16.35

Aerospace Software Engineering

Verification & Validation

Prof. Kristina Lundqvist
Dept. of Aero/Astro, MIT

Would You ...

- ... trust a completely-automated nuclear power plant?
- ... trust a completely-automated pilot whose software was written by yourself? A colleague?
- … dare to write an expert system to diagnose cancer? What if you are personally held liable in a case where a patient dies because of a malfunction of the software

Verification and Validation

- Assuring that a software system meets a user's needs

Verification vs. Validation

"Verification is the act of reviewing, inspecting, testing, checking, auditing, or otherwise establishing and documenting whether or not items, processes, services or documents conform to specified requirements" (ANSI A3-1978).

Validation is, according to its ANSI/IEEE definition, "the evaluation of software at the end of the software development process to ensure compliance with the user requirements". Validation is, therefore, "end-to-end verification."

The V&V Process

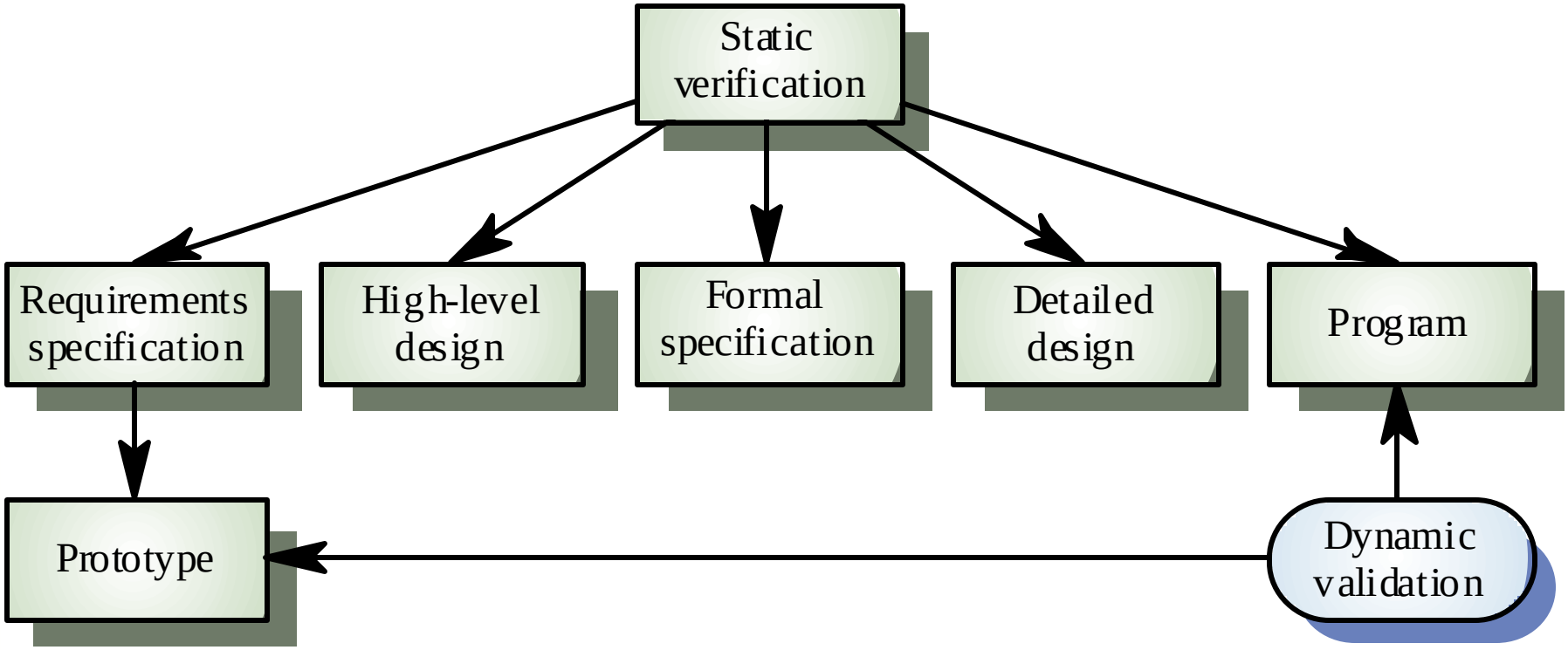
- Is a whole life-cycle process - V&V must be applied at each stage in the software process
- Has two principal objectives
  - The discovery of defects in a system
  - The assessment of whether or not the system is usable in an operational situation

Static and Dynamic Verification

- *Software inspections* Concerned with analysis of the static system representation to discover problems (static verification)
  - May be supplement by tool-based document and code analysis

- *Software testing* Concerned with exercising and observing product behaviour (dynamic verification)
  - The system is executed with test data and its operational behaviour is observed

Static and Dynamic V&V



Program Testing

- Can reveal the presence of errors not their absence
- A successful test is a test which discovers one or more errors
- The only validation technique for non-functional requirements
- Should be used in conjunction with static verification to provide full V&V coverage

Types of Testing

- Defect testing
  - Tests designed to discover system defects.
  - A successful defect test is one which reveals the presence of defects in a system.
- Statistical testing
  - Tests designed to reflect the frequency of user inputs. Used for reliability estimation.

Cost of Testing

Normal SDLC		SDLC TESTING		
Accumulated Test Cost	Accumulated Errors/ 1000 LOC		Accumulated Errors/ 1000 LOC	Accumulated Test Cost
0	20	**REQUIREMENTS 20 ERRORS**	10	10
		Cost Detect = 1		
0	40	**DESIGN 20 ERRORS**	15	25
		Cost Detect = 1		
0	60	**CODE 20 ERRORS**	18	42
		Cost Detect = 1		
480	12	**TEST 80% ERROR REDUCTION**	4	182
		Cost Detect = 10		
1680	0	**PRODUCTION 0 ERRORS**	0	582
		Cost Detect = 100		

V&V Goals

- Verification and validation should establish confidence that the software is fit for purpose
- This does not mean completely free of defects
- Rather, it must be good enough for its intended use and the type of use will determine the degree of confidence that is needed

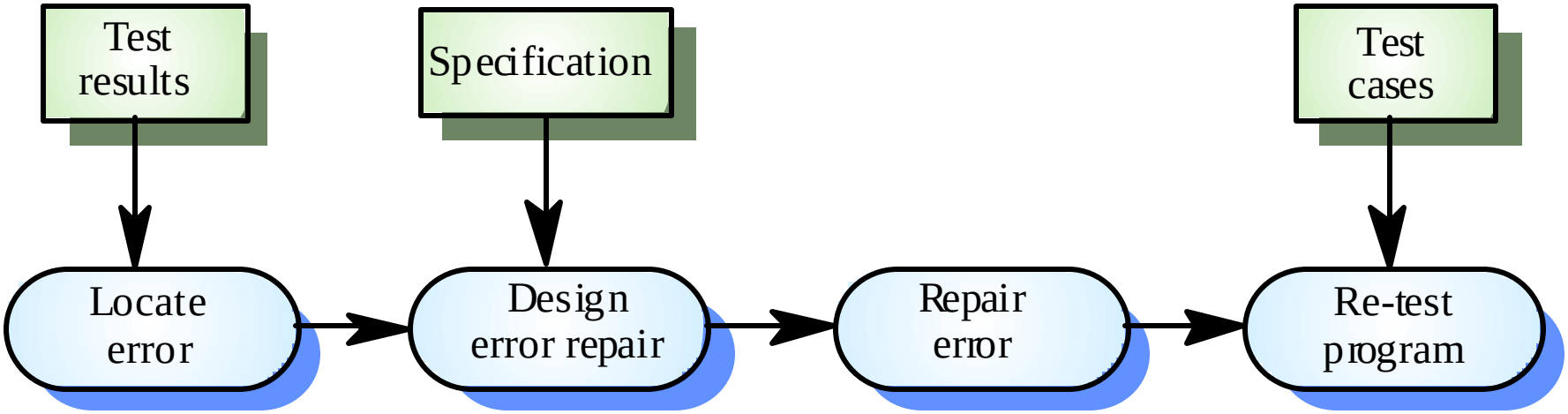
V&V Confidence

- Depends on system's purpose, user expectations and marketing environment
  - Software function
    - The level of confidence depends on how critical the software is to an organisation
  - User expectations
    - Users may have low expectations of certain kinds of software
  - Marketing environment
    - Getting a product to market early may be more important than finding defects in the program

