Software Architecture

Lecture 7:
Quality Assurance and testing

Topics

- Testing basics
- Partition testing
- Measure test quality
- Unit testing and test driven development
- GUI testing
- Test management
- Debugging

Testing Basics

Definition: software quality assurance (QA)

A set of policies and activities to:

- **Define** quality objectives
- Help **ensure** that software products and processes meet these objectives
- **Assess** to what extent they do
- **Improve** them over time

Software quality

Product quality (immediate):

- Correctness
- Robustness
- Security
- Ease of use
- Ease of learning
- Efficiency

Product quality (long-term):

- Extendibility
- Reusability
- Portability

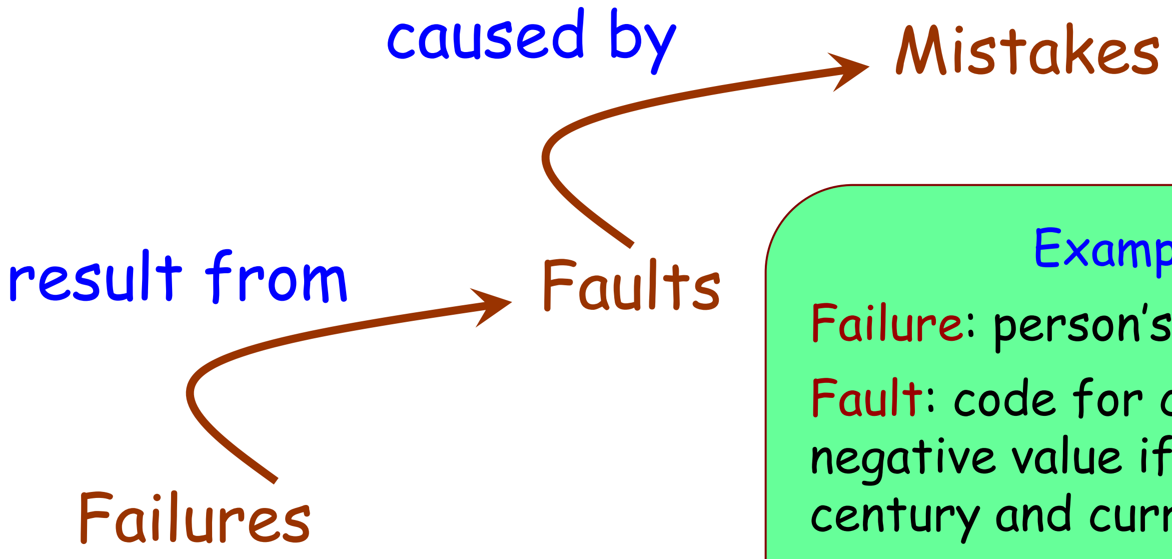
Process quality:

- Timeliness
- Cost-effectiveness
- Self-improvement

Quality, defined negatively

Quality is the absence of "deficiencies" (or "bugs").

More precise terminology (IEEE):



Failures

result from

Faults

caused by

Mistakes

Example: A Y2K issue

Failure: person's age appears as negative!

Fault: code for computing age yields negative value if birthdate is in 20th century and current date in 21st

Mistake: failed to account for dates beyond 20th century

Also: Error

In the case of a failure, extent of deviation from expected result

What is a failure?

For this discussion, a failure is any event of system execution that violates a stated quality objective.

Why does software contain faults?

We make mistakes:

- Unclear requirements
- Wrong assumptions
- Design errors
- Implementation errors

Some aspects of a system are hard to predict:

- For a large system, no one understands the whole
- Some behaviors are hard to predict
- Sheer complexity

Evidence (if any is needed!):
Widely accepted failure of "*n*-version programming"

The need for independent QA

Deep down, we want our software to succeed.

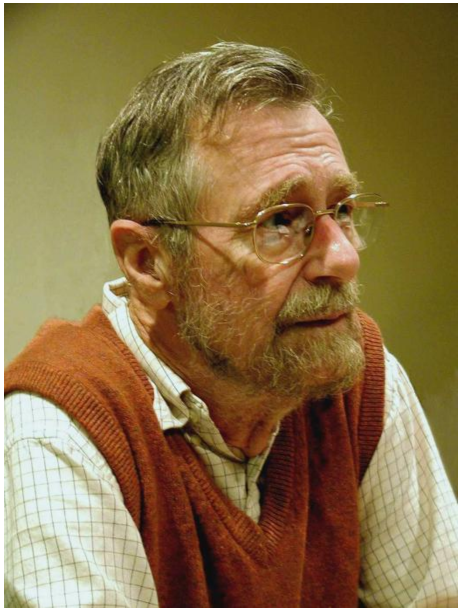
We are generally not in the best position to prevent or detect errors in our own products.

Definition: testing

To test a software system is to try to make it fail

The obligatory quote

"Testing can only show the presence of errors, never their absence"



(Edsger W. Dijkstra, in *Structured Programming*, 1970, and a few other places)

1. Gee, too bad, I hadn't thought of this. I guess testing is useless, then?
2. Wow! Exciting! Where can I buy one?

Limits of testing

Theoretical: cannot test for termination

Practical: sheer number of cases

(Dijkstra's example: multiplying two integers; today would mean 2^{128} combinations)

Consequences of the definition

- The purpose of testing is to find "bugs"

  (*More precisely: to provoke failures, which generally reflect faults due to mistakes*)

- We should really call a test "successful" if it fails

  (*We don't, but you get the idea*)

- A test that passes tells us nothing about the reliability of the Unit Under Test (UUT)

  (***except*** *if it previously failed* (*regression testing*))

- A thorough testing process must involve people other than developers

  (*although it may involve them too*)

- Testing stops at the identification of bugs

  (*it does not include correcting them: that's debugging*)

Testing: the overall process

- Identify parts of the software to be tested
- Identify interesting input values
- Identify expected results (functional) and execution characteristics (non-functional)
- Run the software on the input values
- Compare results & execution characteristics to expectations

Testing, the ingredients: test definition

Implementation Under Test (IUT)

The software (& possibly hardware) elements to be tested

Test case

Precise specification of one execution intended to uncover a possible fault:

- Required state & environment of *IUT* before execution
- Inputs

Test run

One execution of a *test case*

Test suite

A collection of *test cases*

More ingredients: test assessment

Expected results (for a test case)

Precise specification of what the test is expected to yield in the absence of a fault:

- Returned values
- Messages
- Exceptions
- Resulting state of program & environment
- Non-functional characteristics (time, memory…)

Test oracle

A mechanism to determine whether a test run satisfies the expected results

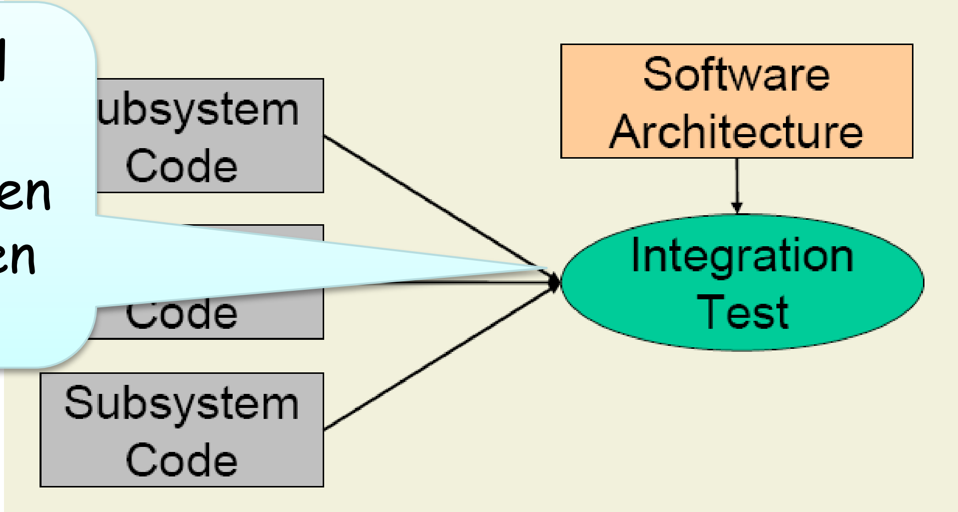
- Output is generally just "pass" or "fail".

Classification: by scope

Unit test: tests a module

Integration test: tests a complete subsystem

We cannot connect our email client to their database driver because ours is written in Eiffel and theirs is written in Java.



System test : tests a complete, integrated application against the requirements

- May exercise characteristics present only at the level of the entire system

Classification: by intent

Functional testing

Goal: evaluate the system's compliance with its specified requirements.

Fault-directed testing

Goal: reveal faults through failures

- Unit and integration testing

Conformance-directed testing

Goal: assess conformance to required capabilities

- System testing

Acceptance testing

Goal: enable customer to decide whether to accept a product

Regression testing

Goal: Retest previously tested element after changes, to assess whether they have re-introduced faults or uncovered new ones.

Mutation testing

Goal: Introduce faults to assess test case quality

Alpha and beta testing

Alpha testing

The first test of newly developed hardware or software in a laboratory setting. When the first round of bugs has been fixed, the product goes into beta test with actual users.

Beta testing

A test of new or revised hardware or software that is performed by users at their facilities under normal operating conditions.

An interesting example: proportional testing of Gmail.

Classification: by available information

White-box testing

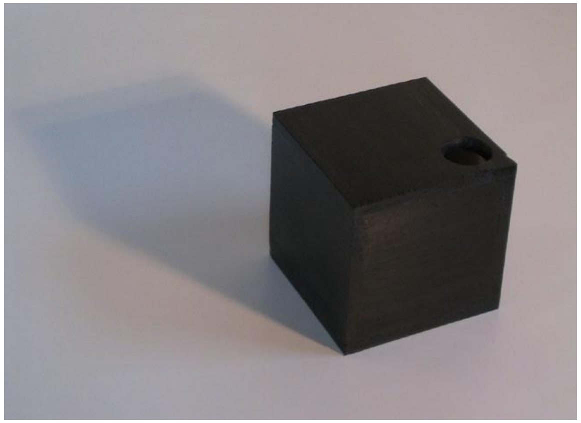
- To define test cases, source code of IUT is available

  Alternative names: implementation-based, structural, “glass box”, “clear box”

Black-box testing

- Properties of IUT available only through specification

  Alternative names: responsibility-based, functional



A comparison

	White-box	Black-box
IUT internals	Knows internal structure & implementation	No knowledge
Focus	Ensure coverage of many execution possibilities	Test conformance to specification
Origin of test cases	Source code analysis	Specification
Typical use	Unit testing	Integration & system testing
Who?	Developer	Developers, testers, customers

Input Partitioning

Limits of testing - revisited

Theoretical: cannot test for termination

Practical: sheer number of cases

(Dijkstra's example: multiplying two integers; today would mean 2^{128} combinations)

Problem: Exhaustive testing is impractical

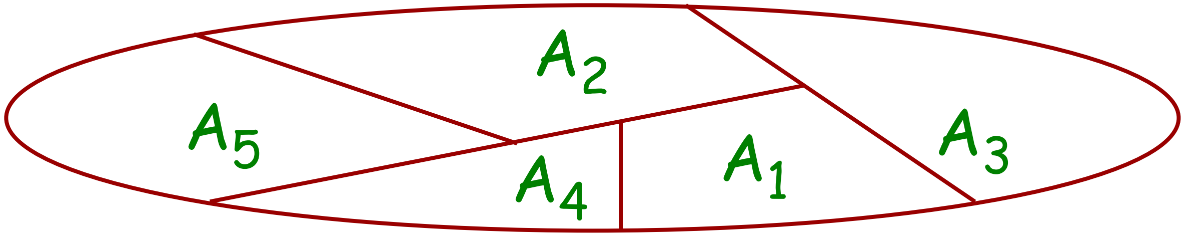
Solution: Select representative input samples, but how?

