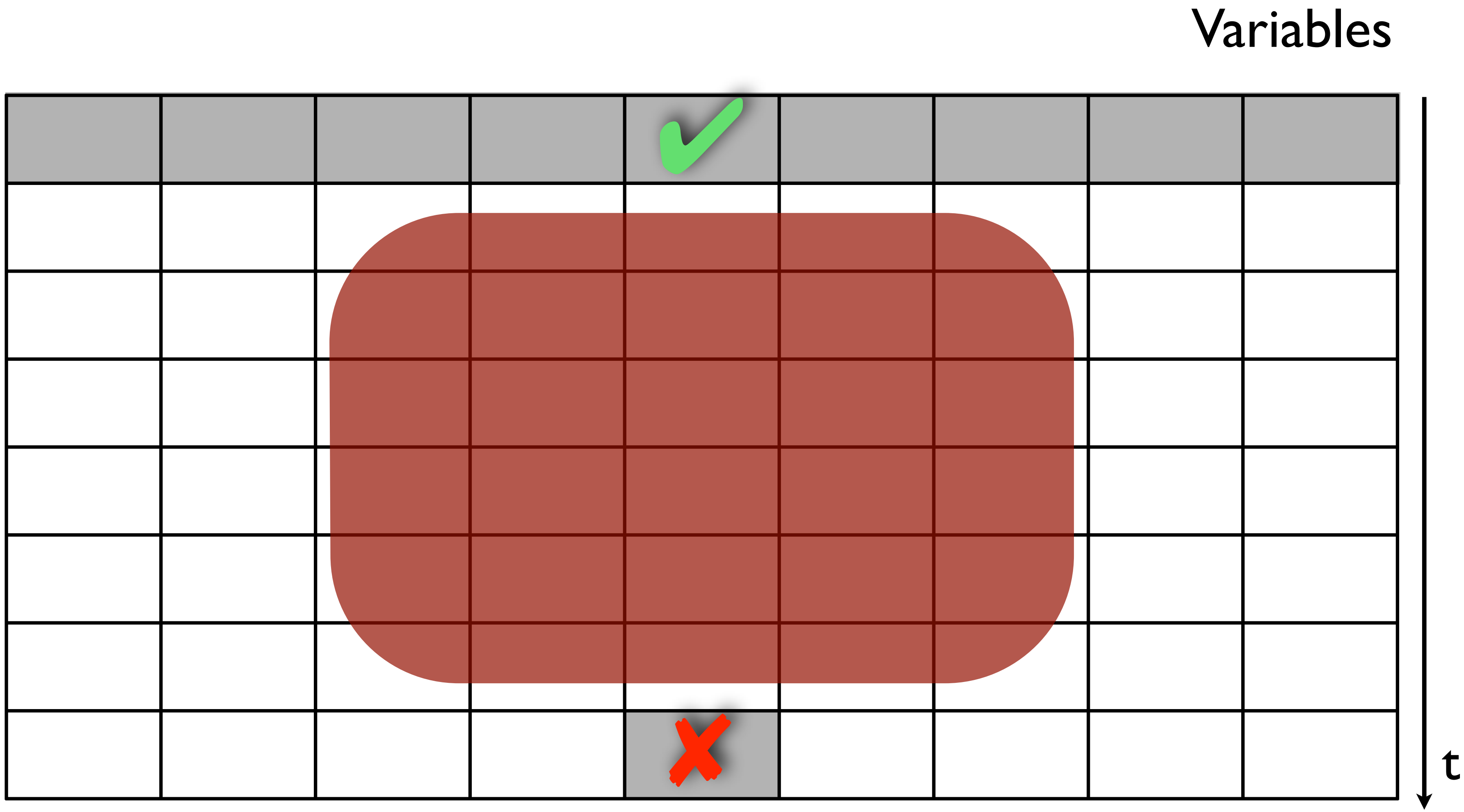
1. The programmer creates a *defect* in the code.
2. When executed, the defect creates an *infection*.
3. The infection *propagates*.
4. The infection causes a *failure*.



