Software Testing: Overview

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Course Administration: Books

- **Main text: Pezzè & Young, Software Testing and Analysis: Process, Principles and Techniques, Wiley, 2007.**
- Paul Ammann and Jeff Offutt, Introduction to Software Testing, Cambridge University Press, Cambridge, UK, ISBN 0-52188-038-1, 2008.
- G.J. Myers, The Art of Software Testing, Second Edition, John Wiley & Sons, New York, 1976.
- B. Marick, The Craft of Software Testing, Prentice Hall, 1995
- C Kaner, J. Bach, B. Pettichord, Lessons Learned in Software Testing, Wiley, 2001.

Material covered via readings, presentations, web resources and practical experience.

Course Administration

- **Course Web page:** http://www.inf.ed.ac.uk/teaching/courses/st/
- Useful: http://www.cs.uoregon.edu/~michal/book/index.html
- Useful: http://www.testingeducation.org
- Alternate: http://www.youtube.com/watch?v=ILkT_HV9DVU Open Lecture by James Bach on Software Testing - where he takes a different perspective on the task.
- Useful Context: http://www.computer.org/web/swebok see the Testing section of the Software Engineering Body of Knowledge

Course Assessment

- **One practical worth 25% of the final mark** — Practical will involve testing a system and producing a group report (group size - 4 or 5).
- **Issued:** week ending 16 January. **Deadline** Monday 16 March at 1600. **Feedback** on draft submissions submitted by 1600 on Monday 23 February.
- In week 9 each group will organise a 30 minute feedback session to demonstrate their practical and get further feedback.
- **One examination worth 75%**. This will be an **open-book** examination.
- **Quizzes and tutorials** — not assessed but doing them will make it much easier to do the examination and practicals

Tutorials

- There are four tutorials available on the course. Each one is *owned* by a different tutor.
- Each tutorial relates to a different section of the practical.
- To access the tutorial you must have evidence of preparation for the tutorial (e.g. your group has completed a small test or has some documentation available).
- When you are ready to do a tutorial you contact the tutor to arrange a time for a tutorial session.
- Each tutorial session will have two groups participating.

Famous quote time!

"...testing can be a very effective way to show the presence of bugs, but is hopelessly inadequate for showing their absence. The only effective way to raise the confidence level of a program significantly is to give a convincing proof of its correctness."

– Edsger Dijkstra

http://www.cs.utexas.edu/users/EWD/transcriptions/EWD03xx/EWD340.html

But often the *bug* is in the Specification

- First launch of Ariane 5.
- Same avionics as Ariane 4.
- Achieves a much higher horizontal velocity in first minute.
- 16 bit number for the velocity overflows . . .

So really, why do we test?

- **To find faults**
  - Glenford Myers, The Art of Software Testing
- **To provide confidence**
  - of reliability
  - of (probable) correctness
  - of detection (therefore absence) of particular faults
- Other issues include:
  - *Performance of systems* (i.e. use of resources like time, space, bandwidth,...).
  - "...ilities" can be the subject of test e.g. usability, learnability, reliability, availability,
- Kaner and Bach: a technical investigation carried out to expose quality-related information on the product under test.

Testing Theory

- But Dijkstra viewed programs as primarily abstract mathematical objects — for the tester they are engineered artifacts — the mathematics informs the engineering — but that is not the whole story (e.g., integers – a common trap for the unwary).
- Plenty of negative results
  - Nothing guarantees correctness
  - Statistical confidence is prohibitively expensive
  - Being systematic may not improve fault detection — as compared to simple random testing
  - Rates of fault detection don't correlate easily with measures of system reliability.
- Most problems to do with the *"correctness"* of programs are formally undecidable (e.g., program equivalence).

What Do We Have Available?

