Testing, Debugging, and Verification

TDA567/DIT082

Introduction

Srinivas Pinisetty

30 October 2017

Software is everywhere

Nordea

Complexity, evolution, reuse, multiple domains/teams, $\cdots$

Software bug· · ·

- Error
- Fault
- Failure
- ...

A software bug is an error, flaw, failure, or fault in a computer program or system that causes it to produce an incorrect or unexpected result, or to behave in unintended ways. – Wikipedia

Introduction: Testing, Debugging, (Specification) and Verification

Introduction to techniques to get (some) certainty that your program does what it is supposed to do.

- Does my program do what it's supposed to do?
  - If not, why?
  - Have I understood exactly what it is supposed to do?

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  - Have I understood exactly what it is supposed to do?
- Can I give any guarantees that my program does the right thing?
- Introduction and overview of main techniques.
  - Orientation of main concepts.
  - If you have taken another course on e.g. testing, some material might be familiar.

Organisational Stuff

Course Home Page

`www.cse.chalmers.se/edu/course/TDA567/`

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- Sign up via course home page (follow News link).
- Changes, updates, questions, discussions.
- Don't post solutions!

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Passing Criteria

- Written exam 09 Jan 2018; re-exam Apr 2018
- Three lab hand-ins
- Exam and labs can be passed separately

Team

Teachers

- Lecturer: Srinivas Pinisetty (`sripin`)
  - Researcher in Formal Methods group.
- Examiner: Wolfgang Ahrendt (`ahrendt`)
  - Associate Professor in the Formal Methods group.

Course Assistants

- Mauricio Chimento (`chimento`). PhD student (FM division)
- Simon Robillard (`simon.robillard`). PhD student (FM division)
- Jeff Yu-Ting Chen (`yutingc`). PhD student (FM division)

office hours: by appointment via email.

. . . append `@chalmers.se` to obtain email address

Contact hours per week

Contact hours

- **Lectures**: Mondays 15:15-17:00, and Thursdays 10:00-11:45.
- **Labs**: Mondays 13:15-15:00.
- **Exercises**: Thursdays 08:00 - 09:45.

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Exceptions

- This Thursday: Lecture 08:00 - 09:45, and 10:00-11:45.
- November 09: Exercise and lecture rescheduled to November 10.

Structure

Course Structure

Topic	# Lectures	Exercises	Lab
Intro	1	✘	✘
Testing and Debugging	4	✔	✔
Formal Specification	3	✔	✔
Formal Verification	2	✔	✔
Guest Lectures	3	✘	✘

Course Literature

Lecture notes, exercise and lab material

- Lecture notes on the course webpage (appear online shortly after each lecture).
- Exercises material on the course webpage (questions before the exercise session, and sample solutions shortly after).

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Some suggested books

- *Why Programs Fail: A Guide to Systematic Debugging*[1)], 2nd edition, A Zeller
- *The Art of Software Testing*[1)], 2nd Edition, G J Myers
- *Introduction to Software Testing*[1)], P Ammann & J Offutt

See course website for a list of books, additional references

1) available online as e-books via Chalmers library

Labs

Labs

- Submission via Fire, linked from course home page
- You must team up in groups of two
    1. team up with the partner of your choice
    2. if you can't find one, call for a partner via Google group
    3. if the above does not work, contact the course assistants (Mauricio, Simon and Jeff)

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If there are Problems

Notify us immediately if you run into problems. e.g.

- Lab partner drops course.
- Problems solving some part of the lab - Ask for help!
- Don't wait until after the deadline.

Exercises

Exercises

- One (or two) exercise session for each topic (6 in all)
- Before each session:
  - we post exercise questions on web page
  - install software on your laptop
  - have a look at home, try to solve
- During each exercise session:
  - bring laptop with relevant software installed
  - ask questions!
  - discuss solutions together

Course Evaluation

- Course evaluation group
  - student representatives: Chalmers (randomly selected), GU (volunteers)
  - feedback meetings with teachers
  - one meeting during the course, one after
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Kevin Chen Trieu	`kevintr`
Rasmus Jemth	`jemthr`
Johannes Mattsson	`jomatts`
Jonatan Nylund	`nylundj`

For email address append: `@student.chalmers.se`

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Representatives GU

Please consider volunteering

Cost of Software Errors

$ 312 billion

(annual global cost)

Source: Cambridge University, Judge Business School 2013

http://www.prweb.com/releases/2013/1/prweb10298185.htm

Cost of Software Errors

estimated

50%

of programmers time spent on finding and fixing bugs.

Cost of Software Errors

$ 407 billion

Size of global software industry in 2013.

