You know …

- **… Software requirements**
- **… Software design**
- **… Software coding**

- …


DILBERT by Scott Adams
YOUR USER REQUIRE-MENTS INCLUDE FOUR HUNDRED FEATURES.
www.dilbert.com
scottadams@aol.com
DO YOU REALIZE THAT NO HUMAN WOULD BE ABLE TO USE A PRODUCT WITH THAT LEVEL OF COMPLEXITY?
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GOOD POINT. I'D BETTER ADD "EASY TO USE" TO THE LIST.

Software Testing

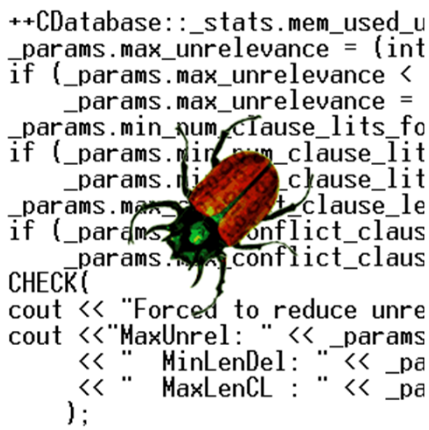
Outline

- **Software Testing?**
- **Why Test?**
- **What Do We Do When We Test ?**
  – Understand basic techniques for software verification and validation
  – Analyze basics of software testing techniques

The Term Bug

- **Bug is used informally**

  - Defect
  - Fault
  - Problem
  - Error
  - Incident
  - Anomaly
  - Variance
  - Failure
  - Inconsistency
  - Product Anomaly
  - Product Incidence
  - Feature



Some "Bug detection" Techniques

- **Formal methods** :proving software correct

- **Testing**: **executing program** in a controlled environment (**input**) and **"validating" output** (IEEE definition).

➡ **Why Test?**

Northeast Blackout of 2003

508 generating units and 256 power plants shut down

Affected 10 million people in Ontario, Canada

Affected 40 million people in 8 US states

Financial losses of $6 Billion USD

The alarm system in the energy management system failed due to a software error and operators were not informed of the power overload in the system

Costly Software Failures !

- NIST report, "The Economic Impacts of Inadequate Infrastructure for Software Testing" (2002)
  - Inadequate software testing costs the US alone between \$22 and \$59 billion annually

- Huge losses due to web application failures
  - Financial services : \$6.5 million per hour (just in USA!)
  - Credit card sales applications : \$2.4 million per hour (in USA)

Discussion …

- Have you heard of other software bugs?
  - In the media?
  - From personal experience?

- Does this embarrass you as a future software engineer?

Cost of Not Testing

Poor Program Managers might say:
"Testing is too expensive."

- **Testing is the most time consuming and expensive part of software development**
- **Not testing is even more expensive**
- **If we do not have enough testing effort early, the cost of testing increases**

Cost of Not Testing

Testing Goals

- **The Major Objectives of Software Testing:**
  - Detect errors (or bugs) as much as possible in a given timeline.
  - Demonstrate a given software product matching its requirement specifications.
  - Validate the quality of a software testing using the minimum cost and efforts.
- **Testing can NOT prove product works 100%- - - even though we use testing to demonstrate that parts of the software works**

Testing Overview

- **Who tests**
  - *Programmers*
  - *Testers/Req. Analyst*
  - *Users*
- **What is tested**
  - **Unit Code** testing
  - **Functional Code** testing
  - Integration/**system** testing
  - **User interface** testing
- **How (test cases designed)**
  - Intuition
  - Specification based (*black box)*
  - Code based (*white-box)*

Software Testing

Exhaustive Testing is Hard

```
int max(int x, int y)
{
  if (x > y)
    return x;
  else
    return x;
}
```

18446744073709551616 possibilities

- Number of possible test cases (assuming 32 bit integers)
  - $2^{32} \times 2^{32} = 2^{64}$
- Do bigger test sets help?
  - **Test set {(x=3,y=2), (x=2,y=3)}**

  will detect the error
  - **Test set {(x=3,y=2),(x=4,y=3),(x=5,y=1)} will not detect the error although it has more test cases**
- It is not the number of test cases
- But, if $T_1 \supseteq T_2$, then T_1 will detect every fault detected by T_2

