

Software Testing: Introduction

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http://ceres.hh.se/mediawiki/DT8021_Ed_2015

Testing and Verification of Embedded Systems (DT8021),
March 23, 2015

Outline

Organization

Why?

What?

How?, When?

Contact information

Courses Web Pages

http://ceres.hh.se/mediawiki/DT8021_Ed_2015

Check for news, updates, course material and much more!

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Objectives and assessment

Learning objectives: Knowledge

1. Explain various classification of test techniques
2. Explain behavioral modeling, techniques and model-based testing and test case generation from behavioral models
3. Explain the latest research trends in the area of testing and alternatives to testing, particularly, model checking

Objectives and assessment

Learning objectives: Skills

1. Apply the traditional test techniques to realistic examples
2. Write abstract behavioral models for embedded systems
3. Use the behavioral models in order to perform model-based testing.

Objectives and assessment

Learning objectives: Judgment

1. Analyse the suitability of various test techniques given the test assumptions and test goals
2. Analyse research results in the field of testing embedded systems

Objectives and assessment

Evaluation method

- ▶ Practical project (P),
- ▶ Research paper and presentation (R), and
- ▶ Written exams (W), closed book.

The final mark = (P + R + W) / 3

Project: WhatsUpHH

General Description

Client:

- ▶ Android-based,
- ▶ connection-based (TCP-IP-based) server,
- ▶ to be implemented in Java,
- ▶ XML interface for adding, editing, and fetching messages.

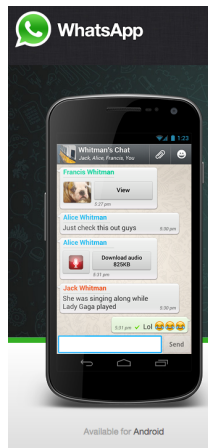


Photo: Copyright WhatsApp Inc.

Project: WhatsUpHH

Testing Perspective

- ▶ test-driven development,
- ▶ unit testing using junit,
- ▶ coverage metrics using Cobertura (or similar tools),
- ▶ integration testing, developing stubs using Mockito (or similar tools),
- ▶ model checking using Uppaal, and
- ▶ UI testing using the Visual GUI Testing tool.

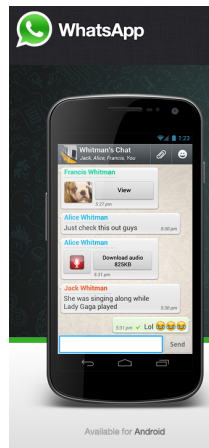


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Project: WhatsUpHH

Schedule and Deadlines

- ▶ Forming Groups: **March 30** at 17:00
- ▶ Phase 1: TDD of a Unit: **April 17**,
- ▶ Phase 2: Integration (Testing) of the Client:
May 1
- ▶ Phase 3: UI Testing: **May 15**



Photo: Copyright WhatsApp Inc.

Project: WhatsUpHH

Schedule and Deadlines

By the deadline:

- ▶ Deliverable to be presented by all group members to the lecturer.

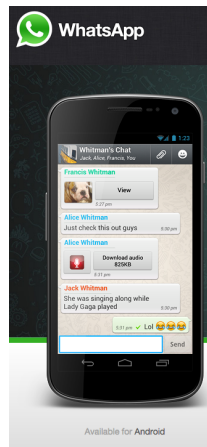


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Our Order of Business

- ▶ Terminology and Functional Testing
- ▶ Test-Driven Development and junit
- ▶ Coverage Criteria
- ▶ Model Checking
- ▶ GUI Testing
- ▶ Slicing and Debugging
- ▶ Reviewing Model Examination
- ▶ Guest Lectures

General Information

- ▶ Text book: P. Ammann and J. Offutt, Introduction to Software Testing, Cambridge University Press, 2008.
- ▶ Recommended: P.C. Jorgensen. Software Testing: A Craftsmans Approach. Auerbach Publications, 3rd edition, 2008.
- ▶ Papers and other recommended books posted on the course page.



Outline

Organization

Why?

