CS_313 High Integrity Systems/ CS_M13 Critical Systems

Course Notes
Additional Material
Chapter 7: Verification, Validation, Testing

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November 23, 2014

7 (a) Basic Notions

7 (b) Dynamic testing

7 (c) Static Analysis

7 (d) Modelling

7 (a) Basic Notions

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No Additional Material

For this subsection no additional material has been added yet.

7 (a) Basic Notions

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(b) Dynamic Testing

- Dynamic testing means that one operates the system under test.
- Done by the execution of **test cases**, which investigates certain aspects of the system.
- Each test set consists of
  - a set of input **test data**
    - often called **test vector**.
  - a specification of the expected output,
    - output is often called **output vector**.
  - a statement of the function being tested.
- In case of interactive programs, the test data will usually a sequence of inputs.

Basic Notions

- With each test cases one associates
  - **pre-conditions**
    - specify the state of the system before the test is executed,
  - **post-condition**
    - define the state the system must be in after the test.
  - So tests will check whether if the test input vector fulfills the pre-condition, the test output vector fulfills the post-condition.
  - The goal is to show that for any input fulfilling the pre-condition the output will fulfil the post-condition.

Basic Notions

- Some tests investigate the operation of the system under the condition that the **pre-conditions are not met**.
  - Used in order to check what happens if the system deviates from its operation.

Basic Notions

- The **input space** of a system is the set of possible inputs.
  - If a system has *n* inputs of a simple type like integer, floating point numbers, it has an **n-dimensional input space**.

Categories of Dynamic Testing

- There are 3 main categories of dynamic testing:
  - **Functional testing,**
  - **structural testing,**
  - **random testing.**

Functional Testing

- **Functional testing** is the testing of functions of the system as defined by its specification.
  - For each aspect of the operation tests are carried out.
  - However, tests might cover more than one function.
  - One has to make sure that all functions are covered by the tests.
- It is **black-box testing**, no details about the implementation are needed.
- Often a **test-matrix** is written, which associates each function with tests. See next slide.
  - Used in order to make sure that one has complete coverage of all functions.

Example Test Matrix

	Function investigated					
Test	1	2	3	4	5	6
1	x					
2		x				
3		x	x			
4		x		x		
5	x			x		
6			x	x		
7			x		x	
8	x					x
9			x			x

Structural Testing

- **Structural testing** looks at the internal structure of a system, and uses it into order to check the operation of individual components and their interactions.
    - In case of **hardware testing** uses test signals to investigate particular modules in the system.
    - In case of **software testing**, this involves tests in order to check certain routines or certain execution paths.
      Allows to investigate critical conditions.
- **Coverage-based testing** is structural testing with the goal of testing a large proportion of the system, by having tests for every branch or loop in the system.
- Structural testing is necessarily **white-box testing**.

Random Testing

- **Random testing** uses a test data which are randomly chosen from the input space.
    - Could be randomly sampled from the entire input space.
    - Could be sampled following some probability distribution.
        - The distribution might match the one expected for the operation.
- Aims at detecting fault conditions which are missed by more systematic techniques.

Dynamic Testing Techniques

- We list some of the techniques used.
- **Test cases based on equivalence partitioning**.
    - The input and outputs of the system/component to be tested is **partitioned** into sets of ranges which are **equivalent**, i.e. expected to be treated the same way.
    - Tests are performed to investigate **each partition**.
    - Both valid and invalid values are partitioned and tested.
    - E.g. for a function dealing with student marks, one might expect that
        - the ranges $40 - 49\%$, $50 - 59\%$ etc. form valid partitions.
        - the ranges $< 0\%$, $> 100\%$ form invalid partitions.

Dynamic Testing Techniques

- **Test cases based on boundary value analysis**.
    - Tests the performance of the system at the **boundaries** of equivalent partitions of inputs and outputs.
    - Again both valid and invalid values are partitioned and tested.
    - For instance, in the above example one might check for
        - valid boundary values like 50%, 49% etc.,
        - for invalid boundary values like -1%, 101%,
        - for valid values at the boundary to invalid values like 0%, 100%.

Dynamic Testing Techniques

- **State transition testing** identifies the different **states** of the component and system.
  - Then tests are preformed in order to investigate
    - **transitions** between states,
    - **events causing** such **transitions**,
    - **actions resulting from** such **transitions**.
- **Probabilistic testing** determines the reliability of a system.
  - Attempts to measure failure rates over a given period of time, or failures on demand.
  - This testing is **difficult** to perform for **critical systems**, since there a very low failure rate is demanded, so probabilistic testing should return a failure rate of 0.

Dynamic Testing Techniques

- **Process simulation** is the simulation of the process or equipment to be controlled by the system.
  - Allows to reproduce lots of situations quickly and safely.
- **Error guessing** means that the test engineer predicts input conditions which are likely to cause problems.
- **Error seeding** means the insertion of errors into a system to see if they are detected by the testing procedures.
  - Is a test for the testing process.
  - May allow to predict the number of unfound errors.