Partition testing (black-box)

We cannot test all inputs, but need realistic inputs

Idea of partition testing: select elements from a *partition* of the input set, i.e. a set of subsets that is

- *Complete*: union of subsets covers entire domain
- *Pairwise disjoint*: no two subsets intersect



Purpose (or hope!):

- For any input value that produces a failure, some other in the same subset produces a similar failure

Common abuse of language: "a partition" for "one of the subsets in the partition" (e.g. A_2)

- Better called "equivalence class"

Examples of partitioning strategies

Ideas for equivalence classes:

- Set of values so that if any is processed correctly then any other will be processed correctly
- Set of values so that if any is processed incorrectly then any other in set will be processed incorrectly
- Values at the center of a range, e.g. 0, 1, -1 for integers
- Boundary values, e.g. MAXINT
- Values known to be particularly relevant
- Values that must trigger an error message (“invalid”)
- Intervals dividing up range, e.g. for integers
- Objects: need notion of “object distance”

Example partitioning

Date-related program

- Month: 28, 29, 30, 31 days
- Year: leap, standard non-leap,
  special non-leap (x100), special leap (x1000)

All combinations: some do not make sense

From Wikipedia:

> The Gregorian calendar, the current standard calendar in most of the world, adds a 29th day to February in all years evenly divisible by four, except for centennial years (those ending in -00), which receive the extra day only if they are evenly divisible by 400. Thus 1600, 2000 and 2400 are leap years but 1700, 1800, 1900 and 2100 are not.

Boundary testing

Many errors occur on or near boundaries of input domain

Heuristics: in an equivalence class, select values at edge

Examples:

- Leap years
- Non-leap commonly mistaken as leap (1900)
- Leap years commonly mistaken as non-leap (2000)
- Invalid months: 0, 13
- For numbers in general: 0, very large, very small

Partition testing: assessment

Applicable to all levels of testing: unit, class, integration, system

Black-box: based only on input space, not the implementation

A natural and attractive idea, applied formally or by many testers, but lacks rigorous basis for assessing effectiveness.

Measure Test Quality

Coverage (white-box technique)

Idea : to assess the effectiveness of a test suite,

Measure how much of the program it exercises.

Concretely:

- Choose a kind of program element, e.g. instructions (instruction coverage) or paths (path coverage)
- Count how many are executed at least once
- Report as percentage

A test suite that achieves 100% coverage achieves the chosen criterion. Example:

" *This test suite achieves* **instruction coverage** *for routine r* "

Means that for every instruction *i* in *r*, at least one test executes *i*.

Taking advantage of coverage measures

Coverage-guided test suite improvement:

- Perform coverage analysis for a given criterion
- If coverage < 100%, find unexercised code sections
- Create c r them

High coverage /= high quality.

The process c alysis tool:

1. Instrument source code by inserting trace instructions
2. Run instrumented code, yielding a trace file
3. From the trace file, analyzer produces coverage report

Coverage criteria

Instruction (or: statement) coverage:

Measure instructions executed

Disadvantage: insensitive to some control structures

Branch coverage:

Measure conditionals whose paths are both executed

Condition coverage:

Count how many atomic boolean expressions evaluates to both true and false

Path coverage:

Count how many of the possible paths are taken

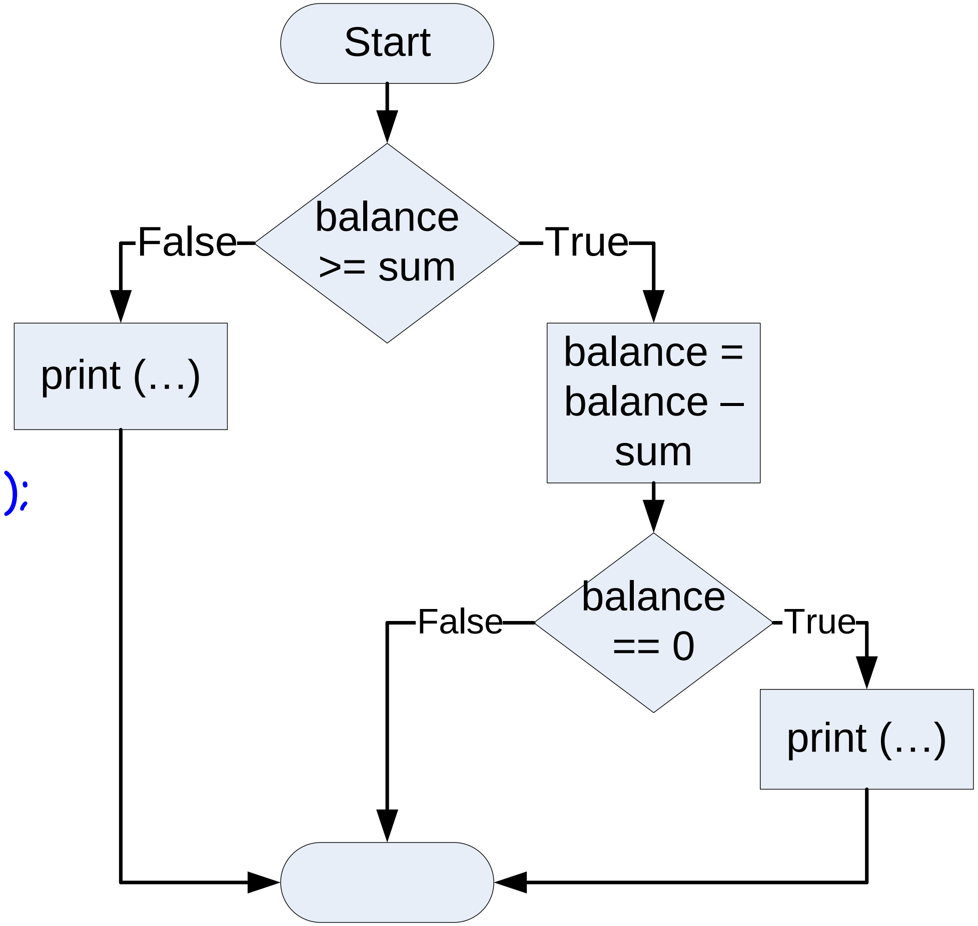
(Path: sequence of branches from routine entry to exit)

Example: source code

```
public class Account {

   private int balance;

   public void withdraw (int sum) {
        if (balance >= sum) {
            balance = balance - sum;
            if (balance == 0)
              System.out.println (
                 "The account is now empty.");
        } else
            System.out.println (
              "There are less than " + sum +
              "CHF in the account.");
  }
...
}
```

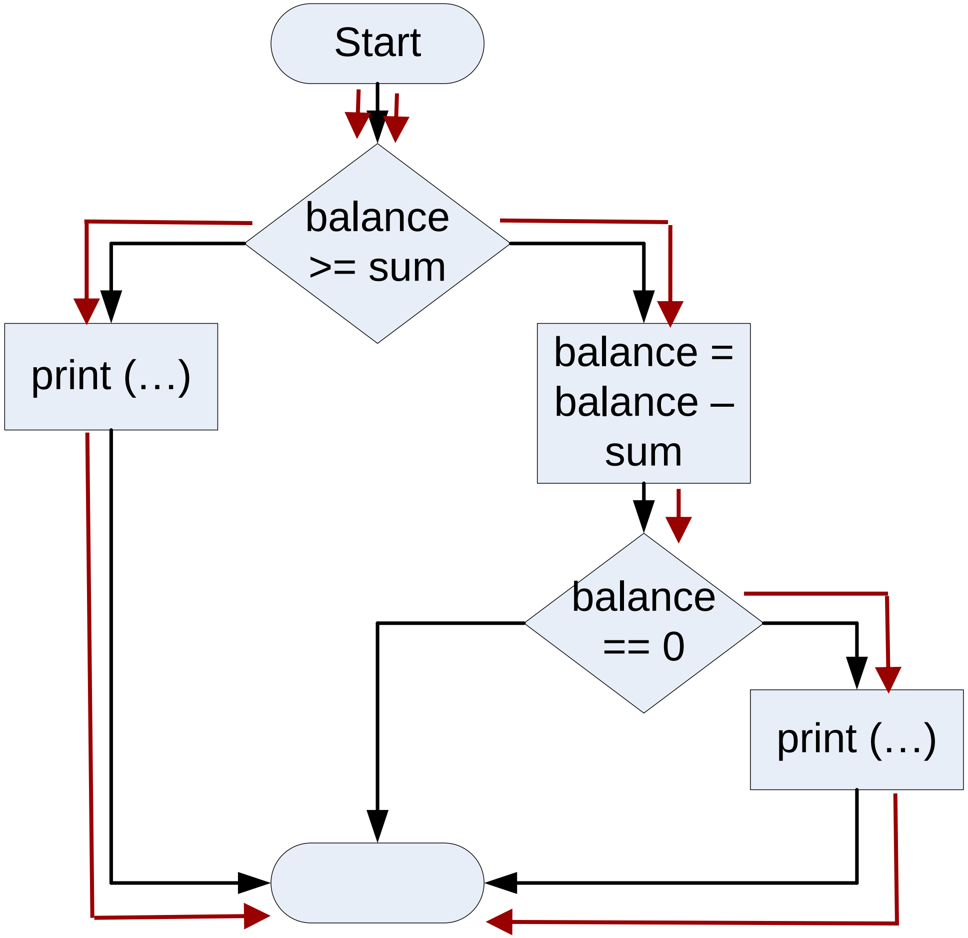


Example: instruction coverage

```
public class Account {

  private int balance;

  public void withdraw(int sum) {
       if (balance >= sum) {
          balance = balance - sum;
          if (balance == 0)
            System.out.println(
               "The account is now empty.");
       } else
          System.out.println(
            "There are less than " + sum +
            "CHF in the account.");
  }
...
}
```



TC1:

```
a = new Account();
a.setBalance(100);
a.withdraw(1000);
```

TC2:

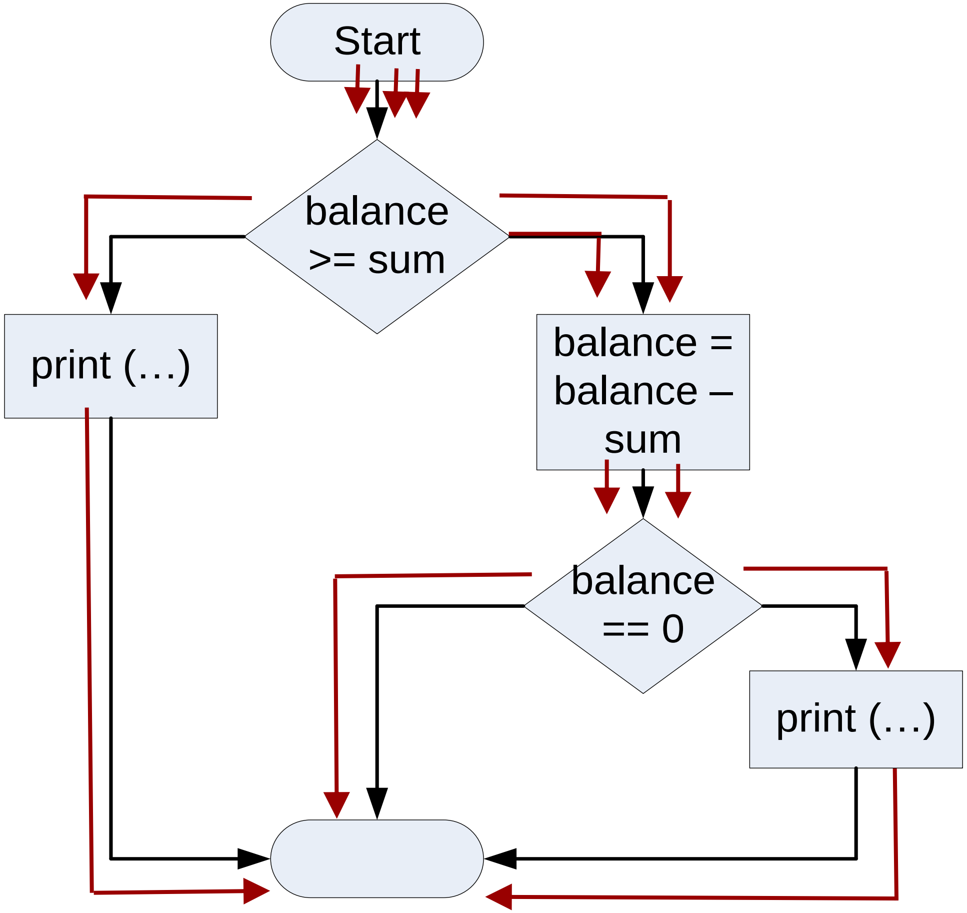
```
a = new Account();
a.setBalance(100);
a.withdraw(100);
```

Example: branch (condition, path) coverage

```
public class Account {

  private int balance;

  public void withdraw(int sum) {
       if (balance >= sum) {
          balance = balance - sum;
          if (balance == 0)
            System.out.println(
               "The account is now empty.");
       } else
          System.out.println(
            "There are less than " + sum +
            "CHF in the account.");
 }
...
}
```



TC1:
a = **new** Account();
a.setBalance(100);
a.withdraw(1000);

TC2:
a = **new** Account();
a.setBalance(100);
a.withdraw(100);

TC3:
a = **new** Account();
a.setBalance(100);
a.withdraw(99);

Specification coverage

Predicate = an expression that evaluates to a boolean value

- e.g.: $a \vee b \vee (f(x) \wedge x > 0)$

Clause = a predicate that does not contain any logical operator

- e.g.: $x > 0$

If specification expressed as predicates on the state, specification coverage translates to predicate coverage.

Predicate coverage (PC)

A predicate is covered iff it evaluates to both true and false in 2 different runs of the system.

Example:

$$a \vee b \vee (f(x) \wedge x > 0)$$

is covered by the following 2 test cases:

- {a=true; b=false; f(x)=false; x=1}
- {a=false; b=false; f(x)=true; x=-1}

Clause coverage (CC)

Satisfied if every clause of a certain predicate evaluates to both true and false.

Example:

$x>0 \vee y<0$

Clause coverage is achieved by:

- $\{x=-1; y=-1\}$
- $\{x=1; y=1\}$

Combinatorial coverage (CoC)

Every combination of evaluations for the clauses in a predicate must be achieved.

Example:

$$((A \vee B) \wedge C)$$

	A	B	C	$((A \vee B) \wedge C)$
1	T	T	T	T
2	T	T	F	F
3	T	F	T	T
4	T	F	F	F
5	F	T	T	T
6	F	T	F	F
7	F	F	T	F
8	F	F	F	F

Mutation testing

Idea: make small changes to the program source code (so that the modified versions still compile) and see if your test cases fail for the modified versions

Purpose: estimate the quality of your test suite

Terminology

Faulty versions of the program = mutants

- We only consider mutants that are not equivalent to the original program!

A mutant is said to be killed if at least one test case detects the fault injected into the mutant

A mutant is said to be alive if no test case detects the injected fault

Mutation operators

Mutation operator = a rule that specifies a syntactic variation of the program text so that the modified program still compiles

Mutant = the result of an application of a mutation operator

The quality of the mutation operators determines the quality of the mutation testing process.

Mutation operator coverage (MOC): For each mutation operator, create a mutant using that mutation operator.

Examples of mutants

Original program:

```
if (a < b)
        b := b - a;
else
        b := 0;
```

Mutants:

```
if (a < b)
if (a <= b)
if (a > b)
if (c < b)
        b := b - a;
        b := b + a;
        b := x - a;
else
        b := 0;
        b := 1;
        a := 0;
```

Mutation operators (classical)

- Replace arithmetic operator by another
- Replace relational operator by another
- Replace logical operator by another
- Replace a variable by another
- Replace a variable (in use position) by a constant
- Replace number by absolute value
- Replace a constant by another
- Replace “while… do…” by “repeat… until…”
- Replace condition of test by negation
- Replace call to a routine by call to another

OO mutation operators

Visibility-related:

- Access modifier change – changes the visibility level of attributes and methods

Inheritance-related:

- Hiding variable/method deletion – deletes a declaration of an overriding or hiding variable/routine
- Hiding variable insertion – inserts a member variable to hide the parent's version

OO mutation operators (continued)

Polymorphism- and dynamic binding-related:

- Constructor call with child class type – changes the dynamic type with which an object is created

Various:

- Argument order change – changes the order of arguments in routine invocations (only if there exists an overloading routine that can accept the changed list of arguments)
- Reference assignment and content assignment replacement
  - example: `list1 := list2 ->`

    ```
    list1 := list2.clone()
    ```

Unit Testing

Unit testing

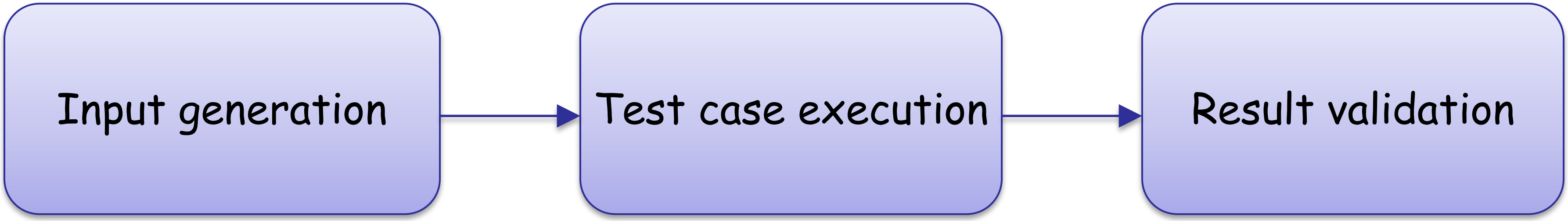
unit testing is a software verification and validation method in which a programmer tests if individual units of source code are fit for use. A unit is the smallest testable part of an application.

The goal of unit testing is to isolate each part of the program and show that the individual parts are correct. A unit test provides a strict, written contract that the piece of code must satisfy.

Unit tests find problems early in the development cycle.

Ideally, each test case is independent from the others.

Components of a test case



xUnit – widely used testing frameworks

xUnit frameworks allow testing of different elements (units) of software, such as functions and classes. The main advantage of xUnit frameworks is that they provide an automated solution with no need to write the same tests many times, and no need to remember what should be the result of each test.

Examples

- JUnit for Java
- NNnit for .NET
- CppUnit for C++

JUnit: Overview

Provides a framework for running test cases

Test cases

- Written manually
- Normal classes, with annotated methods

Input values and expected results defined by the tester

Execution is the only automated step

How to use JUnit

Requires JDK 5

Annotations:

- `@Test` for every routine that represents a test case
- `@Before` for every routine that will be executed before every `@Test` routine
- `@After` for every routine that will be executed after every `@Test` routine

Every `@Test` routine must contain some check that the actual result matches the expected one – use asserts for this

- `assertTrue`, `assertFalse`, `assertEquals`, `assertNull`, `assertNotNull`, `assertSame`, `assertNotSame`

Example: basics

```
package unittests;

import org.junit.Test; // for the Test annotation
import org.junit.Assert; // for using asserts
import junit.framework.JUnit4TestAdapter; // for running

import ch.ethz.inf.se.bank.*;

public class AccountTest {
    @Test public void initialBalance() {
        Account a = new Account("John Doe", 30, 1, 1000);
        Assert.assertEquals(
                "Initial balance must be the one set through the constructor",
                1000,
                a.getBalance());
    }
}
```

To declare a routine as a test case

To compare the actual result to the expected one

Example: set up and tear down

```
package unittests;

import org.junit.Before; // for the Before annotation
import org.junit.After; // for the After annotation
// other imports as before…

public class AccountTestWithSetUpTearDown {

    private Account account;

    @Before public void setUp() {
            account = new Account("John Doe", 30, 1, 1000);
    }
    @After public void tearDown() {
            account = null;
    }
    @Test public void initialBalance() {
            Assert.assertEquals("Initial balance must be the one set through the constructor",
                        1000,
                        account.getBalance());
    }
}
```

Must make account an attribute of the class now

To run this routine before any @Test routine

To run this routine after any @Test routine

@BeforeClass, @AfterClass

A routine annotated with @BeforeClass will be executed once, before any of the tests in that class is executed.

A routine annotated with @AfterClass will be executed once, after all of the tests in that class have been executed.

Can have several @Before and @After methods, but only one @BeforeClass and @AfterClass routine respectively.

Checking for exceptions

Pass a parameter to the @Test annotation stating the type of exception expected:

```
@Test(expected=AmountNotAvailableException.class) public void overdraft ()
    throws AmountNotAvailableException {
        Account a = new Account("John Doe", 30, 1, 1000);
        a.withdraw(1001);
    }
```

The test will fail if a different exception is thrown or if no exception is thrown.