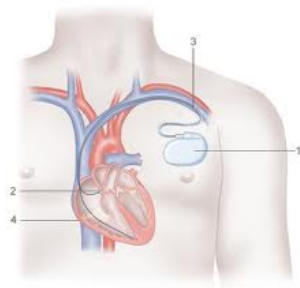
What?

How?, When?

Software at Your Heart. . .

Software glitches in **pacemakers**

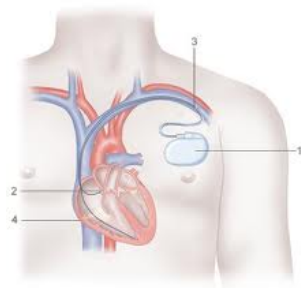
Company said it has not received any reports of **deaths** or clinical complications resulting from the **glitch**, which appears in about 53 out of every 199,100 cases.



Software at Your Heart...

At least **212 deaths** from device **failure** in five different brands of implantable cardioverter-defibrillator (ICD) according to a study reported to the FDA

[Killed by Code, 2010]



Why?

“Bugs”

- ▶ Facts of life! (correct by construction: not always possible / affordable)
- ▶ Serious consequences (Pentium bug, OV Chipcard, etc.)



Why?

A Classic Bug

- ▶ Ariane 5 explosion report:



*This loss of information was due to **specification** and **design errors** in the software ... caused during execution of a data **conversion** from **64-bit floating point** to **16-bit signed integer** value. The floating point number which was converted had a value greater than what could be represented ...*

Why?

The NorthWest Blackout “Bug”

- ▶ Widespread blackouts in 2003
- ▶ Affecting 8 US states and a part of Canada
- ▶ Traced back to a race condition bug
- ▶ Surfaced after 3 million hours of operation



Moral of the Story

If it can go wrong, it will go wrong.

Why?

“Bugs”

- ▶ 2002 Costs: 60 Billion USD (only USA).
- ▶ *Coders introduce bugs at the rate of 4.2 defects per hour of programming. If you crack the whip and force people to move more quickly, things get even worse. [Watts Humphreys]*



Why?

Quest for Quality

- ▶ *Software quality will become the dominant success criterion in the software industry.*
[ACM Workshop on Strategic Directions in Software Quality]
- ▶ Testing:
 - ▶ a way to achieve better quality
 - ▶ >50% of the development costs



Why?

Bezier's Testing Levels

- L0 debugging (ad hoc, few input/outputs)
- L1 showing that software works (validating some behavior)
- L2 showing that software does not work (scrutinizing corner cases)
- L3 reducing risks (organizing and prioritizing test goals)
- L4 mental discipline for quality (central to development)



Outline

Organization

Why?

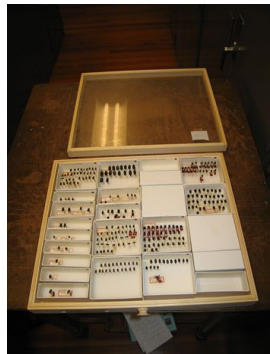
What?

How?, When?

What?

Sorts of "Bug"

- ▶ Fault: incorrect implementation
 - ▶ commission: implement the wrong specification
 - ▶ omission: forget to implement a specification (the more difficult one to find and resolve)



What?

Sorts of "Bug"

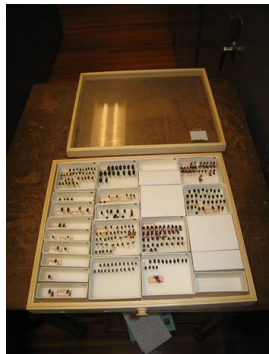
- ▶ Fault: incorrect implementation
 - ▶ commission: implement the wrong specification
 - ▶ omission: forget to implement a specification
(the more difficult one to find and resolve)
- ▶ Error: incorrect system state (e.g., incorrect value for a variable)



What?

Sorts of “Bug”

- ▶ Fault: incorrect implementation
 - ▶ commission: implement the wrong specification
 - ▶ omission: forget to implement a specification
(the more difficult one to find and resolve)
- ▶ Error: incorrect system state (e.g., incorrect value for a variable)
- ▶ Failure (anomaly, incident) : visible error in the behavior



How?