Dynamic Testing Techniques

- **Timing and memory tests** investigate response time and memory consumption of a system.
- **Performance testing** tests that necessary levels of performance are reached.
  - E.g. that a certain number of operations per time unit are achieved.
- **Stress testing** tests the performance of a system under a very high workload.
  - Important for instance for the test of (web-, data base- and other) **servers**.

7 (a) Basic Notions

7 (b) Dynamic testing

7 (c) Static Analysis

7 (d) Modelling

(c) Static Analysis

- Static testing investigates a system **without operating it**.
- Techniques can be
  - performed **manually**,
    - e.g. walkthroughs, inspections, use of checklists,
  - or using automated **static code analysis tools**
    - e.g. conformance tests for hardware, formal methods, data/information flow analysis, semantic analysis, complexity measurement, range checking.

Static Analysis

- Static analysis aims at establishing properties of the software or software which are **true under all circumstances**.
  - In contrast with **dynamic testing**, which can only test a **small subset** of the input set.

Static Analysis Techniques

- A **code walkthrough** means that an engineer leads colleagues through the design or implementation of software and convinces them of its correctness.
- **Design review** means peer review and systematic investigation of documents by a number of engineers.
- **Checklists** consists of a set of (usually very general) questions used in order to critically and systematically check certain aspects of a system.
- **Formal proofs** are used to show the correctness of some aspects of the design or implementation of a system.

Static Analysis Techniques

- **Fagan inspections** form a systematic audit of quality assurance documents in order to find errors and omissions.
  - Consists of **5 stages**:
    - planning,
    - preparation,
    - inspection,
    - rework,
    - follow-up.

Static Analysis Techniques

- **Control flow analysis**
  - Analysis of software to detect poor and potentially incorrect program structure.
  - Looks for inaccessible code, infinite loops, poor or error-prone structural program elements.
  - Performed in SPARK Ada.

Static Analysis Techniques

- **Data flow analysis**
  - Analysis of the flow of data through a program.
  - Checks appropriateness of operations and comparison between actual and required data flow.
  - Checks
    - whether variables are initialised,
    - the input/output behaviour of variables,
    - the dependencies between variables.
  - Performed in SPARK Ada.

Static Analysis Techniques

- **Symbolic execution** uses algebraic variables instead of numeric inputs and computes the result of the program in the form of algebraic expressions.
  - Results of a program can be compared with those predicted by the specification.
  - Usually results too complicated to be analysed, need some form of user guidance.
  - Some tools (**semantic analysers**) perform automatic simplification of data.
  - Check of verification conditions in SPARK Ada together with the simplifier form an example of symbolic execution.

Static Analysis Techniques

- **Metrics** are measures for certain properties of the software.
  - Measure for instance reliability and complexity.
  - Tools perform the analysis of such metrics.
  - Such tools measure for instance:
    - The **graph theoretic complexity** based on the complexity of the program graph.
    - **Module accessibility**, the number of ways a module can be accessed.
    - **Complexity measures**.
    - **Number of entry and exit points per module**

Static Analysis Techniques

- **Sneak circuit analysis**.
  - **Sneak currents** are latent conditions in a system, which cause it to malfunction under certain conditions.
  - Might be
    - physical paths,
    - timing irregularities,
    - ambiguous display messages,
    - and others.
  - **Sneak circuit analysis** aims at locating such weaknesses by looking at basic topological patterns within hardware and software.

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(d) Modelling

- Modelling used especially in the early phases of project development.
- Particularly important when producing the **specification** and the **top-level design**.
- Plays as well an important role later, especially during **system validation**.

Modelling Techniques

- **Formal methods** can be used to model a system.
- **Software prototyping/animation** means that a software prototype is created which represents certain features of the specification.
  - Used for the validation of the specification.

Modelling Techniques

- **Performance modelling** consists of the following steps:
  - A **model of the system processes** and their interactions is constructed.
  - Then the **requirements of processor time** and **memory requirements** for each function of the system are determined.
  - Finally the **total system demand** is determined under average and worst-case conditions.
  - This is used in order to **guarantee** that the system **always satisfies the demand**, including margins for safety.

Modelling Techniques

- **State transition diagrams** means that
  - the system is represented by finitely many discrete states;
  - with the transitions formed by the system, one obtains a **finite state machine**.
  - the system can now be analysed and checked for **completeness**, **consistency**, **reachability**.
  - **Model checking** is a technique based on state transition diagrams.
    - Used especially in hardware verification.

Modelling Techniques

- **Process algebras** and **Petri-nets** model a system in terms of various processes.
  - Conditions like **correctness**, **termination**, **deadlock-freedom** can be examined using these techniques.
  - Commonly used especially for concurrent systems, e.g.
    - railway interlocking systems,
    - networks,
    - verification of the Netscape web-browser.

Modelling Techniques

- **Data flow analysis** (see above) can be considered as well as a modelling technique.
- **Structure diagrams** represent the program structure by a structure chart, which is a tree representing the relationship between the program units.
- **Environmental modelling** means that one simulates the operating environment of a system in order to test it in an almost real environment.