Testing and Debugging

- Defect testing and debugging are distinct processes
- Verification and validation is concerned with establishing the existence of defects in a program
- Debugging is concerned with locating and repairing these errors
- Debugging involves formulating a hypothesis about program behaviour then testing these hypotheses to find the system error

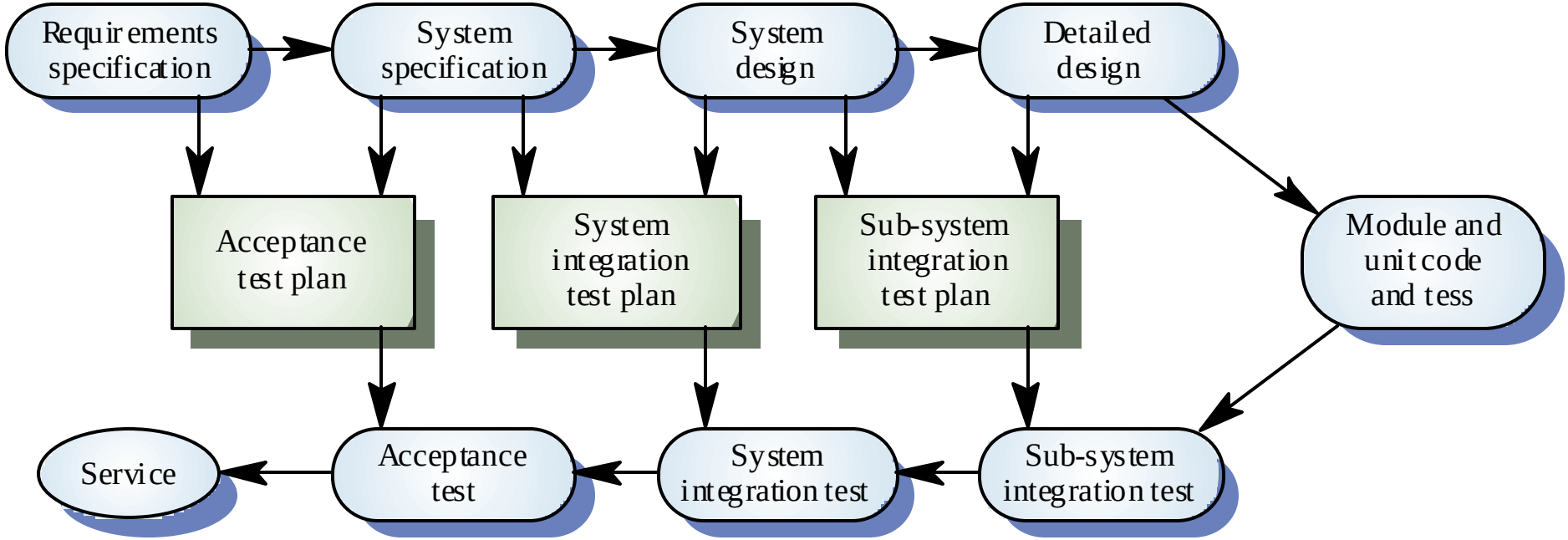
The Debugging Process



V & V Planning

- Careful planning is required to get the most out of testing and inspection processes
- Planning should start early in the development process
- The plan should identify the balance between static verification and testing
- Test planning is about defining standards for the testing process rather than describing product tests

The V-model of Development



The Structure of a Software Test Plan

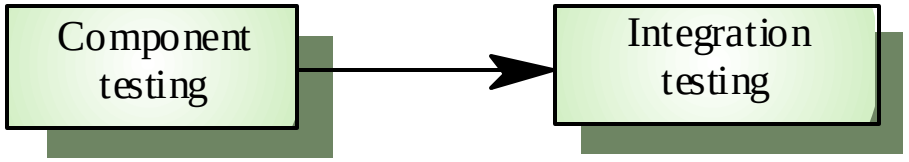
- The testing process
- Requirements traceability
- Tested items
- Testing schedule
- Test recording procedures
- Hardware and software requirements
- Constraints

- X-38 Integrated Test Plan
- Software Test Plan

Defect Testing

- Testing programs to establish the presence of system defects

The Testing Process



- Component testing
  - Testing of individual program components
  - Usually the responsibility of the component developer (except sometimes for critical systems)
  - Tests are derived from the developer's experience
- Integration testing
  - Testing of groups of components integrated to create a system or sub-system
  - The responsibility of an independent testing team
  - Tests are based on a system specification

Defect Testing

- The goal of defect testing is to discover defects in programs
- A *successful* defect test is a test which causes a program to behave in an anomalous way
- Tests show the presence not the absence of defects

Exhaustive Testing

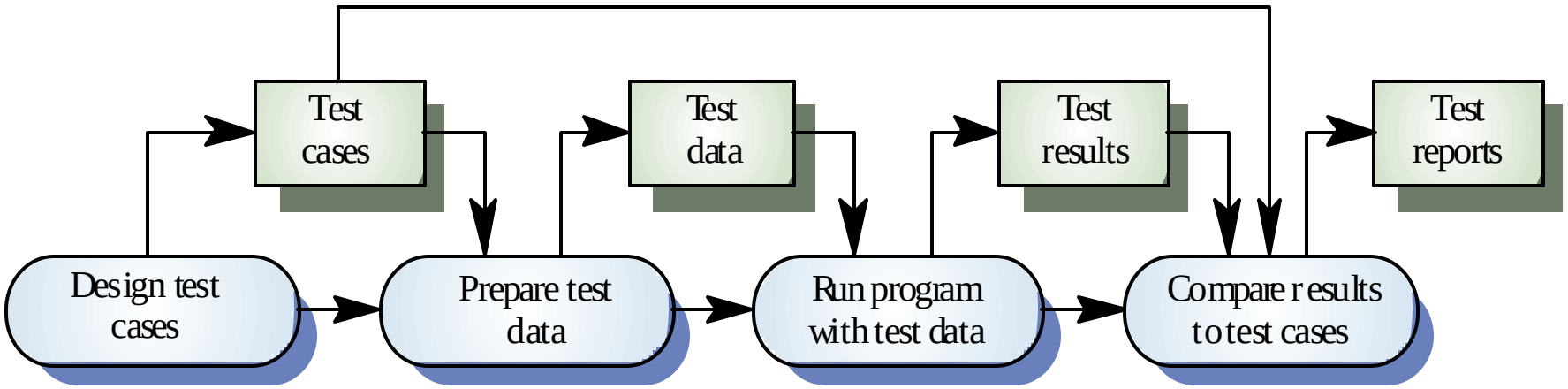
- Only exhaustive testing can show a program is free from defects.

```
for i in 1..100 loop
  if a(i)=true then
    Ada.Integer_Text_IO.put (1);
  else
    Ada.Integer_Text_IO.put (0);
  end if;
end loop;
```

Has 2^{100} different outcomes

Test Data and Test Cases

- *Test data* Inputs which have been devised to test the system
- *Test cases* Inputs to test the system and the predicted outputs from these inputs if the system operates according to its specification



Testing should be:

- Repeatable
  - If you find an error, you'll want to repeat the test to show others
  - If you correct an error, you'll want to repeat the test to check you did fix it
- Systematic
  - Random testing is not enough
  - Select test sets that
    - cover the range of behaviors of the program
    - are representative of real use
- Documented
  - Keep track of what tests were performed, and what the results were

Random Testing is not Enough

Structurally …

```
--Effects: returns True if A=B, False
--         otherwise
if A=B then
  Ada.Text_IO.Put (Item => “True”);
else
  Ada.Text_IO.Put (Item => “False”);
end if;
```

Test strategy: pick random value for A and B and test “equals” on them

Functionally …

```
--Requires: LIST is a list of integers
--Effects:  returns the maximum element
--          in the list

Maximum (LIST)
```

Try these test cases:

Input	Output	Correct?
3 16 4 32 9	32	Yes
9 32 4 16 3	32	Yes
22 32 59 17 88 1	88	Yes
1 88 17 59 32 22	88	Yes
6 1 7 4 5 2 2 5 5 8	8	Yes
8 5 5 2 2 5 4 7 1 6	8	Yes
553 511 1024 332	1024	Yes
332 1024 511 553	1024	Yes

Test Techniques

- Classified according to the criterion used to measure the adequacy of a set of test cases:
  - Coverage-based testing
    - Testing requirements are specified in terms of the coverage of the product to be tested
  - Fault-based testing
    - Fault detecting ability of the test set determines the adequacy
  - Error-based testing
    - Focus on error-prone points, based on knowledge of the typical errors that people make

(Definitions)

- Error
  - Error is a human action that produces an incorrect result
- Fault
  - Consequence of an error is software containing a fault. A fault thus is the manifestion of an error.
- Failure
  - If encountered, a fault may result in a failure
- What we observe during testing are failures.