Source: Gartner, March 2014
`http://www.gartner.com/newsroom/id/2696317`

Cost of bugs approximately 3/4 of the size of the whole industry...

Software fault examples: Ariane 5 rocket

- Exploded right after launch
- Conversion of 64-bit float to 16-bit integer caused an exception (made it crash)
- European space agency spent 10 years and 7 billion USD to produce Ariane 5

Software fault examples: Pentium Floating Point Bug

- Incorrect result through floating point division
- Rarely encountered in practice
- 1 in 9 billion floating point divides with random parameters would produce inaccurate results (Byte magazine)
- 475 million dollars, reputation of Intel.

Cost of Software Errors: Conclusion

Huge gains can be realized in SW development by:

- systematic
- efficient
- tool-supported

testing, debugging, and verification methods

In addition . . .

The earlier bugs can be removed, the better.

Errors in Safety Critical Systems

Not just economic loss...

Therac-25 Radiotherapy Machine (1985-87)

- Patients overdosed.
- Three dead, two severely injured.
- SW bug causing radiation level entry to be ignored.

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Toyota Unintended Acceleration (2000-05)

- Bugs in electronic throttle control system.
- Car kept accelerating on its own.
- May have caused up to 89 deaths in accidents.
- Recalls of 8 million vehicle.

Defects in software: Problem sources

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- Requirements: Incomplete, inconsistent, $\cdots$
- Design: Flaws in design
- Implementation: Programming errors, $\cdots$
- Tools:Defects in support systems and tools used

Brainstorm

How can you get some assurance that a program does what you want it to do?

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Techniques for assurance

- Testing
- Pair programming, code review, $\cdots$
- Formal verification

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- Usually more assurance = more effort
- Research focus on more assurance for less effort

Brainstorming on Course Title

- What is Testing?

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  - Evaluating software by observing its execution
  - Execute program with the intent of finding failures (try out inputs, see if outputs are correct)
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  - The process of finding a defect given a failure
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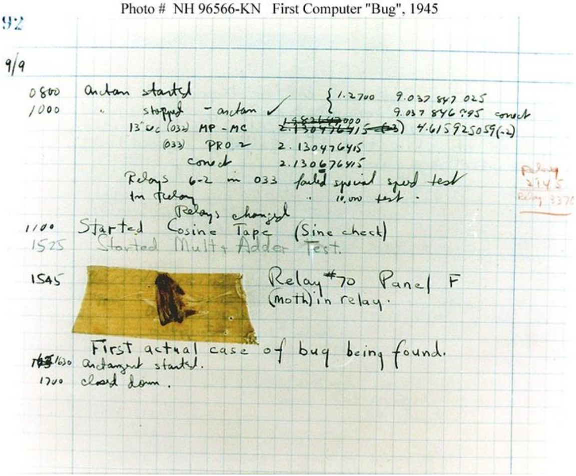
- What is Verification?
  - Determine whether a piece of software fulfils a set of formal requirements in every execution
  - Formally prove method correct (find evidence of absence of failure)

Bug Etymology



Harvard University, Mark II

see www.jamesshuggins.com/h/tek1/first_computer_bug.htm

What is a Bug? Basic Terminology

Bug-Related Terminology

1. Defect (aka bug, fault) introduced into code by programmer (not always programmer's fault, if, e.g., requirements changed)

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Defect — Infection — Propagation — Failure

Failure and Specification

Some failures are obvious

- obviously wrong output/behaviour
- non-termination
- crash
- freeze

. . . but most are not!

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In general, what constitutes a failure, is defined by: a specification!

Specification: Intro

- Specification: An unambiguous description of what a program should do.
- Bug: Failure to meet specification.
- Every program is correct with respect to SOME specification.

Specification: Intro

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Economist:
The cows in Scotland are brown

Specification: Intro



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No, there are cows in Scotland of which one at least is brown!

Specification: Intro

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Logician:
No, there are cows in Scotland of which one at least is brown!

Computer Scientist:
No, there is at least one cow in Scotland, which on one side is brown!!