Exhaustive Testing is Hard

- Assume that the input for the `max` procedure was an integer array of size *n*
  - Number of test cases: $2^{32\times n}$
- Assume that the size of the input array is not bounded
  - Number of test cases: ∞

Generating Test Cases Randomly

```
bool isEqual(int x, int y)
{
  if (x = y)
    z := false;
  else
    z := false;
  return z;
}
```

0.00000000023283064365386962890625

- If we pick test cases randomly it is unlikely that we will pick a case where x and y have the same value
- If x and y can take 2^{32} different values, there are 2^{64} possible test cases. In 2^{32} of them x and y are equal
  - **probability of picking a case where x is equal to y is 2^{-32}**
- It is not a good idea to pick the test cases randomly (with uniform distribution) in this case
- So, naive random testing is pretty hopeless too

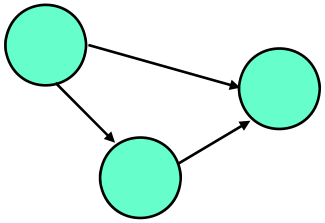
Types of Testing

- **Functional (Black box) vs. Structural (White box) testing**
  - **Functional testing**: Generating test cases based on the functionality of the software
  - **Structural testing**: Generating test cases based on the structure of the program
- **Black box testing and white box testing are synonyms for functional and structural testing, respectively.**
  - **In black box testing** the internal structure of the program is hidden from the testing process
  - **In white box testing** internal structure of the program is taken into account

