UNIVERSITÄT BERN

Introduction to Software Engineering

7. Verification

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Based on a lecture by Oscar Nierstrasz.

Roadmap

- Why Verification Matters
- Sources of Faults
- Tolerance
- Avoidance via Verification
- Testing
  - —White box
  - —Black box
  - —Regression

Software Reliability

The **reliability** of a software system is a measure of how well it provides the services expected by its users, expressed in terms of software failures.

Failures vs. Faults

A **software failure** is an ***execution event*** where the software behaves in an unexpected or undesirable way.

A **software fault** is an ***erroneous portion of software*** which may cause failures to occur if it is run in a particular state, or with particular inputs.

Therac-25

Intel Pentium

NASA Mars Mission

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Common Sources of Software Faults ...

Concurrency is dangerous because *timing differences* can affect overall program behaviour in *hard-to-predict* ways.

—Minimize inter-process dependencies

Recursion can lead to *convoluted logic*, and may exhaust (stack) memory.

—Use recursion in a disciplined way, within a controlled scope

Floating point numbers are *inherently imprecise* and may lead to invalid comparisons.

—Fixed point numbers are safer for exact comparisons

What to do with Faults?

Fault tolerance

developing programs that will *operate despite the presence of faults*

Fault avoidance

development techniques to *reduce the number of faults* in a system

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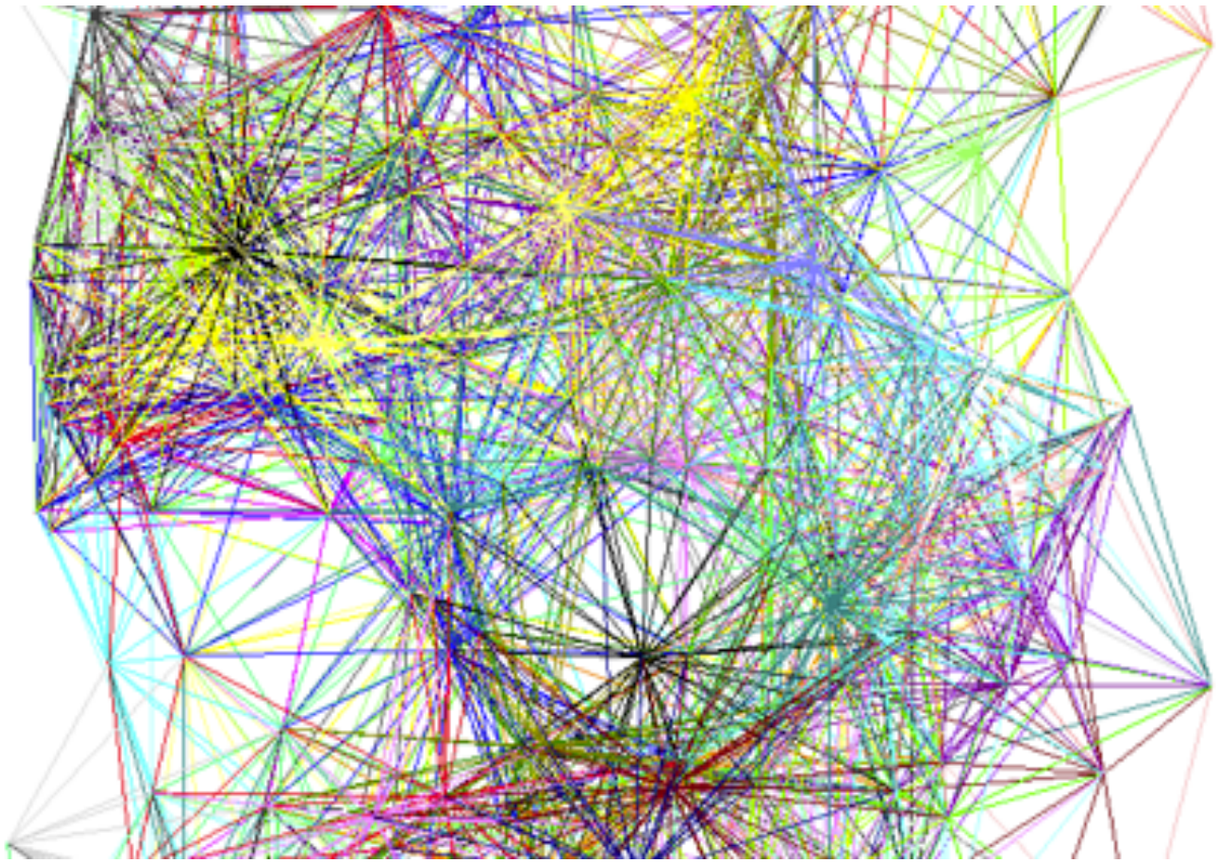
Approaches to Hardware Fault Tolerance



