SOFTWARE TESTING - STATE OF THE ART, METHODS, AND LIMITATIONS

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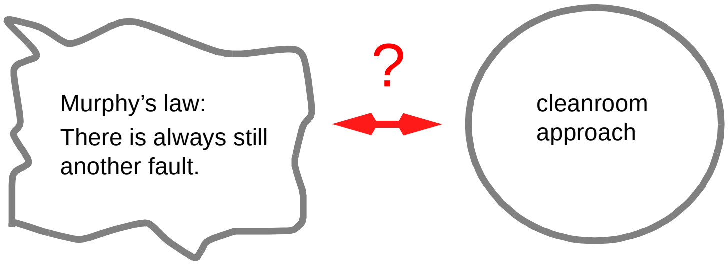


- natural fault rate of seasoned programmers

  -> *about 1-3 % of produced program lines*

- fault-avoidant software **construction** techniques ?

  -> *built-in quality, quality by construction*

- **validation** techniques seem to be unavoidable !

VALIDATION VERSUS TESTING

- **VALIDATION**
  - -> *any confidence-increasing method to trust in the software's quality*
- undecidability of basic questions in software validation
  - program termination
  - equivalence of programs
  - program verification
  - . . .
- validation == testing
- testing portion of total software production effort
  - -> *standard system:* $\geq$ *50 %*
  - -> *extreme availability demands:* $\approx$ *80 %*

CORRECT SOFTWARE

- A software product is formally correct, if the following three items correspond:
  - -> *specification*
    -- *the expected properties*
  - -> *software behavior*
    -- *the observed properties*
  - -> *documentation*
    -- *the product description for application and maintenance*
- 100% totally correct software is possible !!!
  - -> *holds by definition for the empty specification*
- How to **validate** the correspondance ?
  - -> *using the software itself*
  - -> *using a model of the software instead*

. . . model-based software validation

TESTING APPROACH

- checking properties

  -> of the real implementation of the software

  -> in the real environment

  against its specification / documentation

- by reading it

  -> ***STATIC TESTING (HUMAN TESTING)***

- by executing it

  -> ***DYNAMIC TESTING***

PROPERTIES

- properties

(functional) correctness	robustness, reliability, availability	performance/throughput
safety, security	portability, maintainability, readability	real time behavior/ deadline conformance
usability, stability, ...	extendability, ...	resource consumption, ...

- special properties

  -> *specification, usually checked by dynamic testing*

- general properties

  -> *guidelines, usually checked by static testing*

- testing (as any kind of validation)
  can only be as good as the specifications (guidelines) do be

Two Famous Quotes

- E. W. Dijkstra, 1972:

  "Program testing can be used to show the presence of bugs,
  but never to show their absence !"

- G. J. Myers, 1979:

  "Testing means the execution of a program in order to find bugs."

  -> ***if*** *a test run discovers unknown bugs*
  then *it is called successful*
  else *unsuccessful*
  endif

  -> *testing is an inherently destructive task*

  -> *most programmers are unable to test their own programs*

  -> *ask your favourite enemy to test your programs*

Terminology I

- **BUG** - deviation from expected behavior

  -> *fault*

  -> *error*

  -> *failure*

- **TESTING** - discover the bug

- **DEBUGGING** - fix the bug

- testing ≠ debugging

  -> *done at different times*

  -> *by different people*

  -> *using different techniques*

TERMINOLOGY II

- **TEST DATA** - values for all input data
- **TEST CASE** - complete set of
  values for all input data + corresponding output data values
  - -> *A good test case answers one or several questions concerning the test object.*
  - -> *Testing is a highly sophisticated task !*
  - -> *Test data may be generated, test cases not !*

    The generator would have to have the same function as the software being tested.
- **TEST SUITE** - a representative set of test cases
  - -> *table-like test case notation*
- **TEST ORACLE** - assesses a given test case

GENERAL PROCEDURE

- test steps
  - (1) derivation of test cases
    (from a suitable system specification)
    - -> *The outcome is predicted and documented before the test is run !*
  - (2) execution of these test cases
  - (3) assessment of the test results
- what was in the beginning ?
  - -> *test object, i. e. software*
  - -> *test cases*
- simultaneous design of software and its test cases !

Test Case Selection

- exhaustive testing impossible
  - all valid inputs -> correctness, . . .

    -> maybe theoretically finite, but mostly practically infinite
  - all invalid inputs -> robustness, security, reliability, . . .

