

Correctness

- Full correctness is very difficult to achieve and even more difficult to demonstrate
- Some lack of correctness must usually be accepted
 - It can be possible to achieve and prove full correctness for some simple software products
 - For most software products, full correctness is an unaffordable dream
- Full correctness is an important goal but rarely necessary
 - Inspection, testing, and mathematical verification can show incorrectness, but mathematical verification is needed to show correctness

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The Problem

- What behavior does the software product exhibit?
 - Is the behavior correct?
 - Is the behavior acceptable?
- Measures of software quality:
 - **Correctness:** To what extend does the product satisfy its requirements specification?
 - **Reliability:** How probable is correct behavior?
 - **Trustworthiness:** How probable is critical failure?
- Forms of verification and analysis:
 - Inspection
 - Testing
 - Mathematical verification

Reliability

- Reliability is a useful measure when:
 - All errors are considered equally important
 - There are no critical failures
 - The operating conditions are predictable
 - We want to compare risks
- Testing is most useful for measuring reliability

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Trustworthiness

- Some systems have critical requirements that must be fully satisfied by the software product
 - It can be useful to rank the requirements by how critical they are
- Critical requirements may concern such things as:
 - Safety to users and the environment
 - Information security
 - High cost of failure
- Inspection and mathematical verification are useful for measuring trustworthiness, but testing is not
 - Unreliable products are often accepted, but untrustworthy products with critical requirements should never be accepted

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Software Testing

- Testing can show instances of incorrectness, but it is usually not practical for demonstrating correctness and trustworthiness
 - There are often an unbounded number of possible inputs and environmental configurations
 - Only what is executable (code but usually not specifications) can be tested
- Positive testing results are not, by themselves, an indication of software quality
- Testing can be used to assess reliability
 - The smallest components and the lowest levels of the uses hierarchy should be tested first
 - Integration should be done only after the components have been fully tested

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Product Inspection

- The full product, both documentation and code, should be inspected
- The inspection should be **systematic**
 - Guided by checklists and questionnaires
- The inspection should be an **active** process
 - Inspectors use the product documents
 - They document their analysis and provide specifics
 - They produce their own product descriptions from the code which they compare with the product specifications
- The inspection should be performed by a small team that includes people with different kinds of expertise

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Kinds of Code Testing

1. **Black box testing**
 - Based on the specification alone
 - Test cases chosen without looking at the code
 - Can be reused with a new implementation
 - Can be done independently of the designer
2. **Clear box testing**
 - Based on the code
 - Test cases chosen by looking at code
 - Tests the implementation mechanism
3. **Grey box testing**
 - Intended for modules with internal data structures
 - Test cases chosen with respect to the internal data structures
 - Gives better coverage than black box testing

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Kinds of Test Case Selection

1. **Planned:** Test cases selected to cover the behavior of the code
 - Based on specification (black box)
 - Based on code (clear box)
 - Based on internal data structures (gray box)
 - Requires effective machine support
2. **Wild random:** Test cases selected using a uniform random distribution
 - Can find cases nobody thought of
 - Can violate assumptions yielding spurious results
3. **Statistical random:** Test cases selected using an operational profile
 - Provides meaningful reliability figures
 - Only as good as the operational profile

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Mathematical Verification

- Main idea: Use the mathematics process to analyze the behavior of a software product
 - Most effective for high-level design
 - Requires significant human expertise
 - Requires effective machine support
 - Can be very expensive
- The mathematics process consists of three activities:
 1. **Model creation:** Create mathematical models that represent mathematical aspects of the world
 2. **Model exploration:** Explore the models by stating and proving conjectures and by performing calculations
 3. **Model connection.** Connect the models to one another so that results obtained in one model can be used in other models

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Two Approaches

1. Test all possible paths through the program
 - So every possible statement is tested at least once
2. Test all data states
3. Test all degenerate data states
4. Test extreme cases
 - Try very large numbers
 - Try very small numbers
5. Test erroneous cases
6. Think of cases that nobody thinks of

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In most applications, the mathematical verification will be a mixture of these two approaches

General Recommendations (Parnas)

1. Test all possible paths through the program

- So every possible statement is tested at least once

2. Test all data states

3. Test all degenerate data states

4. Test extreme cases

- Try very large numbers
- Try very small numbers

5. Test erroneous cases

6. Think of cases that nobody thinks of

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Application to Software

- Problem: Does an implementation I satisfy a specification S ?
 - First solution:
 - Choose an appropriate axiomatic theory T in an appropriate background logic L
 - Formalize I as a term \tilde{I} in T
 - Formalize S as a unary predicate \tilde{S}
 - Prove in L that $\tilde{S}(\tilde{I})$ is a theorem of T
 - Second solution:
 - Choose an appropriate background logic L
 - Formalize I as a theory T_I in L
 - Formalize S as a theory T_S in L
 - Show that there is an interpretation of T_S in T_I
- The same documentation should be used for inspection, testing, and mathematical verification

References

1. D. Parnas and D. Weiss, "Active design reviews: principles and practices", in: D. Hoffman and D. Weiss, *Software Fundamentals*, Addison Wesley, 2001.
2. D. Parnas, "Inspection of safety-critical software using program-function tables", in: D. Hoffman and D. Weiss, *Software Fundamentals*, Addison Wesley, 2001.

Final Comments

- Verification and analysis should be done at all stages in the development of a software product—the earlier the better
- Inspection, testing, and mathematical verification complement each other
 - Inspection is good for finding things that are missing in the software product and in its documentation
 - Testing is good for finding low-level errors, especially coding errors
 - Mathematical verification is good for finding high-level errors, especially design errors
- The same documentation should be used for inspection, testing, and mathematical verification