Distributed Systems
The Internet

Approaches to Software Fault Tolerance

N-version Programming. *Multiple versions* of the software system are implemented *independently by different teams*.

- runs all the versions in *parallel*
- *compares* their results using a voting system, and
- *rejects* inconsistent outputs

(n > 3 && n % 2 !=0)

Defensive Programming

Use the *type system* to ensure that variables do not get assigned invalid values.

Use *assertions* to detect failures and raise exceptions. Explicitly state and check all invariants for abstract data types, and pre- and post-conditions of procedures as assertions.

Use exception handlers to recover from failures.

Example: Fault Recovery

- Change logs (rollback and replay)
  - Smalltalk image and changes

- Transactional Memory (software and hardware)
  - ACID (Atomicy, Consistency, Isolation, Durability)

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Fault Avoidance Can Benefit From ...

1. *Formal proofs* that certain properties hold
2. *Code reviews* during the development process
3. *System testing* to expose faults and assess reliability

Fault Avoidance Can Benefit From ...

4. *A more zen approach* to writing software

Formal Verification

Mathematically-based. Use mathematical reasoning to demonstrate that program meets specification

—e.g., that invariants are not violated

—e.g., model-checking tools

Static Verification

Program Inspections:

> Small team systematically checks program code

> Inspection checklist often drives this activity

—e.g., “Are all invariants, pre- and post-conditions checked?” ...

Static Program Analyzers:

> Complements compiler to check for common errors

—e.g., variable use before initialization

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Testing vs. Correctness

"Program testing can be a very effective way to show the presence of bugs, but is hopelessly inadequate for showing their absence."

— Edsger Dijkstra, The Humble Programmer, ACM Turing lecture, 1972

Tests are designed to *reveal the presence of defects* in the system.

Testing In Practice

Testing **in practice** can only be representative.

Test data are inputs devised to test the system.

Test cases are input/output specifications for a particular function being tested.

The Testing Process

1. Unit testing:
   - Individual (stand-alone) *components* are tested to ensure that they operate correctly.
2. Module testing:
   - A collection of *related components* (a module) is tested as a group.
3. Sub-system testing:
   - The phase tests a *set of modules* integrated as a sub-system. Since the most common problems in large systems arise from sub-system interface mismatches, this phase focuses on testing these interfaces.

The Testing Process ...

4. System testing:
   — This phase concentrates on (i) detecting errors resulting from unexpected interactions between sub-systems, and (ii) validating that the complete systems fulfils functional and non-functional requirements.
5. Acceptance testing (alpha/beta testing):
   — The system is tested with *real* rather than simulated data.

Bottom-up Testing

- *Start by testing units* and modules
- *Test drivers* must be written to exercise lower-level components
- Works well for *reusable components* to be shared with other projects

Bottom-up testing will not uncover *architectural faults*

Top-down Testing

- *Start with sub-systems*, where modules are represented by "stubs" / mocks
- Similarly test modules, representing functions as stubs
- *Coding and testing* are carried out as a *single activity*
- Design errors can be detected early on, avoiding expensive redesign
- Always have a running (if limited) system!