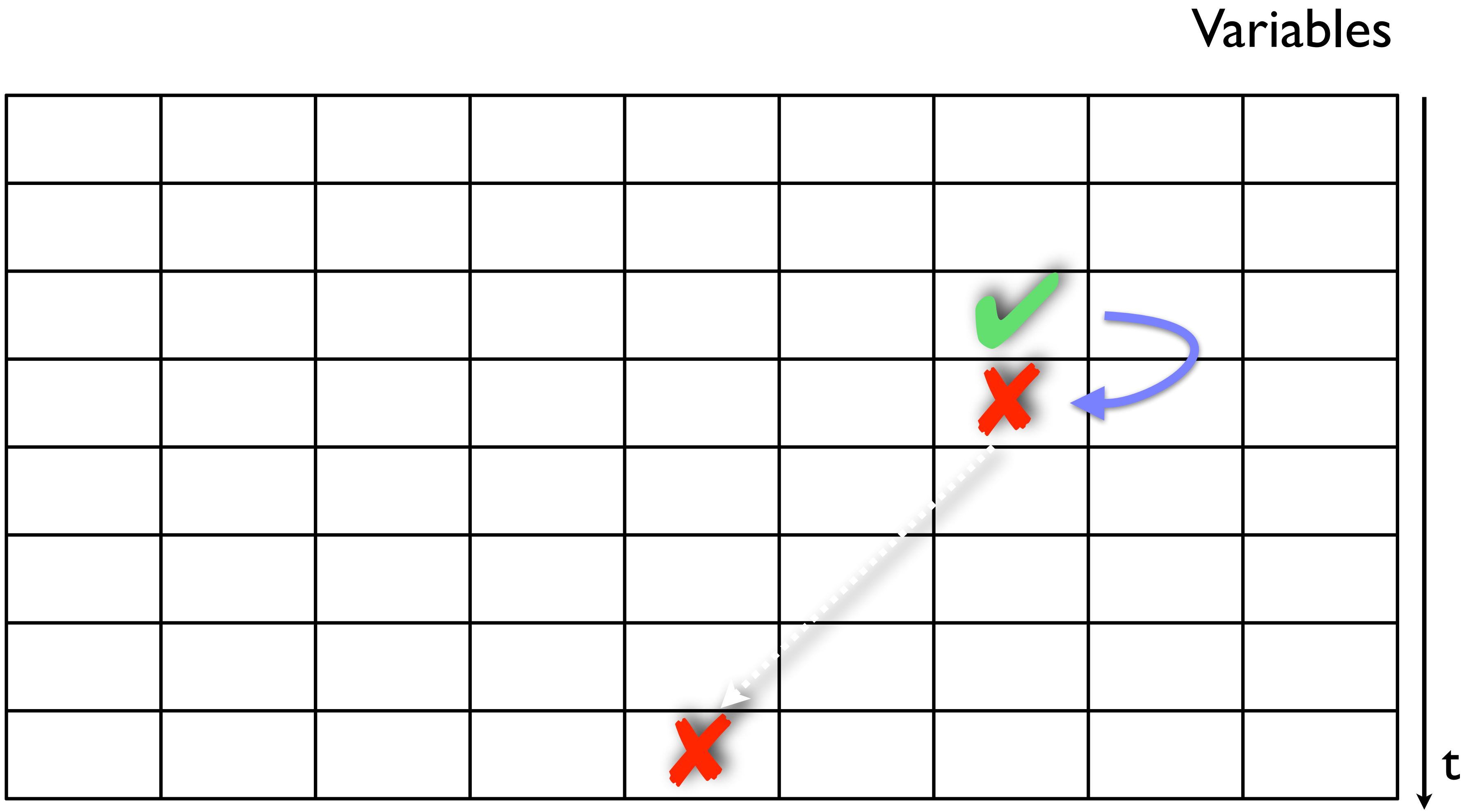

This infection chain must be traced back – and broken.