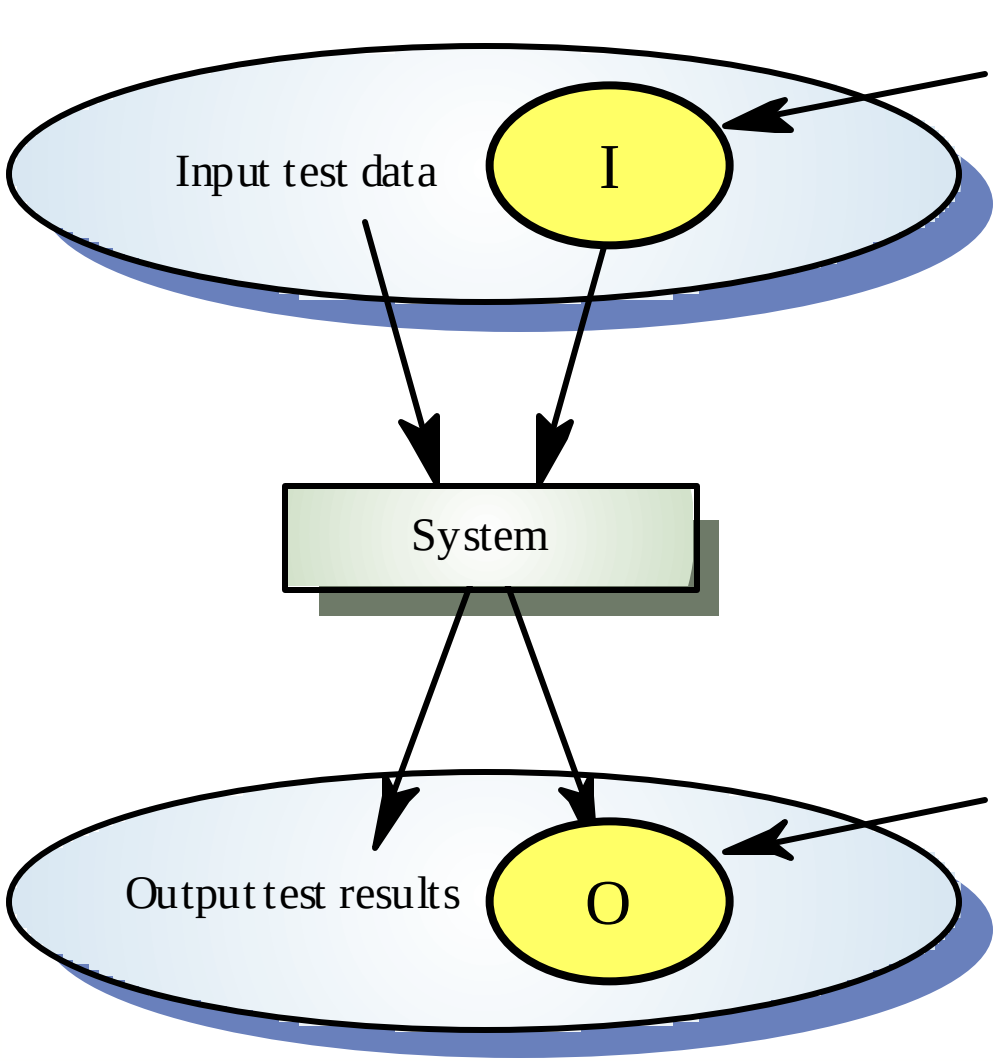
Test Techniques

- Or, classify test techniques based on the source of information used to derive test cases:
  - White (glass) box testing
    - Also called structural or program-based testing
  - Black box testing
    - Also called functional or specification-based testing

Black-box Testing

- An approach to testing where the program is considered as a ‘black-box’
- The program test cases are based on the system specification
- Test planning can begin early in the software process

Black-box Testing



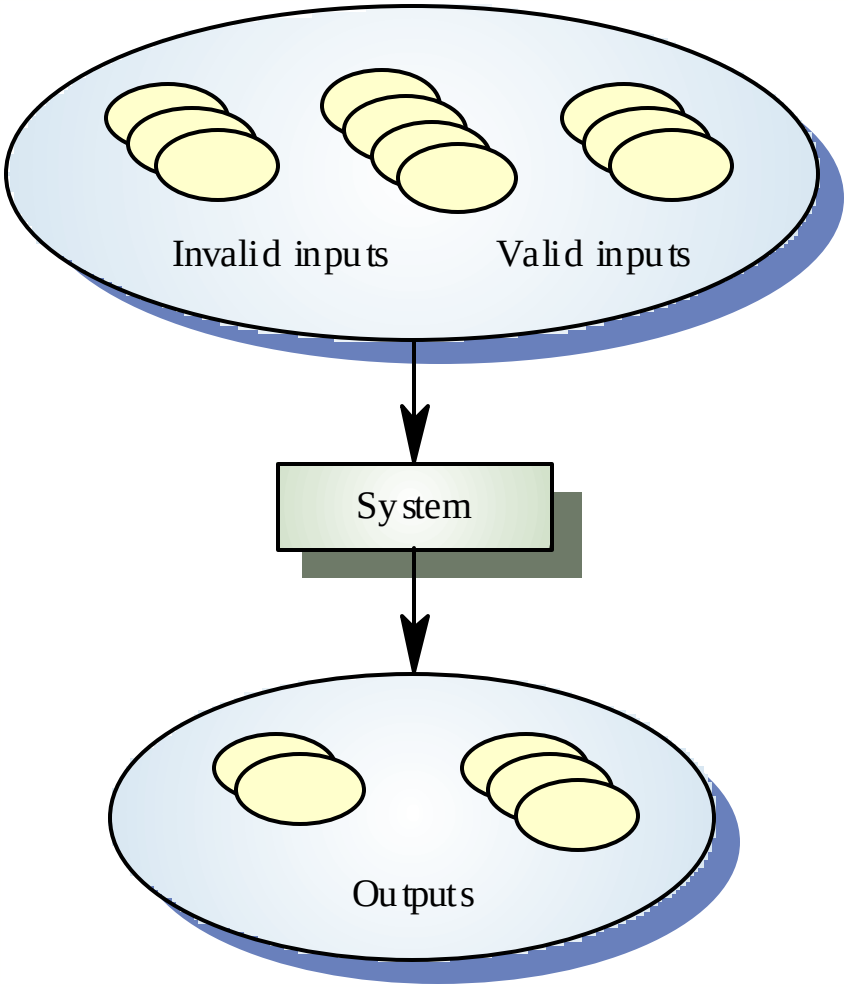
Inputs causing anomalous behavior

Outputs which reveal the presence of defects

Equivalence Partitioning

- Input data and output results often fall into different classes where all members of a class are related
- Each of these classes is an equivalence partition where the program behaves in an equivalent way for each class member
- Test cases should be chosen from each partition