Setting a timeout

Pass a parameter to the @Test annotation setting a timeout period in milliseconds. The test fails if it takes longer than the given timeout.

```
@Test(timeout=1000) public void testTimeout () {
        Account a = new Account("John Doe", 30, 1, 1000);
        a.infiniteLoop();
   }
```

Test-driven development (TDD)

Software development methodology

One of the core practices of extreme programming (XP)

Write test, write code, refactor

More explicitly:

1. Write a small test.
2. Write enough code to make the test succeed.
3. Clean up the code.
4. Repeat.

Always used together with xUnit.

Test-Driven Development (TDD)

Evolutionary approach to development

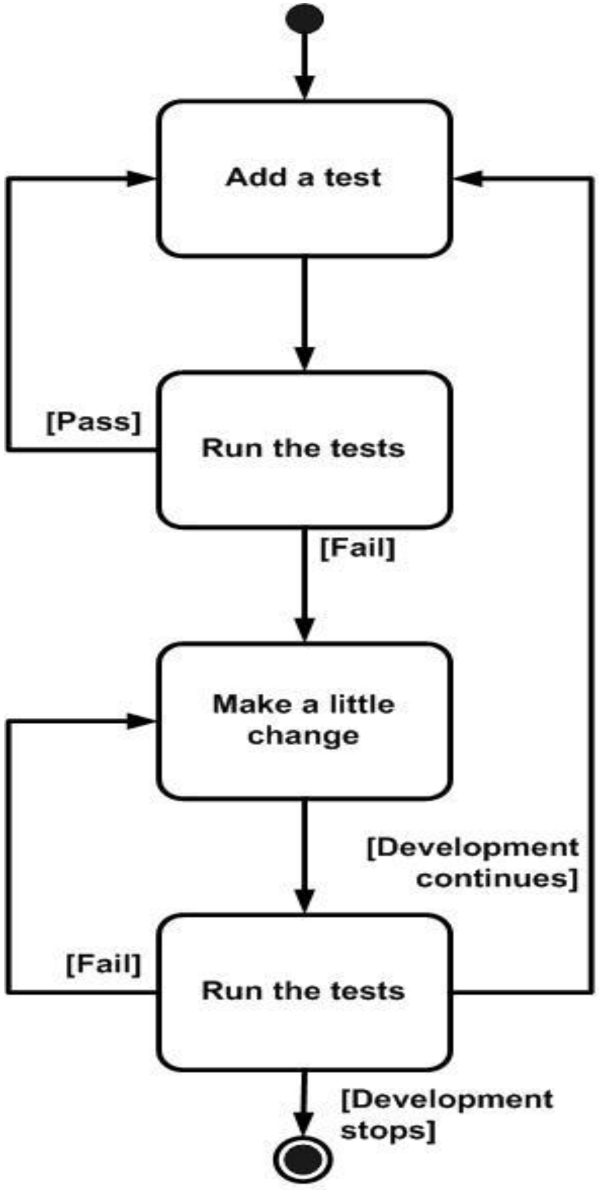
Combines

- Test-first development
- Refactoring

Primarily a method of software design

- Not just method of testing

TDD 1: Test-First Development (TFD)



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TDD 2: Refactoring

A change to the system that leaves its behavior unchanged, but enhances some non-functional quality:

- Simplicity
- Understandability
- Performance

Refactoring does not fix bugs or add new functionality.

Examples of refactoring

Change the name of a variable, class, ...

Convert local variable to attribute

Generalize type

Introduce argument

Turn a block of code into a routine

Replace a conditional with polymorphism

Break down large routine

TDD = TFD + Refactoring

- Apply test-first development.
- Refactor whenever you see fit (before next functional modification).

Why refactoring is so important to TDD?

TDD and extreme programming (XP)

- Easy to give in and not write a test or skip a refactoring.
- Pair-programming partner can help keep you on track.
- Write testable code.

TDD: Kent Beck’s rules

- Write new business code only when a test fails.
- Eliminate any duplication you find.

TDD: consequences for the developer

- You design organically, running code provides feedback between decisions.
- You write your own tests, because you cannot wait.
- Development environment must provide rapid response to small changes.
- Your design must be consist of highly cohesive, loosely coupled components to make testing easier.
- Side effect: easier evolution and maintenance.

TDD: consequences on unit tests

Developers must learn to write good unit tests:

- Run fast (short setup, run, and tear-down)
- Run in isolation (reordering is possible)
- Use data that makes test cases easy to read
- Use real data when needed
- Each test case is one step towards overall goal

TDD & traditional testing

TDD is a programming technique that ensures that source code is thoroughly unit tested.

Need remains for:

- Nonfunctional testing
- User acceptance testing
- System integration testing

XP suggests these tests should also occur early.

TDD & traditional testing

- Failed test case is a success.
- TDD guarantees complete statement coverage (per definition).
- Traditional testing only recommends it.

TDD & documentation

Programmers often do not read documentation.

Instead, they look for examples an play with them.

Good unit tests can serve as

- Examples
- Documentation

TDD & contracts

Bob Martin:

> " *The act of writing a unit test is more an act of design than of verification. It is also more an act of documentation than of verification. The act of writing a unit test closes a remarkable number of feedback loops, the least of which is the one pertaining to verification of function*"

Contracts serve a very similar purpose.

Write header comment and contract before implementation.

Symbiosis:

- Tests make system run, execute assertions.
- Assertions provide additional tests.

TDD: pros and cons

Pros

- Reduce gap between decision and feedback.
- Encourage developers to write code that is easily tested.
- Creates a thorough test bed.

Drawbacks

- Time taken away from core development.
- Some code is difficult to test.

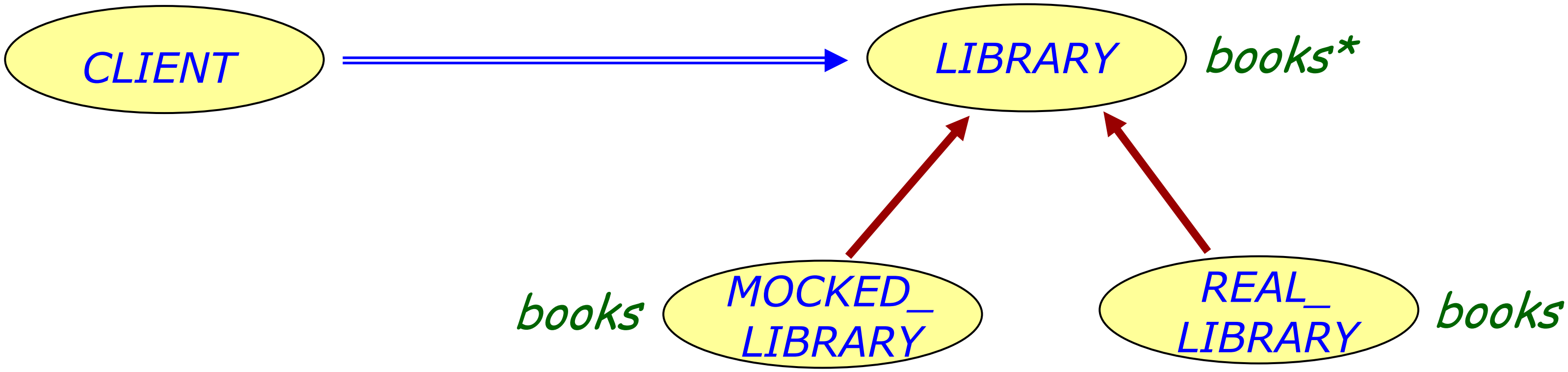
Mock object: reducing test execution time

TDD needs fast test execution for feedback, but some tests reply on calculations that are slow, for example, database conneciton.

Solution: during testing, replace the expensive calculation with its simulated version:

- Simulated version should have the same interface with the original version.
- Simulated version should run fast.

Mock object: an example



```
books: LINKED_LIST [STRING ] -- From MOCKED_LIBRARY
    do
        create Result.make
        Result.extend ("OOSC")
        Result.extend ("Design Patterns")
    end
```

GUI Testing

Why is GUI testing hard?

- GUI
  - Graphics: easy for humans, hard for machines
  - Themable GUIs
  - Simple change to interface, big impact
- Network & Databases
  - Big effort to set up environment
    - Computers
    - Operating Systems
    - Applications
    - Data
    - Network
  - Reproducibility

Why is GUI testing hard?

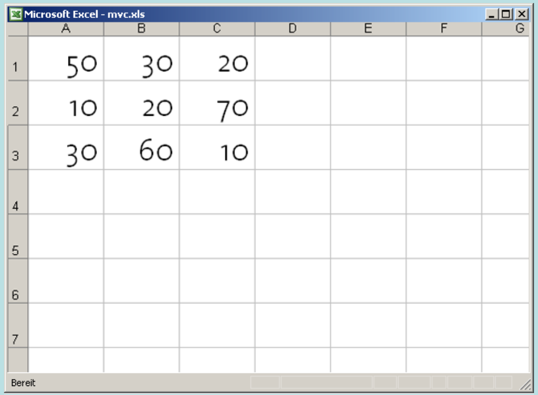
- In the old days things were easy
  - Stdin / Stdout / Stderr
- Modern applications lack uniform interface
  - GUI
  - Network
  - Database
  - …

Minimizing GUI code

- GUI code is hard to test
- Try to keep it minimal
- How?