Not every defect creates an infection – not every infection results in a failure

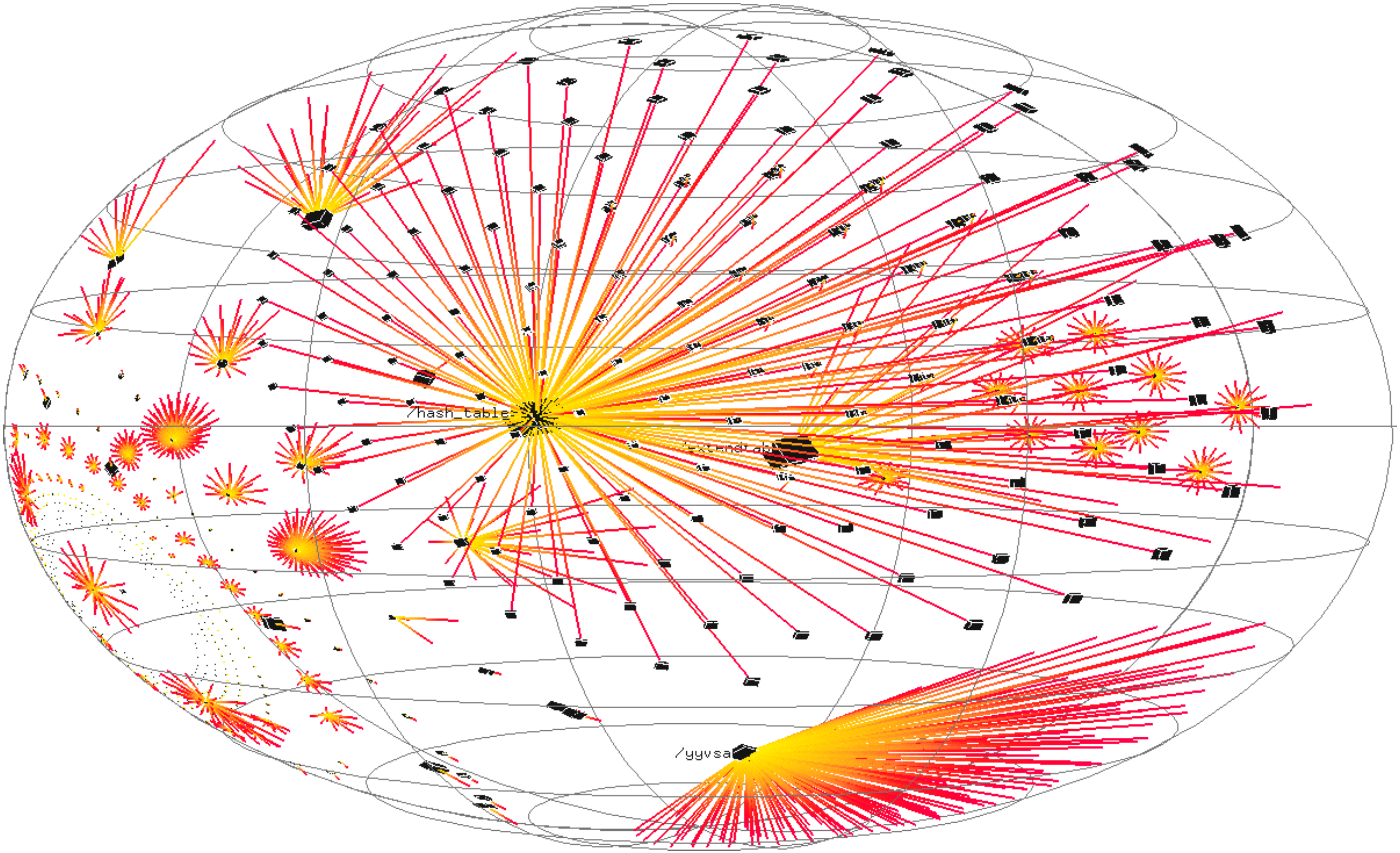
# Finding Origins



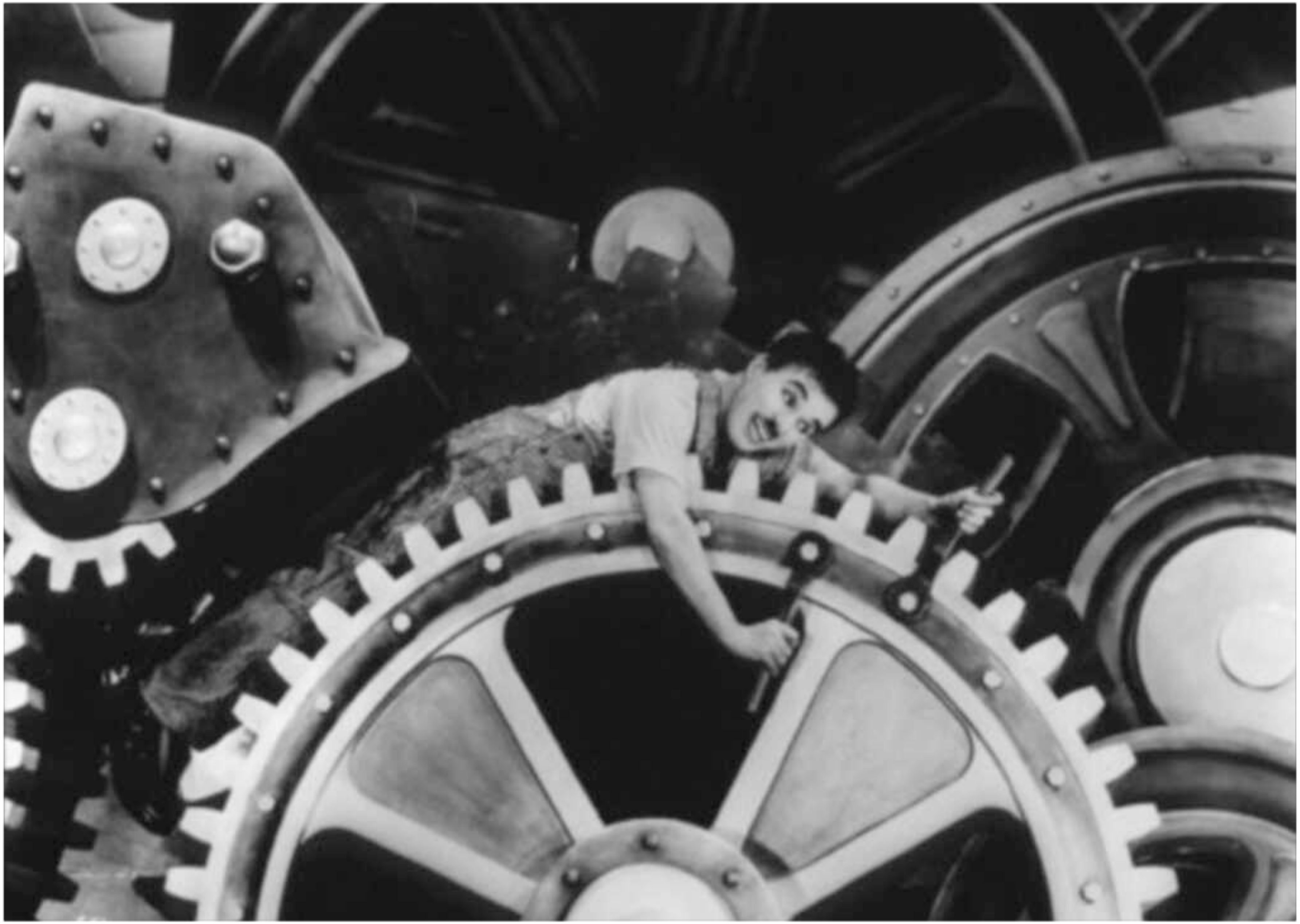