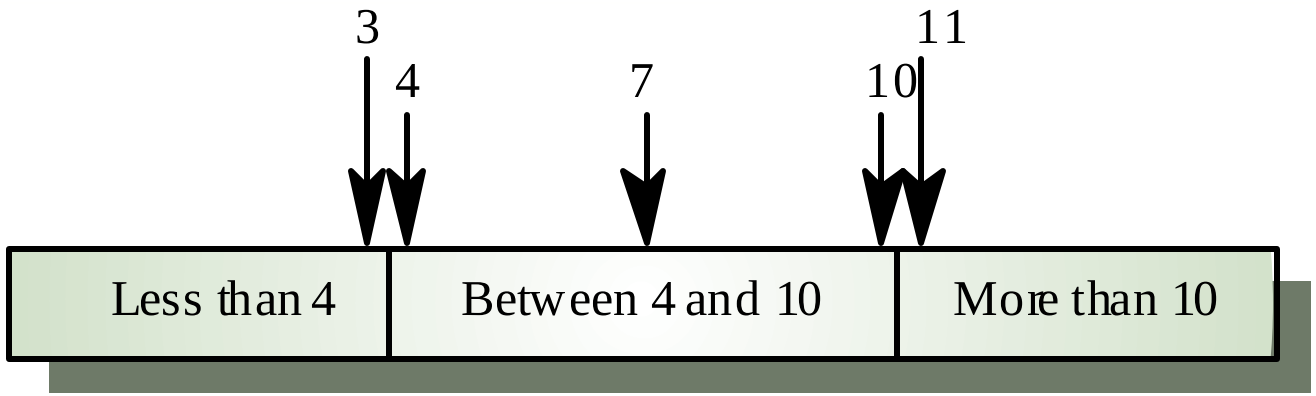
Equivalence Partitioning



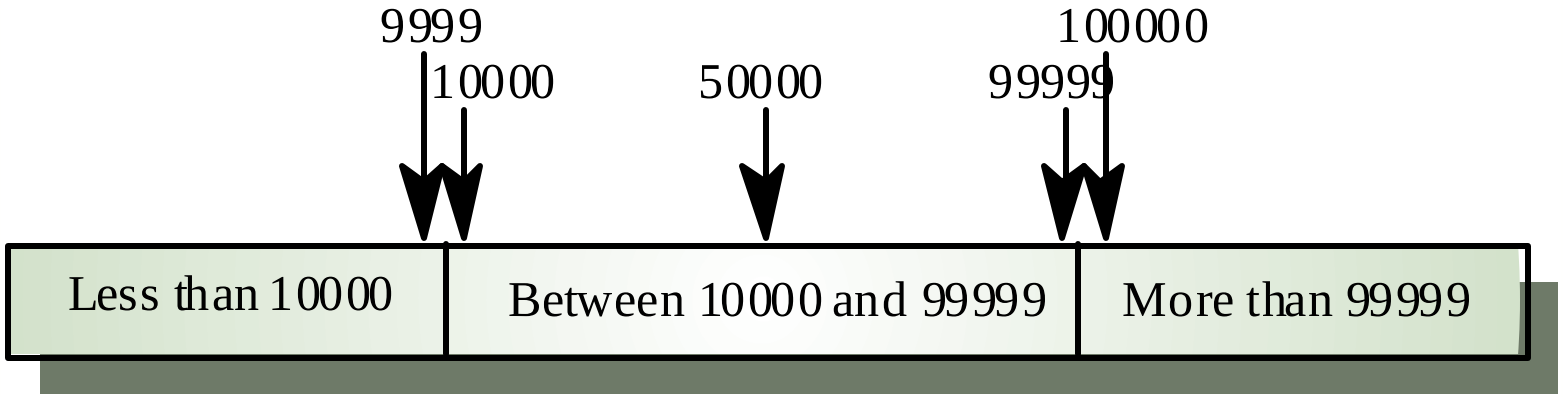
Equivalence Partitioning

- Partition system inputs and outputs into ‘equivalence sets’
  - If input is a 5-digit integer between 10,000 and 99,999, equivalence partitions are <10,000, 10,000-99, 999 and >99,999
- Choose test cases at the boundary of these sets
  - 00000, 09999, 10000, 99999, 100000

Equivalence Partitions



Number of input values



Input values

Search Routine Specification

```
procedure Search (Key   : Elem;
                  T     : Elem_Array;
                  Found : in out Boolean;
                  L     : in out Elem_Index)
```

Pre-Condition

```
-- the array has at least one element
T'First <= T'Last
```

Post-Condition

```
-- the element is found and is referenced by L
( Found and T(L) = Key)
```

or

```
-- the element is not in the array
( not Found and
not (Exists I, T'First >= I <= T'Last, T (I) = Key ))
```

Search Routine - Input Partitions

- Inputs which conform to the pre-conditions
- Inputs where a pre-condition does not hold
- Inputs where the key element is a member of the array
- Inputs where the key element is not a member of the array

Testing Guidelines (Sequences)

- Test software with sequences which have only a single value
- Use sequences of different sizes in different tests
- Derive tests so that the first, middle and last elements of the sequence are accessed
- Test with sequences of zero length

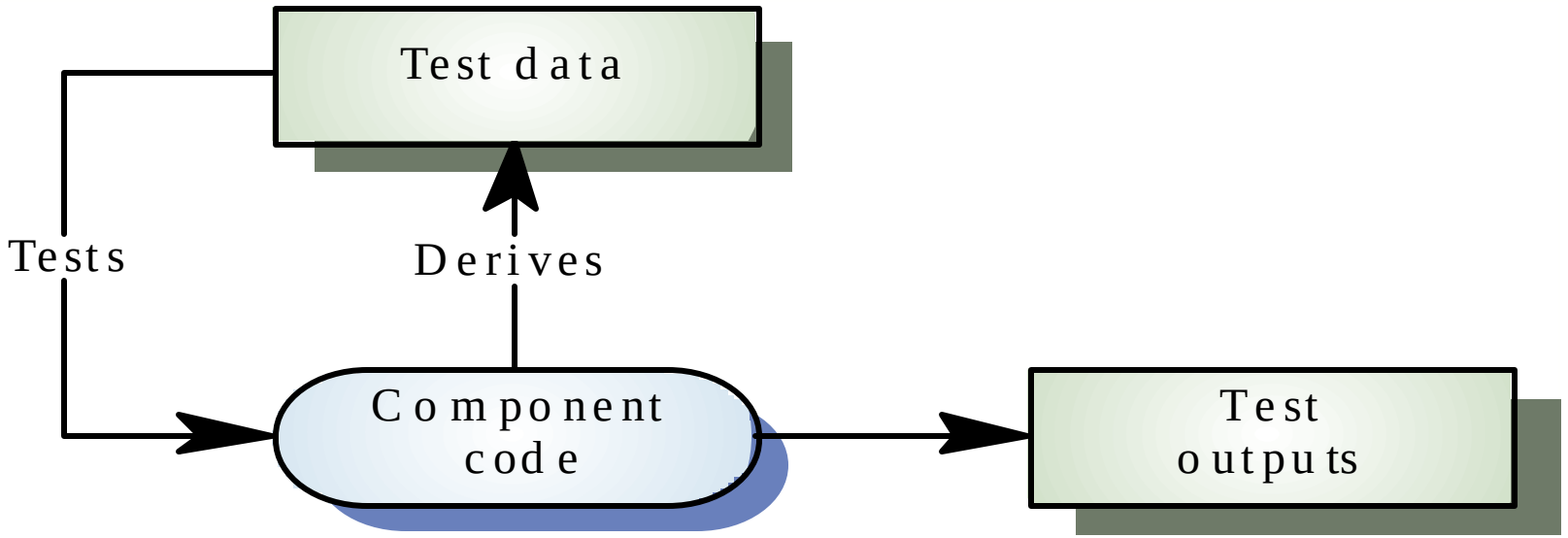
Search Routine - Input Partitions

Array	**Element**
Single value	In sequence
Single value	Not in sequence
More than 1 value	First element in sequence
More than 1 value	Last element in sequence
More than 1 value	Middle element in sequence
More than 1 value	Not in sequence

