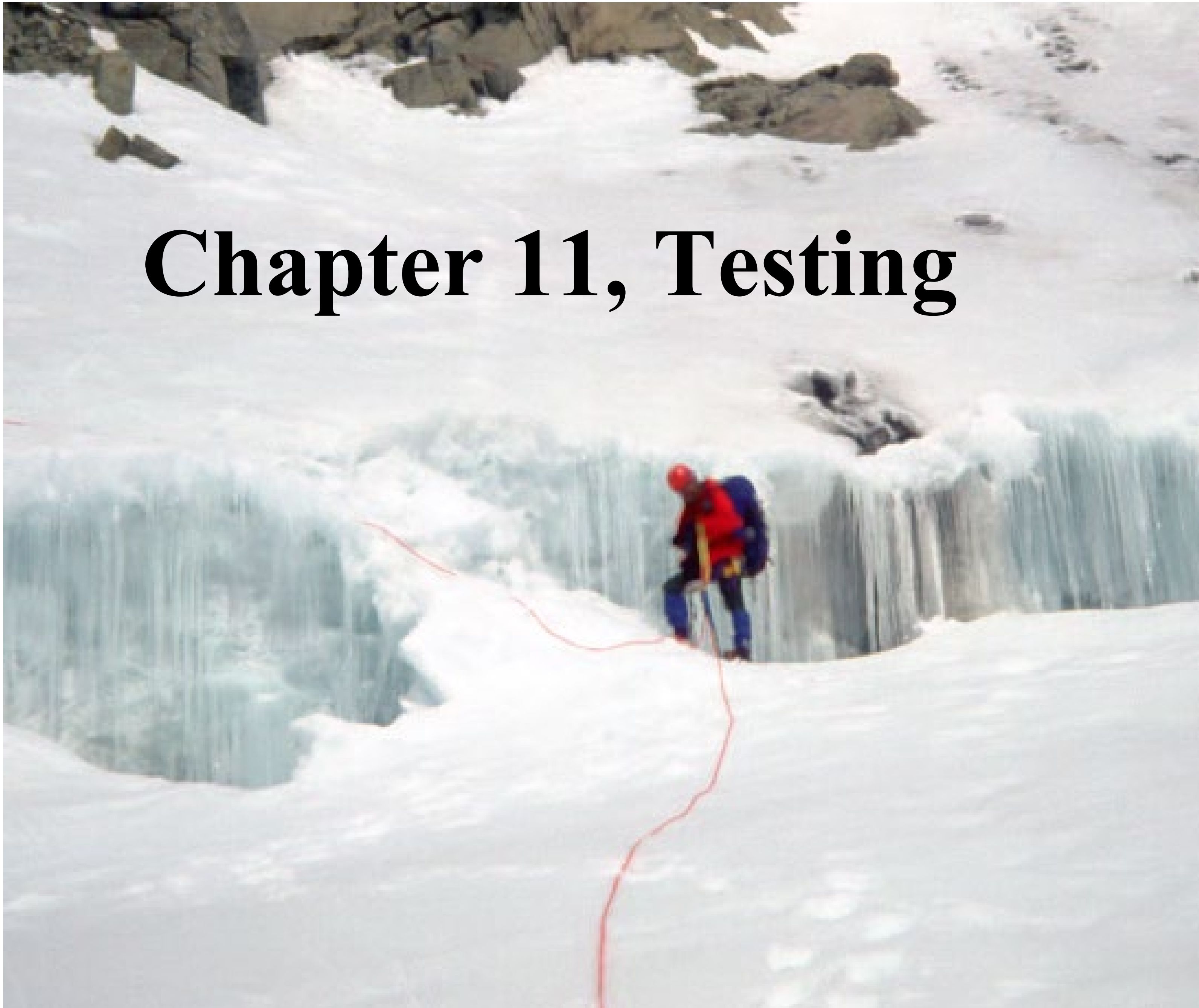
**Object-Oriented Software Engineering**
Using UML, Patterns, and Java

# Chapter 11, Testing

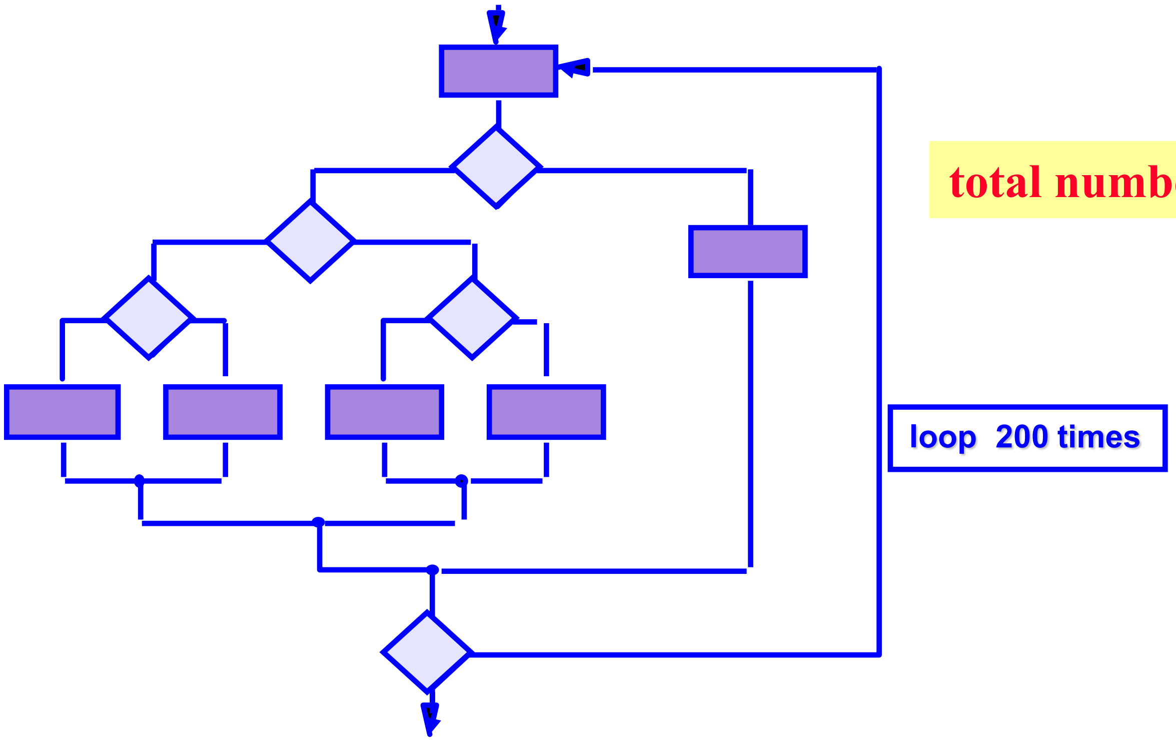


# *Outline*

- Terminology
- Types of errors
- Dealing with errors
- Quality assurance vs Testing
- Component Testing
  - **Unit testing**
  - **Integration testing**
- Testing Strategy
- Design Patterns & Testing
- System testing
  - **Function testing**
  - **Structure Testing**
  - **Performance testing**
  - **Acceptance testing**
  - **Installation testing**

# *Some Observations*

- It is impossible to completely test any nontrivial module or any system
  - **Theoretical limitations: Halting problem** ??
  - **Practial limitations: Prohibitive in time and cost**
- Testing can only show the presence of bugs, not their absence (Dijkstra)