    -> infinite
  - state-preserving software (operating/information systems):
    a (trans-) action depends on its predecessors

    -> all sequences of (trans-) actions had to be regarded !?
- test case design strategy

  -> *finding good test suites,*

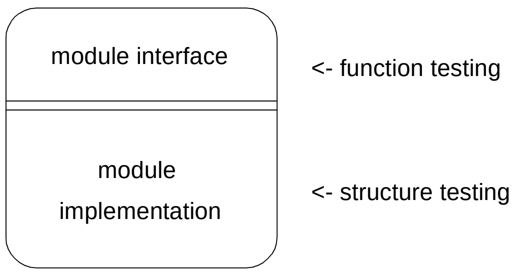
  -> *good = sufficiently small, but high bug discover rate*

Basic Strategies

- structure testing (1)

  -> *white-box testing,*
  developer testing

  -> *basis:*
  inner structure of the test object



- function testing (2)

  -> *black-box testing,*
  user testing

  -> *basis:*
  behavior given by the specification
- diversified testing (3)

  -> *back-to-back testing, mutation testing, perturbation testing*

(1) STRUCTURE TESTING

- based on control structure model (= control flow model)

program elements	control flow graph	Petri net
statements	nodes	transitions
control flow	arcs	places

- control flow - based testing
- data flow - based testing (defs/uses methods)
- TEST COVERAGE
  - relation of executed to existing statements/branches/paths . . .
  - easy to compute by code instrumentation
  - side-effect: hot spots are revealed -> tuning
- main drawback: specification is not checked !

(2) FUNCTION TESTING

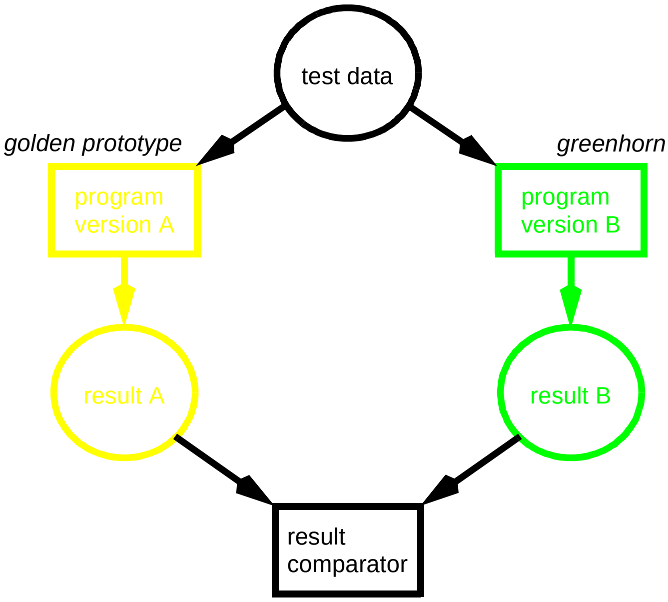
- considerations on the input space
  - -> *equivalence partitioning*
  - -> *boundary value testing*
  - -> *special value testing*

  } *effective selection depends on the skills and experience of the tester*
- random testing, statistical testing
  - -> *estimation of residual defects*
  - -> *suitable combination with equivalence partitioning*
- testing against some model
  - -> *state automaton*
  - -> *cause effect graph*
  - -> *fault tree, . .*

  } test coverages similar to structure testing node/branch/path coverage

(3) Diversified Testing I

- back to back testing



Remark:
Usually, not applicable.

(3) Diversified Testing II

- mutation testing
  - make small changes (mutations) to the program
  - run the mutated program using the same test suite as the program being tested
  - the test suite is adequate, if it finds all mutations
- perturbation testing (fault injection)
  - implementing anomalies for inputs, outputs, and everything in between
  - impact of component bugs on the entire system

    -> fault tolerance

Recommended Procedure

- function testing
  - code instrumentation to observe test coverage
  - design test suite using equivalence classes
  - execute test suite neglecting any reached coverage
- structure testing
  - evaluate reached test coverage
  - design additional test cases to increase test coverage
  - execute additional test cases
  - repeat as long as the specified degree has not been reached
- mutation test
  - test suite assessment
- regression testing
  - each debugging requires re-execution of complete test suite

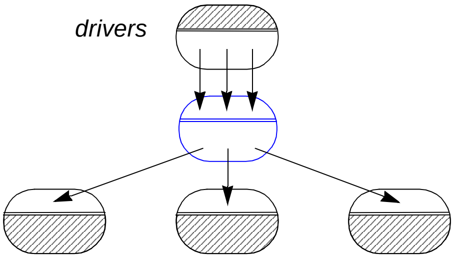
  SUPPORT BY SUITABLE TEST TOOLS !!
- Remark:
  Usually, test suites growth step-wise over time by careful bookkeeping what has been tested before.