BUT: may be impractical for stubs to simulate complex components

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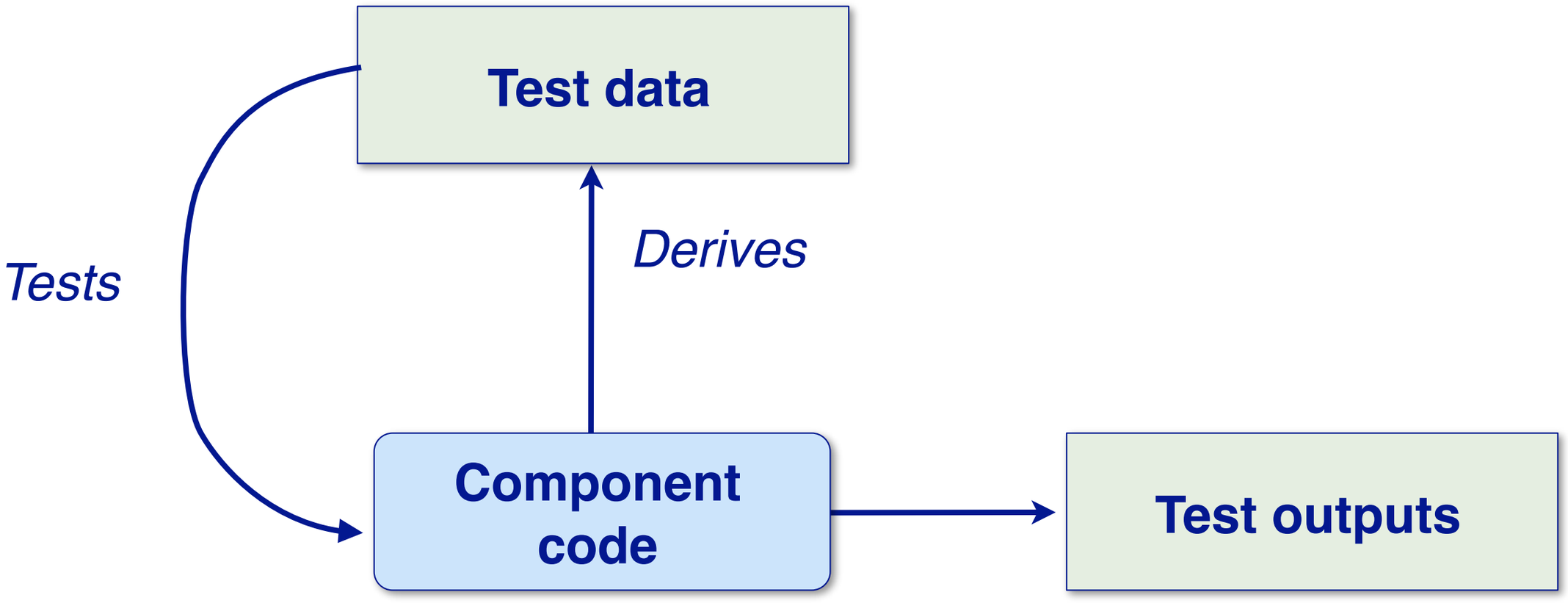
```
class BinSearch {
// This is an encapsulation of a binary search function that takes an array of
// ordered objects and a key and returns an object with 2 attributes namely
// index - the value of the array index
// found - a boolean indicating whether or not the key is in the array
// An object is returned because it is not possible in Java to pass basic types by
// reference to a function and so return two values
// the key is -1 if the element is not found
    public static void search (int key, int [] elemArray, Result r)
    {
        int bottom = 0;
        int top = elemArray.length - 1;
        int mid;
        r.found = false; r.index = -1;                                  (1)
        while ( bottom <= top)                                          (2)
        {
            mid = (top + bottom) / 2;
            if (elemArray [mid] == key)                                 (3)
            {
                r.index = mid;                                          (8)
                r.found = true;
                return ;                                                -> (9)
            } // if part
            else
            {
                if (elemArray [mid] < key)                              (4)
                        bottom = mid + 1;                               (5)
                else
                        top = mid -i;                                   (6)
            }                                                           (7)
        } //while loop
    } //search                                                          (9)
} //BinSearch
```

