# Software Validation and Testing

## Part 1

# Confusion

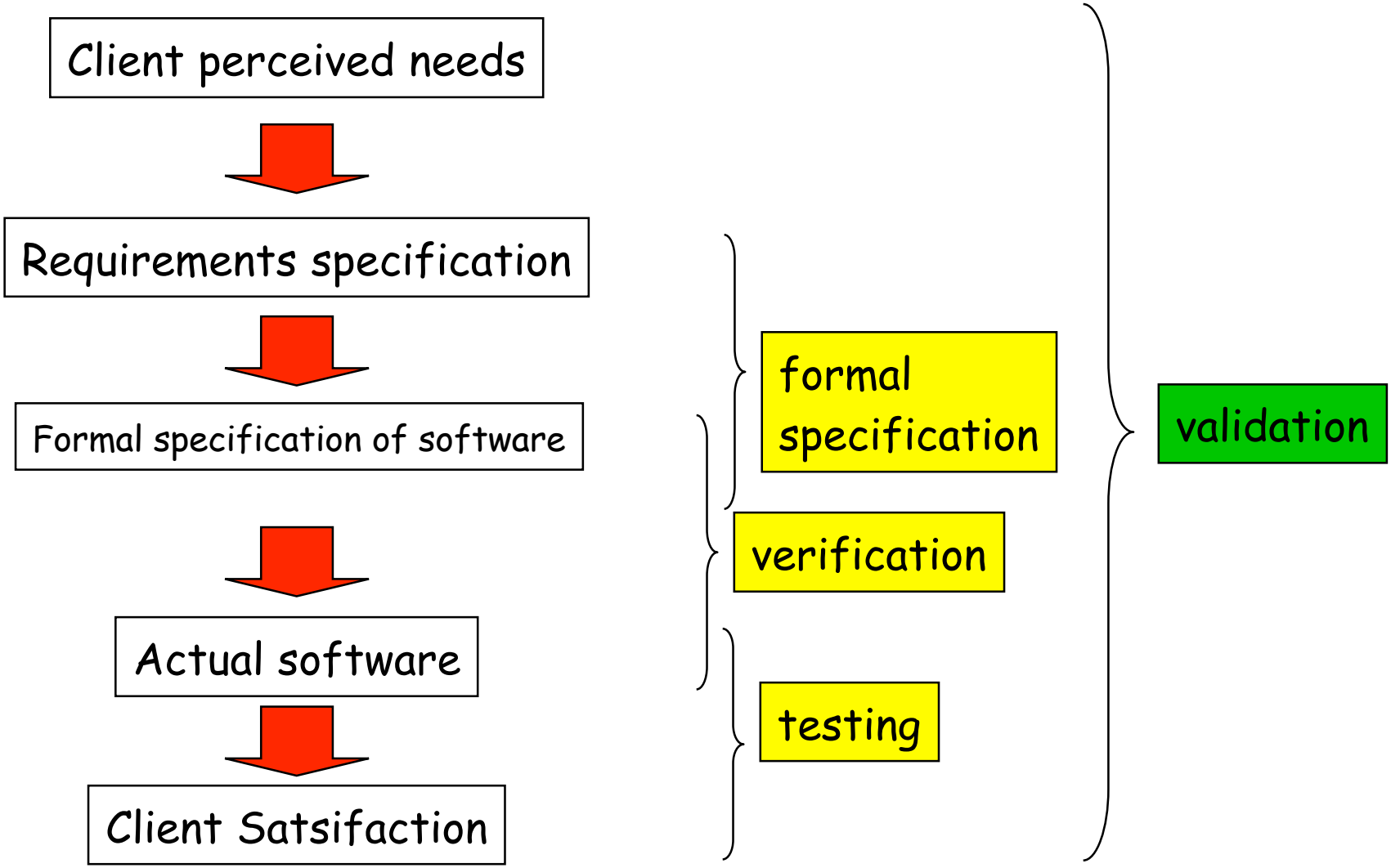
- The terminology is not standardized.
- Some people use "verification" to mean one of:
  - validation
  - testing

# Verification vs. Validation: Our Definitions

- **Verification**: using formal techniques and tools to assess correctness of the product with respect to specifications.

- **Validation**: establishing that the software developed correctly capture the user's needs and intent.

# Validation vs. Verification vs. Testing



# Sometimes heard...

- **Verification**: *Are we building the product right?*
- **Validation**: *Are we building the right product?*
- *Apparently due to Barry Boehm (the spiral model guy).*

# Validation may involve Testing

- **Testing:** discovering errors in the product, for purposes of eradicating them. Also, enhancing confidence in the product when no errors found.
- **Verification**: using specifications, logical techniques and tools to assess correctness of the product.
- The two can be mutually supportive, in ways to be discussed.

Testing is Necessary,
but not really sufficient

# Recall Famous Dijkstra Quote:

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

- **Rare** exception: When the set of all inputs is **finite** and of a reasonable size, **exhaustive testing** can be used.

- Exhaustive testing is only feasible for small systems, typically hardware units, that are finite-state machines.

# Exhaustive Testing

- Suppose we wanted to test a 32-bit multiply routine exhaustively. How long would it take?

- $2^{32} \times 2^{32} = 2^{64}$ input combinations at, say, 1 combination per nanosecond

- about 585 years

# Verification alone is not sufficient either

- Creating a formal specification is hard, sometimes even harder than developing the software.
- A formal specification seldom captures ***all*** needs and intent.
- It is difficult to ascertain that all needs are covered until the system is built.
- Therefore, validation may not be complete without testing in addition to verification.

# Problems Attributable to Lack of Testing

- Costly (dollars and lives) catastrophic failures:
  - Therac 25
  - Ariane 5
  - Mars Polar Orbiter
  - and many more ($59.5 Billion in 2003 -- NIST)
- Worms, viruses, and other infestations (adware, spyware, who-knows-what-ware)

# Standard Testing Terminology

- **Unit testing** tests self-contained units: classes, methods, functions, procedures.
- **Integration testing** tests combinations of units, such as packages, that have already been unit-tested, by having them mutually form an environment similar to actual use.
- **System testing** is top-level integration testing.
- **Acceptance testing** tests the final product according to pre-agreed criteria of the customer.

# Regression Testing

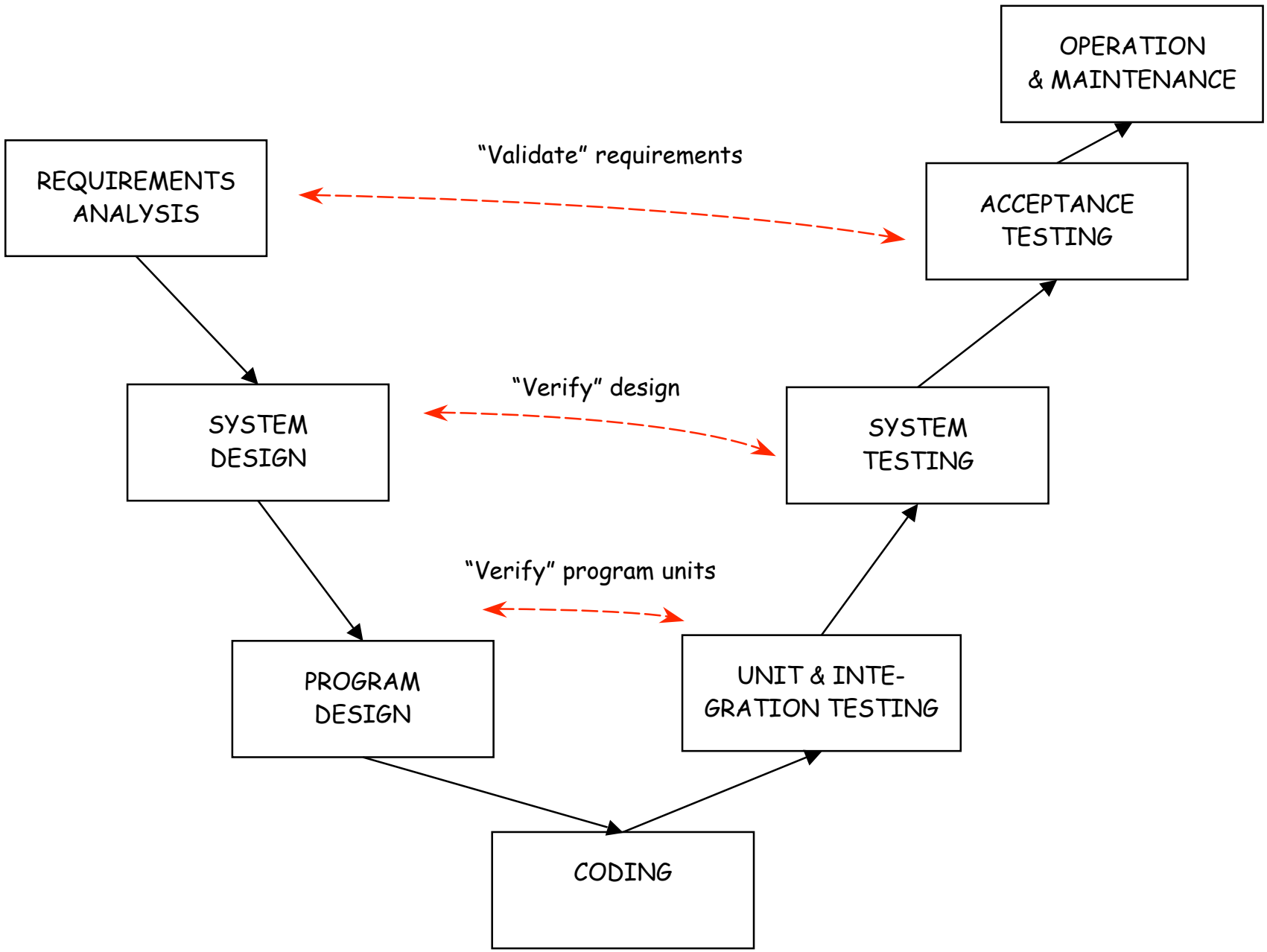
- **Regression testing**: when changes are made, re-test previous test cases to ascertain that no new errors were introduced in the changes.