# The Defect



# A Program State



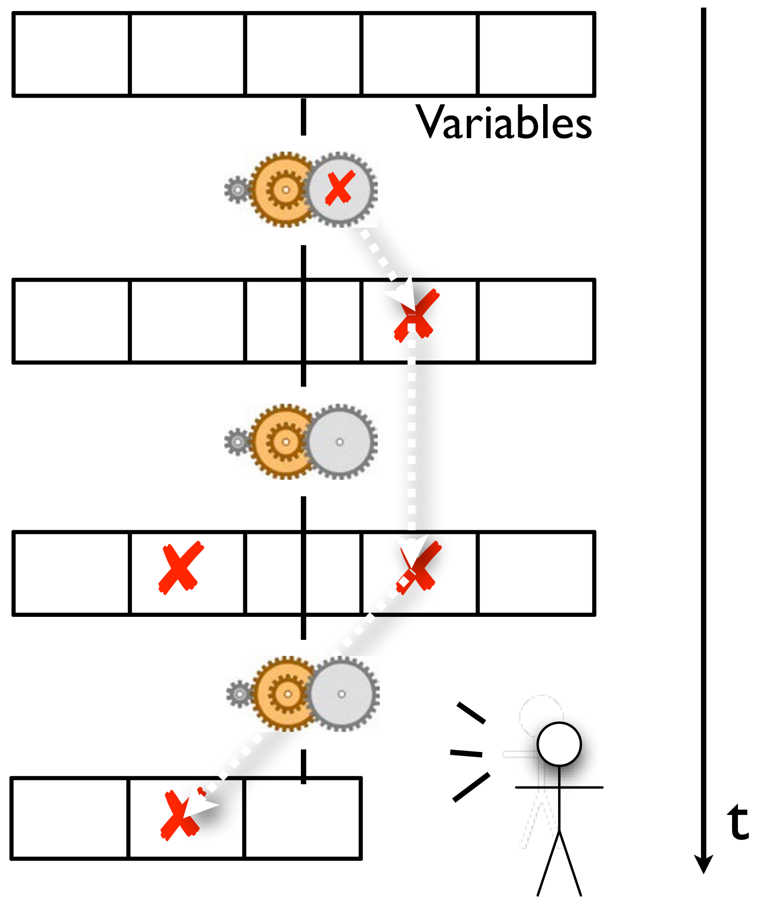
T
R
A
F
F
I
C



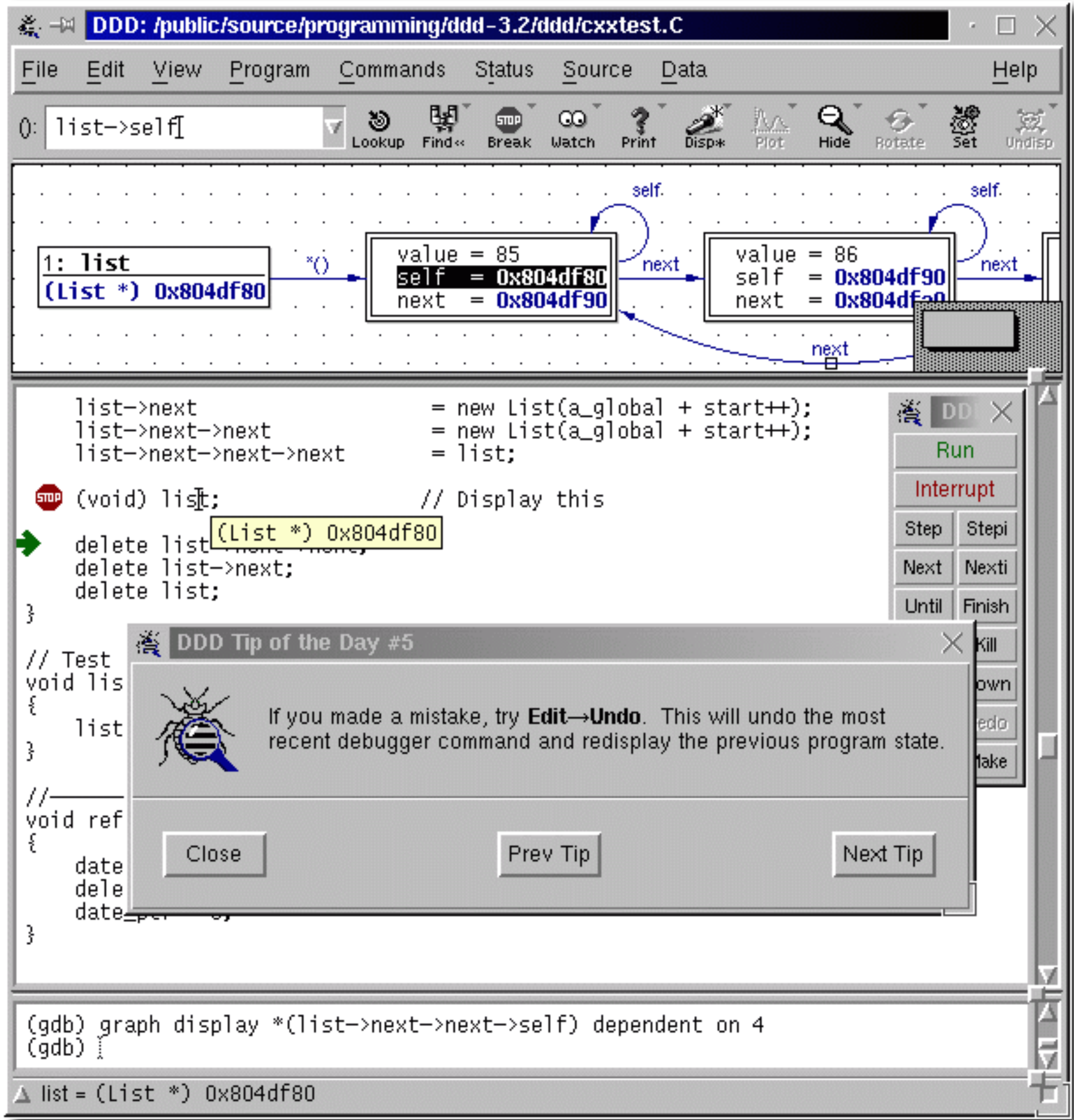
T R A F F I C