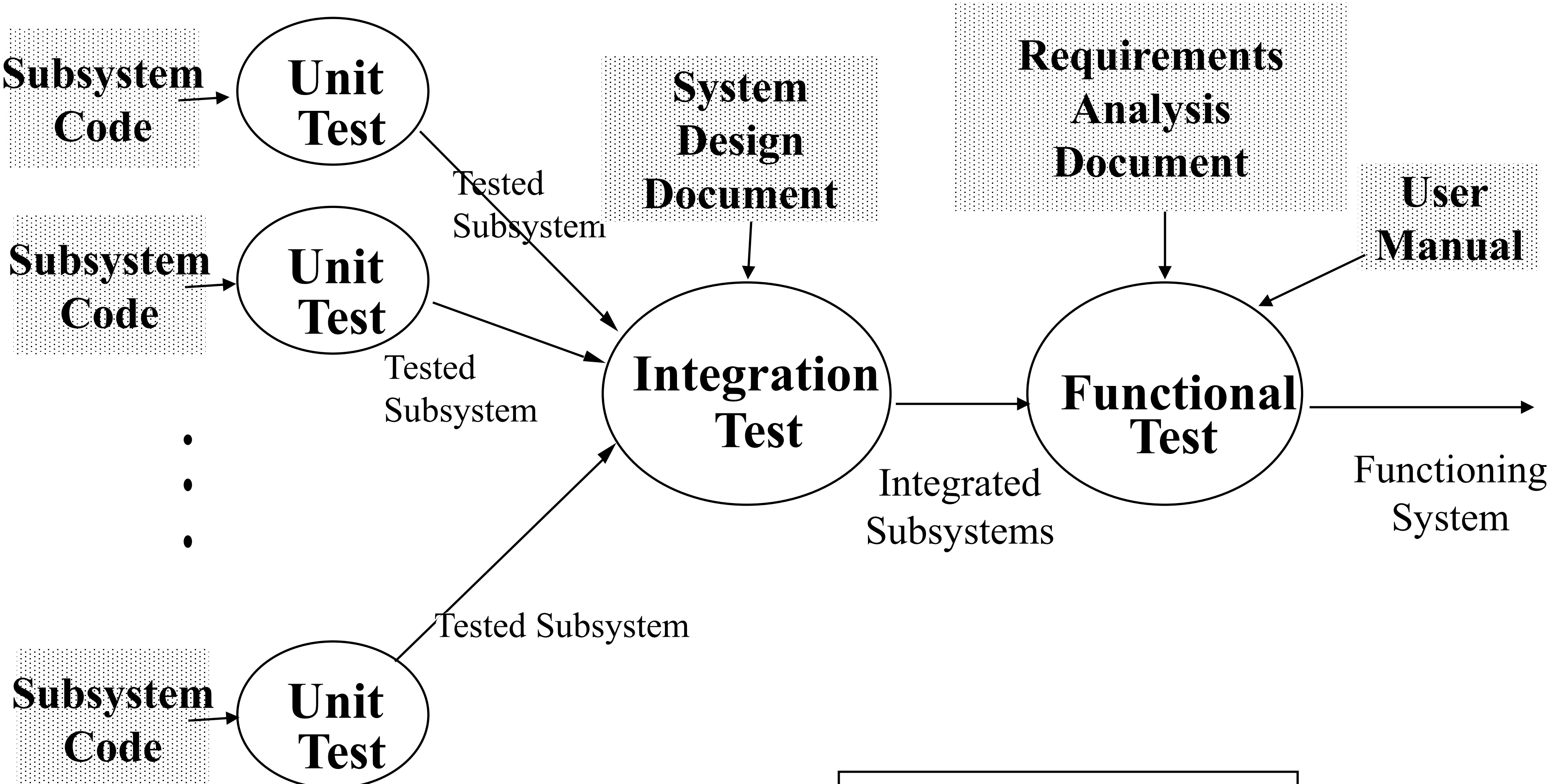



**total number of execution paths?**

# *Testing Takes Creativity*

- Testing often viewed as dirty work.
- To develop an effective test, one must have:
    - **Detailed understanding of the system**
    - **Knowledge of the testing techniques**
    - **Skill to apply these techniques in an effective and efficient manner**
- Testing is done best by independent testers
    - **We often develop a certain mental attitude that the program should in a certain way when in fact it does not.**
- Programmer often stick to the data set that makes the program work
    - **"Don’t mess up my code!"**
- A program often does not work when tried by somebody else.
    - **Don't let this be the end-user.**