Model-View-Controller

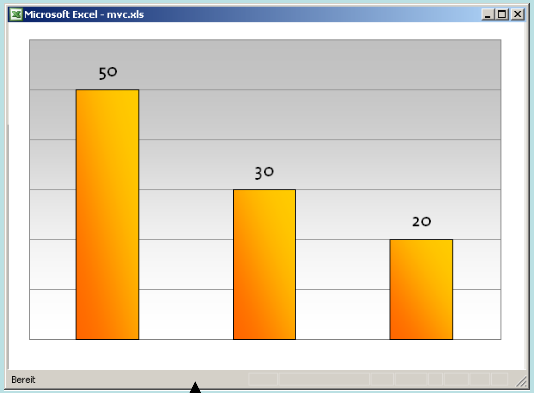
Views

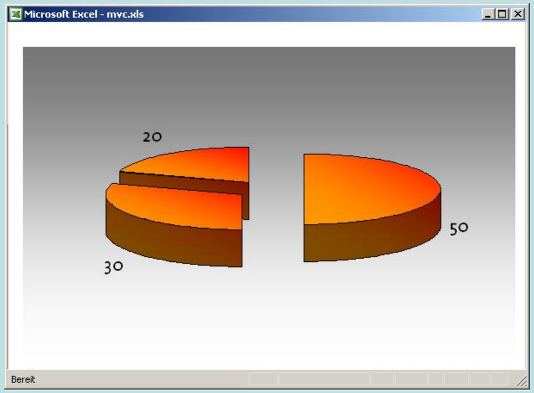


Microsoft Excel - mvc.xls

	A	B	C	D	E	F	G
1	50	30	20				
2	10	20	70				
3	30	60	10				
4							
5							
6							
7							

Bereit

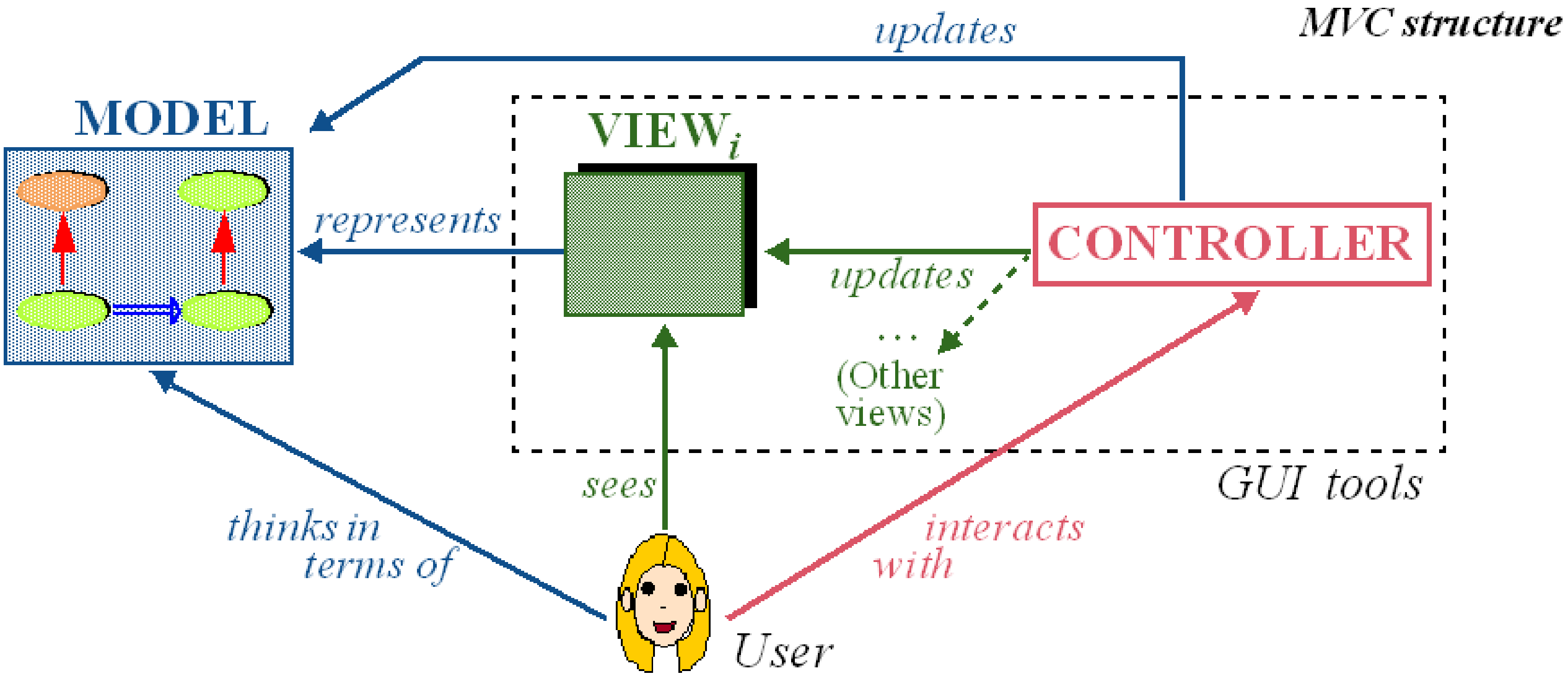




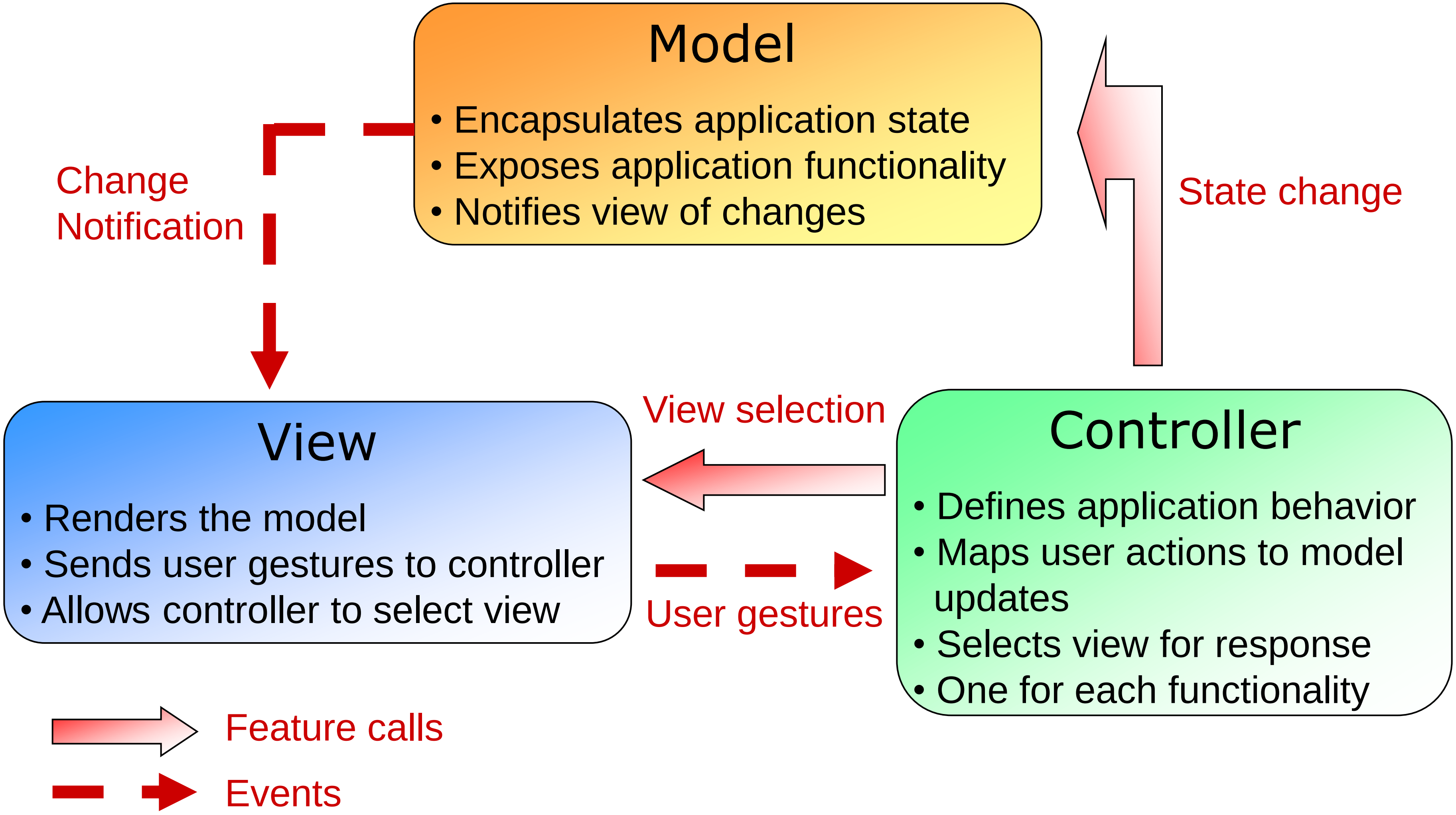
Model

A = 50%
B = 30%
C = 20%

Model-View Controller



Model View Controller (2/2)



Model

- Encapsulates application state
- Exposes application functionality
- Notifies view of changes

Change Notification

State change

View

- Renders the model
- Sends user gestures to controller
- Allows controller to select view

View selection

User gestures

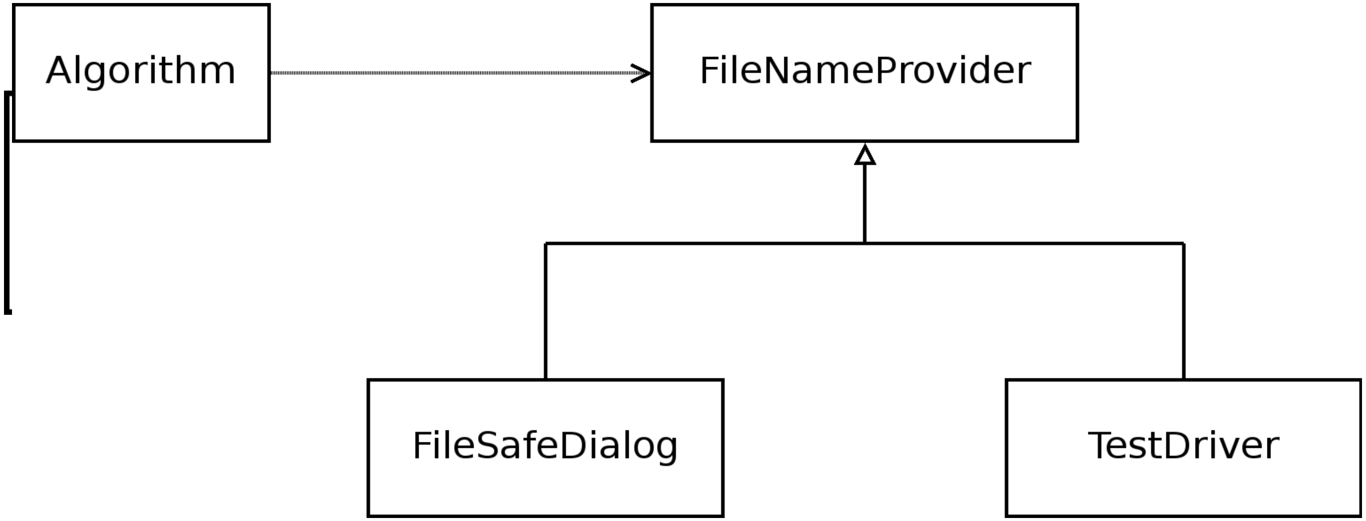
Controller

- Defines application behavior
- Maps user actions to model updates
- Selects view for response
- One for each functionality

Feature calls

Events

Example: Abstracting the GUI away



- Algorithm needs to save file
- Algorithm queries Dialog for name
- Makes Algorithm hard to test
- Solution:
    - Abstract interactivity away
    - Makes more of your software easy to test

Capture and replay

Capture

Run GUI application manually, capture all the input events such as keystrokes, mouse moves and clicks.

Replay

Rerun the application automatically, spawn recorded events, check if the system responses as expected.

Problems

Fragile to changes, hard to define correctness.

WebDriver, a web-based testing tool

WebDriver is a tool for automating testing web applications, and in particular to verify that they work as expected

```
 public static void main(String[] args) {
    WebDriver driver = new HtmlUnitDriver(); // Create a new html unit driver

    driver.get("http://www.google.com");       // And now use this to visit Google

    // Find the text input element by its name
    WebElement element = driver.findElement(By.name("q"));

    element

    // Now                                                                      ement
    element.submit();

    // Check the title of the page
    System.out.println("Page title is: " + driver.getTitle());
 }
}
```

How to check if a page is rendered correctly?