Spec: A program that inputs an integer, and outputs $2 * i^3$.

```
int i;  
i << cin;  
i = 2 * i;  
i = exp(i,3);  
cout << i;
```

How?

Spec: A program that inputs an integer, and outputs $2 * i^3$.

```
1: int i;  
2: i << cin;  
3: i = 2 * i;  
4: i = exp(i,3);  
5: cout << i;
```

- ▶ Conceptual mistake: confusing the binding power of operators

How?

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- ▶ Conceptual mistake: confusing the binding power of operators
- ▶ Fault: Statements 3 and 4 are in the wrong order

How?

Spec: A program that inputs an integer, and outputs $2 * i^3$.

```
1: int i;  
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3: i = 2 * i;  
4: i = exp(i,3);  
5: cout << i;
```

- ▶ Conceptual mistake: confusing the binding power of operators
- ▶ Fault: Statements 3 and 4 are in the wrong order
- ▶ Failure:
Test-case: on input **1**, the program must output **2**.
input **1** ... output **8!**

What?

Validation vs. Verification

- ▶ Validation: Have we made the right product; compliance with the intended usage
often: user-centered, manual process, on the end product
- ▶ Verification: Have we made the product right; compliance between artifacts of different phases
often: artifact-driven, formalizable and mechanizable process among all phases

What?

Testing

- ▶ Planned experiments to:

1. reveal bugs (turn **faults** into **failures**, test to **fail**),

Testing can show the presence of bugs, but not the absence.
[Dijkstra]

2. gain confidence in software quality (test to **pass**)

What?

RIP Process

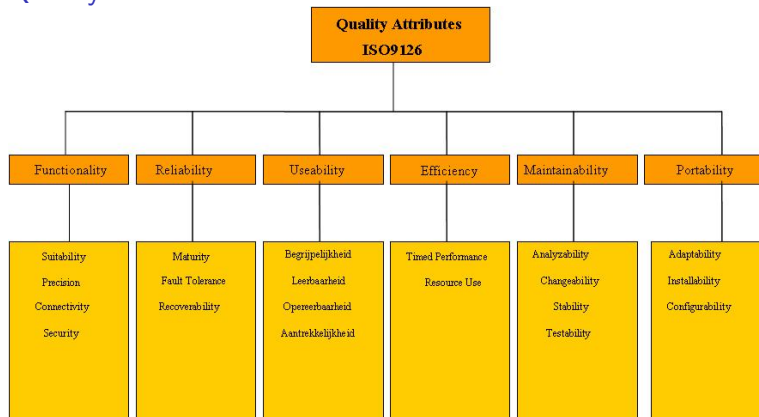
- ▶ Reachability: triggering the statements containing the fault,
- ▶ Infection: triggering the fault to produce incorrect state
- ▶ Propagation: carrying the fault to the visible behavior (output)

What?

- ▶ Test case (the plan):
input (execution condition / behavior) and output (pass / fail conditions)
- ▶ Testing: planning and executing test-cases (how?).

What?

Quality Attributes



Outline

Organization

Why?

What?

How?, When?

How?

Testing



How?

- ▶ Testing: planning and executing test-cases.
 1. **designing** test-cases (manual, automatic: models, formal specs),
 2. **executing** them (manual or automatic: scaffolding, fixture),
 3. distinguishing **failures** or correct executions (manual: experts, automatic: oracles, models)
 4. giving feed back for **debugging** / changing specification

How?

Moral of the Story

Testing aims at **covering** some (abstract) artifacts; examples:

- ▶ Functional testing: requirements (logical partitions, formulae, graphs, trees)
- ▶ Structural testing: program (control or data flow graphs)

How?

Coverage Criterion

A set of predicates on test cases (formalization of a test requirement)

Examples:

1. For a software with an integer input x :
 $C = \{x < 0, x = 0, 0 \leq x \leq 10, x = 10, x > 10\}$
2. For a program with a set of statements S $C = \{s \text{ is executed at least once} \mid s \in S\}$.

How?

Coverage

A test suite T satisfies a coverage criterion C , if for each $c \in C$, there exists a $t \in T$ such that t satisfies C .