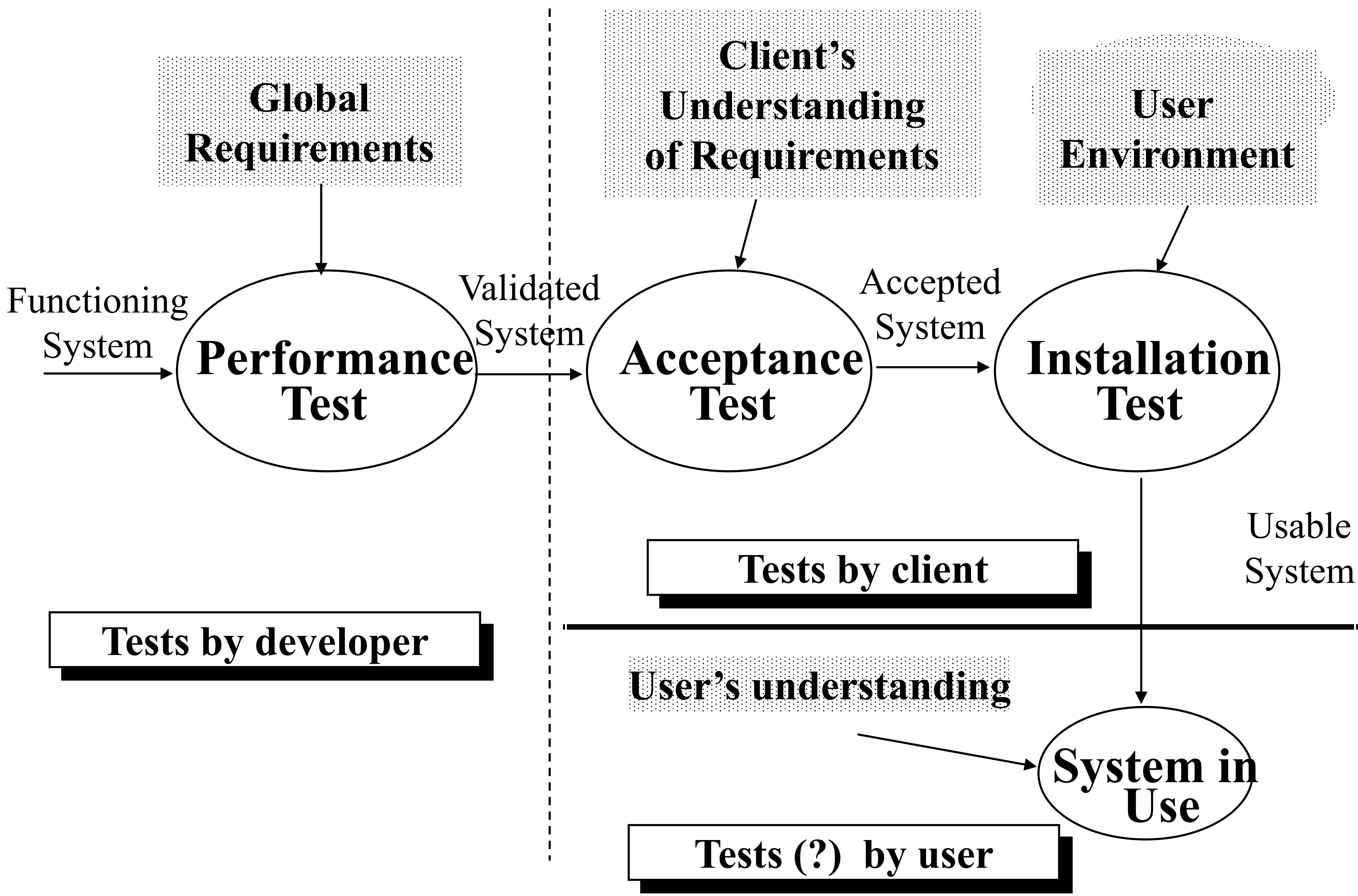
# *Testing Activities*



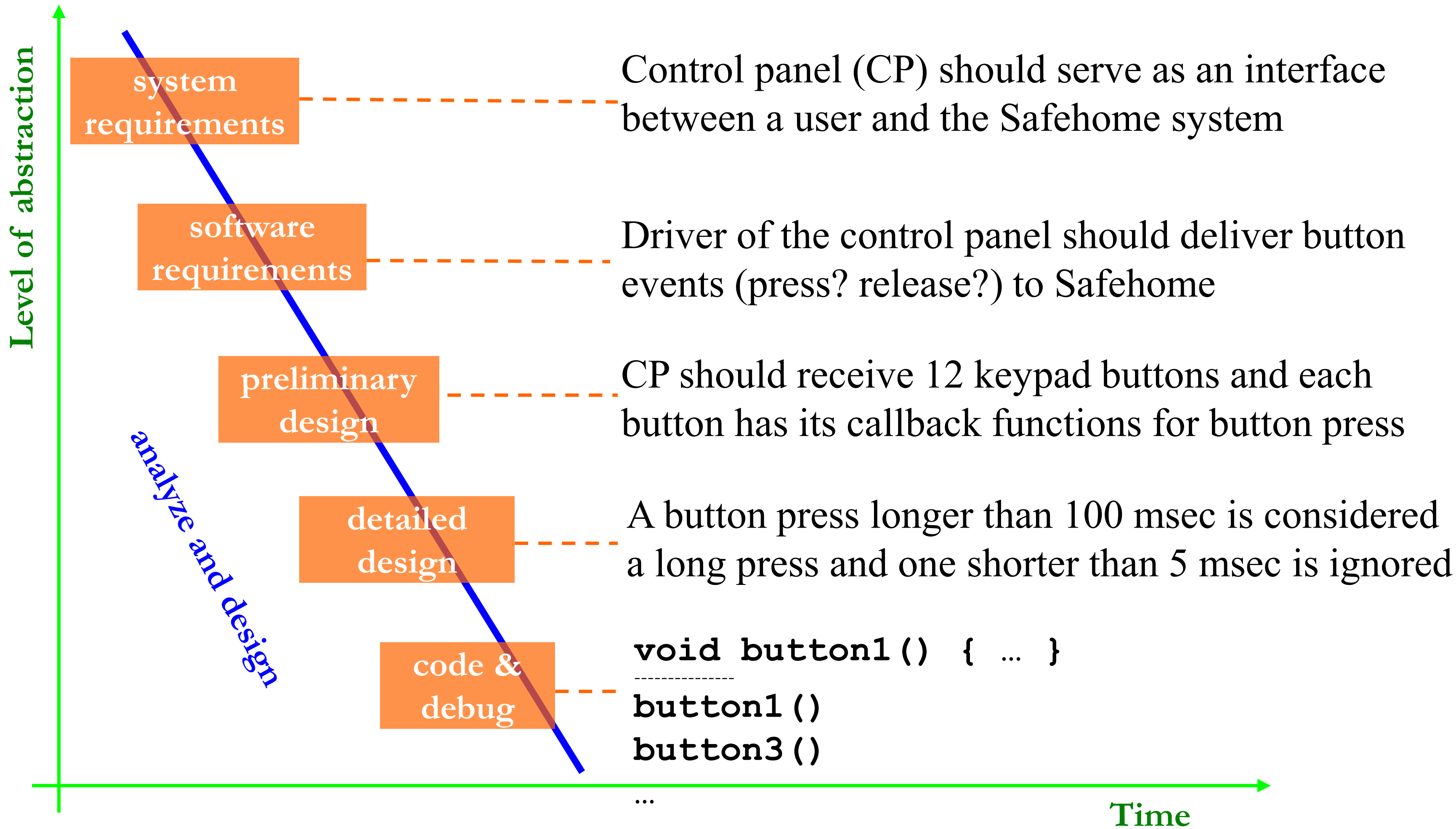

**All tests by developer**

**Cf. levels of testing**

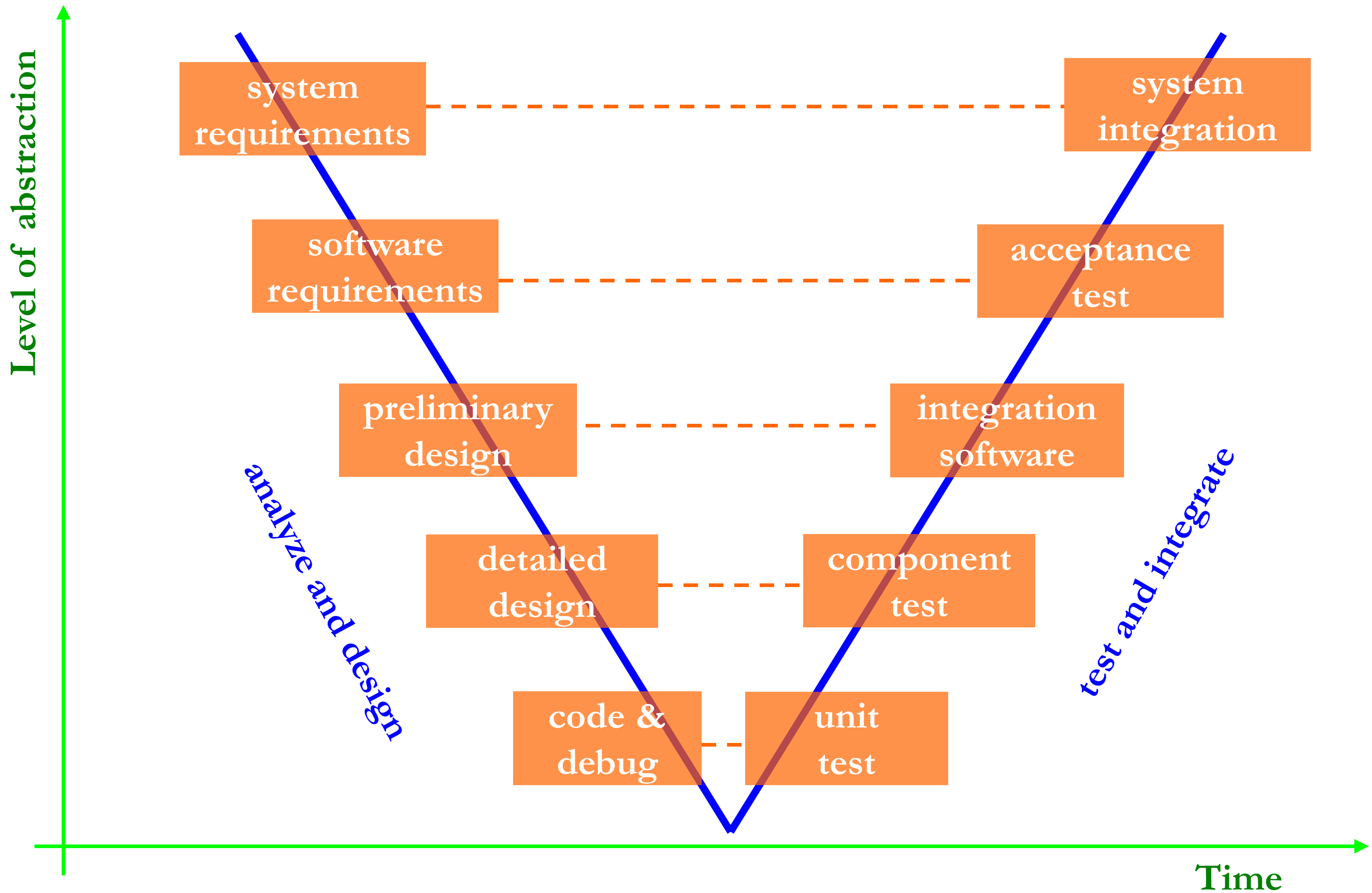
# *Testing Activities continued*



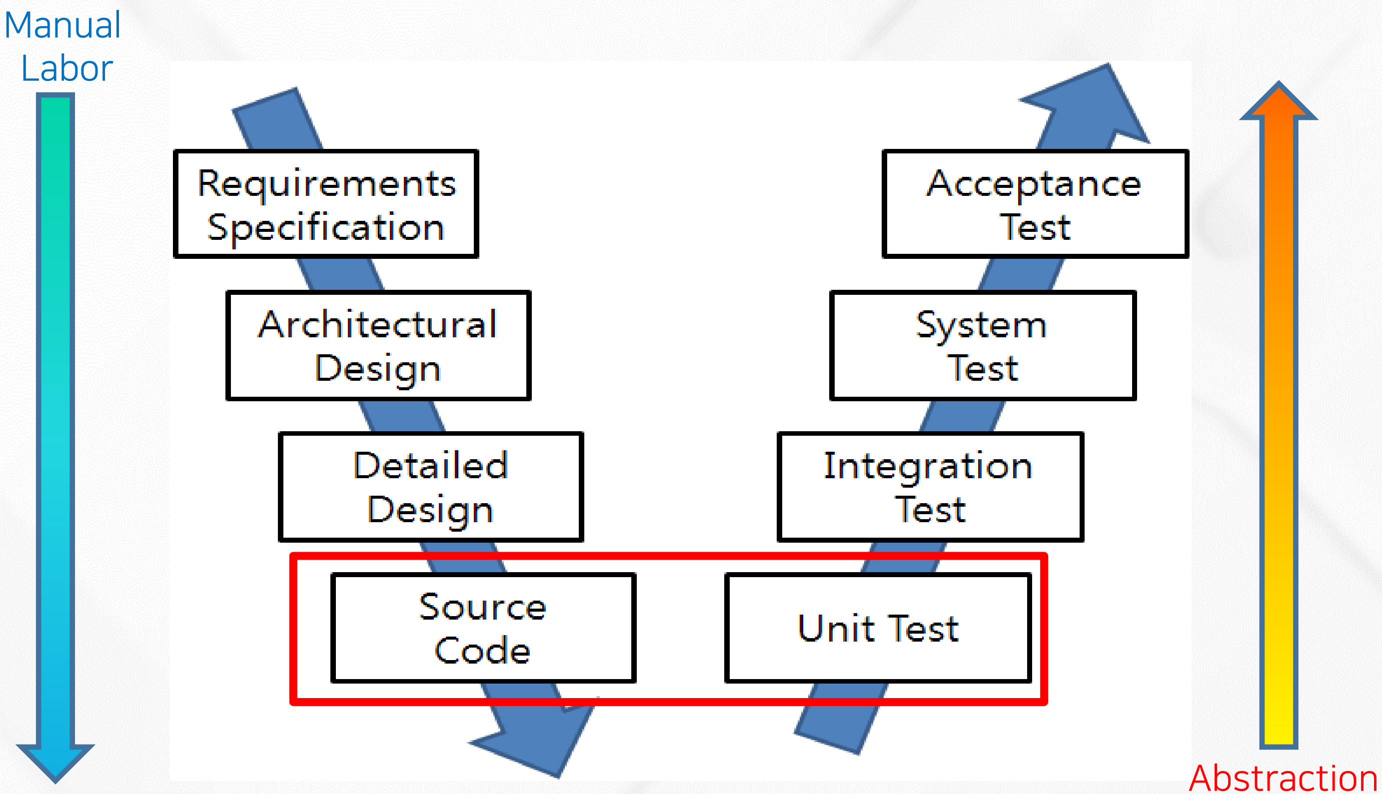
# *Safehome Example: Levels of Designs in V Model*