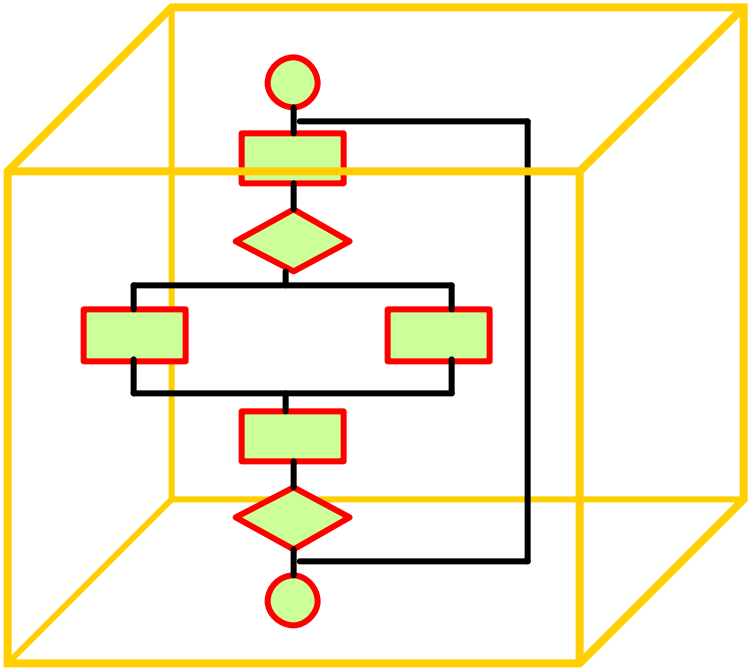
Input sequence (T)	**Key** (Key)	**Output** (Found, L)
17	17	true, 1
17	0	false, ??
17, 29, 21, 23	17	true, 1
41, 18, 9, 31, 30, 16, 45	45	true, 7
17, 18, 21, 23, 29, 41, 38	23	true, 4
21, 23, 29, 33, 38	25	false, ??

Structural Testing

- Also called white-box testing
- Derivation of test cases according to program structure. Knowledge of the program is used to identify additional test cases
- Objective is to exercise all program statements



White box testing

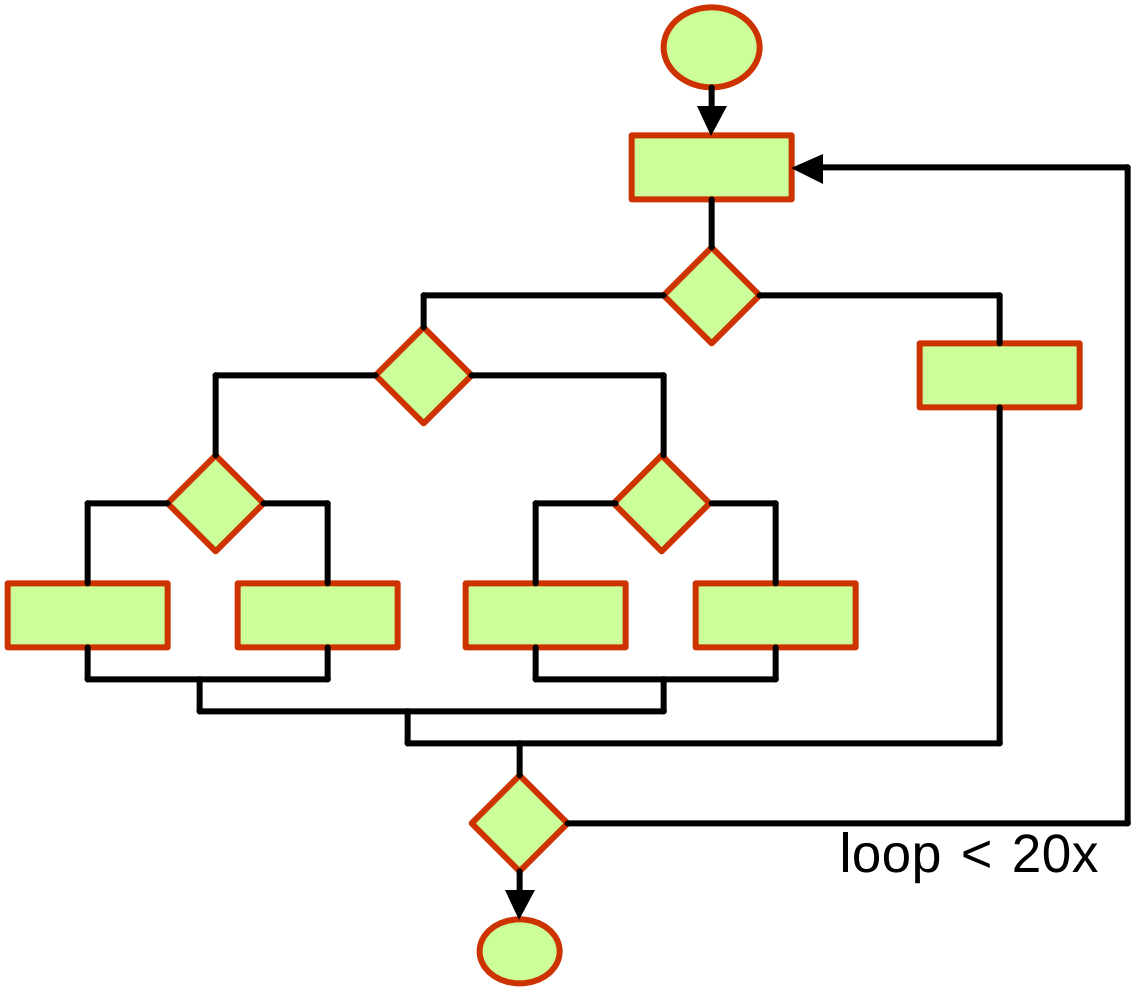


- Exercise all independent paths within a module at least once
- Exercise all logical decisions on their true and false sides
- Exercise all loops at their boundaries and within their operational bounds
- Exercise all internal data structures to assure their validity

Why White Box Testing

- Why not simply check that
  - Requirements are fulfilled?
  - Interfaces are available and working?
- Reasons for white-box testing:
  - logic errors and incorrect assumptions are inversely proportional to a path's execution probability
  - we often believe that a path is not likely to be executed; in fact, reality is often counter intuitive
  - typographical errors are random; it's likely that untested paths will contain some

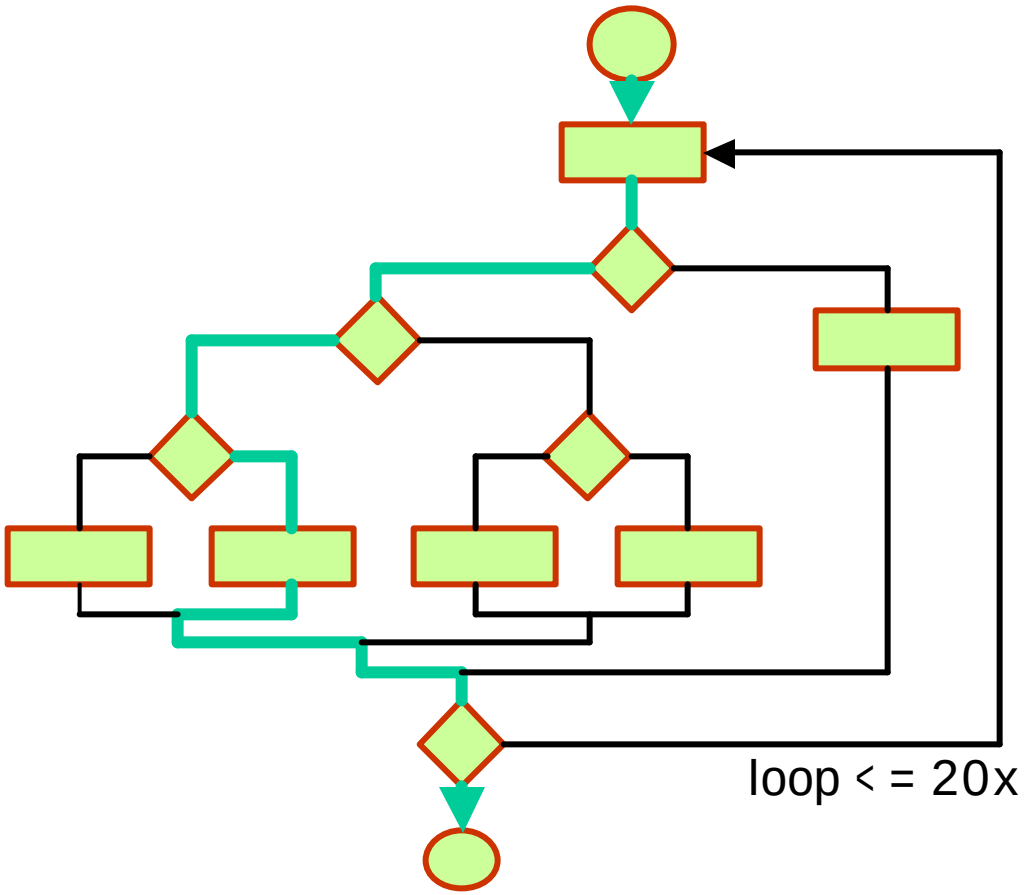
Exhaustive Testing



There are $5^{20=}10^{14}$ possible paths

If we execute one test per millisecond, it would take 3,170 years to test this program