# Finding Origins

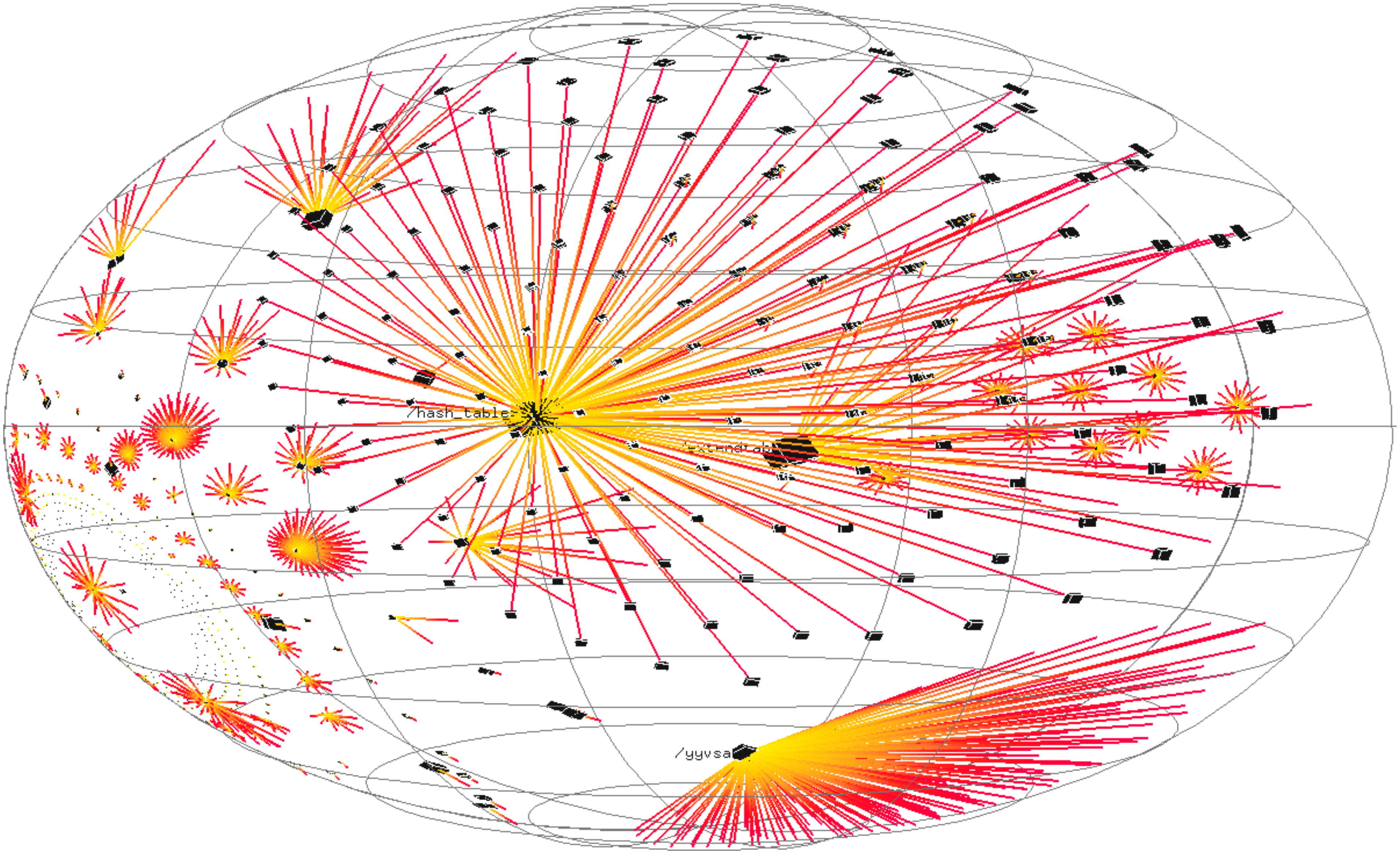
1. We start with a *known infection* (say, at the failure)
2. We search the infection in the *previous state*