# Levels of Testing in V Model



# SW Development and Testing Model (V model)

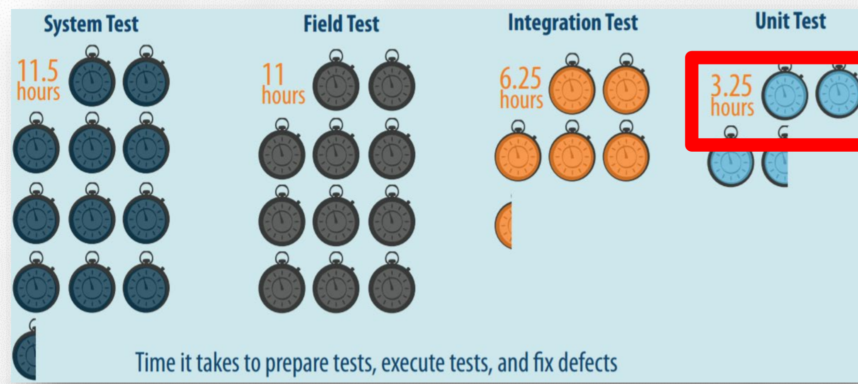


# Many Benefits of Unit Testing

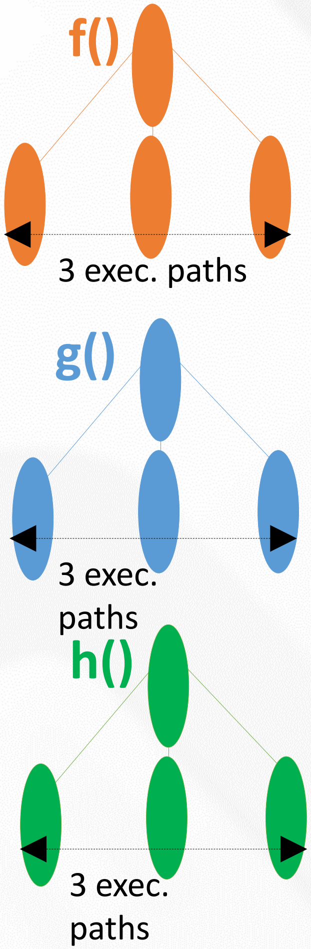
- **Bug correction cost: 7x cheaper** than system tests
  - $937 (unit test) vs $7,136 (system test)

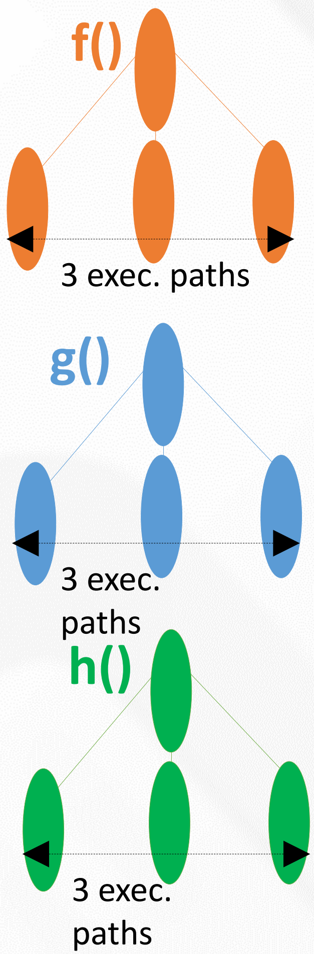

Source: B. Boehm and V. Basil, Software Defect Reduction Top 10 List, IEEE Computer, January 2001

- **Bug correction time: 3x faster** than system testing
  - 3.25 hours vs 11.5 hours

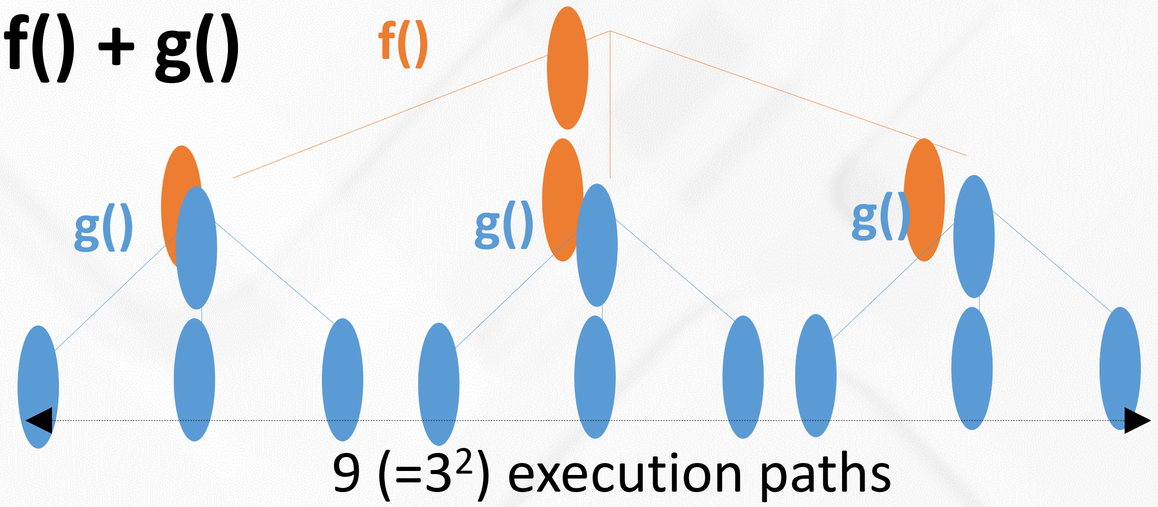


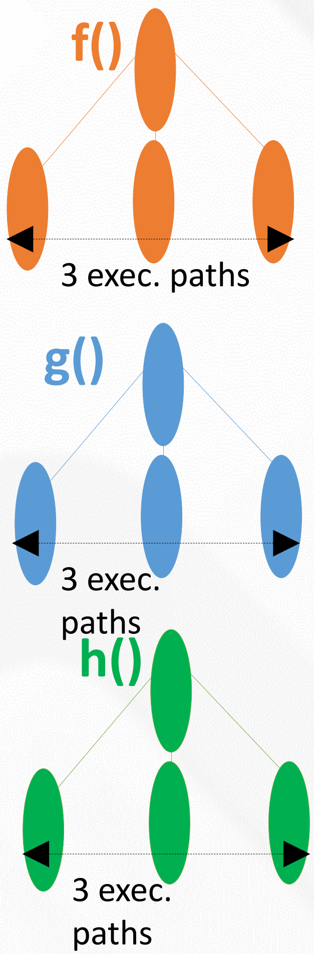

Source: Capers Jones, Applied Software Measurement: Global Analysis of Productivity and Quality