Test management

Testing strategy

Planning & structuring the testing of a large program:

- Defining the process
  - Test plan
  - Input and output documents
- Who is testing?
  - Developers / special testing teams / customer
- What test levels do we need?
  - Unit, integration, system, acceptance, regression
- Order of tests
  - Top-down, bottom-up, combination
- Running the tests
  - Manually
  - Use of tools
  - Automatically

Who tests

Any significant project should have a separate QA team

Why: the almost infinite human propensity to self-delusion

Unit tests: the developers

- My suggestion: pair each developer with another who serves as "personal tester"

Integration test: developer or QA team

System test: QA team

Acceptance test: customer & QA team

Classifying reports: by severity

Classification must be defined in advance

Applied, in test assessment, to every reported failure

Analyzes each failure to determine whether it reflects a fault, and if so, how damaging

Example classification (from a real project):

- Not a fault
- Minor
- Serious
- Blocking

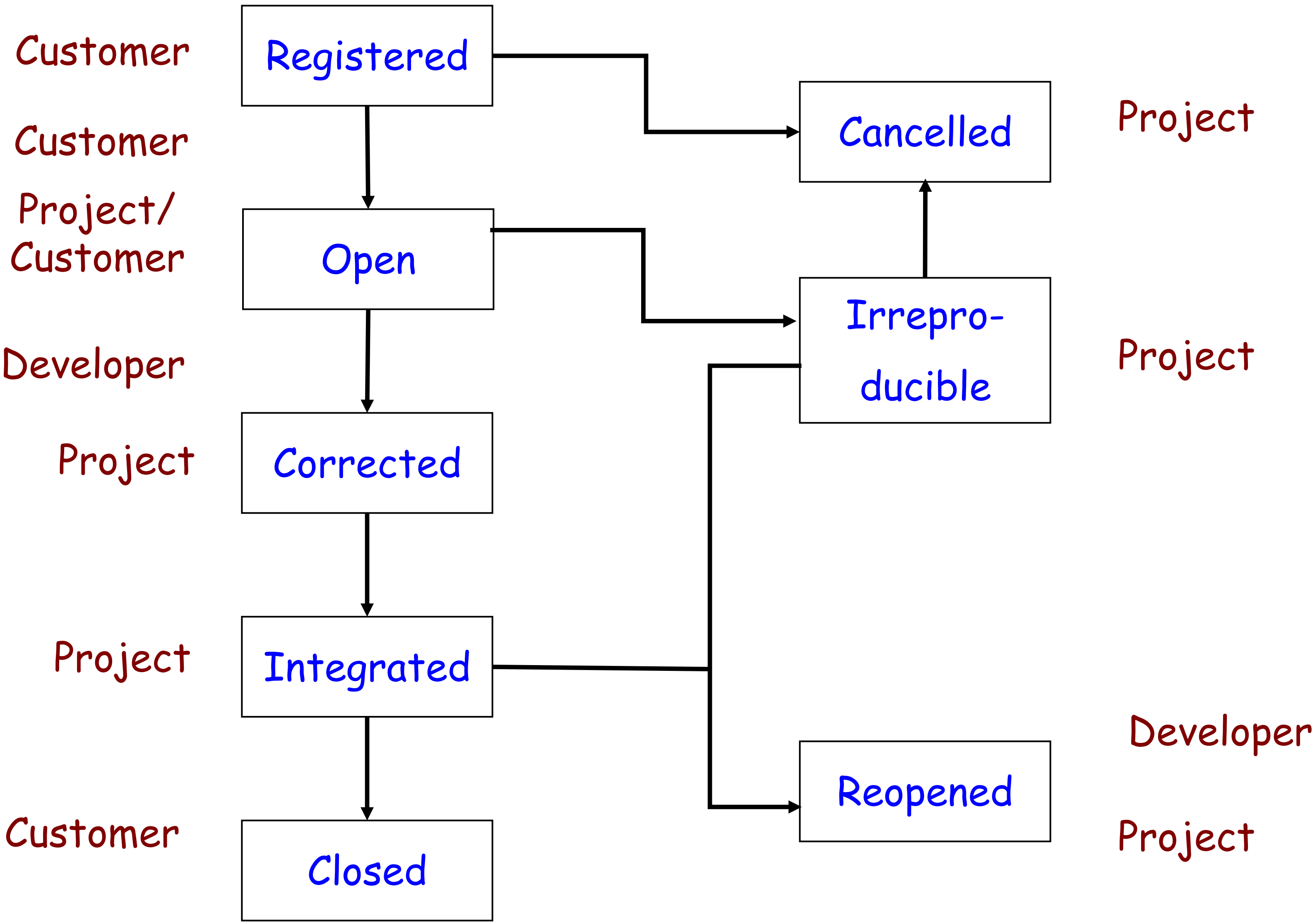
Classifying reports: by status

From a real project:

- Registered
- Open
- Re-opened
- Corrected
- Integrated
- Delivered
- Closed
- Irreproducible
- Cancelled

Regression bug!

Assessment process (from real project)



Some responsibilities to be defined

Who runs each kind of test?

Who is responsible for assigning severity and status?

What is the procedure for disputing such an assignment?

What are the consequences on the project of a failure at each severity level?

(e.g. "the product shall be accepted when two successive rounds of testing, at least one week apart, have evidenced fewer than *m* serious faults and no blocking faults").

Debugging

Debugging: **topics and scope**

What is Debugging?

Problem Management

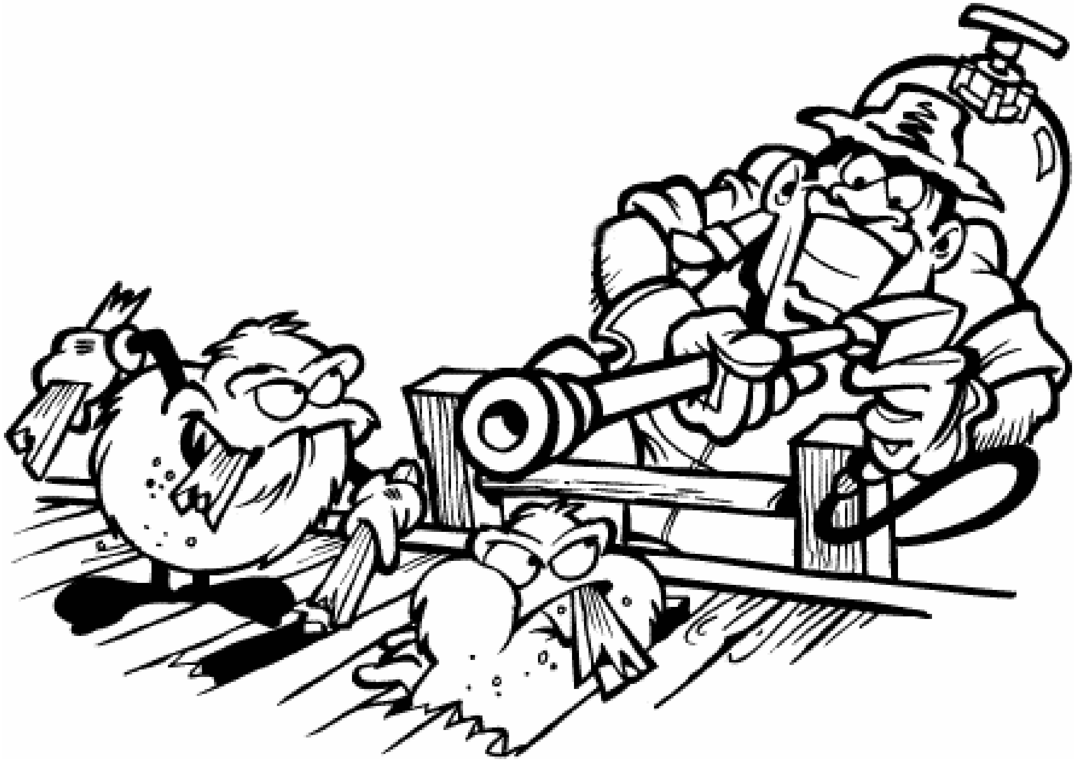
How Failures Come to Be?

Scientific Debugging

Techniques

- Delta Debugging

What is Debugging?



What Is Debugging?

Debugging is the work required to diagnose and correct a bug.

Testing is not debugging.

Debugging is not testing.

Debugging typically occurs after a failure has been observed.

Tracking problems

Large projects have many bugs reported.

Bugs are not always fixed immediately.