Incremental Testing

- most programs are too complicated to understand all details at a glance
- white-box testing becomes more and more impractical with increasing size of the test component
- way out: modular programming with sound interfaces (ADT),
  BUT: all interfaces are sources of confusion
- consequences: step-wise bottom up / top down testing
  - unit testing — procedures, . . .
  - module testing — set of procedures + interface
  - integration testing — interaction of several modules
  - system testing — complete software product

MUNCHAUSEN'S TEST MIRACLE

- step-wise testing requires
  - test **DRIVERS**
    simulating the calling modules
  - test **STUBS**
    simulating the called modules



- these test environments must be programmed and tested too,

  . . .

  . . .

  . . . . . .

CLASSIFICATION OF TEST METHODS

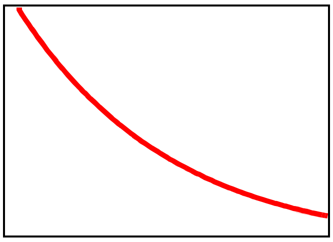
criteria	test method	remarks
kind of test execution	inspection of program code running of executables	review, walk-through, . . .
kind of knowledge of the test object	structure test (white box test, developer test) function test (black box test, user test)	basis: inner structure of the test object basis: behavior given by the specification
size of the test object	unit testing module testing integration testing system testing	procedures, . . . set of procedures + interface interaction of several modules complete software product

SPECIAL CHALLENGES

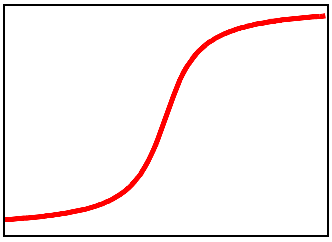
- ❑ testing of alternative programming paradigms using
  - -> *declarative programming languages*
  - -> *functional programming languages*
  - -> *object-oriented programming languages*
- ❑ programs which can hardly be described by an IO function
  - -> *GUI*
  - -> *state-preserving software*
  - -> *reactive systems's software*
- ❑ systematic testing of concurrent programs
  - -> *is much more complicated than of sequential ones*

CRITERIA TO FINISH TESTING

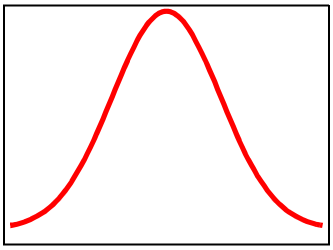
- ❑ common
  - time is over (time-to-market pressure)
  - all test cases successful
- ❑ better (?)
  - Discover a given amount of bugs !
  - Reach a specified degree of test coverage(s) !
  - Reach a specified fault rate ! (number of found bugs per time)



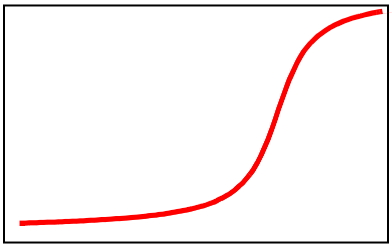
optimistic view



pessimistic view



realistic view (?)



ageing model

State of the Art

- ❑ effective testing is still a challenge in real-life software development
- ❑ validation needs knowledgeable professionals
  - -> *study / job specialization*
  - -> *profession of “software tester”*
- ❑ testing is very time and resource consuming
  - -> *’external’ quality pressure*
- ❑ There is no such thing as a fault-free program !
  - -> *sufficient dependability for a given user profile*
  - -> *how to characterize a user profile ?*
- ❑ sophisticated testing is not manageable without tool support -> exercises

Limitations of Testing

- ❑ Testing (as any kind of validation) is no substitute for thinking !
- ❑ testing can only be as good as the specification
  - -> *readable* <-> *unambiguous*
  - -> *complete* <-> *limited size*
- ❑ (dynamic) testing needs an executable
- ❑ “Program testing can be used to show the presence of bugs, but never to show their absence !” [Dijkstra 72]
  - sophisticated *static analyses (***CONTEXT CHECKING***)* to prove the absence of certain types of bugs
  - *correctness proofs (***VERIFICATION***),* similar to the proof of a mathematical theorem

  } *next slide*

SOFTWARE VALIDATION METHODS