Selective Testing

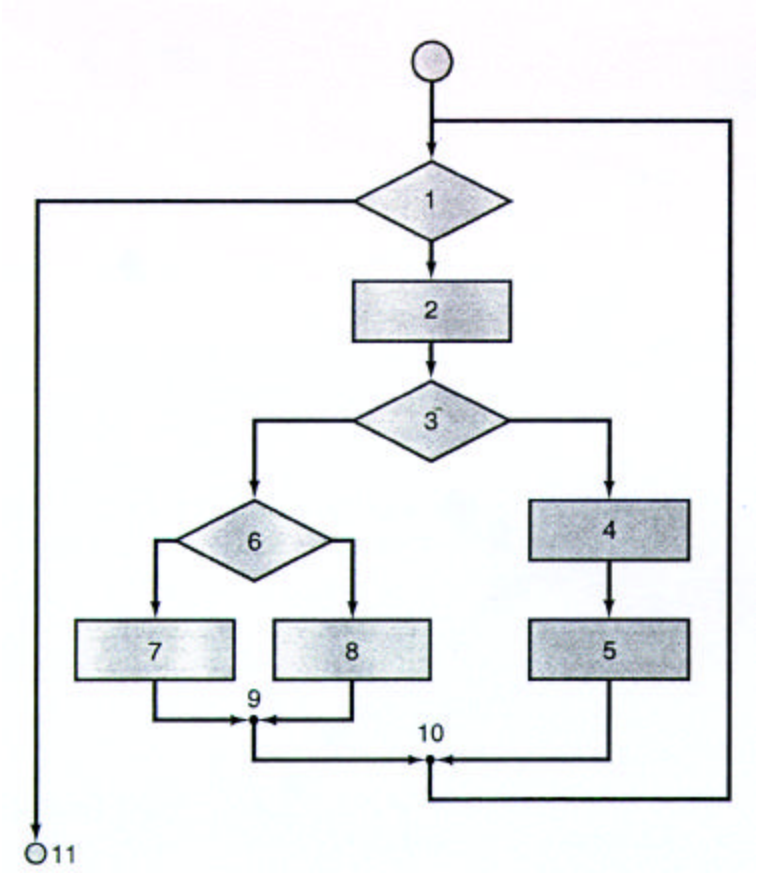


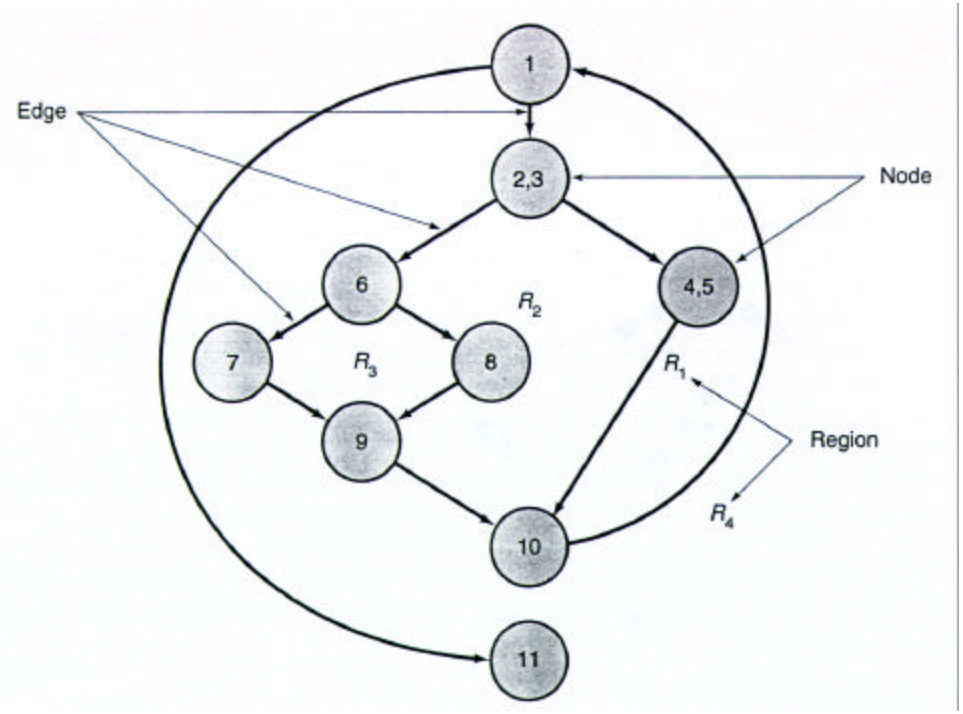
- Basis path testing
- Condition testing
- Loop testing
- Dataflow testing

Basis Set

- Basis set of execution paths = set of paths that will execute all statements and all conditions in a program at least once
- Cyclomatic complexity defines the number of independent paths in the basis set
- Basis set is not unique
- Goal: Define test cases for basis set