Specification: Putting it into Practice

Example

A Sorting Program:

```
public static Integer[] sort(Integer[] a) { ...
}
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Specification: Putting it into Practice

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Specification

Requires: `a` *is an array of integers*

Ensures: *returns sorted array*

Example Cont'd

Example

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public static Integer[] sort(Integer[] a) { ...
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Is this a good specification?

Example Cont'd

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Is this a good specification?

$\mathrm{sort}(\{2,1,2\}) == \{1,2,2,17\}$ ✘

Example Cont'd

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public static Integer[] sort(Integer[] a) { ...
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Example Cont'd

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$\mathtt{sort}(\{2,1,2\}) == \{1,1,2\}$ ✘

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Requires: `a` *is an array of integers*

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Requires: `a` *is an array of integers*
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sort(null) throws `NullPointerException` ✘

Example Cont'd

Example

```
public static Integer[] sort(Integer[] a) { ...
}
```

Specification

Requires: `a` *is a non-null array of integers*
Ensures: *returns a permutation of* `a` *that is sorted*

The Contract Metaphor

Contract is preferred specification metaphor for procedural and OO PLs

first propagated by B. Meyer, *Computer* 25(10)40–51, 1992

Same Principles as Legal Contract between a Client and Supplier

- **Supplier:** (callee) aka implementer of a method
- **Client:** (Caller) implementer of calling method, or human user for `main()`
- **Contract:** One or more pairs of ensures/requires clauses defining mutual obligations of supplier and client

The Meaning of a Contract

Specification (of method `C.m()`)

Requires: *Precondition*
Ensures: *Postcondition*

"If a caller of `C.m()` fulfills the required Precondition, then the callee `C.m()` ensures that the Postcondition holds after `C.m()` finishes."

Specification, Failure, Correctness

What constitutes a failure

A method fails when it is called in a state fulfilling the required precondition of its contract and it does not terminate in a state fulfilling the postcondition to be ensured.

Specification, Failure, Correctness

What constitutes a failure

A method fails when it is called in a state fulfilling the required precondition of its contract and it does not terminate in a state fulfilling the postcondition to be ensured.

A method is correct means:

whenever it is started in a state fulfilling the required precondition, then it terminates in a state fulfilling the postcondition to be ensured.

Correctness amounts to proving absence of failures! A correct method cannot fail!

This course

Introduction to techniques to get (some) certainty that your program does what it is supposed to.

Testing

Test: try out inputs, see if outputs are correct

Testing means to execute a program with the intent of detecting failure

This course:terminology, testing levels, unit testing, black box vs white box, principles of test-set construction/coverage, automated and repeatable testing (JUnit)

Debugging

Understand why a program does not do what it is supposed to, usually via tool support such as the Eclipse debugger

- Testing attempts exhibit new failures
- Debugging is a systematic process that finds (and eliminates) the defect that led to an observed failure

This course: Input minimisation, systematic debugging, logging, program dependencies (tracking cause and effect)

Verification

Testing cannot guarantee correctness, i.e., absence of failures

Verification: Mathematically prove method correct

- Goal: find evidence for absence of failures

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Code

Formal specification

Verification

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correct?

Code $\longrightarrow$ Formal specification

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correct?

Code → Formal specification

Program Verification System

Verification

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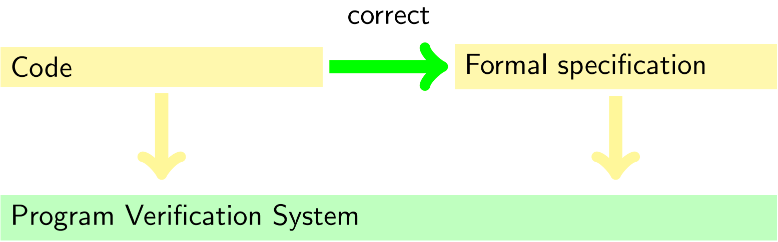

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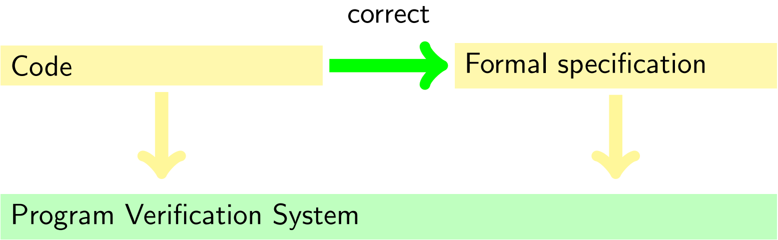

This course: Formal verification (logics, tool support)
Follow-up course: Formal Methods in Software Development

Course contents

How do we get some certainty that your program does what it is supposed to?

- Testing: Try out inputs, does what you want?
  terminology, testing levels, unit testing, black box vs white box, principles of test-set construction/coverage, automated and repeatable testing (JUnit)
- Debugging: What to do when things go wrong
  Input minimisation, systematic debugging, logging, program dependencies (tracking cause and effect)
- Formal specification & verification: Prove that there are no bugs
  Logic, define specification formally, assertions, invariants, formal verification tools, formal proofs

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Tools

Tools Used in This Course

- Automated running of tests: JUnit
- Debugging: Eclipse debugger.
- Formal specification and verification: Dafny