Structural (white box) Testing

Structural testing treats a component as a *"white box"* or "glass box" whose *structure can be examined to generate test cases.*

Derive test cases to *maximize coverage* of that structure, yet *minimize the number of test cases*.



Program flow graphs

- Each branch is shown as a separate path and loops are shown by arrows looping back to the loop condition node

- The number of tests to test all control statements equals the *cyclomatic complexity*

Cyclomatic complexity = Number of edges - Number of nodes +2

Path Testing

Test cases should be chosen to cover all *independent paths* through a routine:

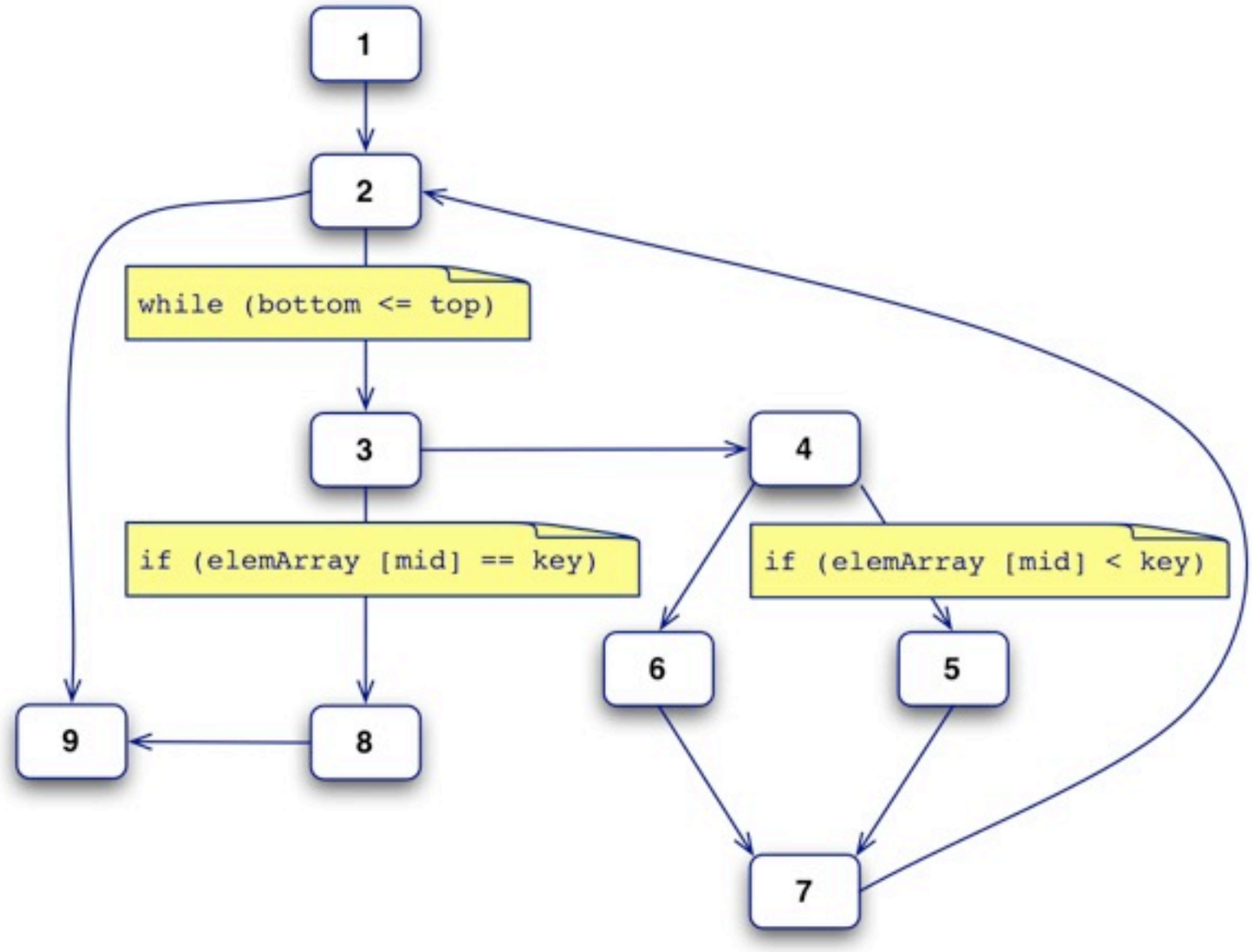
—1, 2, 9

—1, 2, 3, 8, 9

—1, 2, 3, 4, 5, 7, 2, 9

—1, 2, 3, 4, 6, 7, 2, 9

(Each path traverses at least one new edge)



Coverage criteria

- *every statement* at least once
- *all portions of control flow* at least once
- *all possible values of compound conditions* at least once
- *all portions of data flow* at least once
- for *all loops* L, with n allowable passes:
  - I. skip the loop;
  - II.1 pass through the loop
  - III.2 passes
  - IV.m passes where 2 < m < n
  - V.n-1, n, n+1 passes

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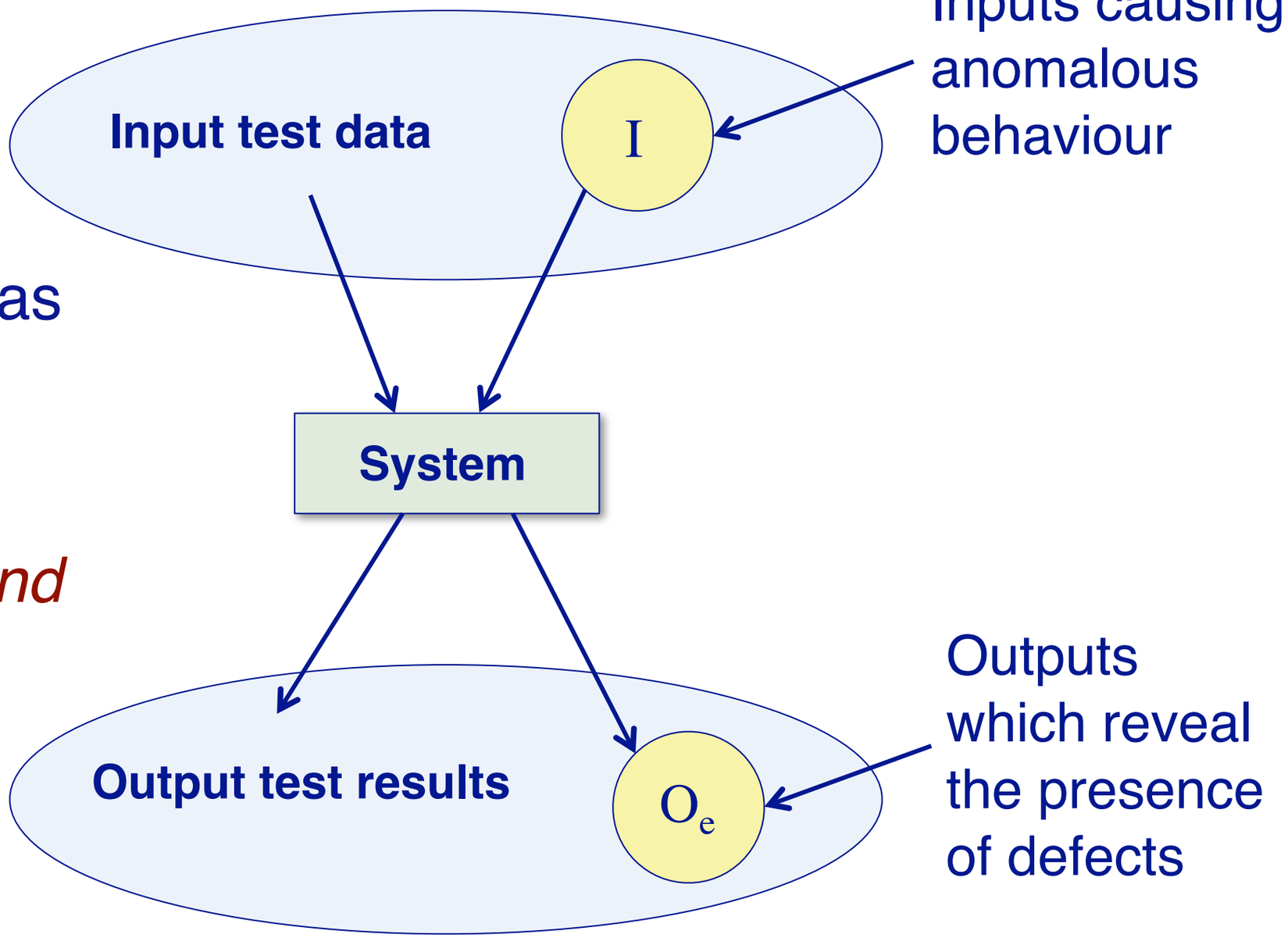
Functional (black box) testing