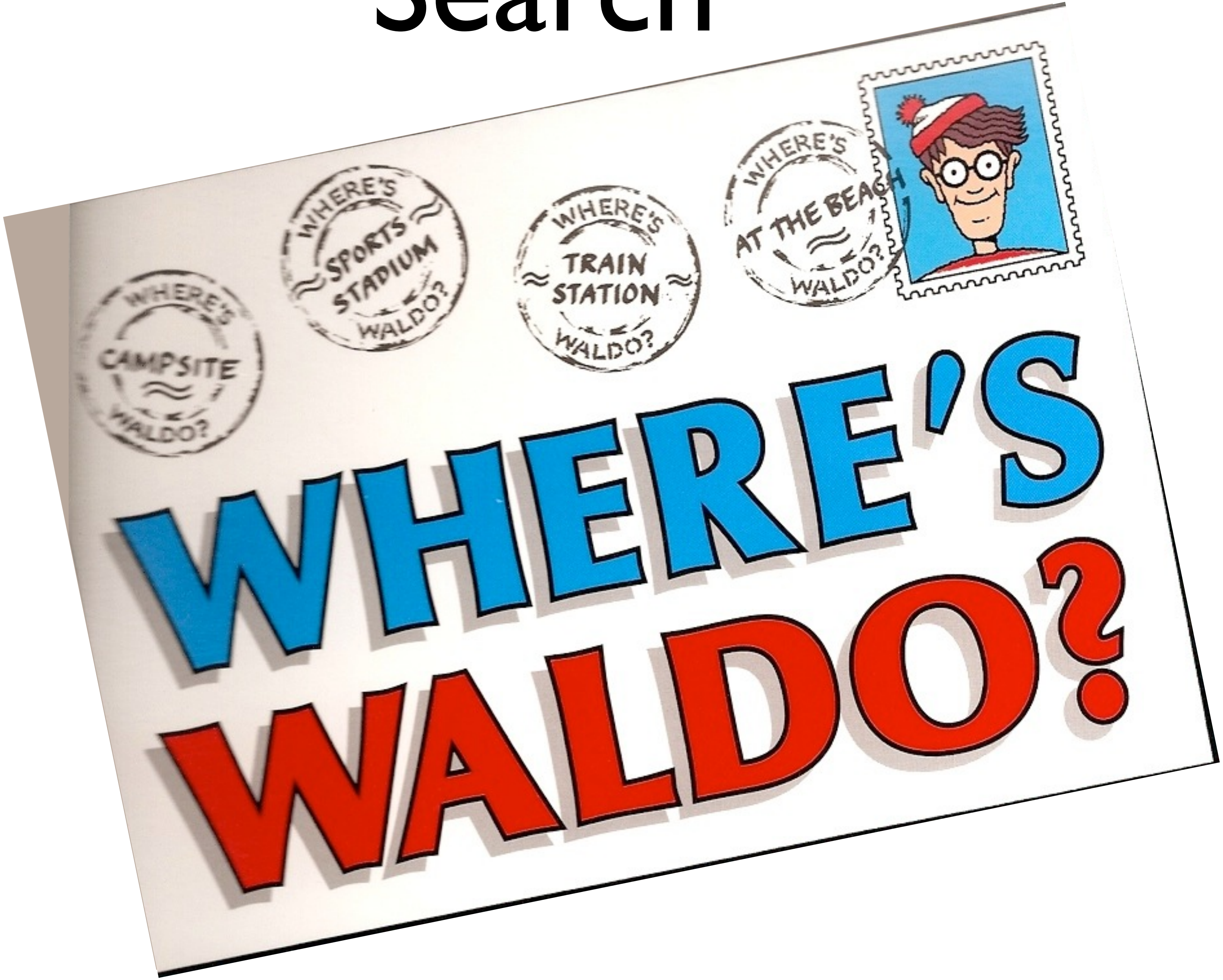
T
R
A
F
F
I
C


DDD: /public/source/programming/ddd-3.2/ddd/cxxtest.C
File Edit View Program Commands Status Source Data Help
(): list->self
Lookup Find« Break Watch Print Disp* Plot Hide Rotate Set Undisp
1: list
(List *) 0x804df80
value = 85
self = 0x804df80
next = 0x804df90
value = 86
self = 0x804df90
list->next = new List(a_global + start++);
list->next->next = new List(a_global + start++);
list->next->next->next = list;
(void) list; // Display this
(List *) 0x804df80
delete list->next;
delete list;
DDD Tip of the Day #5
If you made a mistake, try Edit→Undo. This will undo the most recent debugger command and redisplay the previous program state.
Close
Prev Tip
Next Tip
Run
Interrupt
Step Stepi
Next Nexti
Until Finish
(gdb) graph display *(list->next->next->self) dependent on 4
(gdb)
list = (List *) 0x804df80

# A Program State



# Search


WHERE'S CAMPSITE WALDO?
WHERE'S SPORTS STADIUM WALDO?
WHERE'S TRAIN STATION WALDO?
WHERE'S AT THE BEACH WALDO?
WHERE'S WALDO?

# 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!

T
R
A
F
F
I
C

# 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

T
R
A
F
F
I
C

# 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
}
```

# 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

T
R
A
F
F
I
C

# 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
}
```