Criteria Based on Structures

Structures : Four ways to model software

1. Graphs



2. Logical Expressions

(not X or not Y) and A and B

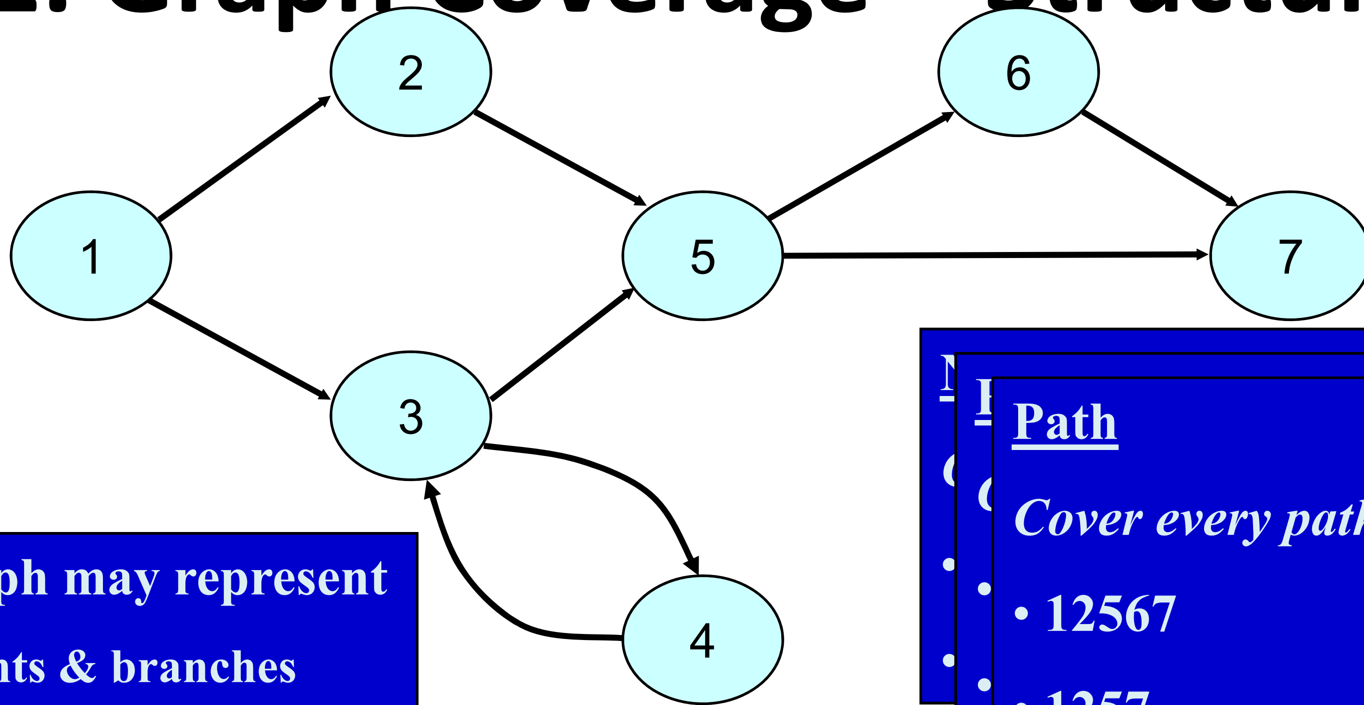
3. Input Domain Characterization

A: {0, 1, >1}
B: {600, 700, 800}
C: {swe, cs, isa, infs}

4. Syntactic Structures

```
if (x > y)
    z = x - y;
else
   z = 2 * x;
```

1. Graph Coverage – Structural



This graph may represent

- **statements & branches**
- **methods & calls**
- **components & signals**
- **states and transitions**

⋮

Path

Cover every path

- **12567**
- **1257**
- **13567**
- **1357**
- **1343567**
- **134357 …**

1. Graph Coverage – Structural

- **Coverage metrics**
  - ***Statement coverage***: all statements in the programs should be executed at least once
  - ***Branch coverage***: all branches in the program should be executed at least once
  - ***Path coverage***: all execution paths in the program should be executed at lest once

Statement Coverage

```
areTheyPositive(int x, int y)
{
  if (x >= 0)
    print("x is positive");
  else
    print("x is negative");
  if (y >= 0)
    print("y is positive");
  else
     print("y is negative");
}
```

Following test set will give us statement coverage:
T_1 = {(x=12,y=5), (x= –1,y=35), (x=115,y=–13),(x=–91,y= –2)}

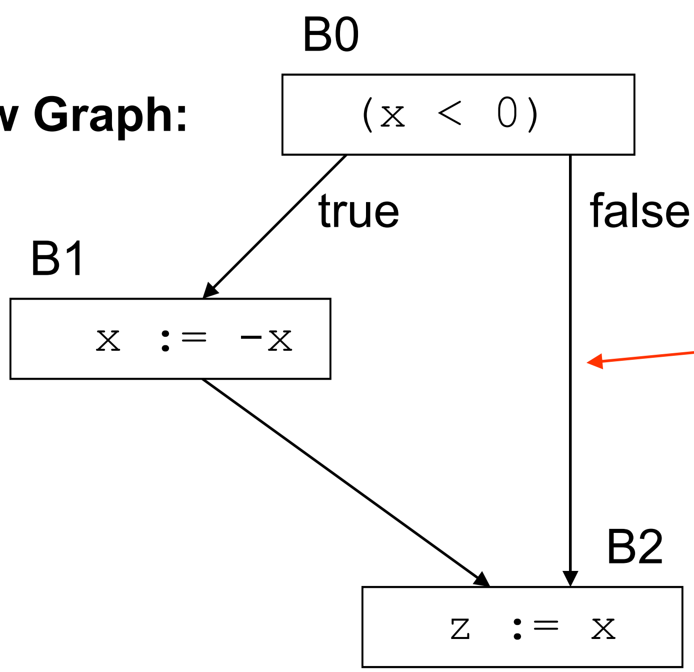
There are smaller test cases which will give us statement coverage too:
T_2 = {(x=12,y= – 5), (x= –1,y=35)}

Statement vs. Branch Coverage

```
assignAbsolute(int x)
{
  if (x < 0)
    x := -x;
  z := x;
}
```

Consider this program segment, the test set T = {x=–1} will give statement coverage, however not branch coverage