Functional testing treats a component as a *"black box"* whose behaviour can be determined only by studying its *inputs and outputs*.



Equivalence partitioning

```
public static void search(int key, int [] elemArray, Result r)
    { … }
```

Check input partitions:

- Do the inputs fulfil the *pre-conditions*?
  - is the array sorted, non-empty ...
- Is the key in the array?
  - leads to (at least) 2x2 equivalence classes

Check boundary conditions:

- Is the array of length 1?
- Is the key at the start or end of the array?
  - leads to further subdivisions (not all combinations make sense)

Test Cases and Test Data

Generate test data that cover all *meaningful* equivalence partitions.

Test Cases	***Test Data***
Array length 0	key = 17, elements = { }
Array not sorted	key = 17, elements = { 33, 20, 17, 18 }
Array size 1, key in array	key = 17, elements = { 17 }
Array size 1, key not in array	key = 0, elements = { 17 }
Array size > 1, key is first element	key = 17, elements = { 17, 18, 20, 33 }
Array size > 1, key is last element	key = 33, elements = { 17, 18, 20, 33 }
Array size > 1, key is in middle	key = 20, elements = { 17, 18, 20, 33 }
Array size > 1, key not in array	key = 50, elements = { 17, 18, 20, 33 }
...	

Coverage Criteria

Test cases are derived from the *external specification* of the component and should cover:

- **all exceptions**
- **all data ranges** (incl. invalid) generating different classes of output
- **all boundary values**

Test cases can be derived from a component's *interface*, by assuming that the component will behave similarly for all members of an *equivalence partition* ...

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Regression testing

"Testing *old capabilities* is more important than testing new capabilities."

Regression testing means testing that everything that used to work *still works* after changes are made to the system!

What you should know

- Failures, Faults, and Reliability
- Test cases vs. test data
- How to do black-box testing
- How to do white-box testing
- What is regression testing and why it matters
- How to design an OO system that is testable

Can you answer the following questions?

- When would you combine black-box testing with white-box testing?
- Is it acceptable to deliver a system that is not 100% reliable?
- What is the goal of path testing?
- Why is regression testing important?
- How can we increase the chance that a system avoids failures?

Further Reading / Watching

The Clean Code Talks -- Unit Testing (Google Tech Talk)

Software Engineering, Chapter 7, I. Sommerville, 9th Edn., 2011.

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