- **Specifications** (formal or informal)
  - To check an output is correct for given inputs
  - for Selection, Generation, Adequacy of test sets
- **Designs/Architecture**
  - Useful source of abstractions
  - We can design for testability
  - Architectures often strive to separate concerns
- **Code**
  - for Selection, Generation, Adequacy
  - Code is not always available
  - Focus on fault/defect finding can waste effort
- **Usage** (historical or models) — e.g., in telecom traffic
- **Organisation experience** — Processes + process data

Testing for Reliability

- Reliability is statistical, and requires a statistically valid sampling scheme
- Programs are complex human artifacts with few useful statistical properties
- In some cases the environment (usage) of the program has useful statistical properties
  - Usage profiles can be obtained for relatively stable, pre-existing systems (telephones), or systems with thoroughly modelled environments (avionics)

A Hard Case: Certifying Ultra-High Reliability

- Some systems are required to demonstrate very high reliability (e.g., an aircraft should only fail completely once in 10^{11} hours of flying).
- So aircraft components have to be pretty reliable (but think about how many single points of failure a car has).
- How can we show that the avionics in a fly-by-wire aircraft will only fail once in 10^9 hours of flying.
- Butler & Finelli estimate
  for 10^{-9} per 10 hour mission
  requires: 10^{10} hours testing with 1 computer
  or: 10^6 hours (114 years) testing with 10,000 computers
  [also Littlewood and Strigini]

Standard Testing Activities

Modelling the environment of the software
- What is the right abstraction for the interface?

Selecting test scenarios
- How shall we select test cases?
  - Selection; Generation

Running and evaluating test scenarios
- Did this test execution succeed or fail?
  - Oracles
- What do we know when we have finished?
  - Assessment

Measuring testing progress/quality
- How do we know when we have tested enough?
  - Adequacy
- identifying issues in the process

Modelling the Environment

- *Testers identify and simulate interfaces that a software system uses*

- **Common interfaces** include: Human interfaces, Software interfaces (aka APIs), File system interfaces, Communication interfaces

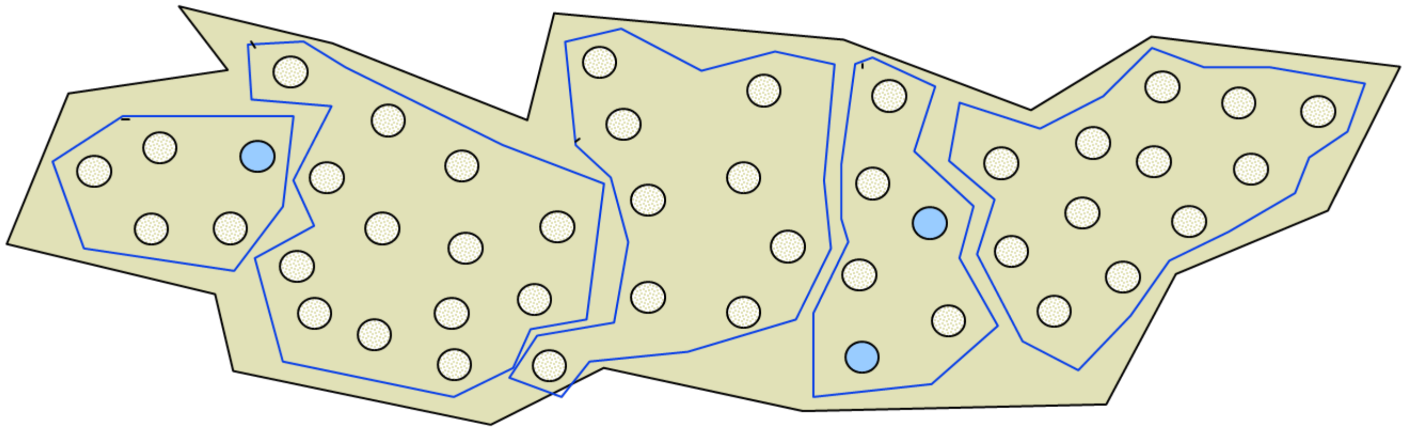
- **Identify interactions** that are beyond the control of the system, e.g.:
  - Hardware being powered off and on unexpectedly
  - Files being corrupted by other systems/users
  - Contention between users/systems

- **Issues in building abstractions** include: choosing representative values, combinations of inputs, sequence (finite state machine models are often used)

Modelling: Partition the Input Space

Basic idea: Divide program input space into (what we think might be) classes that require similar behaviour.