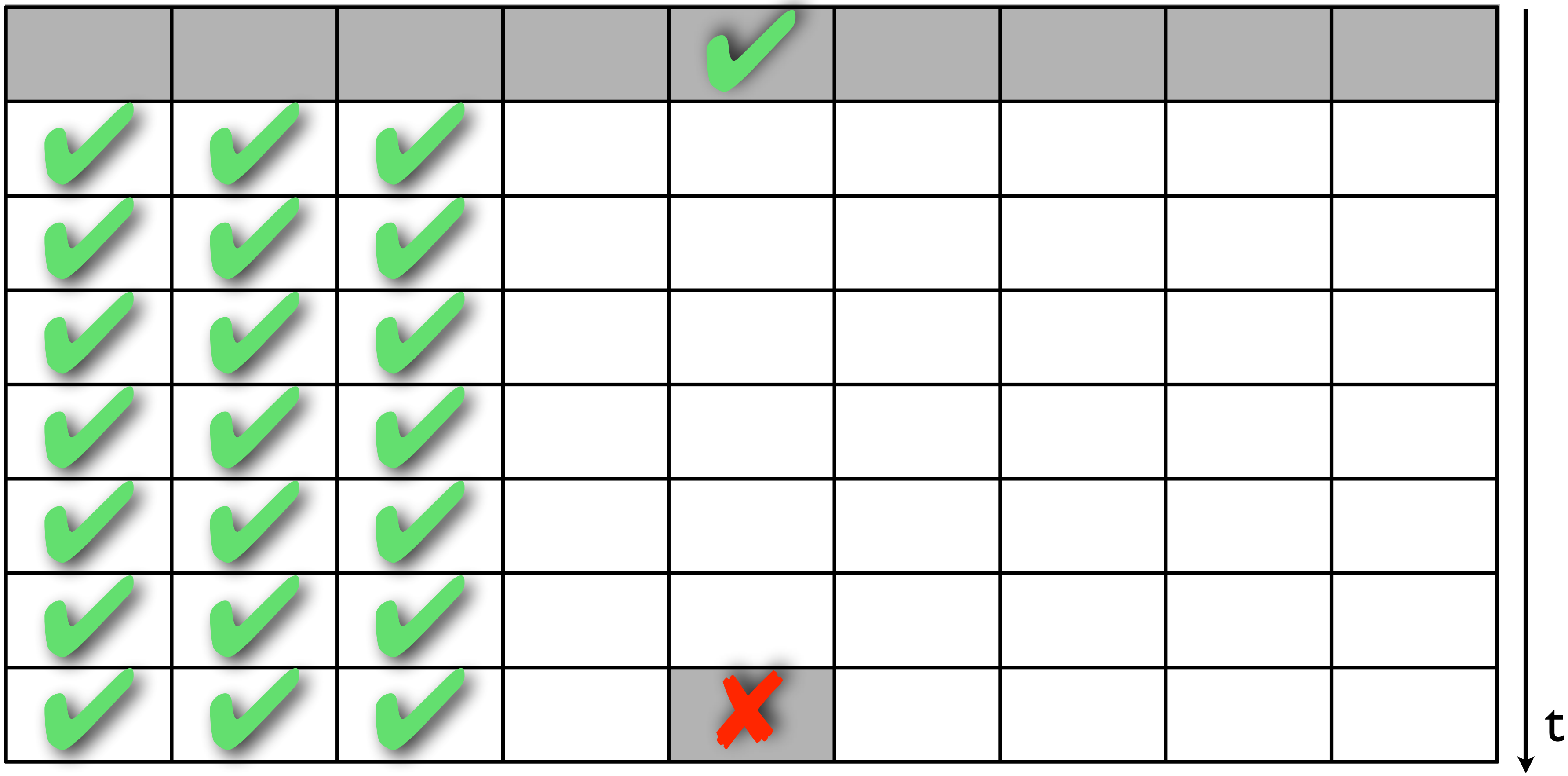
T
R
A
F
F
I
C

# Complex Invariants

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

      return true;
  }
}
```

# Assertions



# Focusing

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

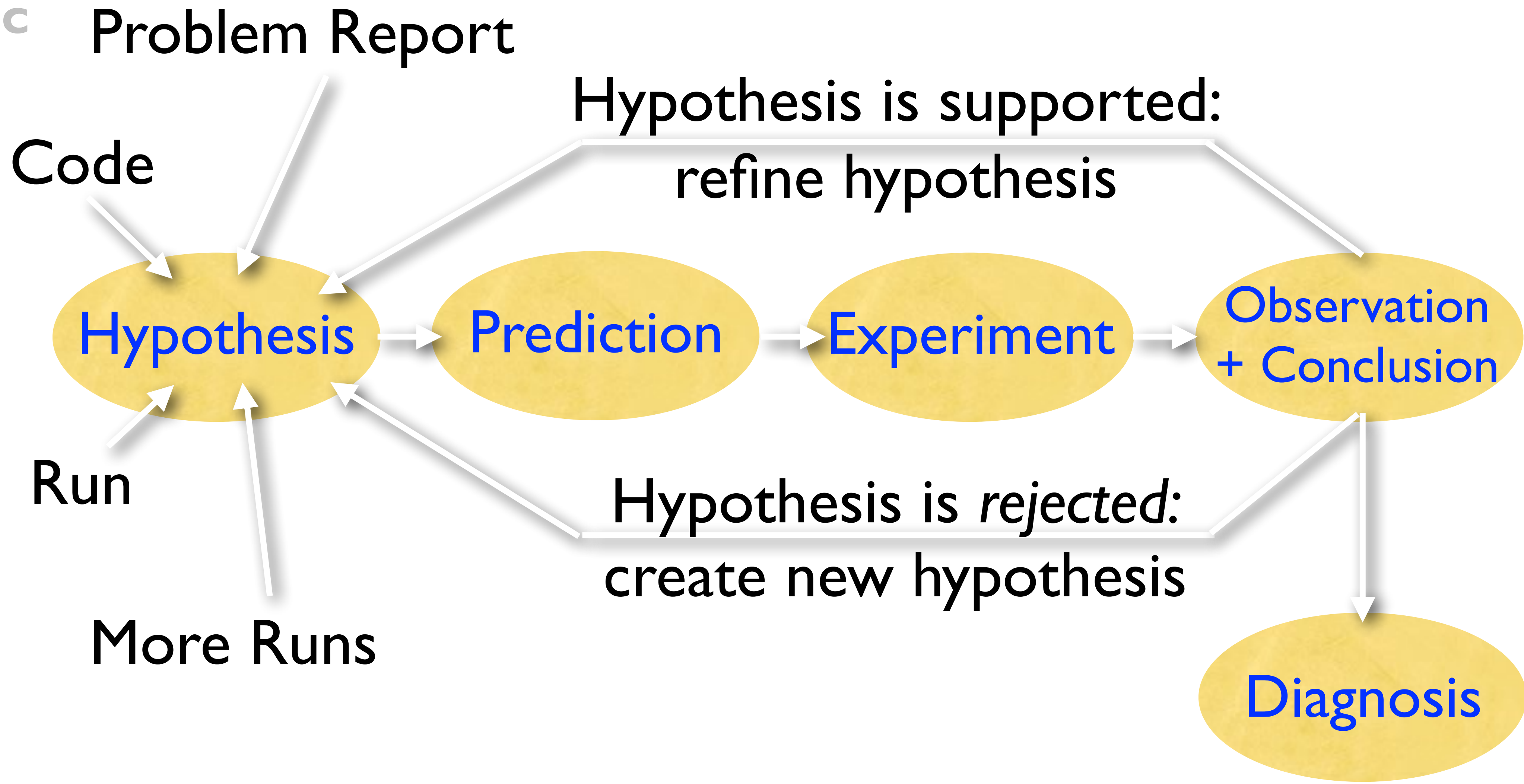
# Isolation

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

# 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



TRAFFIC


MASTERMIND
The Challenging Game of Logic and Deduction
Break the hidden code!
New sleek design with
improved built in storage
tray and code shield!
Pressman
MASTERMIND
MASTERMIND

# Explicit Hypotheses

| | |
|---|---|
| Hypothesis | The exec… …auses a[0] = 0 |
| Prediction | At L… …hould hold. |
| Experiment | … Line 37. |
| Observati… | …olds as predicted. |
| Conclusion | … …hesis is <u>confirmed.</u> |

Keeping everything in memory is like playing mastermind blind!