- "**Smoke test**": A coarse form of regression test to determine that the product doesn't simply crash as a result of recent changes.
  [Apply to see if there is any "smoke" (sign of new errors).]

# Mutation Testing

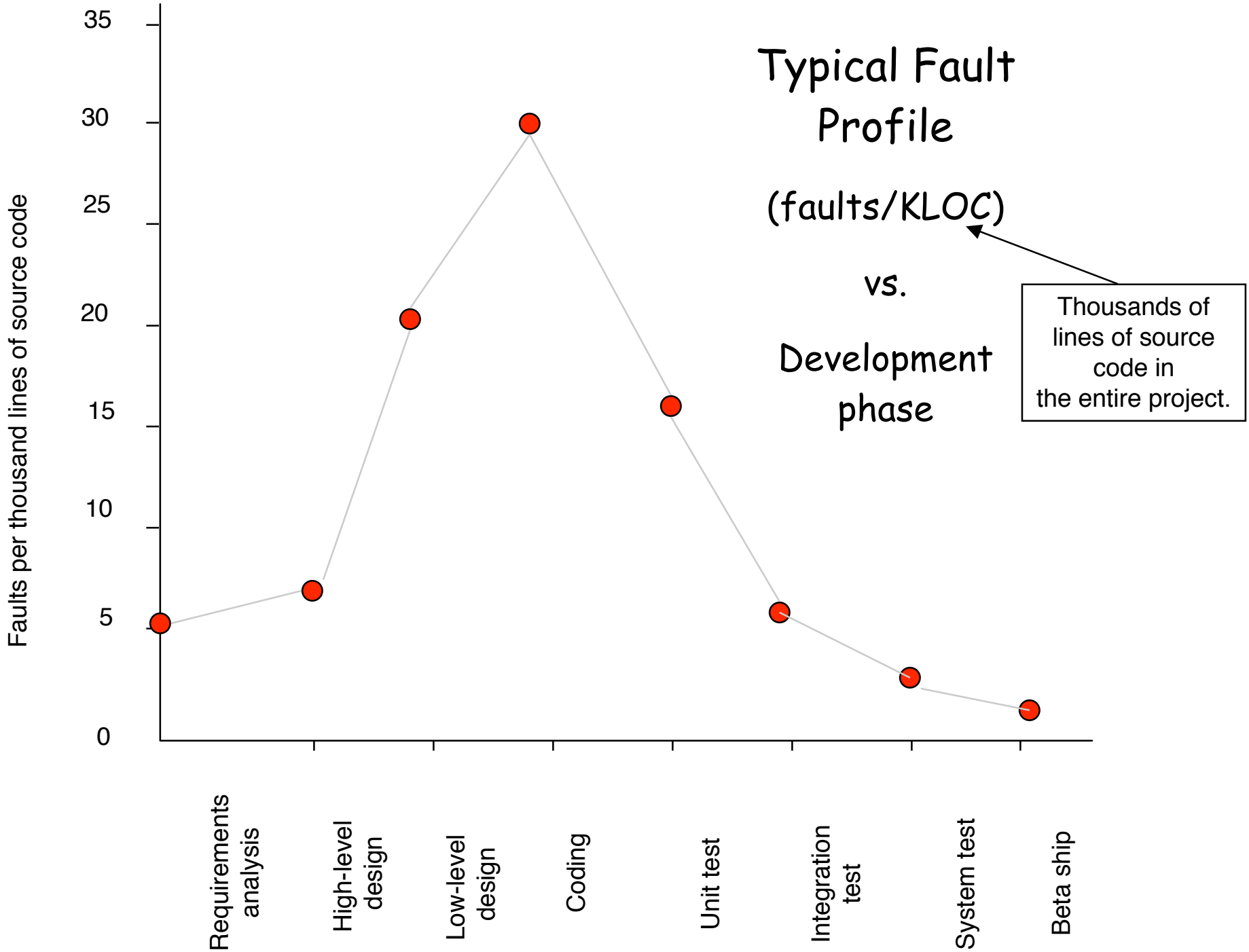
- A scheme for **testing tests**, by gauging their ***effectiveness*** of a **given test**.
- Assume that we have a test T which the code passes.
- The code is subjected to "mutation".
  If the mutated code also *passes* test T, then T is less-likely to be regarded as a good test.

# "V": *model*: A possible incorporation of testing in the software life-cycle

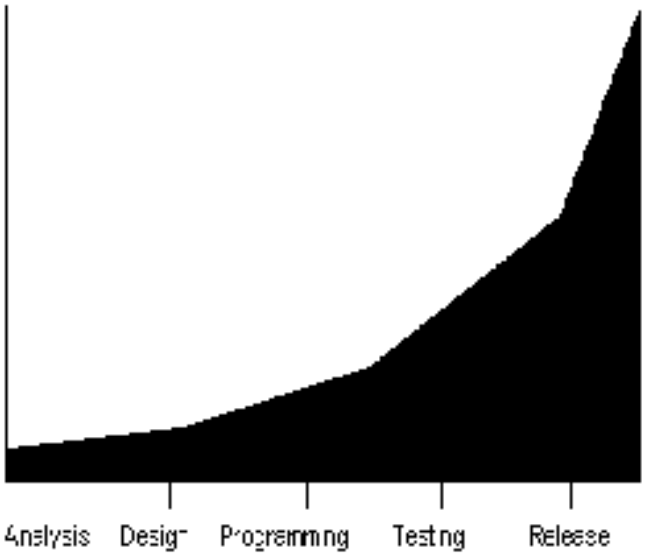


# "Fault" vs. "Failure" Terminology

- A **fault** is an error in the code.
- A **failure** is the manifestation of a fault at runtime.
- The mapping from failures to faults is many-to-one.
- (A **flaw** is an error in the design.)

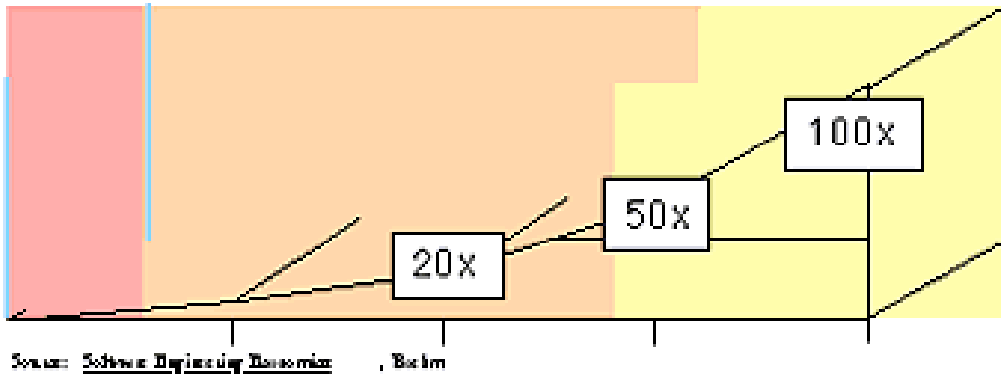

Typical Fault Profile
(faults/KLOC)
vs.
Development phase
Thousands of lines of source code in the entire project.
Faults per thousand lines of source code
35
30
25
20
15
10
5
0
Requirements analysis
High-level design
Low-level design
Coding
Unit test
Integration test
System test
Beta ship

# Relative **Cost** of Fixing Errors vs. Phase (typical)




(Ambler)

No scale given




(Boehm)

# An Example

- The "Y2K Problem" probably would have cost 1/1000 (ignoring inflation) as much to fix at design/coding time as it actually took to fix in the field.