Flow Graph Notation

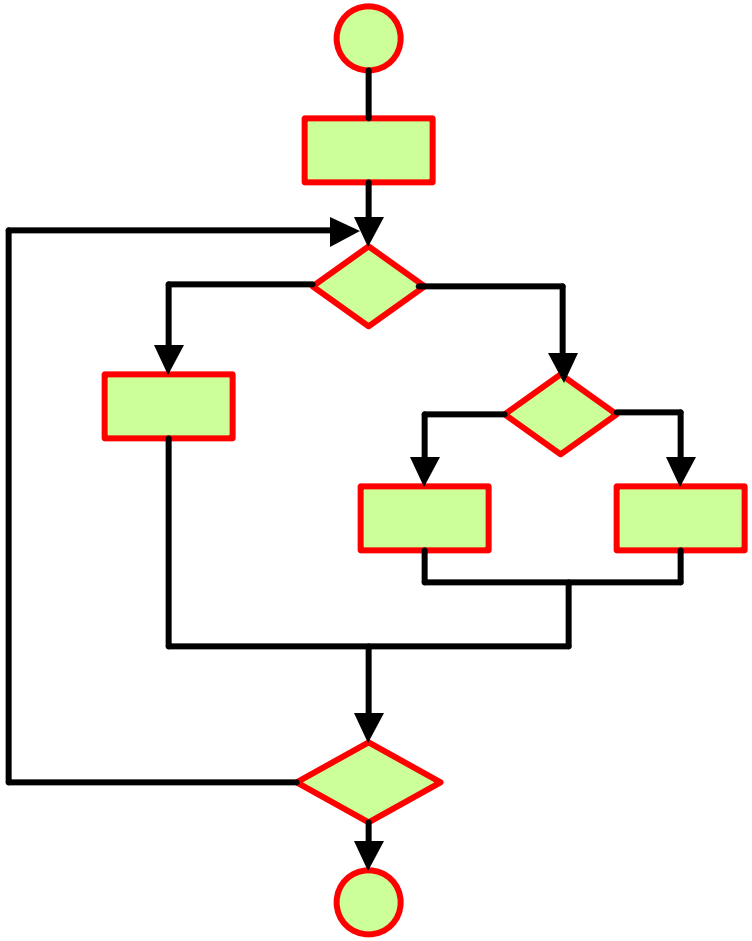




Graph Cyclomatic Number V(G) = e – n + p

Cyclomatic Complexity CV(G) = V(G) + 1

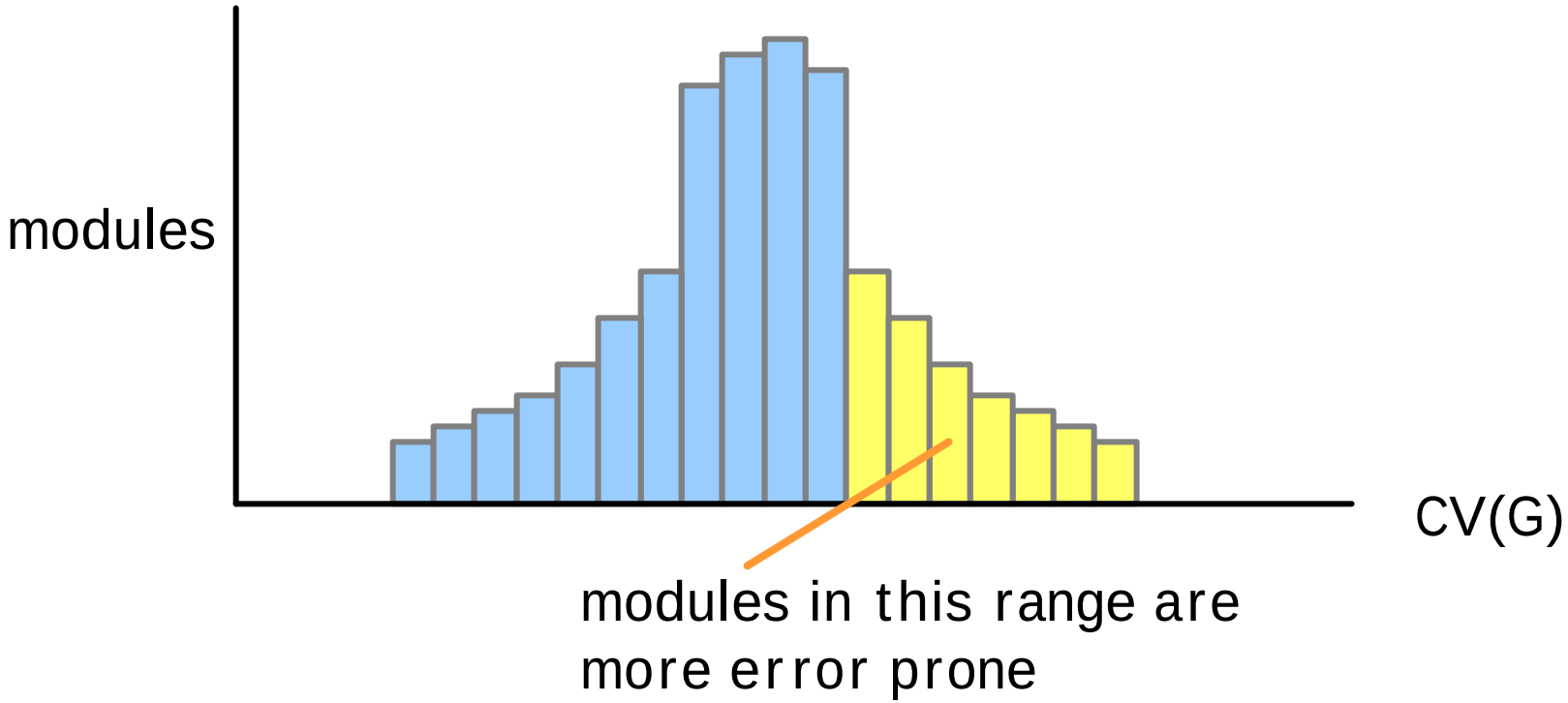
Basis Path Testing



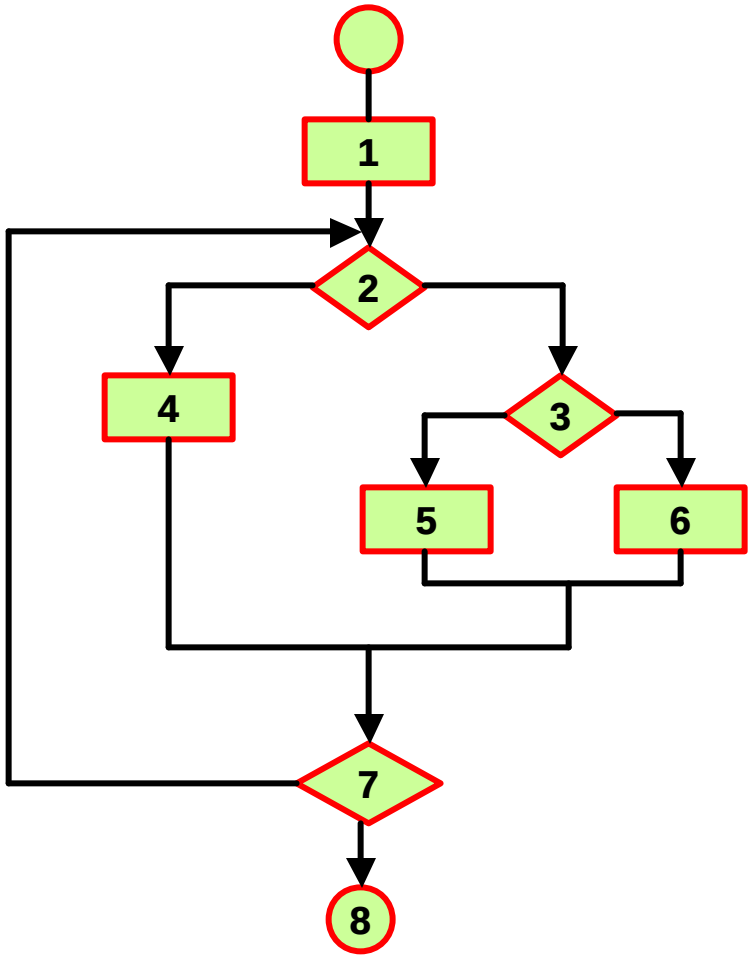
- Derive a logical complexity measure
  - Cyclomatic complexity CV(G)
    - Number of simple decisions +p (compound decisions have to be split)
    - Number of enclosed areas+1 (uses flow-graph notation)
  - In this case, CV(G) = 4
- Use CV(G) to define a basis set of execution paths
  - CV(G) provides an lower bound of tests that must be executed to guarantee coverage of all programs

Cyclomatic Complexity

A number of industry studies have indicated that the higher CV(G), the higher the probability of errors.



Basis Path Testing



CV(G) = 4

There are four paths

Path 1:	1,2,3,6,7,8
Path 2:	1,2,3,5,7,8
Path 3:	1,2,4,7,8
Path 4:	1,2,4,7,2…7,8

We derive test cases to exercise these paths.

Selective Testing

- Basis path testing
- Condition testing
- Loop testing
- Dataflow testing

Condition Testing

- Exercises each logical condition in a program module
- Possible conditions:
  - Simple condition:
    - Boolean variable (T or F)
    - Relational expression (a<b)
  - Compound condition:
    - Composed of several simple conditions ((a=b) and (c>d))

Condition Testing Methods

- Branch testing:
  - Each branch of each condition needs to be exercised at least once
- Domain testing:
  - Relational expression a<b:
    - 3 tests: a<b, a=b, a>b
  - Boolean expression with n variables
    - 2n tests required

Selective Testing

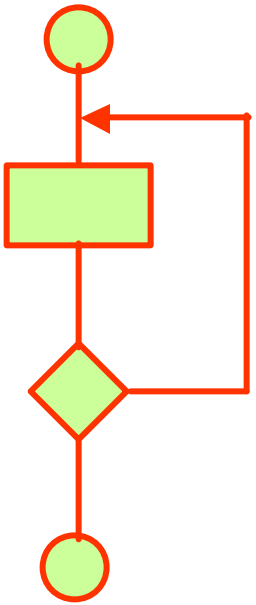
- Basis path testing
- Condition testing
- Loop testing
- Dataflow testing

Loop Testing

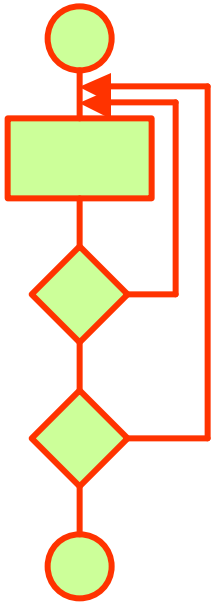
- Loops are the cornerstone of every program
- Loops can lead to non-terminating programs
- Loop testing focuses exclusively on the validity of loop constructs

```
while X < 20 loop
   do something
end loop;
```