Examples:

1. The set of (x, y) input-output $\{(-1, -1), (0, 0), (10, 100), (11, -1)\}$ satisfies $C = \{x < 0, x = 0, 0 < x < 10, x = 10, x > 10\}$
2. A test suite that runs every control-flow simple path satisfies $C = \{s \text{ is executed at least once} \mid s \in S\}$.

How?

Aspects of Testing

- ▶ Functional testing:
 - assumption: software is a **function** from inputs to outputs
 - coverage criterion defined based on **specification**
 - suitable for **black-box** testing (but can be enhanced with information from the code)
 - + program independent: tests can be **planned early**
 - + tests are **re-usable**
 - **gaps**: untested pieces of software
 - **redundancies**: the same statements may be tested several times

Functional Testing: Mortgage Example

Spec. Write a program that takes three **inputs**: gender (boolean), age([18-55]), salary ([0-10000]) and **output** the total mortgage for one person

Mortgage = salary * factor,
where factor is given by the following table.

Category	Male	Female
Young	(18-35 years) 75	(18-30 years) 70
Middle	(36-45 years) 55	(31-40 years) 50
Old	(46-55 years) 30	(41-50 years) 35

From: P.C. Jorgensen. Software Testing: A Craftsmans Approach.

An Implementation

```
Mortgage (male:Boolean, age:Integer, salary:Integer): Integer
if male then
  return ((18 ≤ age < 35)?(75 * salary) : (31 ≤ age <
    40)?(55 * salary) : (30 * salary))
else {female}
  return ((18 ≤ age < 30)?(75 * salary) : (31 ≤ age <
    40)?(50 * salary) : (35 * salary))
end if
```

Is this implementation correct?

An Implementation

```
Mortgage (male:Boolean, age:Integer, salary:Integer): Integer
if male then
  return ((18 ≤ age < 35)?(75 * salary) : (31 ≤ age <
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else {female}
  return ((18 ≤ age < 30)?(75 * salary) : (31 ≤ age <
    40)?(50 * salary) : (35 * salary))
end if
```

Is this implementation correct? **No way, 12 bugs!**

Functional Testing

```
Mortgage (male:Boolean, age:Integer, salary:Integer): Integer
if male then
  return ((18 ≤ age < 35)?(75 * salary) : (31 ≤ age <
    40)?(55 * salary) : (30 * salary))
else {female}
  return ((18 ≤ age < 30)?(75 * salary) : (31 ≤ age <
    40)?(50 * salary) : (35 * salary))
end if
```

Possible coverage:

for each age range and for each gender and salary 1, the input combination is in this range

output: factors as given by the table

(similar to equivalence testing; wait till next sessions!)

How?

Aspects of Testing

- ▶ Structural testing:
coverage criterion based on abstraction of **program**
examples: code coverage, branch coverage
 - + giving insight to the effectiveness of test
 - more complicated than functional testing
 - incapable of detecting errors of omission

Structural Testing

Spec.: input: an integer x [$1..2^{16}$]

output: x incremented by two, if x is less than 50,
 x decremented by one, if x is greater than 50, and
50, otherwise.

```
if  $x < 50$  then  
   $x = x + 1$ ;  
end if  
if  $x > 50$  then  
   $x = x - 1$ ;  
end if  
return  $x$ 
```

Structural Testing

```
if x < 50 then  
  x = x + 1;  
end if  
if x > 50 then  
  x = x - 1;  
end if  
return x
```

Coverage criterion: all statements are at least executed once, manually check the outputs with the spec.

Input	Output	Pass/Fail
1540	1539	P
2783	2782	P
3222	3221	P
30	31	F

Structural Testing

First “Debugged” Version:

```
if x < 50 then
  x = x + 2;
end if
if x > 50 then
  x = x - 1;
end if
return x
```

Input	Output	Pass/Fail
1540	1539	P
2783	2999	P
3222	3221	P
30	32	P

Have we tested enough?