- (Then there is the cost of "fixing the fixes".)

# Testing Approaches

- Test your own code
- Test code of other people in your group
- One person dedicated to testing
- Outside testing group
- Independent testing company
- Cleanroom approach

# "Cleanroom" Approach

- Programmers do *not* test, or otherwise execute, their code.
- Instead, programmers establish correctness by formal reasoning methods and construction techniques.
- The actual testing takes place in the integration phase, which is done by a different team from the programmers.

# Approach testing as an *intellectual challenge* in its own right

- Think as if testing **someone else**'s program, not your own.
- The objective is to find as many ***distinct*** problems as possible.
- Remember that you are testing the ***program*** and not the ***person***.

# Things Testing Can't/Shouldn't Do

- Don't expect testing in itself to improve a poor design.
- As a developer, don't *rely* on testing by others as the prime method for identifying your own mistakes.

# Testing Example (1)

- A reputable programmer has produced a binary search **method** for searching an array:

  int search(float* a, int M, int N, float sought);

  The method is supposed to determine the least index in the range of indices M to N-1 where the value sought would be inserted, assuming that the array is to be maintained in increasing order.
  It is to be assumed that search will be called with
  M <= N. If the element is greater than any in the array, the returned value should be N.

- Suggest how you would test this method, examining any trade-offs.

# Testing Example (2)

- Another reputable programmer has produced class definition for a **circular buffer**: an implementation of a queue that uses a wrap-around array rather than a linked-list. (The purpose of wrap-around is so that elements of the array can be reused without shifting the array, which could take time proportional to the number of elements in the array.)
- The constructor of the circular buffer specifies an upper bound on the number of items to be stored.
- The primitives are boolean enqueue(Item), Item dequeue(), and boolean isEmpty().
- The return value of enqueue() is false if the buffer is already full.

- Suggest how you would test this class, examining any trade-offs.

# Testing Terminology

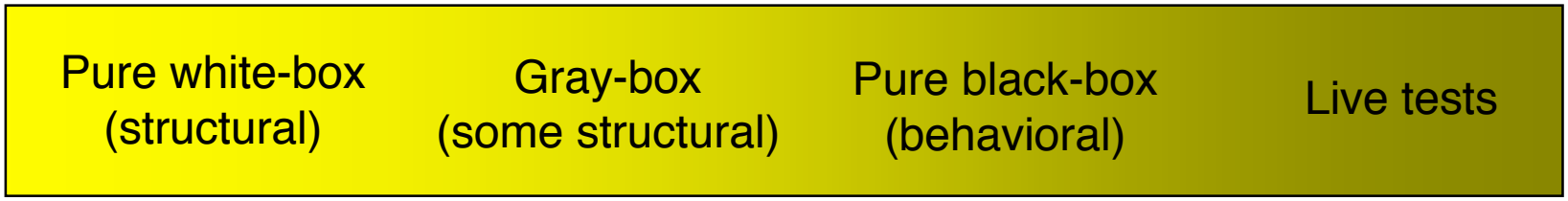
- **Black-box** (or opaque box) testing tests software against the operating environment, without using knowledge of internal structure.
  Also called: **Functional Testing**

- **White-box** (or clear-box) testing uses *knowledge of internal structure* to test specific pieces.
  Also called: **Structural Testing**

# Testing Terminology

- **Gray-box**: Functional Testing assisted by structural knowledge to reduce unnecessary blind testing.

# Testing Continuum




Development activity

Testing activity

Technical support,
beta testing

# Black- vs. White Box

- **Black-box** focuses on the **specification**: What is in the **spec** that the program doesn't do?
- **White-box** focuses on the **program**: What does the **program** do that is not in the spec?
- If possible, don't rely on one or the other exclusively.

# Basic Testing Tools

- **Plan & Checklists**: tests to perform
  - With each test, pre-condition, post-condition
- **Test matrix/spreadsheet**: listing tests against use cases and potential error areas
- **Logging capability**
  - Note pad
  - Keystroke recorder (for playback)
  - Event logger
  - Screen recorder
  - Video camera
- **Tracking Database**

# Testing Matrix

| Tested by | | | | | |
|---|---|---|---|---|---|
| | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 |
| Use Case 1 | x | | | | |
| Use Case 2 | | x | x | | |
| Use Case 3 | | x | | x | x |

# Test Result Categorization

- Area of defect
- Severity level of defect
- Follow up:
  - Responsibility
  - Time to fix
  - Lines of code affected

# 10 Sample Severity Levels, with examples (Boris Beizer)

- **Mild**: misspellings in output
- **Moderate**: misleading or redundant behavior
- **Annoying**: truncated names, etc.
- **Disturbing**: some transactions not processed
- **Serious**: lost transaction
- **Very serious**: incorrect output
- **Extreme**: frequent "very serious" errors
- **Intolerable**: data corrupted
- **Catastrophic**: shutdown
- **Infectious**: shutdown spreading to others

# 4 Possible Reaction Levels to failed tests

- **Defer**: fix as time permits
- **Schedule**: fix by some future date
- **Required**: fix before acceptance
- **Immediate**: fix before testing is continued

# Testing Forms and Tracking

- Discrepancy report form
- Error investigation form
- Error reporting/tracking system/database

# Discrepancy Report Form

## (Sherry Pfleeger)

DISCREPANCY REPORT FORM

DRF Number:_____ Tester name:_____
Date: _____ Time: _____
Test Number: _____
Script step executed when failure occurred: _____
Descripton of failure: _____
_____
_____
_____
Activities before occurrence of failure:
_____
_____
Expected results:
_____
_____
Requirements affected:
_____
_____
Effect of failure on test:
_____
_____
Effect of failure on system:
_____
_____
Severity level:
(LOW) 1 2 3 4 5 (HIGH)

# FAULT REPORT S.P0204.6.10.3016

**ORIGINATOR:** Joe Bloggs

**BRIEF TITLE:** Exception 1 in dps_c.c line 620 raised by NAS

**FULL DESCRIPTION** Started NAS endurance and allowed it to run for a few minutes. Disabled the active NAS link (emulator switched to standby link), then re-enabled the disabled link and CDIS exceptioned as above.
(I think the re-enabling is a red herring.)

**ASSIGNED FOR EVALUATION TO:** **DATE:**

**CATEGORISATION:** **0 (1) 2 3 Design Spec Docn**
**SEND COPIES FOR INFORMATION TO:**
**EVALUATOR:**  **DATE:** 8/7/92

| CONFIGURATION ID | ASSIGNED TO | PART |
|---|---|---|
| dpo_s.c | | |
| | | |
| | | |

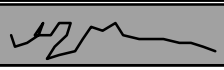
**COMMENTS:** dpo_s.c appears to try to use an invalid CID, instead of rejecting the message. AWJ

**ITEMS CHANGED**

| CONFIGURATION ID | IMPLEMENTOR/DATE | REVIEWER/DATE | BUILD/ISSUE NUM | INTEGRATOR/DATE |
|---|---|---|---|---|
| dpo_s.c v.10 | AWJ 8/7/92 | MAR 8/7/92 | 6.120 | RA 8-7-92 |
| | | | | |
| | | | | |

