Software Engineering

Software Testing and Verification- Introduction

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Software is everywhere

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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- Can I give any guarantees that my program does the right thing?
- Introduction and overview of main techniques.
  - Orientation of main concepts.

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.

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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

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- Pair programming, code review, $\cdots$
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- Usually more assurance = more effort
- Research focus on more assurance for less effort

Testing Debugging and Verification

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  - The process of finding a defect given a failure
  - Relating a failure to a defect

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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)

What is a Bug? Basic Terminology

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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.

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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:
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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:

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public static Integer[] sort(Integer[] a) { ...
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Specification

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

Ensures: *returns sorted array*

Example Cont'd

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

Example Cont'd

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

Client:	(Caller) implementer of calling method, or human user for `main()`
Supplier:	(callee) aka implementer of a method
Contract:	One or more pairs of requires / ensures 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.

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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 Module

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

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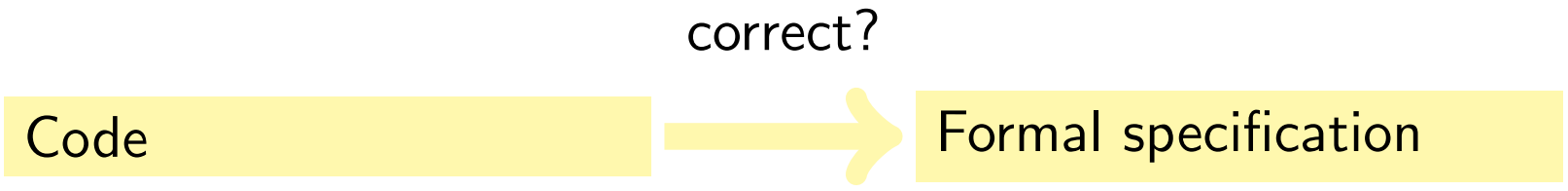

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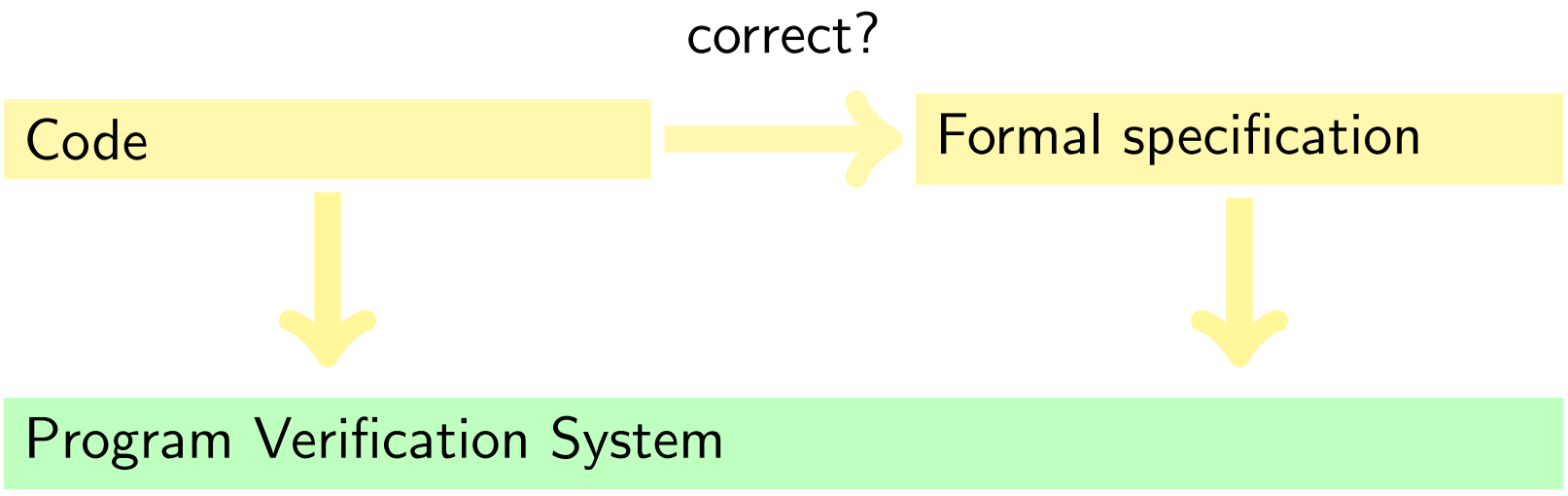

