

## 07. Verification and Analysis

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### 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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### 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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### The Problem

- What behavior does the software product exhibit?  
Is the behavior correct?  
Is the behavior acceptable?
- Measures of software quality:
  - **Correctness:** To what extent 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

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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)
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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## 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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## 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. **Informal but rigorous:** Models are expressed using a natural language and are explored by informal conjecture proving and computation
  - All the work is done by humans
  - Usually not feasible for problems with many details
2. **Formal and mechanized:** Models are expressed and explored using a **mechanized mathematics system** like a theorem proving system or computer algebra system
  - A major portion of the work is done by machine

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

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<div data-bbox="1421 117 1458 575" data-label="Section-Header"> <h2>Application to Software</h2> </div> <div data-bbox="868 138 1383 858" data-label="List-Group"> <ul style="list-style-type: none"> <li>• Problem: Does an implementation <math>I</math> satisfy a specification <math>S</math>?</li> <li>• First solution:             <ul style="list-style-type: none"> <li>– Choose an appropriate axiomatic theory <math>T</math> in an appropriate background logic <math>L</math></li> <li>– Formalize <math>I</math> as a term <math>\bar{I}</math> in <math>T</math></li> <li>– Formalize <math>S</math> as a unary predicate <math>\bar{S}</math></li> <li>– Prove in <math>L</math> that <math>\bar{S}(\bar{I})</math> is a theorem of <math>T</math></li> </ul> </li> <li>• Second solution:             <ul style="list-style-type: none"> <li>– Choose an appropriate background logic <math>L</math></li> <li>– Formalize <math>I</math> as a theory <math>T_I</math> in <math>L</math></li> <li>– Formalize <math>S</math> as a theory <math>T_S</math> in <math>L</math></li> <li>– Show that there is an interpretation of <math>T_S</math> in <math>T_I</math></li> </ul> </li> </ul> </div> <div data-bbox="821 795 839 819" data-label="Page-Footer"> <p>13</p> </div>	<div data-bbox="1421 1121 1458 1327" data-label="Section-Header"> <h2>References</h2> </div> <div data-bbox="1128 1129 1360 1858" data-label="List-Group"> <ol style="list-style-type: none"> <li>1. D. Parnas and D. Weiss, "Active design reviews: principles and practices", in: D. Hoffman and D. Weiss, <i>Software Fundamentals</i>, Addison Wesley, 2001.</li> <li>2. D. Parnas, "Inspection of safety-critical software using program-function tables", in: D. Hoffman and D. Weiss, <i>Software Fundamentals</i>, Addison Wesley, 2001.</li> </ol> </div> <div data-bbox="821 1797 839 1820" data-label="Page-Footer"> <p>15</p> </div>
<div data-bbox="660 117 698 436" data-label="Section-Header"> <h2>Final Comments</h2> </div> <div data-bbox="100 138 615 858" data-label="List-Group"> <ul style="list-style-type: none"> <li>• Verification and analysis should be done at all stages in the development of a software product—the earlier the better</li> <li>• Inspection, testing, and mathematical verification complement each other             <ul style="list-style-type: none"> <li>– Inspection is good for finding things that are missing in the software product and in its documentation</li> <li>– Testing is good for finding low-level errors, especially coding errors</li> <li>– Mathematical verification is good for finding high-level errors, especially design errors</li> </ul> </li> <li>• The same documentation should be used for inspection, testing, and mathematical verification</li> </ul> </div> <div data-bbox="58 795 76 819" data-label="Page-Footer"> <p>14</p> </div>	