**COMMENTS:**

**CLOSED**

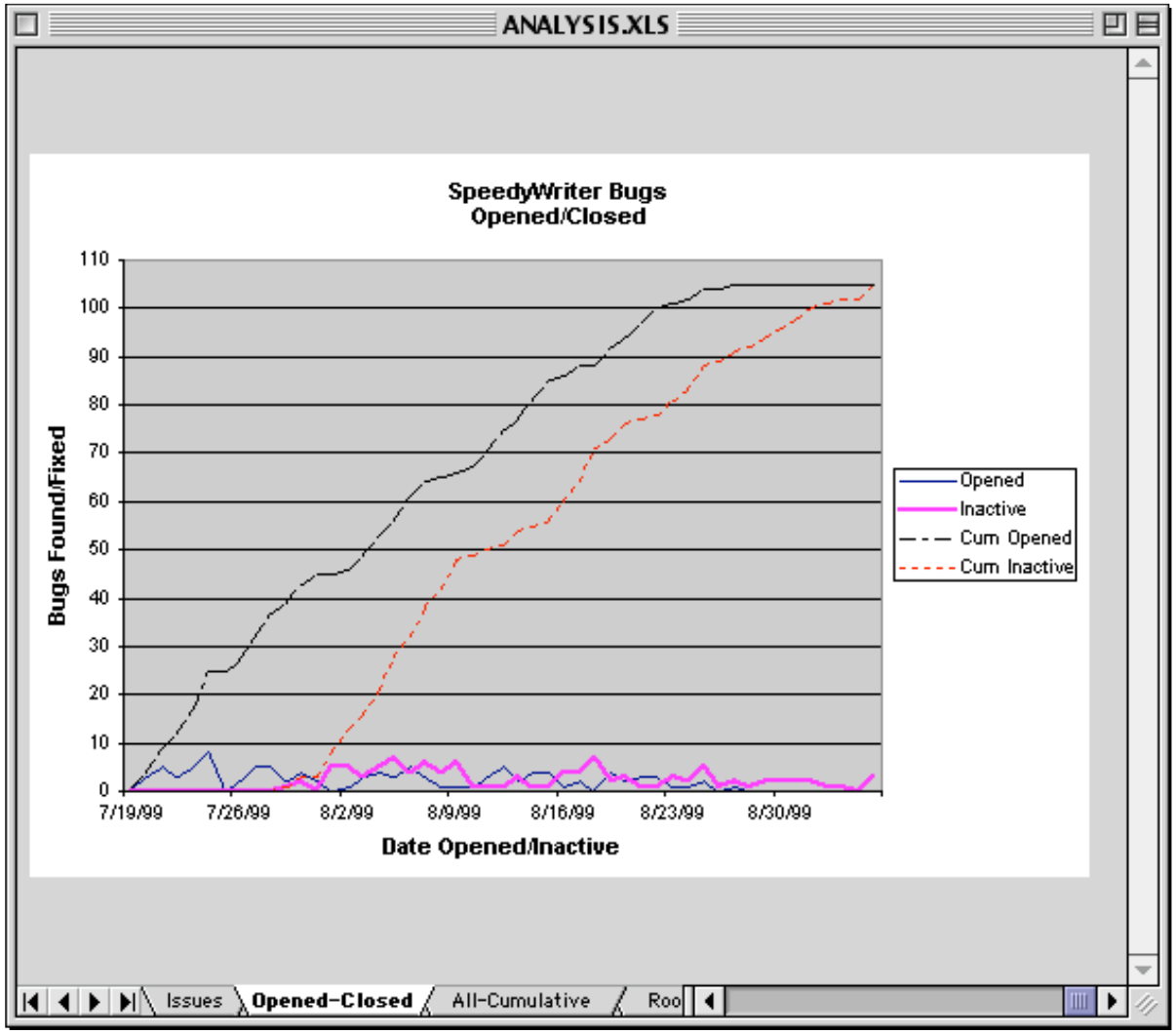
**FAULT CONTROLLER:**  **DATE: 9/7/92**

# Testing Issue Spreadsheet

ANALYSIS.XLS

| | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Date Open | Sev | Pric | Risk | Owner | Estimated | Su | Ste | Isc | St | Subsystem | Configuration | Close Date | Resolution | Root Cause | |
| 2 | 7/21/99 | 1 | 1 | 1 | Muhammad Zam | 8/12/99 | du | du | du | du | Edit Engine | A.X.0.0.001 | 8/3/99 | | Functional | |
| 3 | 7/21/99 | 2 | 2 | 4 | Chuck Chavall | 7/28/99 | du | du | du | du | User Interface | A.X.0.0.001 | 7/30/99 | | System | |
| 4 | 7/24/99 | 3 | 3 | 9 | Jenny Chung | 8/12/99 | du | du | du | du | Edit Engine | A.Y.0.0.001 | 8/1/99 | | Process | |
| 5 | 7/23/99 | 3 | 3 | 9 | Muhammad Zam | 7/24/99 | du | du | du | du | Edit Engine | A.Z.0.0.001 | 8/2/99 | | Data | |
| 6 | 7/24/99 | 1 | 4 | 4 | Chuck Chavall | 7/31/99 | du | du | du | du | User Interface | B.Y.0.0.001 | 8/1/99 | | Functional | |
| 7 | 7/24/99 | 2 | 5 | 10 | Jenny Chung | 8/17/99 | du | du | du | du | Tools | C.X.0.0.001 | 8/7/99 | | System | |
| 8 | 7/23/99 | 3 | 3 | 9 | Larry Kanemetsu | 8/4/99 | du | du | du | du | Edit Engine | C.Y.0.0.001 | 8/4/99 | | Process | |
| 9 | 7/20/99 | 4 | 1 | 4 | Frank Currant | 8/14/99 | du | du | du | du | User Interface | C.Z.0.0.001 | 8/5/99 | | Data | |
| 10 | 7/22/99 | 5 | 1 | 5 | Chuck Chavall | 8/18/99 | du | du | du | du | Edit Engine | D.Z.0.0.001 | 8/5/99 | | Functional | |
| 11 | 7/22/99 | 1 | 1 | 1 | Jenny Chung | 7/28/99 | du | du | du | du | User Interface | A.X.0.0.001 | 8/4/99 | | Documentation | |
| 12 | 7/23/99 | 2 | 2 | 4 | Muhammad Zam | 8/17/99 | du | du | du | du | User Interface | A.X.0.0.001 | 8/7/99 | | Functional | |
| 13 | 7/23/99 | 1 | 3 | 3 | Chuck Chavall | 7/26/99 | du | du | du | du | Edit Engine | A.X.0.0.001 | 8/3/99 | | System | |
| 14 | 7/21/99 | 2 | 1 | 2 | Jenny Chung | 8/13/99 | du | du | du | du | Other | A.X.0.0.001 | 8/5/99 | | Process | |
| 15 | 7/23/99 | 1 | 2 | 2 | Larry Kanemetsu | 7/27/99 | du | du | du | du | Unknown | A.X.0.0.001 | 8/7/99 | | Data | |
| 16 | 7/24/99 | 2 | 3 | 6 | Frank Currant | 7/25/99 | du | du | du | du | N/A | A.Y.0.0.001 | 8/7/99 | | System | |
| 17 | 7/24/99 | 3 | 4 | 12 | Chuck Chavall | 8/13/99 | du | du | du | du | Edit Engine | A.Z.0.0.001 | 8/2/99 | | Functional | |
| 18 | 7/24/99 | 4 | 1 | 4 | Jenny Chung | 8/19/99 | du | du | du | du | User Interface | B.Y.0.0.001 | 8/1/99 | | Functional | |
| 19 | 7/21/99 | 1 | 2 | 2 | Muhammad Zam | 7/27/99 | du | du | du | du | Tools | C.X.0.0.001 | 7/30/99 | | System | |
| 20 | 7/19/99 | 1 | 3 | 3 | Chuck Chavall | 7/27/99 | du | du | du | du | File | C.Y.0.0.001 | 8/1/99 | | Process | |
| 21 | 7/22/99 | 2 | 4 | 8 | Jenny Chung | 8/18/99 | du | du | du | du | User Interface | C.Z.0.0.001 | 8/1/99 | | Data | |
| 22 | 7/21/99 | 3 | 5 | 15 | Larry Kanemetsu | 7/22/99 | du | du | du | du | Edit Engine | D.Z.0.0.001 | 7/29/99 | | Process | |
| 23 | 7/20/99 | 4 | 3 | 12 | Muhammad Zam | 8/13/99 | du | du | du | du | User Interface | C.Y.0.0.001 | 8/4/99 | | Documentation | |
| 24 | 7/20/99 | 1 | 2 | 2 | Chuck Chavall | 7/30/99 | du | du | du | du | Edit Engine | C.Z.0.0.001 | 8/2/99 | | Functional | |
| 25 | 7/24/99 | 4 | 3 | 12 | Jenny Chung | 8/12/99 | du | du | du | du | User Interface | D.Z.0.0.001 | 8/5/99 | | System | |
| 26 | 7/24/99 | 5 | 4 | 20 | Larry Kanemetsu | 8/8/99 | du | du | du | du | User Interface | A.X.0.0.001 | 8/2/99 | | Process | |
| 27 | 7/28/99 | 1 | 5 | 5 | Frank Currant | 8/22/99 | du | du | du | du | Edit Engine | A.X.0.0.001 | 8/7/99 | | Data | |
| 28 | 7/29/99 | 2 | 3 | 6 | Chuck Chavall | 8/20/99 | du | du | du | du | Other | A.X.0.0.001 | 8/11/99 | | Code | |
| 29 | 7/31/99 | 1 | 3 | 3 | Jenny Chung | 8/5/99 | du | du | du | du | Unknown | A.X.0.0.001 | 8/9/99 | | Functional | |
| 30 | 7/28/99 | 2 | 3 | 6 | Larry Kanemetsu | 8/17/99 | du | du | du | du | Edit Engine | B.Y.0.0.001 | 8/8/99 | | System | |
| 31 | 7/27/99 | 1 | 1 | 1 | Muhammad Zam | 8/1/99 | du | du | du | du | User Interface | B.Y.0.0.001 | 8/10/99 | | Process | |
| 32 | 7/30/99 | 2 | 2 | 4 | Chuck Chavall | 8/20/99 | du | du | du | du | Tools | C.X.0.0.001 | 8/6/99 | | Data | |
| 33 | 7/27/99 | 3 | 3 | 9 | Jenny Chung | 8/3/99 | du | du | du | du | File | C.Y.0.0.001 | 8/5/99 | | Code | |
| 34 | 7/26/99 | 4 | 4 | 16 | Muhammad Zam | 8/14/99 | du | du | du | du | Install/Config | C.Z.0.0.001 | 8/2/99 | | System | |
| 35 | 7/27/99 | 1 | 5 | 5 | Chuck Chavall | 8/12/99 | du | du | du | du | Edit Engine | D.Z.0.0.001 | 8/4/99 | | Functional | |