f()
3 exec. paths
g()
3 exec. paths
h()
3 exec. paths

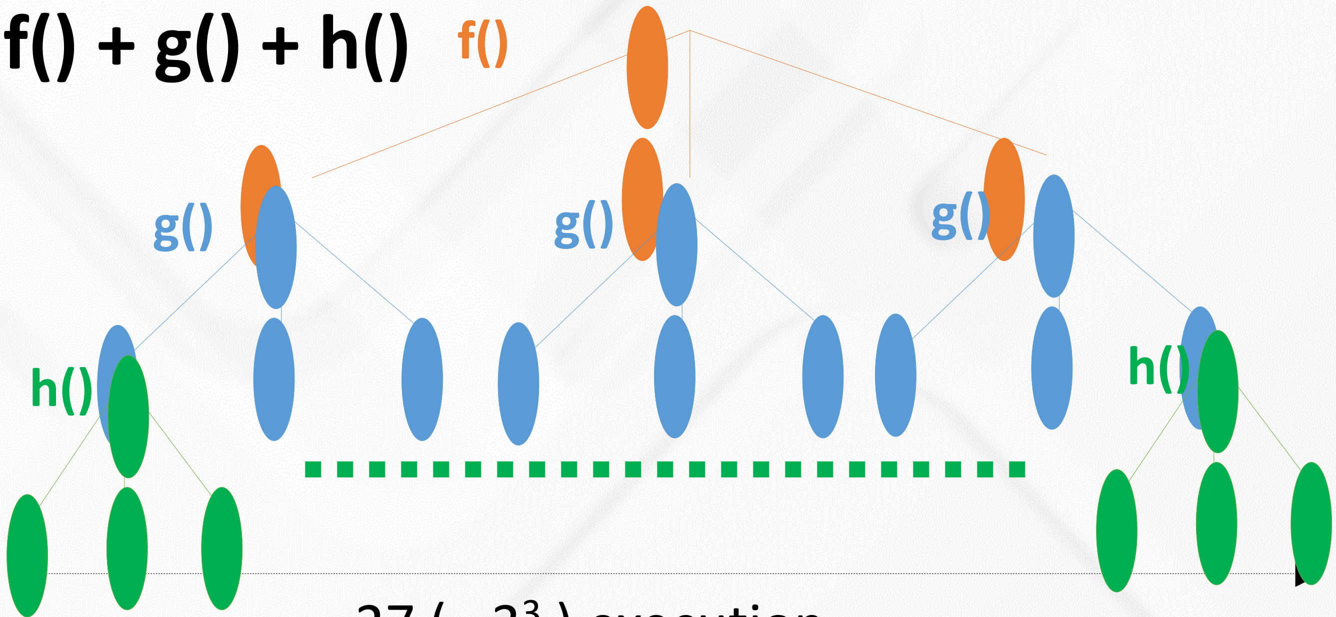

f()
3 exec. paths
g()
3 exec. paths
h()
3 exec. paths

# f() + g()


f()
g()
g()
g()
9 (=$3^2$) execution paths




# f() + g() + h()

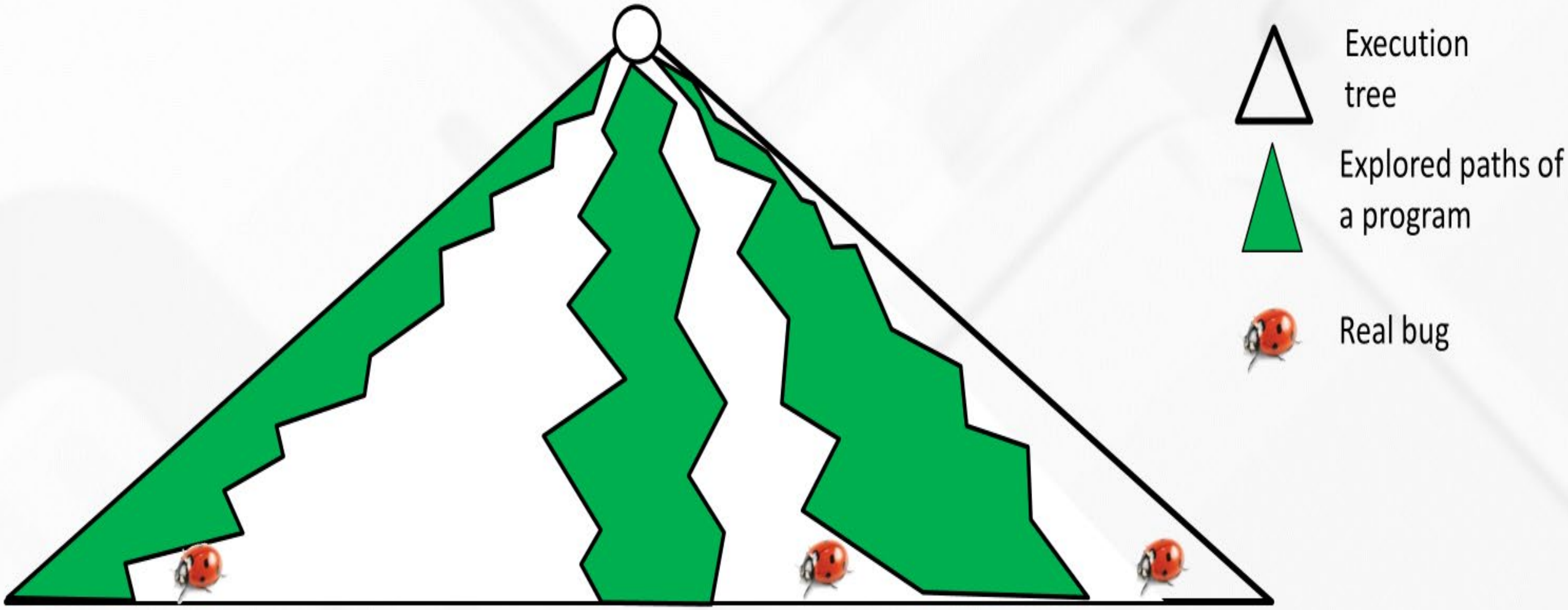



27 (= $3^3$ ) execution paths

# Pros and Cons of Auto. Test Gen. in **System-level**

› Pros: **No false alarms**

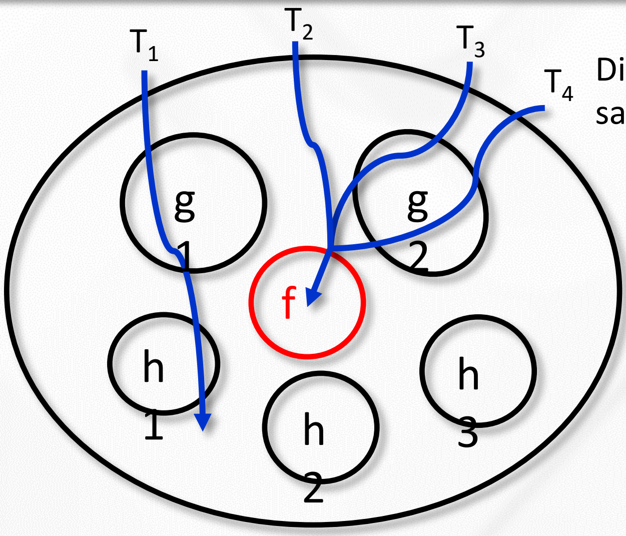
› Cons: Low bug detection power due to **large search space**



# Automated Test Generation in **System-Level**

Pros
+ Can be easy to generate system TCs due to clear interface specification
+ No false alarm (i.e., no assert violation caused by infeasible execution scenario)

**Cons**
**- Low controllability of each unit**
**- Large and complex search space to explore in a limited time**
**- Hard to detect bugs in corner cases**

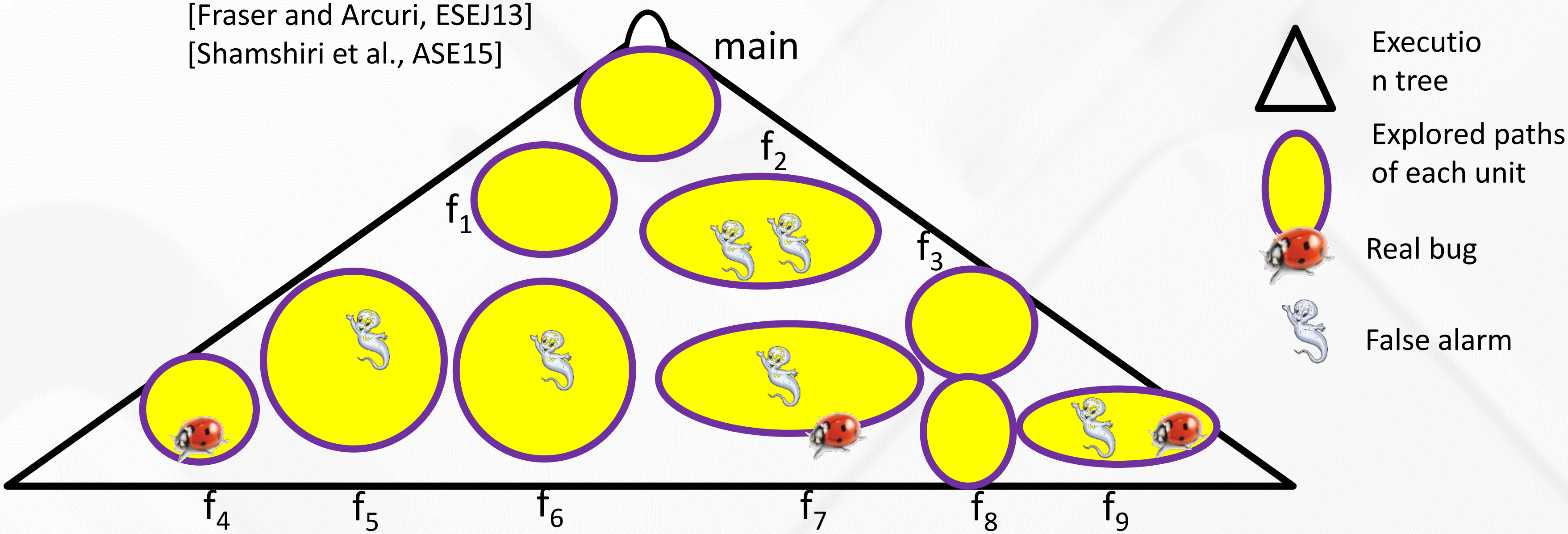



Different system tests $T_2$ to $T_4$ exercise the same behavior of the target unit