- Use representatives of the **"similarity classes"** to model the domain
- Worry that our partitions might not correspond to regions that require essentially the same behaviour.



Modelling: Specification-Based Partition Testing

- *Divide the program input space according to cases in the specification*
  - May emphasise boundary cases
  - Combining domains can create a very large number of potential cases
  - Abstractions can lose dependencies between inputs
- Testing could be based on systematically **“covering”** the categories
  - The space is very large and we probably still need to select a subset.
  - May be driven by scripting tools or input generators
  - Example: Category-Partition testing [Ostrand]
- Many systems do not have particularly good specifications.
- Some development approaches use tests as a means of specification.

Quiz: Testing Triangles (G. Myers)

- You are asked to test a method $Triangle.scalene(int, int, int)$ that returns a Boolean value.

- $Triangle.scalene(p, q, r)$ is true when p, q and r are the lengths of the sides of a scalene triangle.

- Scalene as opposed to equilateral or isosceles

- Construct an adequate test set for such a method.

Quiz: Does having the code help?

```
public class Triangle {
    public boolean scalene(int p, int q, int r) {
     int tmp;
     if(q>p) { tmp = p; p = q; q = tmp; }
     if(r>p) { tmp = p; p = r; r = tmp; }
      return ((r>0) && (q>0) && (p>0) &&
                (p<(q+r))&& ((q>r) || (r>q)));
    }
}
```

Note: this code contains at least one bug!

Quiz: Summary

- The code is less than 10 lines long – we seem to need at least the same number of tests to check it.
- Many modern systems are multi-million line systems.
- Daunting task to work out how to test such systems.
- Part of the approach is to change the way systems are built.

Selecting: Selecting Tests

What criteria can we use to cut down the number of tests?

- Common criteria are **coverage criteria**: We have executed **all statements**; We have executed **all branches**; We have executed **all possible paths** in the program; We have covered **all possible data flows**.

- We might also try to evaluate the effectiveness of test cases by seeding errors in the code and seeing how well a test set does in finding the errors.

- We might also consider statistical measures, e.g., that we have a statistically valid sample of the possible inputs (but here we need a good idea of the distribution of inputs).

Selecting: Test Adequacy

- **Ideally:** adequate testing ensures some property (proof by cases)
  - It is very hard to establish non-trivial properties using these methods (unless the system is clearly finite)
  - Origins in [Goodenough and Gerhart], [Weyuker and Ostrand]

- **Practically:** *"adequacy"* criteria are safety measures designed to identify holes in the test set
  - If we have not done this kind of test some instances of this kind of test should be added to the test set.

Selecting: Systematic Testing

- Systematic (non-random) testing is aimed at program improvement
  - Finding faults not trying to predict the statistical behaviour of the program
  - Obtaining valid samples and maximising fault detection require different approaches; it is unlikely that one kind of testing will be satisfactory for both

- *"Adequacy"* criteria mostly negative: indications of important omissions
  - Positive criteria (assurance) are no easier than program proofs

Selecting: Structural Coverage Testing

- (In)adequacy criteria
  - If significant parts of program structure are not tested, testing is surely inadequate

- Control flow coverage criteria
  - Statement (node, basic block) coverage
  - Branch (edge) and condition coverage
  - Data flow (syntactic dependency) coverage
  - Various control-flow criteria

- Attempted compromise between the impossible and the inadequate

Selecting: Fault-Based Testing

- Given a fault model
  - hypothesised set of deviations from correct program
  - typically, simple syntactic mutations; relies on coupling of simple faults with complex faults

- Coverage criterion: Test set should be adequate to reveal (all, or x%) faults generated by the model
  - similar to hardware test coverage

Selecting: Fault Models

- Fault models are key to semiconductor testing
  - Test vectors graded by coverage of accepted model of faults (e.g., “stuck-at” faults)
- What are fault models for software?
  - What would a fault model look like?
  - How general would it be? Across application domains? Across organisations? Across time?
- Defect tracking is a start — gathering collections of common faults in an organisation — rigorous process — links to CMMI (Capability Maturity Model Integration) and optimising organisations.