# Explicit Hypotheses

# 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

Study in Summer –
Call for Volunteers

# 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

# 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

# The Devil's Guide to Debugging

Don't waste time understanding the problem.

- Most problems are trivial, anyway.

# 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

# 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

WINNER OF JOLT PRODUCTIVITY AWARD

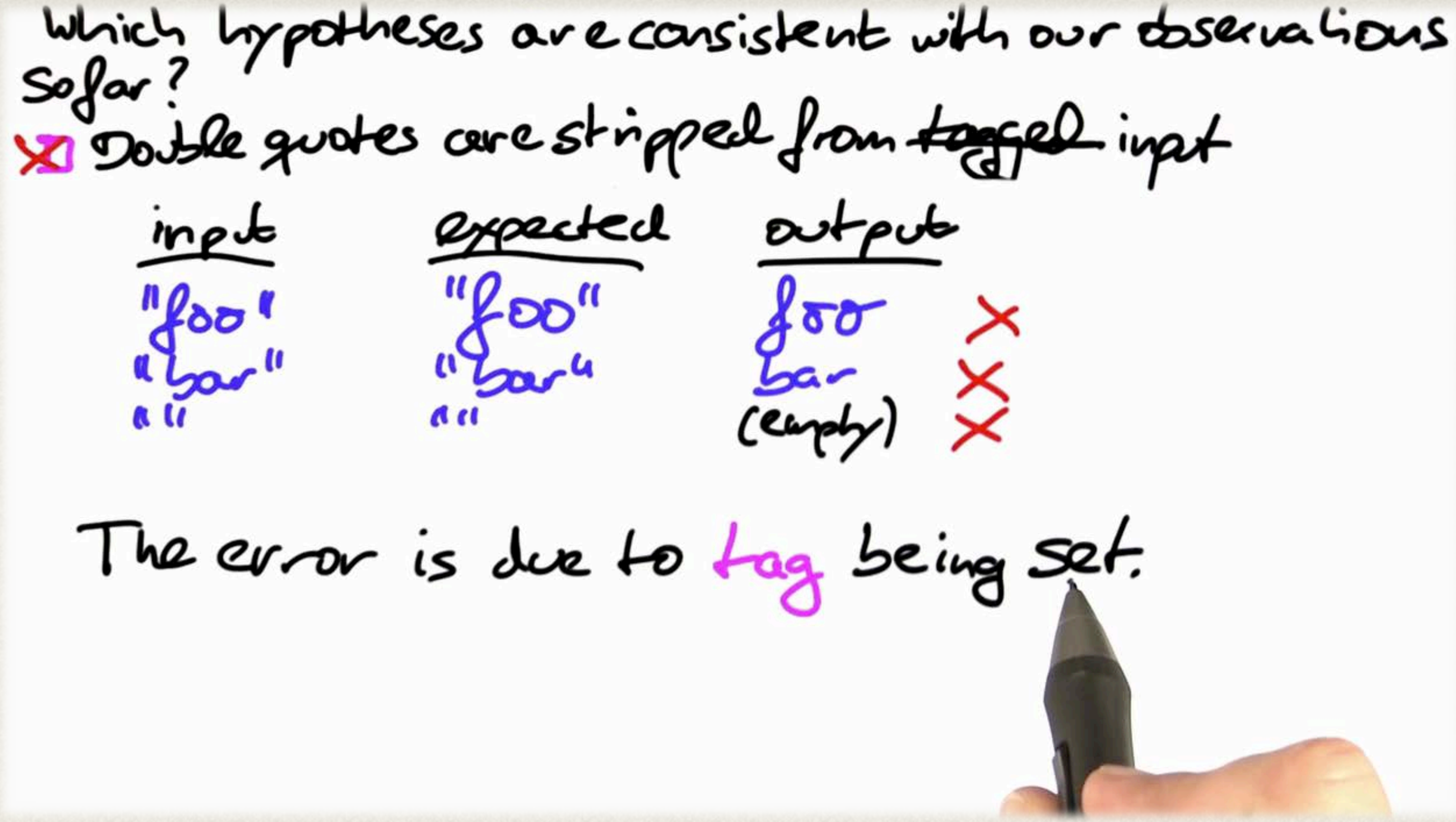
ANDREAS ZELLER

# WHY PROGRAMS FAIL

## A GUIDE TO SYSTEMATIC DEBUGGING

SECOND EDITION

MORGAN KAUFMANN




# Automated Debugging (WS 2014/15)

# Summary

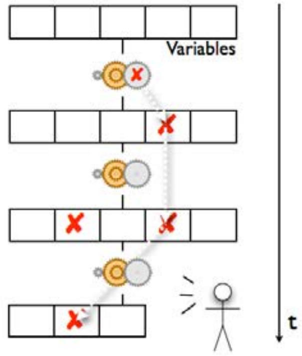
## The Process

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

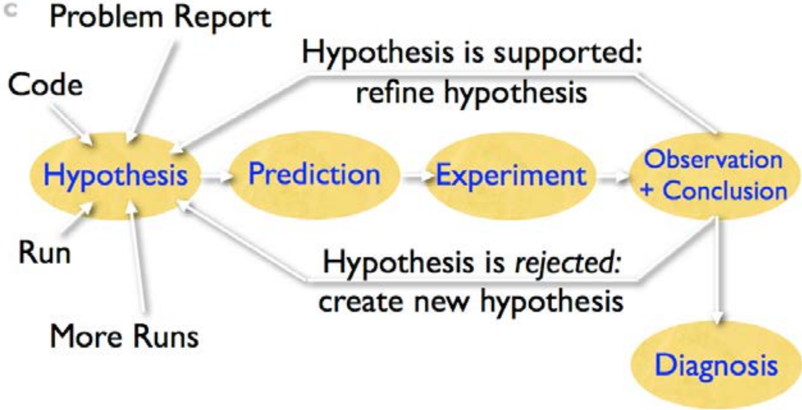
## Finding Origins

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.




## Scientific Method




## Online Course on Debugging