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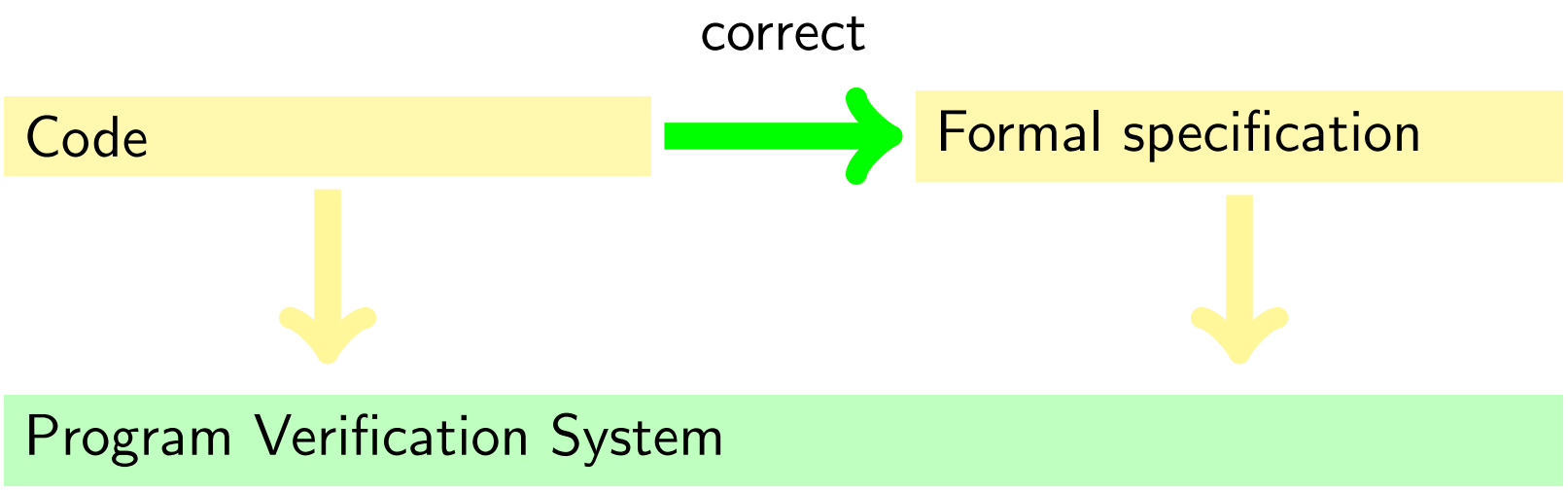

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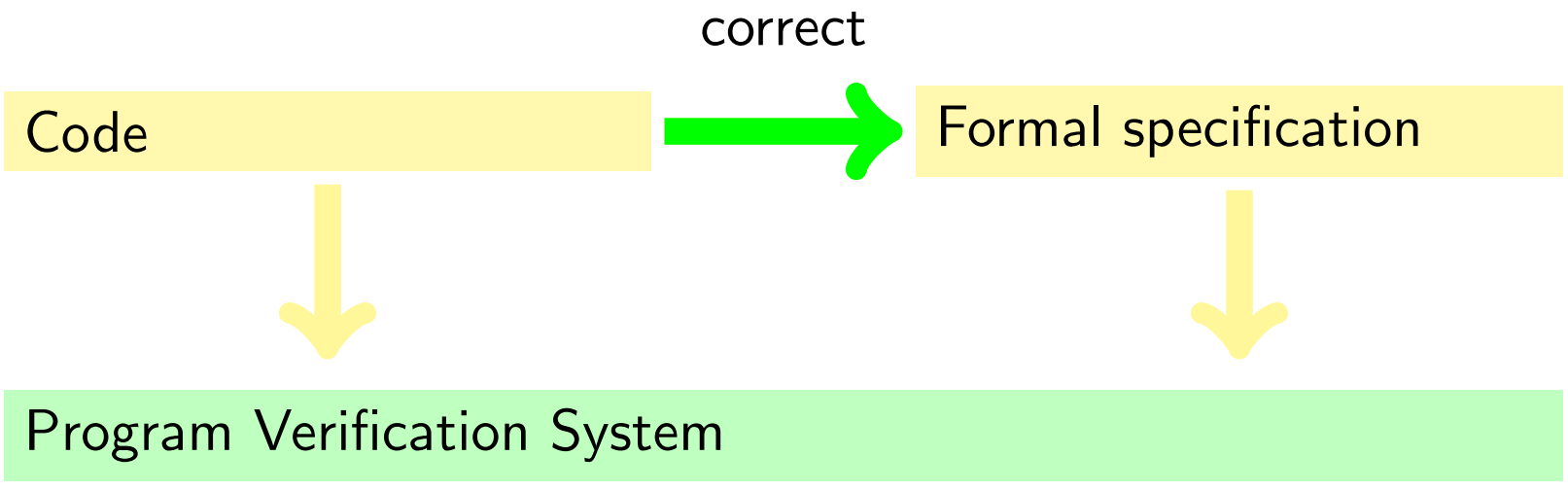

This course: Formal verification (logics, tool support)

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Tools

Tools Used

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