# Open/Closed Bug Tracking



# General Testing Approach

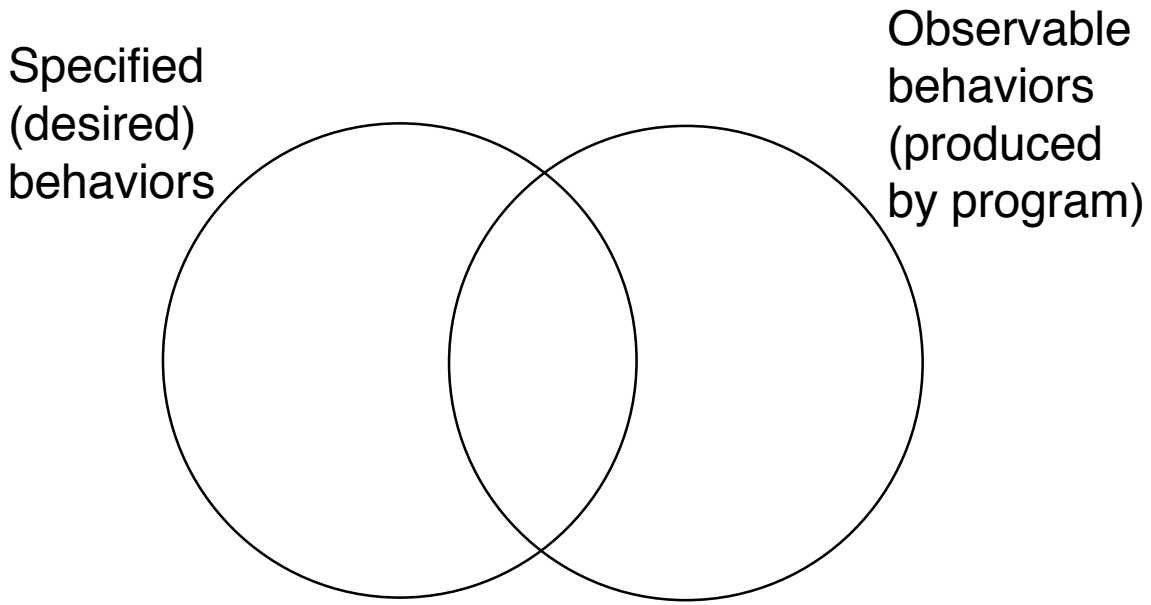
- Create lists of **potential** problems and categorize them by area.
- Design **repeatable** tests, for proof of problems and problem resolutions.

# Broad Categories for Errors

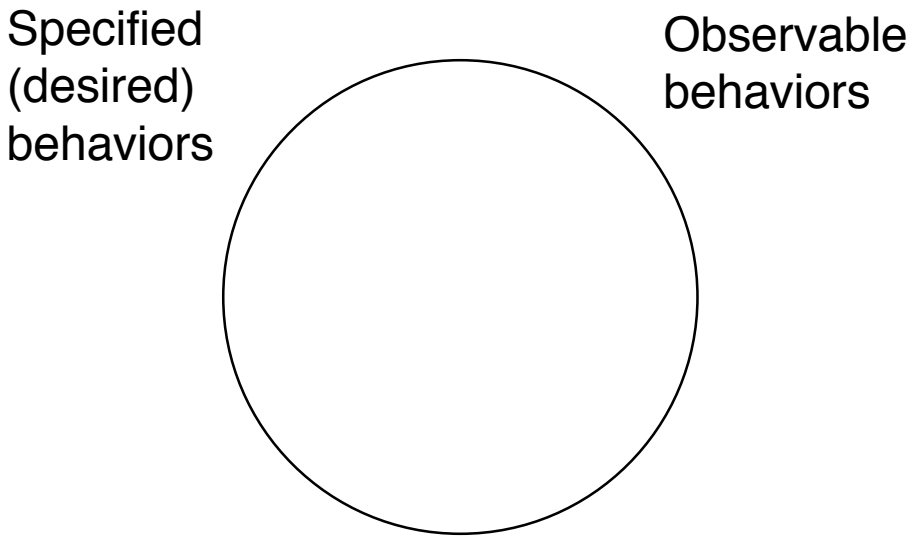
- Errors in interpreting requirements
- Errors in translating requirements into design, i.e. in programming
- Errors in implementing design
- Errors in the testing process itself