# Pros and Cons of Auto. Test Gen. in **Unit-level**

- Pros: High bug detection power for **small search space**
- Cons: **Many false alarms** due to over-approximated context of a unit

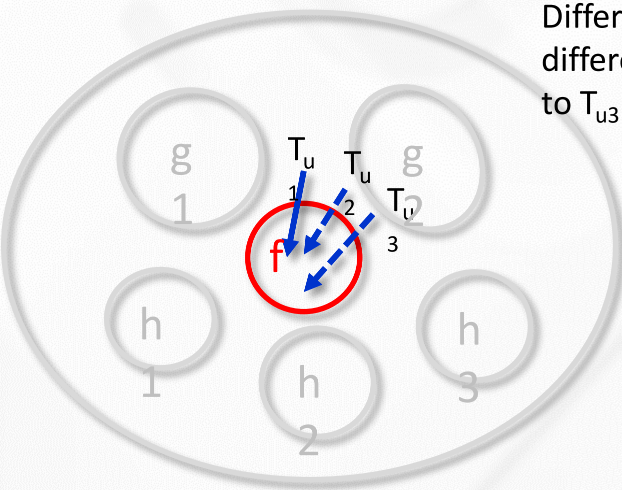
[Gross et al., ISSTA12]
[Fraser and Arcuri, ESEJ13]
[Shamshiri et al., ASE15]



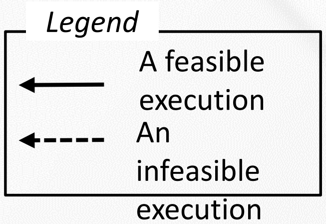
# Automated Test Generation in Unit-Level

Pros
+ High controllability of a target unit
+ Smaller search space to explore than system testing
+ High effectiveness for detecting corner cases bugs

**Cons**
**- Hard to write down accurate unit test drivers/stubs due to unclear unit specification**
**- High false/true alarm ratio**




Different unit tests $T_{u1}$ to $T_{u3}$ directly exercise different behaviors of the target unit, but $T_{u2}$ to $T_{u3}$ exercise infeasible paths