Structural Testing

```
if x < 50 then
  x = x + 2;
end if
if x > 50 then
  x = x - 1;
end if
return x
```

Input	Output	Pass/Fail
49	50	F

Pesticide paradox: debugging old faults may produce **new bugs** (or “wake” old bugs up).

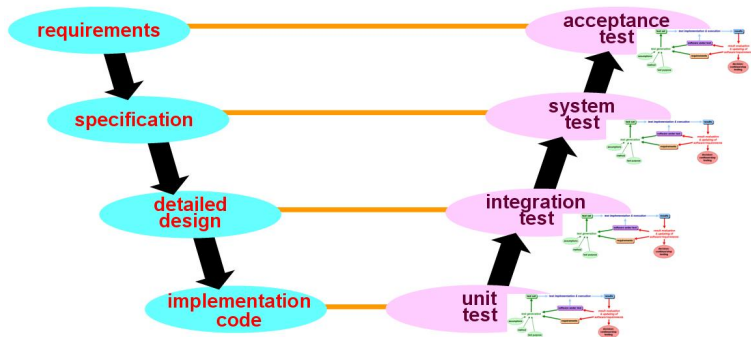
How?

Ideal Mix

- ▶ Functional and structural testing at various levels (unit, integration, system)
- ▶ Structural measures for the effectiveness of functional test-cases

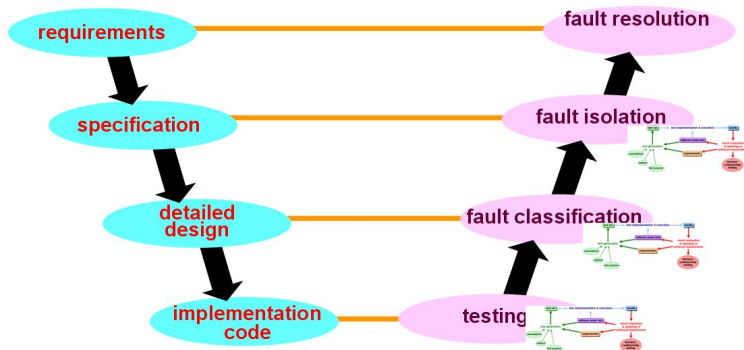
When?

V Model



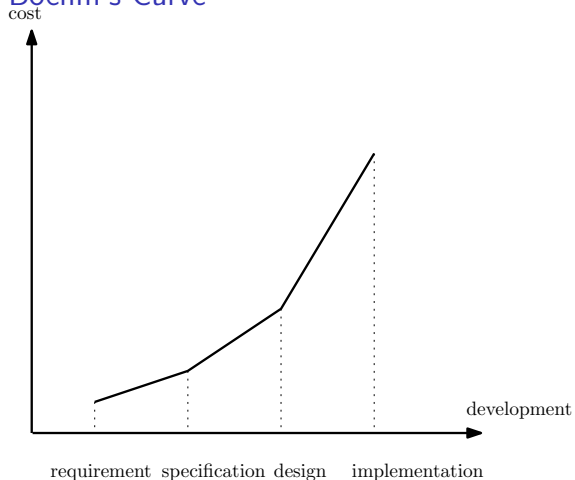
When?

V Model



When?

Boehm's Curve



When?

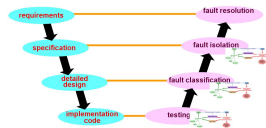
Dealing with Bugs

1-4 Putting errors in (producing bugs),

5-7 finding bugs:

- ▶ testing
- ▶ fault classification
- ▶ fault isolation

8 removing bugs



What Else?

Alternatives

- ▶ Static Analysis:
 - test **abstract** properties **without running** the program, e.g., uninitialized/unused variables, empty/unspecified cases, coding standards, checking for design (anti)patterns.
 - + automatic and scalable for generic and abstract properties;
 - + existing powerful tools;
 - involves approximation (true negatives and false positives); complicated (may involve theorem proving) for concrete and specific properties (proving the abstraction function to be “correct”)

What Else?

Alternatives

- ▶ Model Checking:
test the **state-space** for **formally** specified properties.
 - + rigorous analysis, push-button technology;
 - not (yet) applicable to many industrial cases (state-space explosion)