# Program Behavior Views

## (sets of behaviors taken over all inputs)



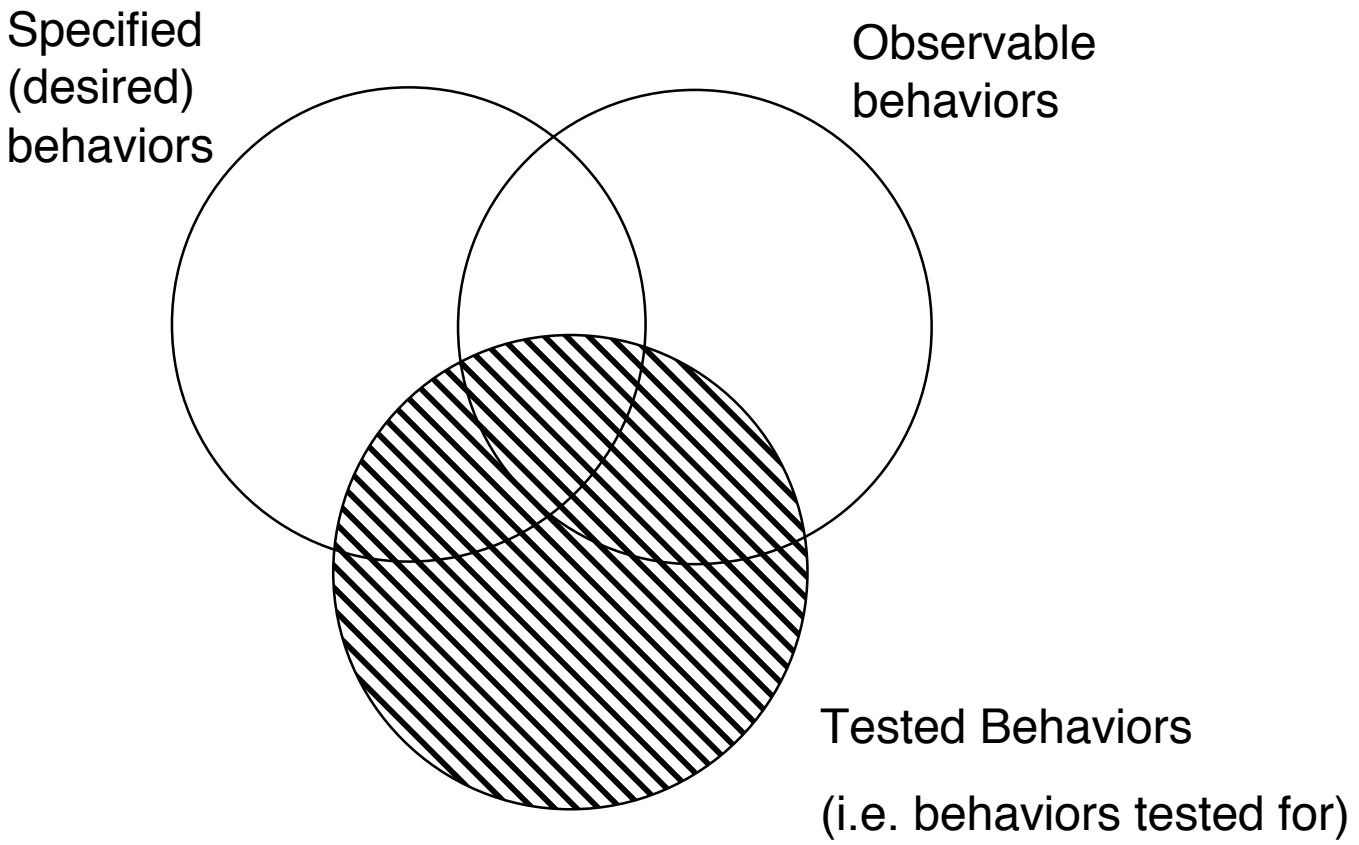
# The Ideal



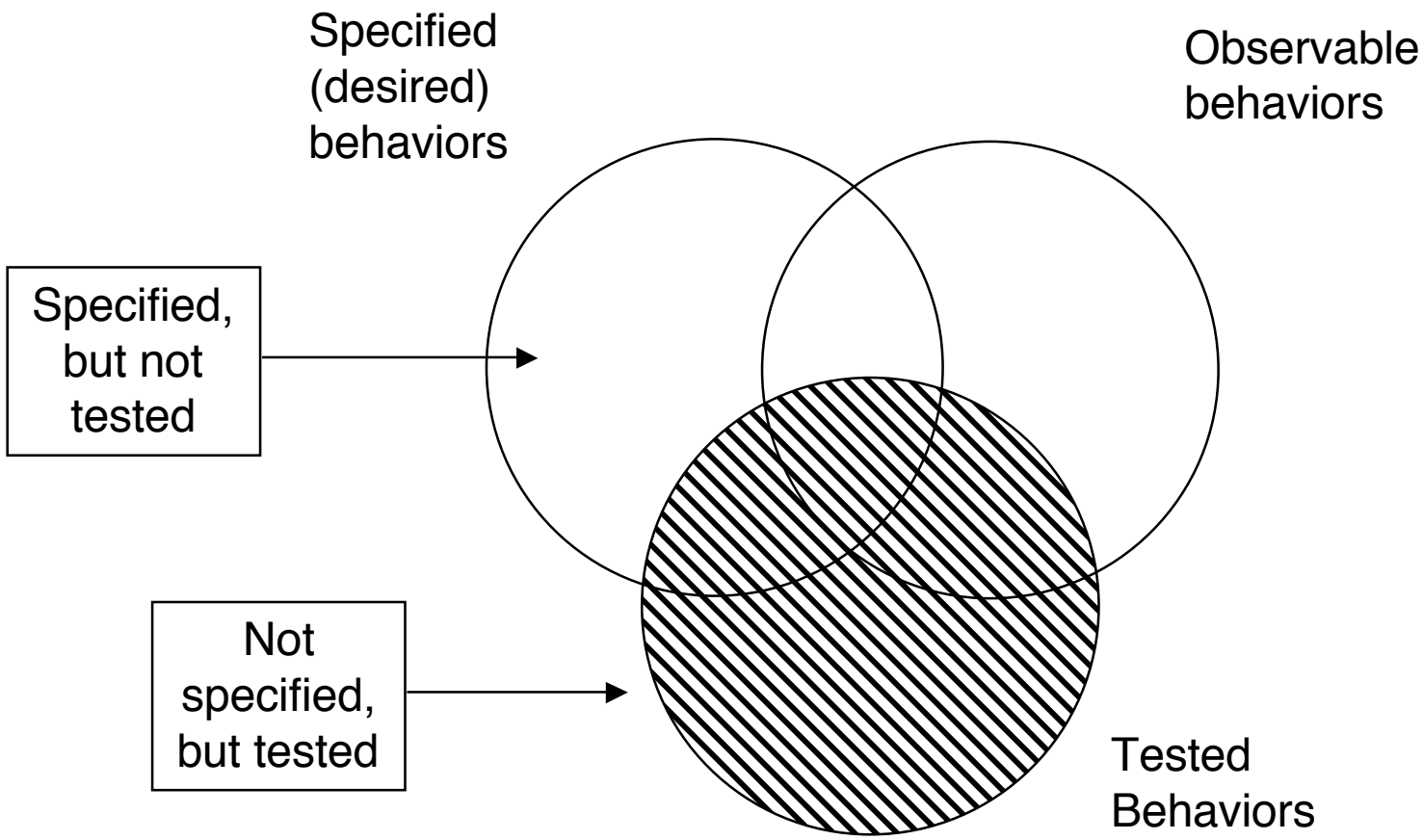
# The ideal might not be fully realizable because

- Some aspects of a specification may be left arbitrary, unspecified,
- meaning either:
  - The specification is to be regarded as incomplete, or
  - Any behavior ***consistent with*** the specification will be accepted.

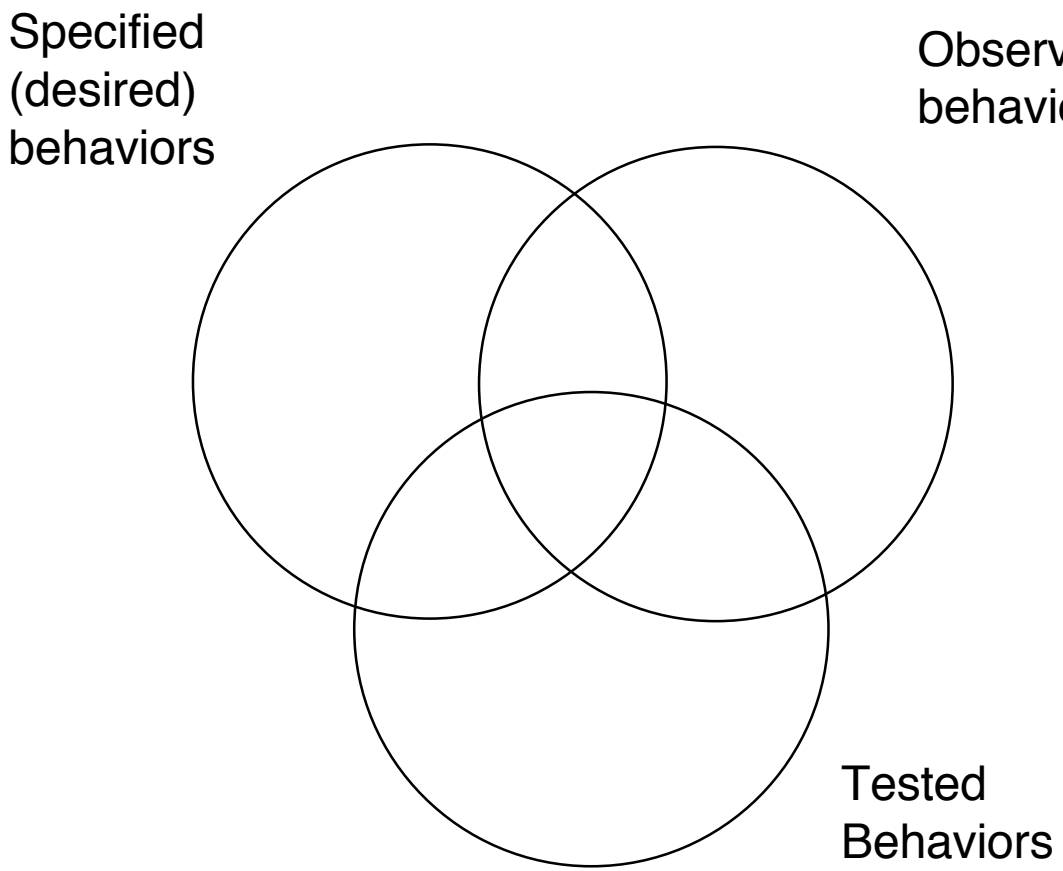
# Testing asks questions:
# Does a behavior occur?