Need for Bug tracking system

- Bugzilla
- Origo

Classifying Problems

Severity

- Blocker
- Critical
- Major
- Normal
- Minor
- Trivial
- Enhancement

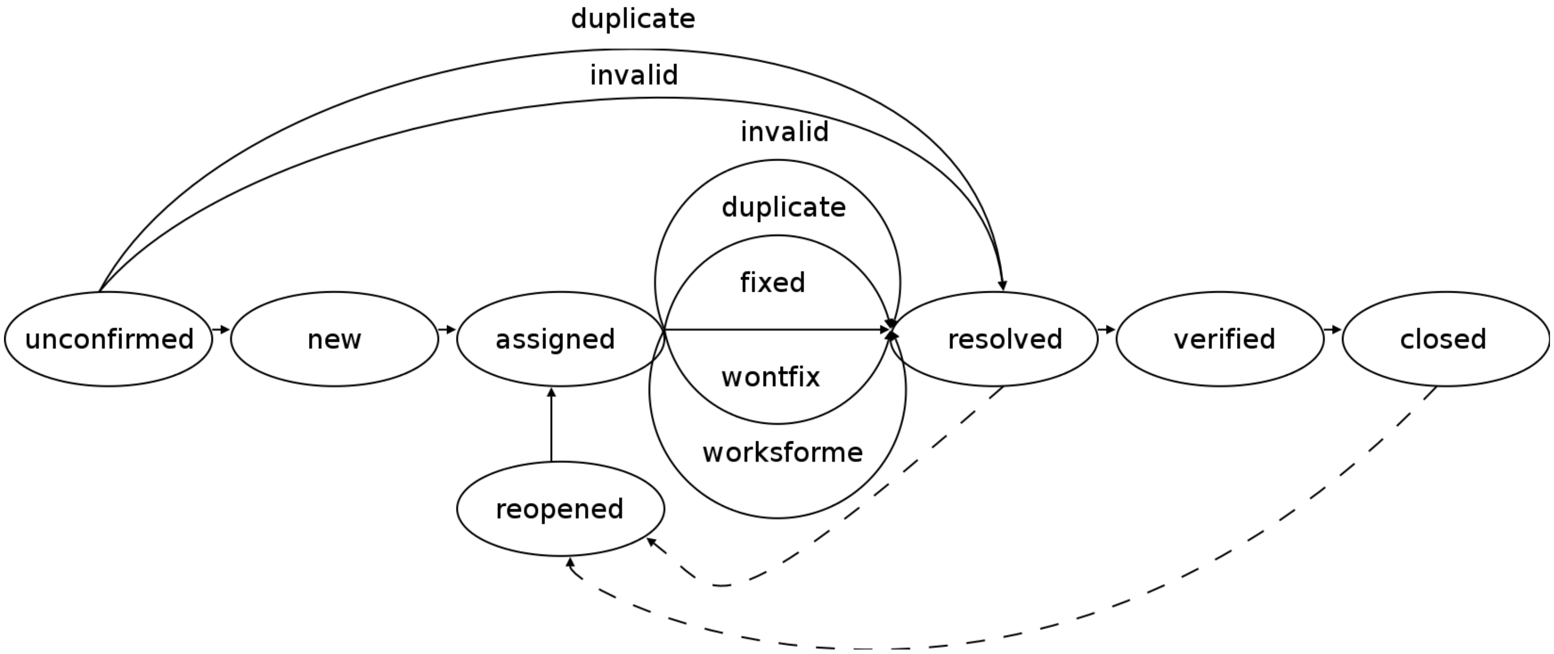
Priority

Identifier

Comments

Notifications

Bug Lifecycle

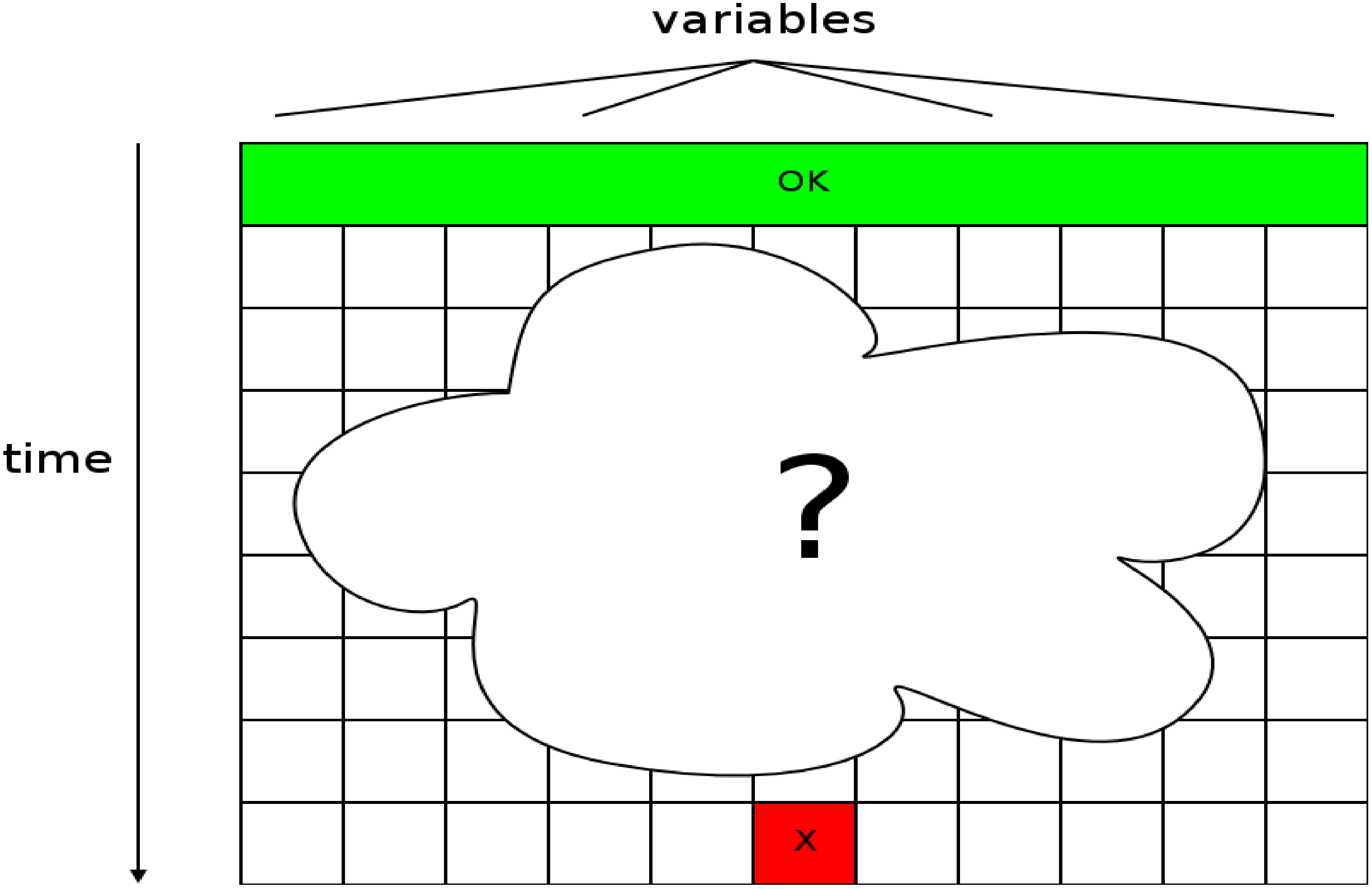


Testing and bug prevention

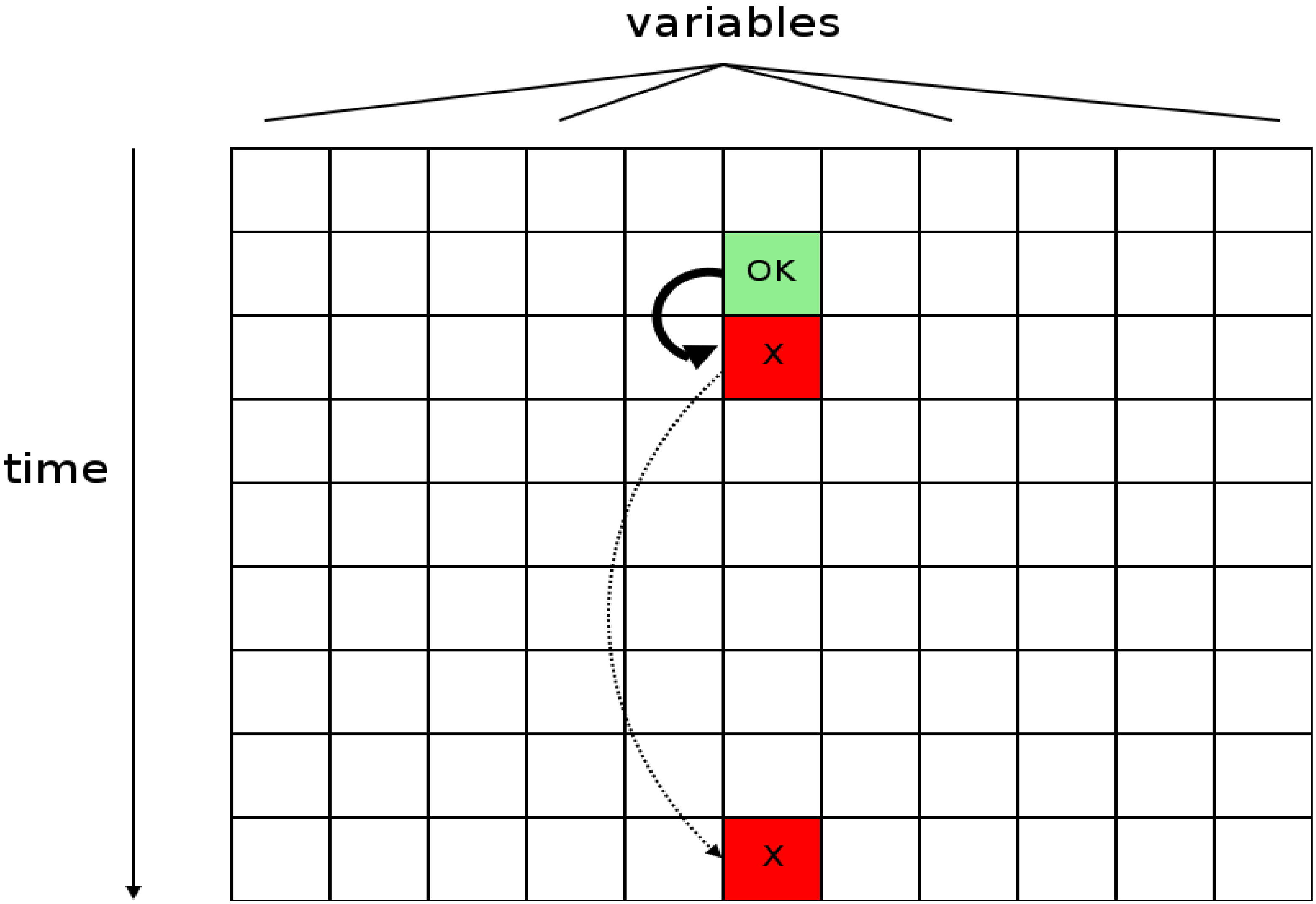
Three questions about each bug you find (Van Vleck):

- "*Is this mistake somewhere else also?*"
- "*What next bug is hidden behind this one?*"
- "*What should I do to prevent bugs like this?*"