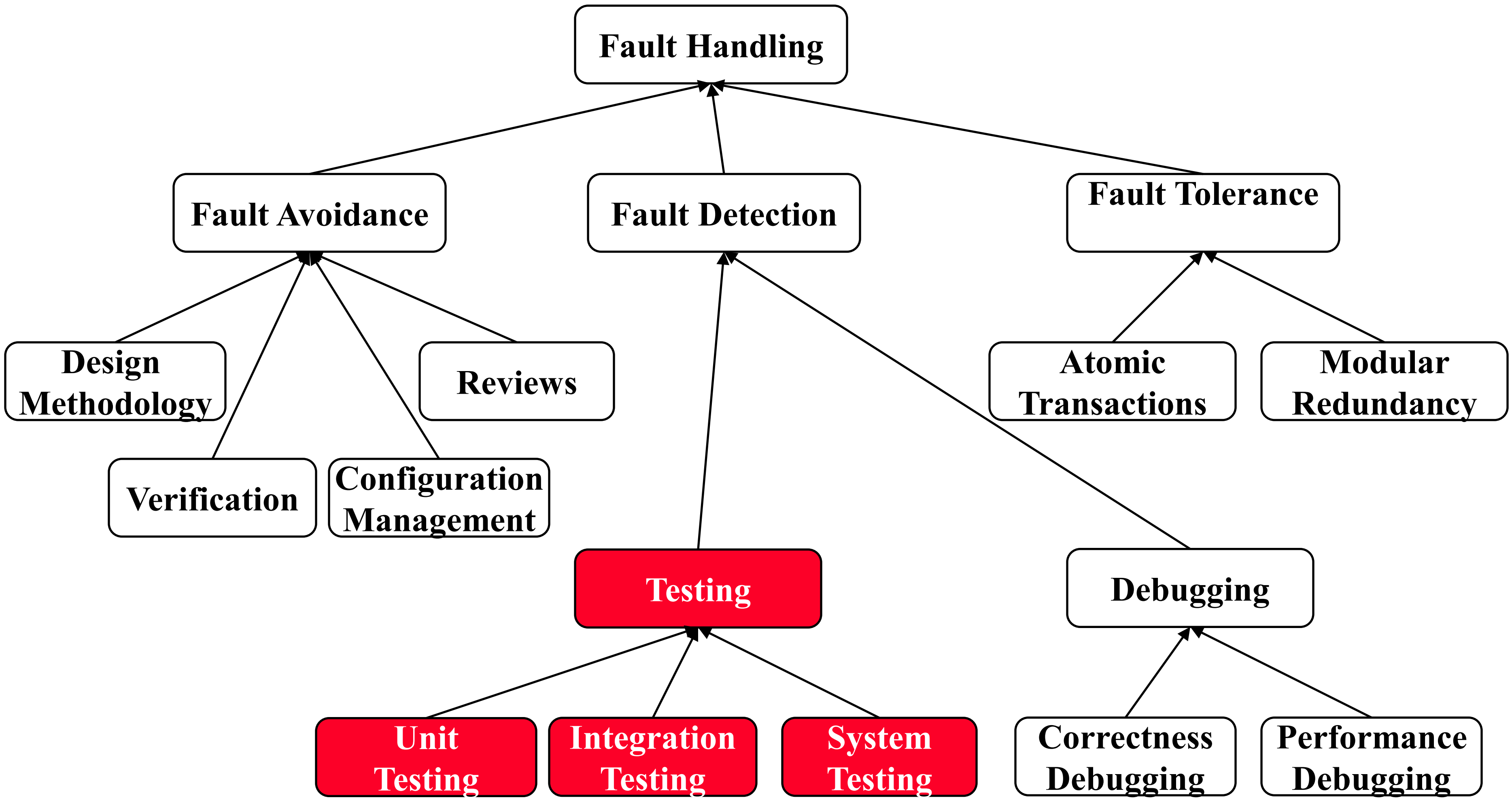


# *Test Planning*

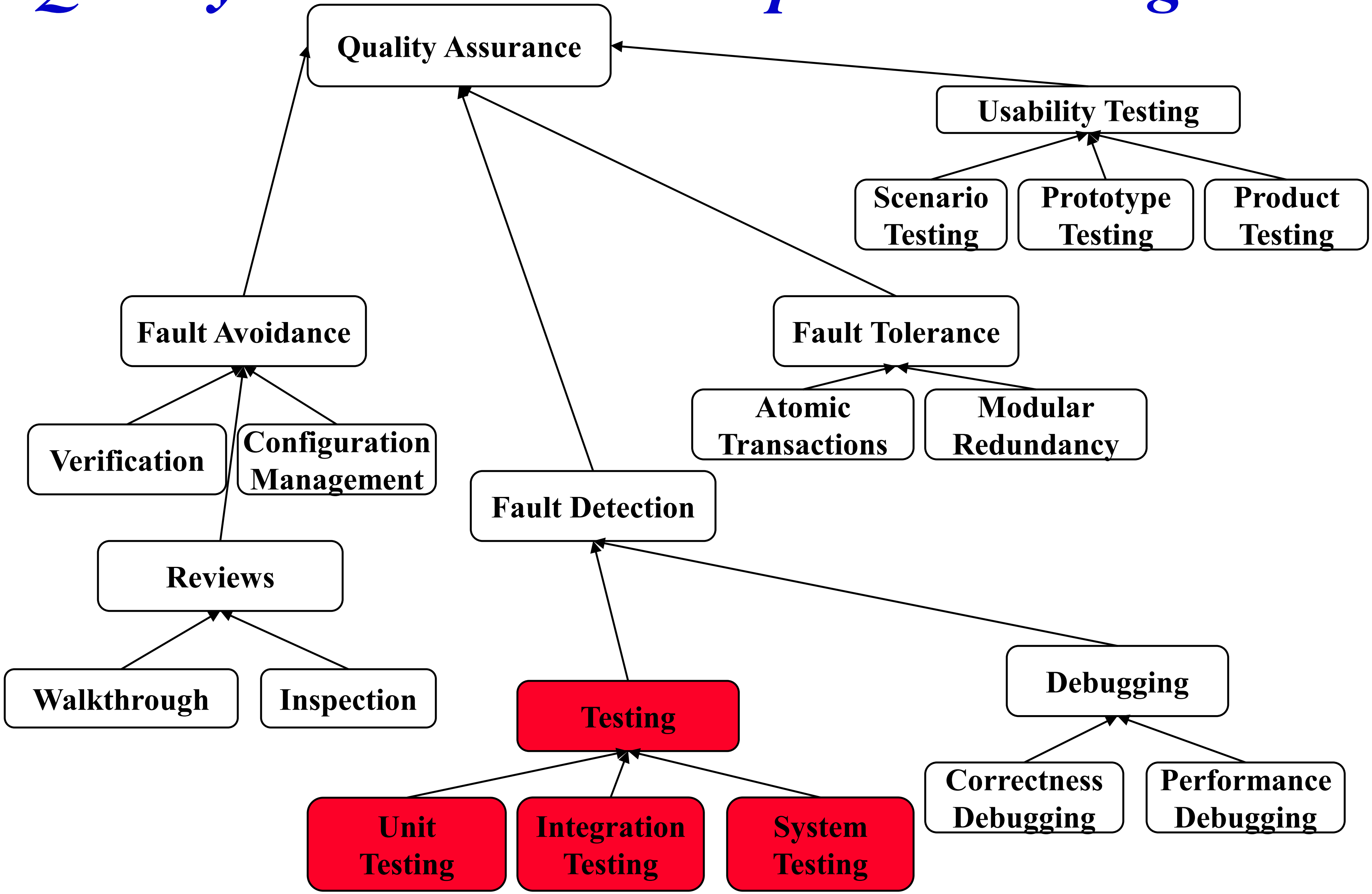
*[Pressman]*

- A Test Plan:
  - **covers all types and phases of testing**
  - **guides the entire testing process**
  - **who, why, when, what**
  - **developed as requirements, functional specification, and high-level design are developed**
  - **should be done before implementation starts**
    - **test driven development (TDD)**
- A test plan includes:
  - **test objectives**
  - **schedule and logistics**
  - **test strategies**
  - **test cases**
    - **procedure**
    - **data**
    - **expected result**
  - **procedures for handling problems**

# Fault Handling Techniques



# Quality Assurance encompasses Testing



# *Another View on How to Deal with Errors*

- **Error prevention** (before the system is released):
  - **Use good programming methodology to reduce complexity**
  - **Use version control to prevent inconsistent system**
  - **Apply verification to prevent algorithmic bugs**
- **Error detection** (while system is running):
  - **Testing: Create failures in a planned way**
  - **Debugging: Start with an unplanned failures**
  - **Monitoring: Deliver information about state. Find performance bugs**
- **Error recovery** (recover from failure once the system is released):
  - **Data base systems (atomic transactions)**
  - **Modular redundancy**
  - **Recovery blocks, check points**

# *Types of Testing*

- **Unit** Testing:
  - **Individual *subsystem***
  - **Carried out by developers**
  - **Goal: Confirm that subsystems is correctly coded and carries out the intended functionality**
- **Integration** Testing:
  - **Groups of subsystems (collection of classes) and eventually the entire system**
  - **Carried out by developers**
  - **Goal: Test the *interface* among the subsystem**

# *System Testing*

Terminology:
system testing here = validation testing

- **System** Testing:
  - **The entire system**
  - **Carried out by developers**
  - **Goal: Determine if the system meets the *requirements* (functional and *global*)**
- **Acceptance** Testing:

2 kinds of Acceptance testing

  - **Evaluates the system delivered by developers**
  - **Carried out by the *client*. May involve executing typical transactions on site on a trial basis**
  - **Goal: Demonstrate that the system meets customer *requirement*s and is ready to use**
- Implementation (Coding) and testing go hand in hand

# *Unit Testing*

- Informal:
  - **Incremental coding**

**Write a little, test a little**

- Static Analysis:
  - **Hand execution: Reading the *source code***
  - **Walk-Through (informal presentation to others)**
  - **Code Inspection (formal presentation to others)**
  - **Automated Tools checking for**
    - **syntactic and semantic errors**
    - **departure from coding standards**
- Dynamic Analysis:
  - **Black-box testing (Test the input/output behavior)**
  - ***White-box* testing (Test the internal logic of the subsystem or object)**
  - **Data-structure based testing (Data types determine test cases)**

**Which is more effective, static or dynamic analysis?**

# *Black-box Testing*

- Focus: I/O behavior. If for any given input, we can predict the output, then the module passes the test.
  - **Almost always impossible to generate all possible inputs ("test cases")** *why?*
- Goal: Reduce number of test cases by equivalence partitioning:
  - **Divide input conditions into equivalence classes**
  - **Choose test cases for each equivalence class. (Example: If an object is supposed to accept a negative number, testing one negative number is enough)**

- **If x = 3 then …**
- **If x > -5 and x < 5 then …**

*What would be the equivalence classes?*

# *Black-box Testing (Continued)*

- Selection of equivalence classes (***No*** rules, only guidelines):
  - **Input is valid across range of values. Select test cases from 3 equivalence classes:**
    - **Below the range**
    - **Within the range**
    - **Above the range**
  - **Input is valid if it is from a discrete set. Select test cases from 2 equivalence classes:**
    - **Valid discrete value**
    - **Invalid discrete value**
- Another solution to select only a limited amount of test cases:
  - **Get knowledge about the inner workings of the unit being tested => white-box testing**

***Are these complete?***

# *White-box* *Testing*

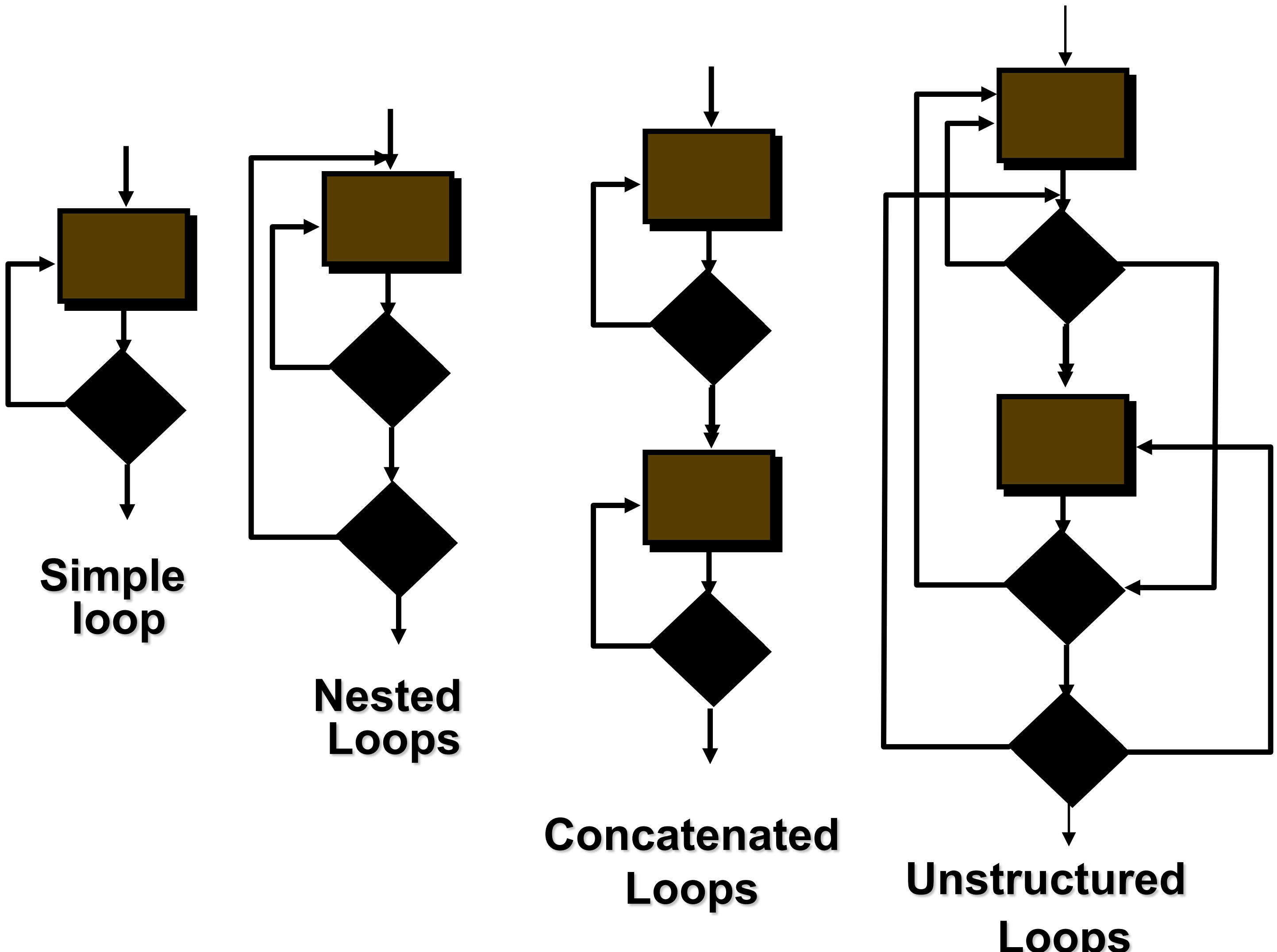
- Focus: Thoroughness (Coverage). Every statement in the component is executed at least once.
- Four types of white-box testing
  - **Statement Testing**
  - **Branch Testing**
  - **Loop Testing**
  - **Path Testing**