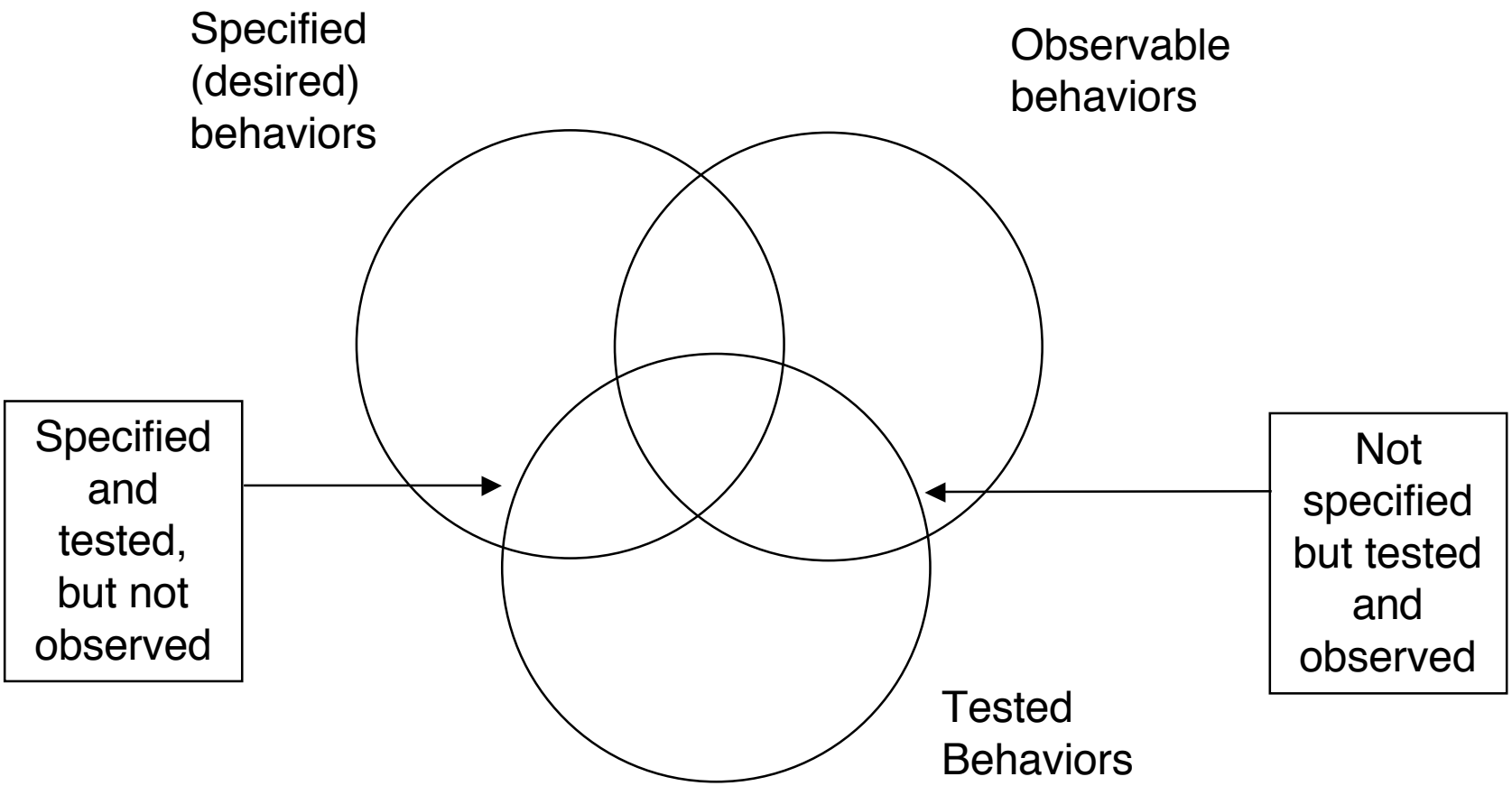
# Testing


Specified (desired) behaviors
Observable behaviors
Specified, but not tested
Not specified, but tested
Tested Behaviors

# Which regions of the diagram indicate errors?



# Which regions of the diagram indicate errors?

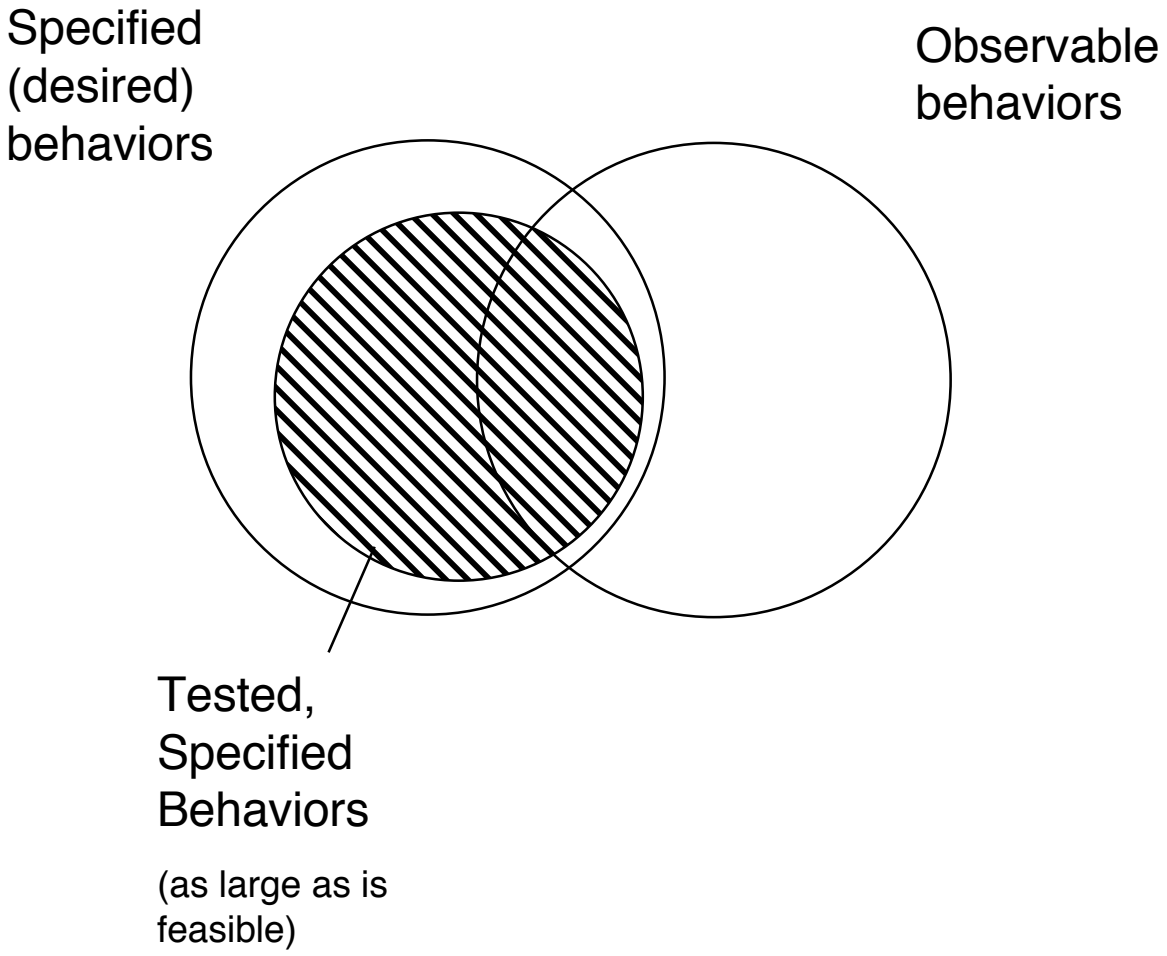


# Black- vs. White Box
## (recap)

- **Black-box** focuses on the **specification**: What is in the **spec** that the program doesn't do?
- **White-box** focuses on the **program**: What does the **program** do that is not in the spec?
- Normally don't rely on one or the other exclusively.

# Black-Box Testing

# Good Black-Box Test Plan



# Testing Example (3)

- A third reputable programmer has produced a self-contained program "triangle" that reads triples of numbers at a time and classifies them as to whether they are the lengths of the sides of some triangle, and if so, what kind.
- Negative side-length counts as a side with the length as absolute value of the specified length.
- The sides are in a specified range between 1E-150 and 1E150.

# Testing Example (3)

- The possible outputs are:
  - "not a triangle"
  - "equilateral triangle"
  - "isosceles triangle"
  - "scalene triangle"
  - Either of the last two above preceded by "right".
  - Or none of the above, with an indication that one or more of the inputs is out of range.
- "All classifications are based on native machine arithmetic".
- Determine how you would test this program.

# Black-Box Techniques

- Recall that "black box" means we do not get to see the code; we only have access to an installation of the product.
- Also called "functional testing" (vs. "structural testing", which would be "white box")
- Driven by requirements, use cases

# Black-Box Techniques

- **Equivalence Partitioning**:
  - Use a small number of test **equivalence classes**, rather than a large number of individual test data points.
  - The actual tests are representatives of the equivalence classes.
  - Partitioning based on their relative likelihood of exposing logic errors in the code.
  - Example: Partition a number space into:
    - less than 0
    - equal to 0
    - greater than 0, less than 100
    - greater than or equal to 100

# Black-Box Techniques

- Equivalence Partitioning Examples (cont'd):
  - Partition a **two-dimensional** number space into (x, y) where:
    - x < y
    - x == y
    - x > y
  - Why these?