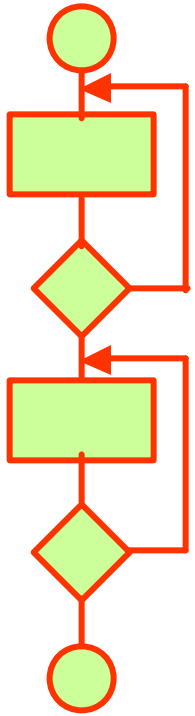
Loop Testing



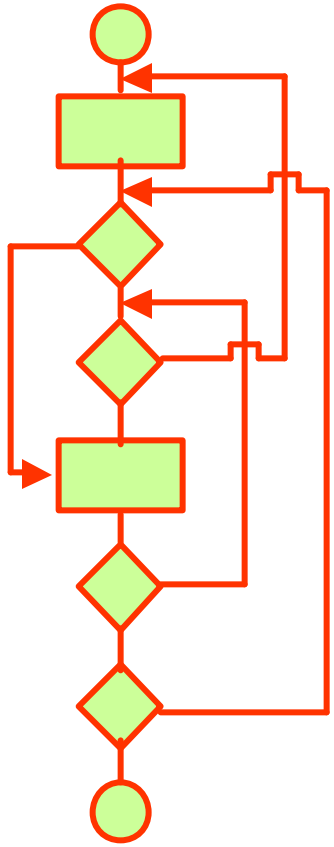
simple loop



nested loops

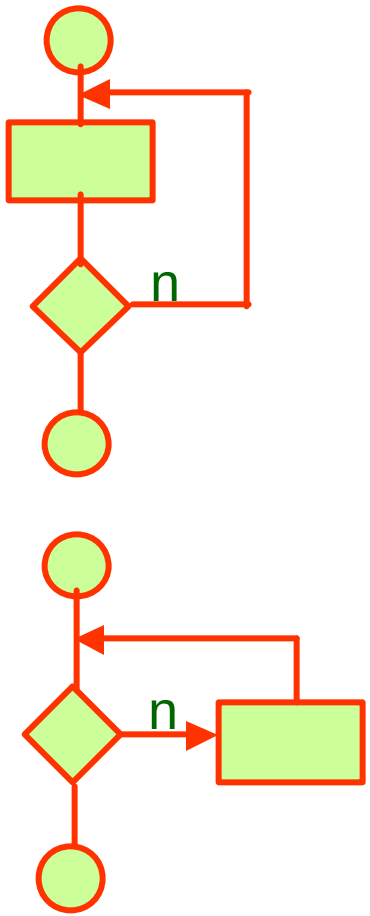


concatenated loops



unstructured loops

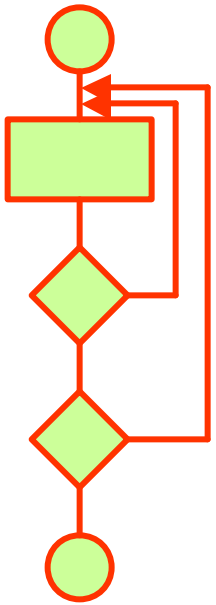
Testing Simple Loops



- Minimum conditions - simple loops
  - skip the loop entirely
  - only one pass through the loop
  - two passes through the loop
  - m passes through the loop m < n
  - (n-1), n, and (n+1) passes through the loop

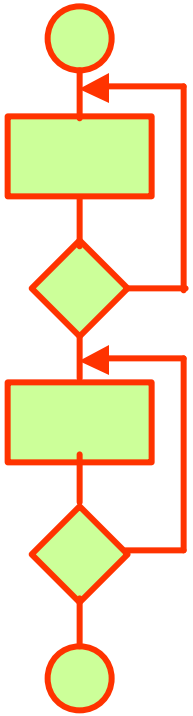
    n = maximum number of allowable passes

Testing Nested Loops



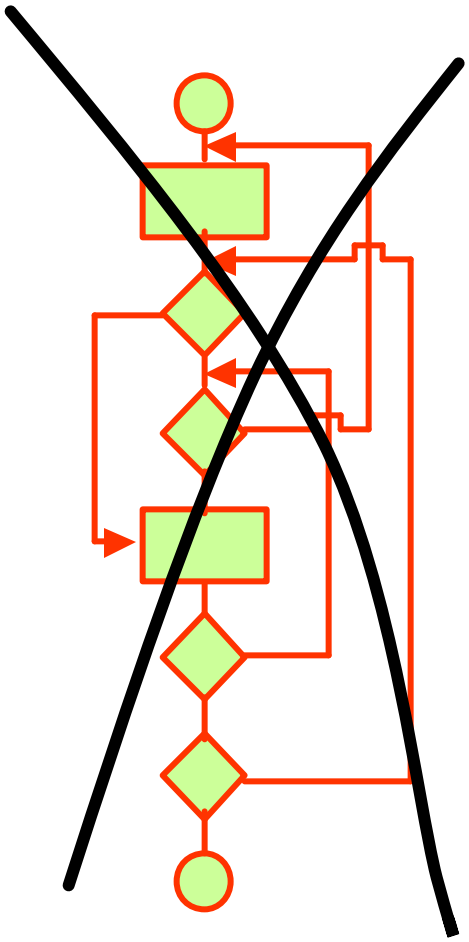
- Just extending simple loop testing: number of tests grows geometrically
- Reduce the number of tests:
  - start at the innermost loop; set all other loops to minimum values
  - conduct simple loop test; add out-of-range or excluded values
  - work outwards while keeping inner nested loops to typical values
  - continue until all loops have been tested

Testing Concatenated Loops



- Loops are independent of each other:
  - Use simple-loop approach
- Loops depend on each other:
  - Use nested-loop approach

Testing Unstructured Loops

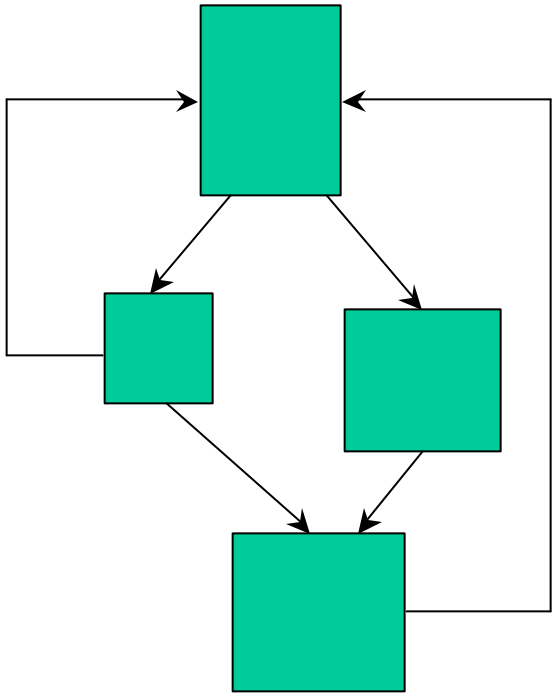


Bad Programming!

Selective Testing

- Basis path testing
- Condition testing
- Loop testing
- Dataflow testing

Dataflow Testing



- Partition the program into pieces of code with a single entry/exit point.
- For each piece find which variables are set/used.
- Various covering criteria:
  - For all set-use pairs
  - For all set to some use

Key Points

- Verification and validation are not the same thing. Verification shows conformance with specification; validation shows that the program meets the customer's needs
- Test plans should be drawn up to guide the testing process
- Static verification techniques involve examination and analysis of the program for error detection

Key Points

- Test parts of a system which are commonly used rather than those which are rarely executed
- Equivalence partitions are sets of test cases where the program should behave in an equivalent way
- Black-box testing is based on the system specification
- Structural testing identifies test cases which cause all paths through the program to be executed
- Test coverage measures ensure that all statements have been executed at least once

- Examination schedule
  - Wednesday, Dec 18. 1:30 pm – 4:30 pm.
- web.mit.edu/www/16.35
  - Questions and Answers section on project page
- Software development plan and problem set 1.
- SRS document due on Monday 9/30
  - X-38 Software Requirements Specification
  - Software Requirements Specification Template