Selecting: Test Selection — Standard Advice

- **Specification coverage is good for selection as well as adequacy**
  - applicable to informal as well as formal specs
- **Fault-based tests**
  - usually ad hoc, sometimes from check-lists
- **Program coverage last**
  - to suggest uncovered cases, not just to achieve a coverage criterion

Selecting: The Bottom Line — The Budget Coverage Criterion

- A common answer to *'When is testing finished?'*
  - When the money is used up
  - When the deadline is reached
- This is sometimes a rational approach!
  - **Implication 1:** Test selection is more important than stopping criteria per se.
  - **Implication 2:** Practical comparison of approaches must consider the cost of test case selection
- Example: testing of SAFEBUS (communications bus for Boeing aircraft) — started out with a pile of money and stopped when they ran out (could have more money if it was still flakey).

Running: Running and Evaluating Tests

- The magnitude of the task is a problem than can require tools to help — automated testing means we can do more testing but in some circumstances it is hard (e.g. GUIs).
- Is the answer right? Usually called the Oracle problem — often the oracle is human.
- Two approaches to improving evaluation: better specification to help structure testing; embedded code to evaluate structural aspects of testing (e.g. providing additional interfaces to normally hidden structure).
- Through life testing: most programs change (some are required not to change by law) — regression testing is a way of ensuring the next version is a least as good as the previous one.
- Reproducing errors is difficult — attempt to record sequence of events and replay — issues about replicating the environment.

Running: The Importance of Oracles

- Much testing research has concentrated on adequacy, and ignored oracles

- Much testing practice has relied on the "eyeball oracle"
  - Expensive, especially for regression testing — makes large numbers of tests unfeasible
  - Not dependable

- Automated oracles are essential to cost-effective testing

Running: Sources of Oracles

- Specifications
  - sufficiently formal (e.g., SCR tables)
  - but possibly incomplete (e.g., assertions in embedded assertion languages such as Anna, ADL, APP, Nana)

- Design, models
  - treated as specifications, as in protocol conformance testing

- Prior runs (capture/replay)
  - especially important for regression testing and GUIs; hard problem is parameterization

Running: What can be automated?

- Oracles
  - assertions; replay; from some specifications
- Selection (Generation)
  - scripting; specification-driven; replay variations
  - selective regression test
- Coverage
  - statement, branch, dependence
- Management

Running: Design for Test — Three Principles

1. **Observability**
   - Providing the right interfaces to observe the behavior of an individual unit or subsystem
2. **Controllability**
   - Providing interfaces to force behaviours of interest
3. **Partitioning**
   - Separating control and observation of one component from details of others

Measuring: Measuring Progress (Are we done yet?)

- **Structural:**
  - Have I tested for common programming errors?
  - Have I exercised all of the source code?
  - Have I forced all the internal data to be initialised and used?
  - Have I found all seeded errors?
- **Functional:**
  - Have I thought through the ways in which the software can fail and selected tests that show it doesnt?
  - Have I applied all the inputs?
  - Have I completely explored the state space of the software?
  - Have I run all the scenarios that I expect a user to execute?

Summary

- We have outlined the main testing activities:
  - Modelling the environment
  - Test Selection
  - Test execution and assessment
  - Measuring progress

- These are features of all testing activity.

- Different application areas require different approaches

- Different development processes might reorganise the way we put effort into test but the amount of test remains fairly constant for a required level of product quality.

Readings

Required Readings

- **Textbook (Pezzè and Young):** Chapter 1, Software Test and Analysis in a Nutshell
- **Textbook (Pezzè and Young):** Chapter 2, A Framework for Test and Analysis
- Whittaker, J.A., What is software testing? And why is it so hard?, IEEE Software, vol.17, no.1, pp.70-79, Jan/Feb 2000.

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