  - Partition a String space into
    - length = 0
    - length = 1
    - length = 2
    - length = 3
    - length between 4 and 100
    - length greater than 100

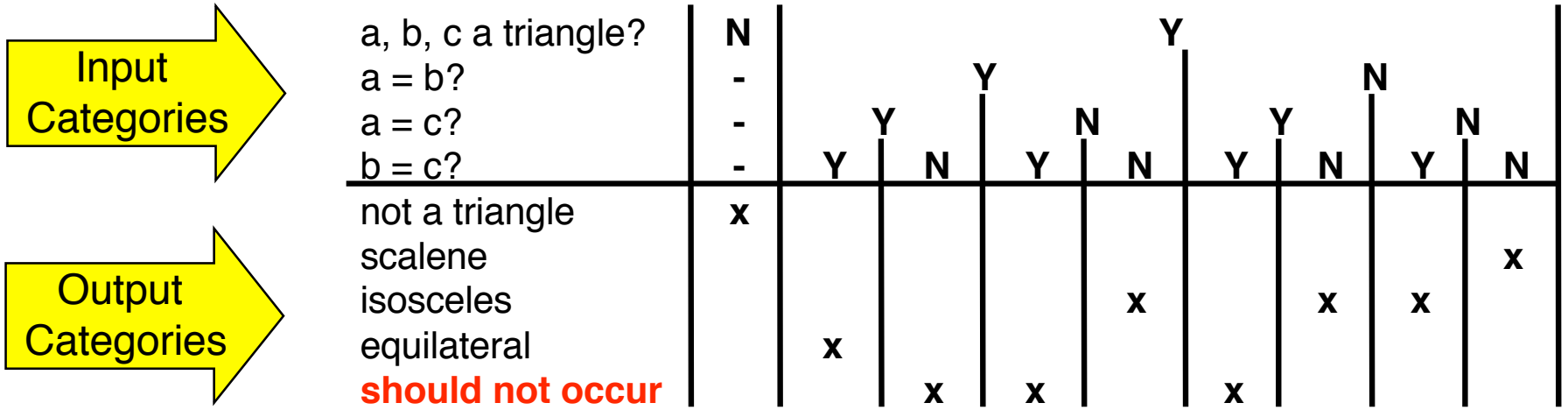
# Black-Box Techniques

- How would you equivalence-partition the triangle program input space?

# Decision Table

A "declarative" means to categorize input

- Partitions input space (triples of numbers) into equivalence classes.
- All inputs in a cell should have the same anticipated equivalence class.



# Decision Table Variant

- Slightly more condensed, based on logical equivalences
- Eliminate or reduce "should not occur" entries

Input Categories

Output Categories

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| a, b, c a triangle? | **N** | **Y** | | | | | |
| a = b? | - | **Y** | | **N** | | | |
| a = c? | - | **Y** | **N** | **Y** | **N** | | |
| b = c? | - | **Y** | **N** | **N** | **Y** | **N** | |
| not a triangle | **x** | | | | | | |
| scalene | | | | | | **x** | |
| isosceles | | | **x** | **x** | **x** | | |
| equilateral | | **x** | | | | | |

# Black-Box Techniques

- **Boundary-value testing**: Pick test cases near to "natural" boundaries in data space, so as to test whether the program performs the correct classification of borderline cases.

# Black-Box Techniques

- **Logarithmic testing**: Repeatedly split the data space into two, testing sample points in the upper and lower halves of the split, then repeat on the lower half only.

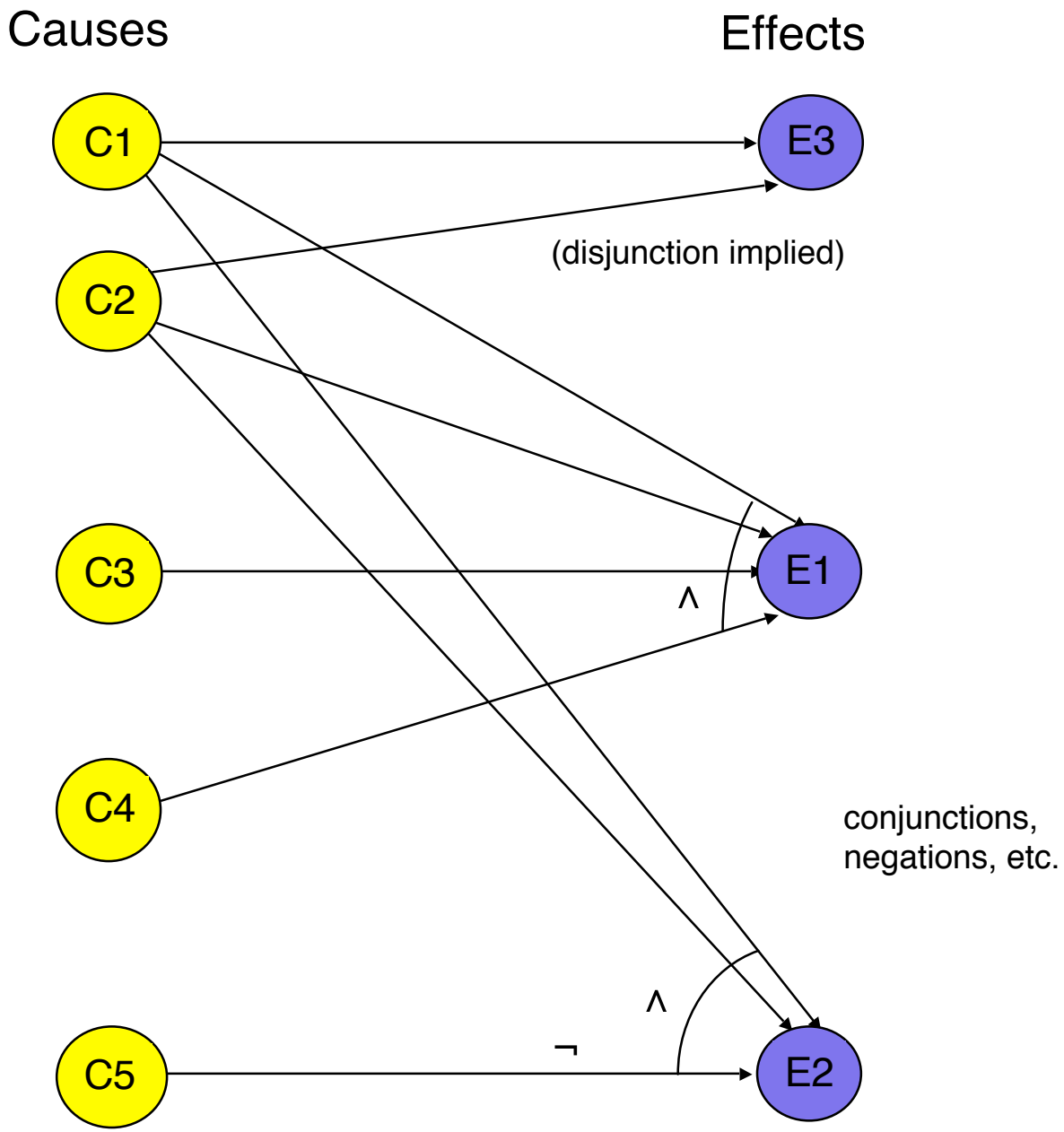
# Black-Box Techniques

- **Cause-Effect Graphing**: Examine requirements specification for logical **chains of conditions**; develop test cases that check whether these chains are actually observed.
  - Example: "If the clipboard is empty, then the paste menu option should *not* be selectable."
  - Therefore: Develop a test in which the clipboard should be empty, and check that the menu option is not selectable.

# Black-Box Techniques

- **Cause-Effect Graphing**, possible relationships:
  - A condition *implies* an action
  - A condition *precludes* an action
  - Two actions are *mutually* exclusive
  - A *combination* (conjunction) of two conditions implies an action
  - etc.

# Example Cause-Effect Graph



# Black-Box Techniques

- **Comparison Testing**:

  Test product side-by-side with a "**gold standard**",

  a program believed to be correctly operating (such as an earlier version having most, if not all, of the features)

# Black-Box Techniques

- **Garbage-In Test**: See if unusual input characters, click sequences, etc. can force the system into inconsistent states.
  - **Open-Book Test**
- **Data-Quantity Stress Test**: See if unusually large amounts of data cause nominal values to be exceeded, revealing untested overflow conditions, etc.