# *White-box Testing (Continued)*

- Statement Testing: Test single statements
- Branch Testing (Conditional Testing): Make sure that each possible outcome from a condition is tested at least once
- ```
  if ( i =TRUE) printf("YES\n"); else printf("NO\n");
  ```
  **Test cases: 1) i = TRUE; 2) i = FALSE**
- Loop Testing:
  - **Cause execution of the loop to be skipped completely. (Exception: Repeat loops)**
  - **Loop to be executed exactly once**
  - **Loop to be executed more than once**
- Path testing:
  - **Make sure all paths in the program are executed**
  ```

# *Loop Testing*

*[Pressman]*




**Why is loop testing important?**

# *Comparison of White & Black-box Testing 25.1.2002*

- White-box Testing:
  - **Potentially infinite number of paths have to be tested**
  - **White-box testing often tests what is done, instead of what should be done**
  - **Cannot detect missing use cases**
- Black-box Testing:
  - **Potential combinatorical explosion of test cases (valid & invalid data)**
  - **Often not clear whether the selected test cases uncover a particular error**
  - **Does not discover extraneous use cases ("features")**
- Both types of testing are needed
- White-box testing and black box testing are the extreme ends of a testing continuum.
- Any choice of test case lies in between and depends on the following:
  - **Number of possible logical paths**
  - **Nature of input data**
  - **Amount of computation**
  - **Complexity of algorithms and data structures**

# *Guidance for Test Case Selection*

- Use *analysis knowledge* about functional requirements (black-box testing):
  - Use cases
  - **Expected input data**
  - **Invalid input data**
- Use *design knowledge* about system structure, algorithms, data structures (white-box testing):
  - **Control structures**
    - **Test branches, loops, ...**
  - **Data structures**
    - **Test records fields, arrays, ...**

- Use *implementation knowledge* about algorithms:
  - **Examples:**
  - **Force division by zero**
  - **Use sequence of test cases for interrupt handler**

# *Unit-testing Heuristics*

1. Create unit tests as soon as object design is completed:
   - **Black-box test: Test the use cases & functional model**
   - **White-box test: Test the dynamic model**
   - **Data-structure test: Test the object model**
2. Develop the test cases
   - **Goal: Find the minimal number of test cases to cover as many paths as possible**
3. Cross-check the test cases to eliminate duplicates
   - **Don't waste your time!**
4. Desk check your source code
   - **Reduces testing time**
5. Create a test harness
   - **Test drivers and test stubs are needed for integration testing**
6. Describe the test oracle
   - **Often the result of the first successfully executed test**
7. Execute the test cases
   - **Don't forget regression testing**
   - **Re-execute test cases every time a change is made.**

***Big cost -> what should be done?***

8. Compare the results of the test with the test oracle
   - **Automate as much as possible**

# *OOT Methods: Behavior Testing* *[Pressman]*

**The tests to be designed should achieve *all state coverage* [KIR94]. That is, the operation sequences should cause the Account class to make transition through all allowable states**

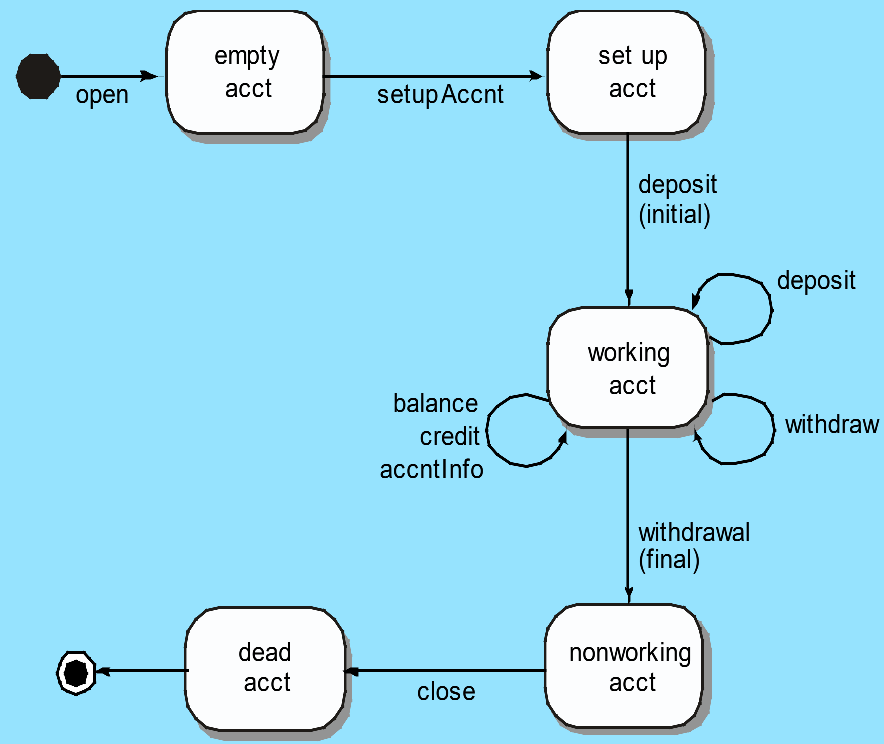
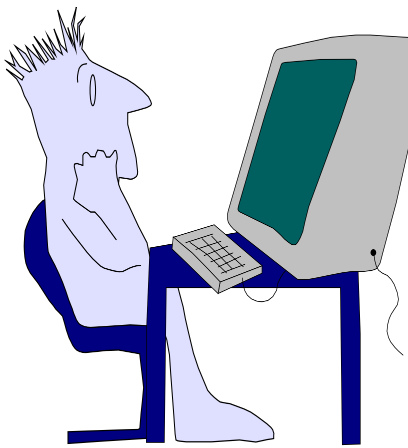



Figure 14.3 State diagram for Account class (adapted from [KIR94])

*This can act as an oracle*

# *Who Tests the Software?*

*[Pressman]*

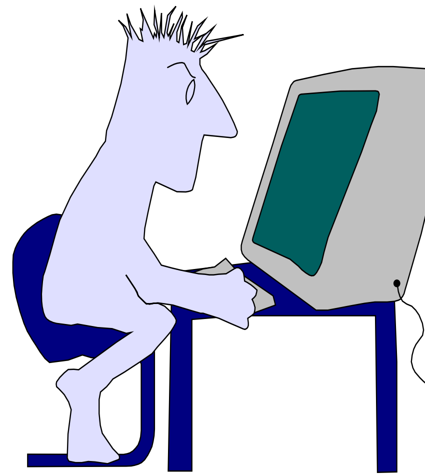


***developer***

**Understands the system**

**but, will test "gently"**

**and, is driven by "*delivery*"**



***independent tester***

**Must learn about the system,**

**but, will attempt to break it**

**and, is driven by *quality***

# *NFRs: Reliability*

[Chung, RE Lecture Notes]]

## Counting Bugs

- **Sometimes reliability requirements take the form:**
  ***"The software shall have no more than X bugs/1K LOC"***
  **But how do we measure bugs at delivery time?**

- ***Bebugging Process - based on a Monte Carlo technique for statistical analysis of random events.***
  **1. before testing, a known number of bugs (seeded bugs) are secretly inserted.**
  **2. estimate the number of bugs in the system**
  **3. remove (both known and new) bugs.**

  ***# of detected seeded bugs/ # of seeded bugs = # of detected bugs/ # of bugs in the system***
  ***# of bugs in the system = # of seeded bugs x # of detected bugs /# of detected seeded bugs***

  **Example:** ***secretely seed 10 bugs***
  ***an independent test team detects 120 bugs (6 for the seeded)***
  ***# of bugs in the system = 10 x 120/6 = 200***
  ***# of bugs in the system after removal = 200 - 120 - 4 = 76***

- **But, deadly bugs vs. insignifant ones; not all bugs are equally detectable; ( Suggestion [Musa87]:**

  ***"No more than X bugs/1K LOC may be detected during testing"***
  ***"No more than X bugs/1K LOC may be remain after delivery,***
  ***as calculated by the Monte Carlo seeding technique"***

# *Summary*

- Testing is still a ***black art***, but many rules and heuristics are available
- Testing consists of component-testing (unit testing, integration testing) and system testing, and …
- OOT and architectural testing, still challenging
- User-oriented reliability modeling and evaluation not adequate
- Testing has its own lifecycle