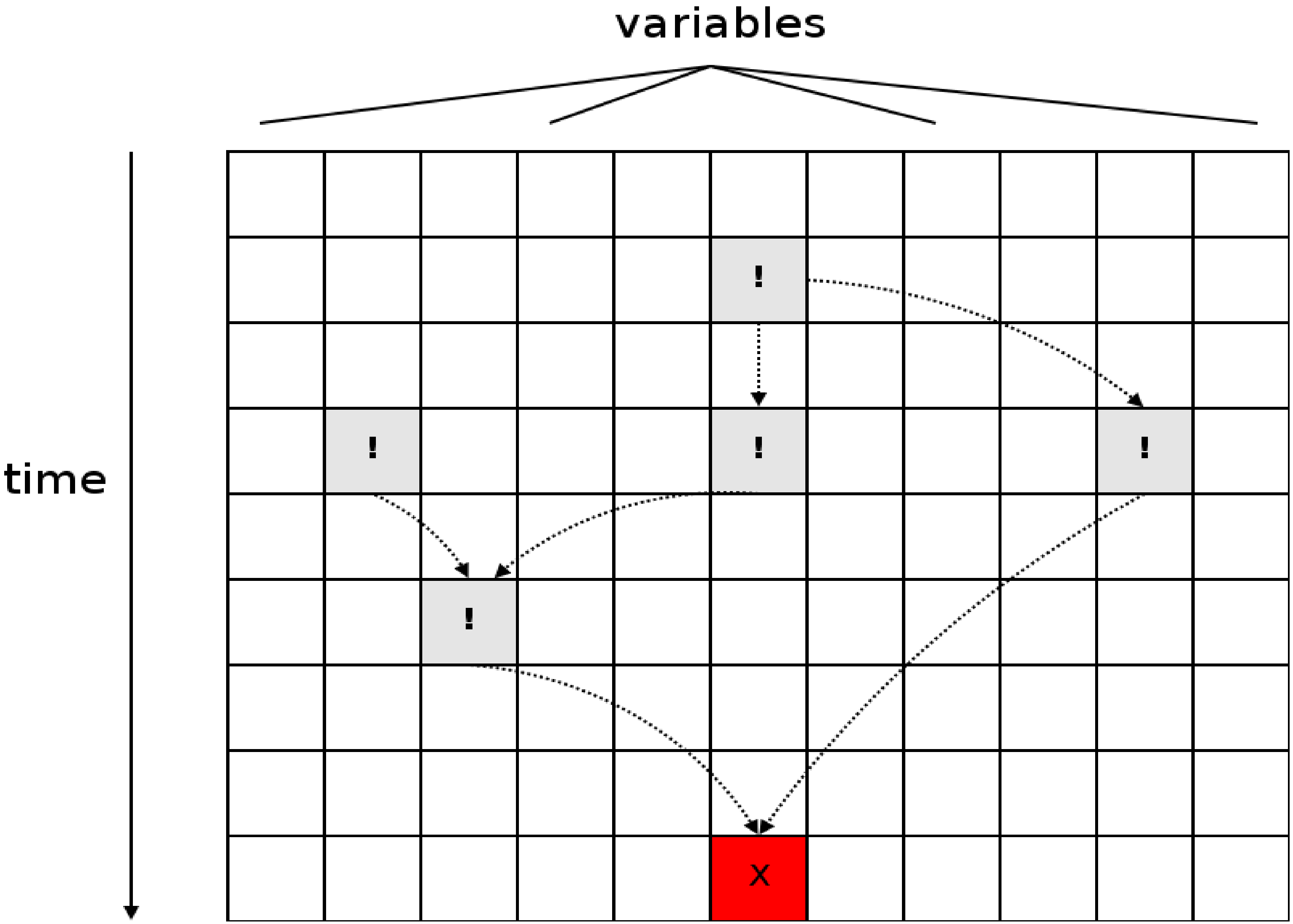
How Failures Come to Be 1/3



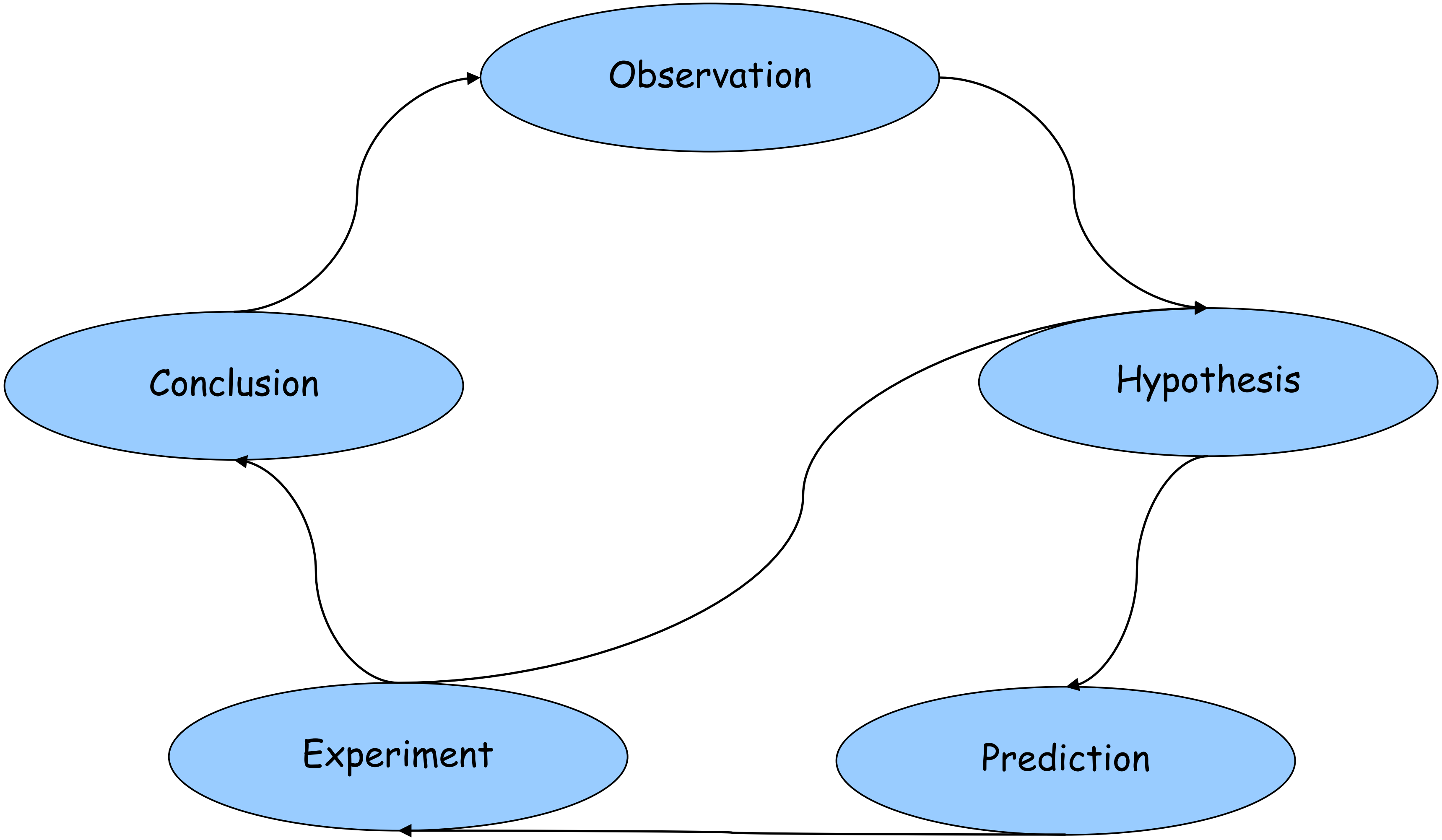
How Failures Come to Be 2/3



How Failures Come to Be 3/3



Scientific method



Debugging basics: breakpoints

A breakpoint is a signal that tells the debugger to temporarily suspend execution of your program at a certain point.

When your program stops in debugger, you can evaluate expressions in each level in the call stack.

A conditional breakpoint is a breakpoint which only stops when the given condition evaluates to True.

“Scientific Debugging” (Zeller)

Observe failure.

Invent hypothesis, consistent with observation.

Use hypothesis to make prediction.

Test prediction by experiment or observation:

- If prediction satisfied, then refine hypothesis.
- Otherwise, create alternative hypothesis.

Debugging Techniques

Delta Debugging

Bug Example: Mozilla

```
<td align=left valign=top>
<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
NT">Windows NT<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<OPTIONVALUE="BeOS">BeOS<OPTION VALUE="HP-UX">HP-
UX<OPTION
VALUE="IRIX">IRIX<OPTION VALUE="Neutrino">Neutrino<OPTION VALUE="OpenVMS">OpenVMS<OPTION
VALUE="OS/2">OS/2<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>
</td>
<td align=left valign=top>
<SELECT NAME="bug severity" MULTIPLE SIZE=7>
<OPTION VALUE="blocker">blocker<OPTION VALUE="critical">critical<OPTION VALUE="major">major<OPTION
VALUE="normal">normal<OPTION VALUE="minor">minor<OPTION VALUE="trivial">trivial<OPTION
VALUE="enhancement">enhancement</SELECT>
```

Bug Example: Mozilla

Looking at the input it is hard to understand the real cause of the bug.

Can we simplify the input?

Delta Debugging: Characteristics

Simplification algorithm for bug reproducing examples.

Reduces size of input or program.

Easy to implement and customize.

Assumptions

- Input can be split into parts
- Working program
- Failing program

Delta Debugging: Example 2/5

Assume the following makes Mozilla crash:

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

Approach:

Remove parts of input and see if it still crashes.

Delta Debugging: Example 3/5

Bold parts remain in the input

1	**<SELECT NAME="priority" MULTIPLE SIZE=7>**	F
2	<SELECT NAME="priori**ty" MULTIPLE SIZE=7>**	P
3	**<SELECT NAME="priori**ty" MULTIPLE SIZE=7>	P
4	<SELECT NA**ME="priority" MULTIPLE SIZE=7>**	P
5	**<SELECT NA**ME="priori**ty" MULTIPLE SIZE=7>**	F
6	**<SELECT NA**ME="priority" MULTIP**LE SIZE=7>**	F
7	**<SELECT NA**ME="priority" MULTIPLE SIZE=7>	P
8	<SELE**CT NA**ME="priority" MULTIP**LE SIZE=7>**	P
9	**<SELE**CT NAME="priority" MULTIP**LE SIZE=7>**	P
10	**<SELECT NA**ME="priority" MULTIPLE SI**ZE=7>**	F
11	**<SELECT NA**ME="priority" MULTIPLE SIZE=7>	P
12	<S**ELECT NA**ME="priority" MULTIPLE SI**ZE=7>**	P
13	**<S**EL**ECT NA**ME="priority" MULTIPLE SI**ZE=7>**	P

Fail

Pass

Delta Debugging: Example 4/5

14	**<SEL**EC**T** **NA**ME="priority" MULTIPLE SI**ZE=7>**	P
15	**<SELEC**T **NA**ME="priority" MULTIPLE SI**ZE=7>**	P
16	**<SELECT** NAME="priority" MULTIPLE SI**ZE=7>**	F
17	**<SELECT** NAME="priority" MULTIPLE SIZE**=7>**	F
18	**<SELECT** NAME="priority" MULTIPLE SIZE=7**>**	F
19	<**SELECT** NAME="priority" MULTIPLE SIZE=7**>**	P
20	**<**S**ELECT** NAME="priority" MULTIPLE SIZE=7**>**	P
21	**<S**E**LECT** NAME="priority" MULTIPLE SIZE=7**>**	P
22	**<SE**L**ECT** NAME="priority" MULTIPLE SIZE=7**>**	P
23	**<SEL**E**CT** NAME="priority" MULTIPLE SIZE=7**>**	P
24	**<SELE**C**T** NAME="priority" MULTIPLE SIZE=7**>**	P
25	**<SELEC**T NAME="priority" MULTIPLE SIZE=7**>**	P
26	**<SELECT** NAME="priority" MULTIPLE SIZE=7**>**	F

Delta Debugging: Example 5/5

After 26 tries we found:

```
<SELECT>
```

causes Mozilla to crash.

Delta Debugging: Limitations

Delta Debugging does not guarantee smallest possible example.

- It only guarantees an example where every line is relevant.

We need to be able to replay inputs.

We need to be able to split inputs.

Empty input must not trigger failure.

Debugging: conclusion

Debugging

Failures

Problem Management

Scientific Debugging

Techniques

- Delta Debugging