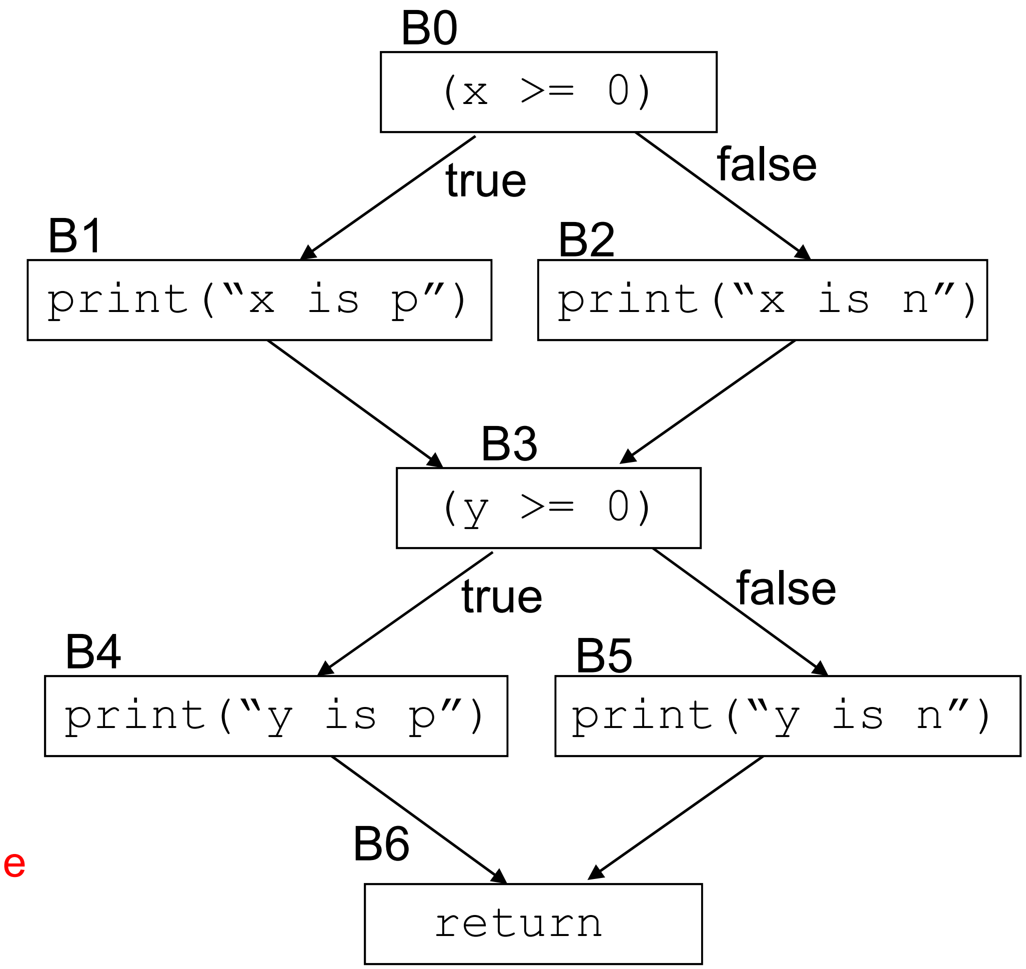
Control Flow Graph:



Test set {x=–1} does not execute this edge, hence, it does not give branch coverage

Path Coverage

```
areTheyPositive(int x, int y)
{
  if (x >= 0)
     print("x is positive");
  else
    print("x is negative");
  if (y >= 0)
    print("y is positive");
  else
     print("y is negative");
}
```



Test set:

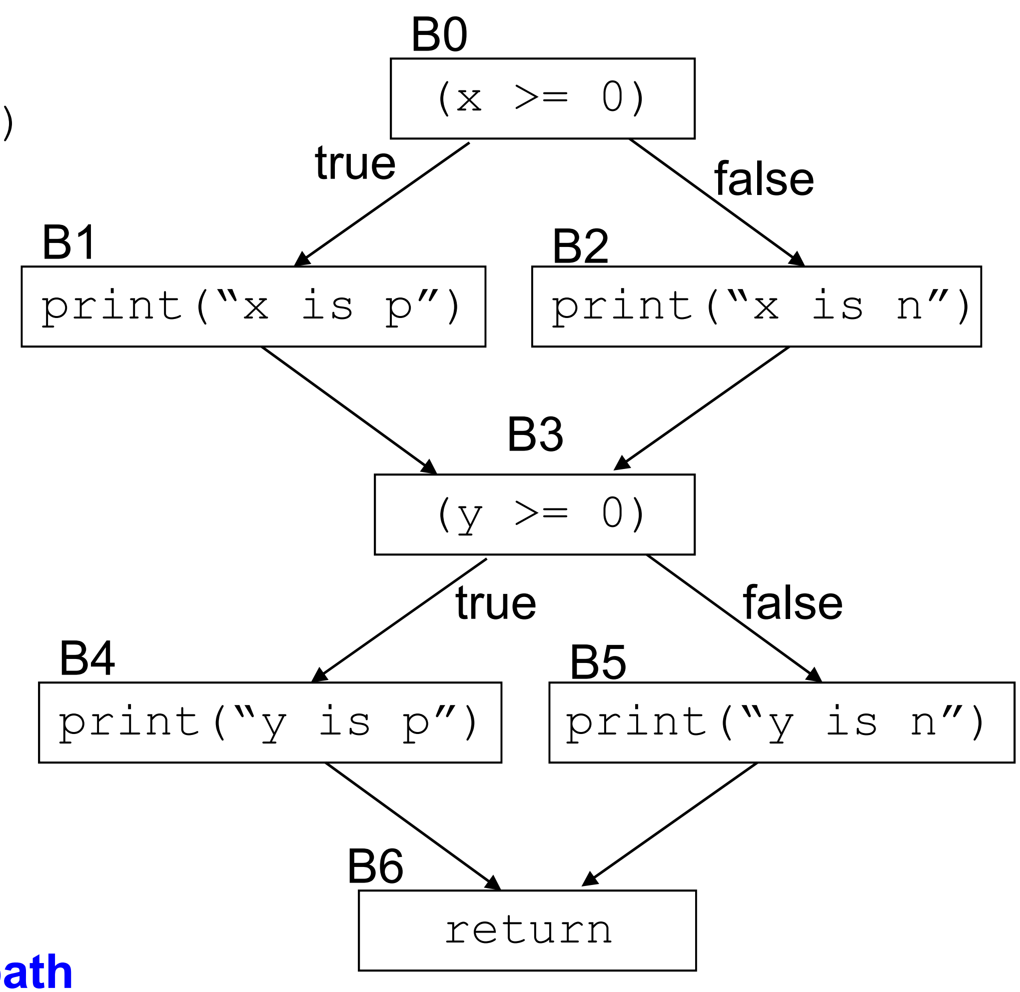
T_2 = {(x=12,y= – 5), (x= –1,y=35)} gives both branch and statement coverage but it does not give path coverage

Set of all execution paths: {(B0,B1,B3,B4,B6), (B0,B1,B3,B5,B6), (B0,B2,B3,B4,B6), (B0,B2,B3,B5,B6)}

Test set T_2 executes only paths: (B0,B1,B3,B5,B6) and (B0,B2,B3,B4,B6)

Path Coverage

```
areTheyPositive(int x, int y)
{
  if (x >= 0)
     print("x is positive");
  else
    print("x is negative");
  if (y >= 0)
    print("y is positive");
  else
     print("y is negative");
}
```



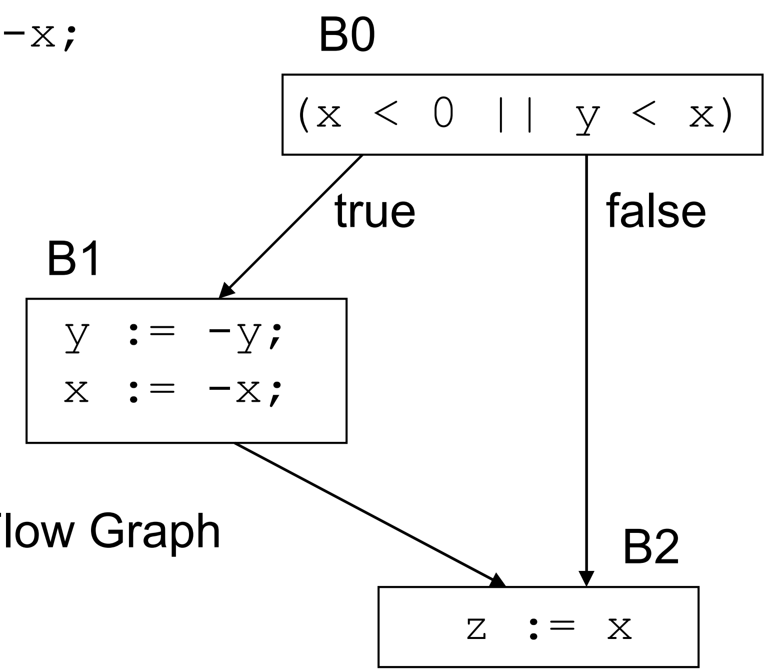
Test set:

T_1 = {(x=12,y=5), (x= –1,y=35), (x=115,y=–13),(x=–91,y= –2)} gives both branch, statement and path coverage

Condition Coverage

```
something(int x)
{
  if (x < 0 ||  y < x)
  {
    y := -y;
    x := -x;
  }
  z := x;
}
```

T = {(x=–1, y=1), (x=1, y=1)} will achieve **statement, branch and path coverage, however T will not achieve condition coverage** because the boolean term `(y < x)` never evaluates to true. This test set satisfies part (1) but does not satisfy part (2).



Control Flow Graph

T = {(x=–1, y=1), (x=1, y=0)} **will not achieve condition coverage either**. This test set satisfies part (2) but does not satisfy part (1). It does not achieve branch coverage since both test cases take the true branch, and, hence, it does not achieve condition coverage by definition.

T = {(x=–1, y=–2), {(x=1, y=1)} achieves condition coverage.

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- **How (test cases designed)**
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  - **Specification based (*black box*)**
  - **Code based (*white-box*)**

Unit testing

Objectives	• To test the function of a program or unit of code such as a program or module • To test internal logic • To verify internal design • To test path & conditions coverage • To test exception conditions & error handling
When	• After modules are coded
Input	• Internal Application Design • Master Test Plan • Unit Test Plan
Output	• Unit Test Report

Who	• Developer
Methods	• White Box testing techniques • Test Coverage techniques
Tools	• Debug • Re-structure • Code Analyzers • Path/statement coverage tools
Education	• Testing Methodology • Effective use of tools

Integration testing

Objectives	• To technically verify proper interfacing between modules, and within sub-systems
When	• After modules are unit tested
Input	• Internal & External Application Design • Master Test Plan • Integration Test Plan
Output	• Integration Test report

Who	• Developers
Methods	• White and Black Box techniques • Problem / Configuration Management
Tools	• Debug • Re-structure • Code Analyzers
Education	• Testing Methodology • Effective use of tools

System Testing

Objectives	• To verify that the system components perform control functions • To perform inter-system test • To demonstrate that the system performs both functionally and operationally as specified • To perform appropriate types of tests relating to Transaction Flow, Installation, Reliability, Regression etc.
When	• After Integration Testing
Input	• Detailed Requirements & External Application Design • Master Test Plan • System Test Plan
Output	• System Test Report

Who	•Development Team and Users
Methods	•Problem / Configuration Management
Tools	•Recommended set of tools
Education	•Testing Methodology •Effective use of tools

Four Fundamental Challenges to Competent Testing

- Complete testing is impossible
- Testers misallocate resources because they fall for the company’s process myths
- Test groups operate under multiple missions, often conflicting, rarely articulated
- Test groups often lack skilled programmers, and a vision of appropriate projects that would keep programming testers challenged

Testing Pitfalls

Software Testing