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(From a software engineering perspective.)

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▷ No crash, memory leak, undefined behavior, etc.
▷ Conform to the functional specification

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- Ease of bug fixing and code evolution
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Principles

Rigor

▷ Think

There ARE bugs in your code. Problem: (re)produce, minimize, understand and fix them. Might as well be early and in simple circumstances. A few concrete ideas in this lecture...
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- Review and peer-review
- Systematize

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A few concrete ideas in this lecture...
Static analysis
Formal methods

Theory
Model-checking, deductive verification, abstract interpretation, certified code generation, etc.

Practice

▶ Why, Frama-C, etc.
▶ At Microsoft
  ▶ MSR Tools: SLAM, Boogie, Z3... 
  ▶ Every code change checked by verification tools. Not necessarily complete nor correct! 
    ▶ correct: finds all bugs (and false alerts) 
    ▶ complete: finds only real bugs (but misses some) 
  ▶ Sparse: check annotations in the Linux kernel

What if we cannot / do not know how to use those tools?
Avoid the worst

Choose a disciplined language

- Variable declarations: avoid typos
- Static typing: guarantee simple invariants
  - more types $\Rightarrow$ more expressible invariants
    - Use enumerations rather than magic numbers
    - More in Prog. 2 (L3)
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Exploit your compiler as much as possible

Even with a strong and statically typed language, the compiler is not necessarily very constraining by default.

OCaml, C/C++, Scala, etc.: activate options to obtain more warnings, and treat them as errors.
In addition to the compiler (but still static)

Check style and good practices

Tools such as lint, cpplint, scalastyle, etc.

- Long lines, spacing, naming conventions
- Enforce type annotations on public methods
- Impose block delimiters for if
- Avoid return and var

Simple analyzers

Look for memory leaks, unchecked errors, trivial tests, library misuse, etc. in a more or less syntactic way.

- cppcheck, clang static analyzer, PVS studio, etc.
- Scala linter (demo)
Contracts
Code contracts

A *metaphore* for Floyd-Hoare logic:
pre-conditions, post-conditions, invariants, etc.
A design *methodology*: design by contract

Support

- Native language support: Eiffel, SpeC#
- Extension (comments): JML

Use

- Proof of programs
- Documentation generation
- Unit test generation
- Runtime verification
Assertions

It may be hard to prove the spec, but it can often easily be executed.

- Detect anomalies earlier.
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The assert function(s)

Take a boolean and raise an error if it’s false.

```plaintext
let add ?(needs_check=true) x rules kb =
    assert (needs_check || not (mem_equiv x kb)) ;
    if not (needs_check && mem_equiv x kb) then
        add (fresh_statement x) kb
```

Often part of the core language, with an erasing facility:

```
ocamlc -noassert ..., g++ -DNDEBUG ..., etc.
```
Using assertions

No-no

- If assert raises an exception, it should not be caught!
  (At least not permanently.)
  
  ```
  let main () =
    try ... with _ -> eprintf "Oops!\n" ; main ()
  ```

- Erasing assertions should not change the behavior of the code!
  *(Could we systematically detect such problems?)*
Using assertions

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► When is an assertion too costly?
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- When is an assertion too costly?
  Beware premature optimization.
  Consider multiple assertion levels.
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- When is an assertion too costly?
  *Beware premature optimization.*
  *Consider multiple assertion levels.*

- Should we release software with assertions enabled?
  Rather not, so as to benefit from precise errors.
  Consider changing them into BIG warnings.
Test
Tests

Focus on debugging, not conformance to requirements. Remember defensive (offensive?) programming.

Goals

- Detect problems earlier
- Facilitate identification of root cause
- Reproduce
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Testing granularity

- Unit testing on ... basic units
- Integration testing, complete system testing

Which properties? Explicit spec and/or “good behavior”.
White box

**Goal:** relevant tests based on the structure of the code.

Idea of **coverage:**
- the testing suite must “explore” as many behaviors as possible.

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- Criteria: lines, control flow, conditions, values, states, etc.

*Program testing can be used to show the presence of bugs, but never to show their absence! — E.W. Dijkstra*
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Choosing test values, based on code and spec:
partitions, equivalence classes, boundaries...

**Example:** `triangle.ml`
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By hand, or using the machine...
Pex 1 (C#)

Generate “interesting” test values, by symbolic execution and constraint solving. Demo: http://www.pexforfun.com

public class Point {
    public readonly int X, Y;
    public Point(int x, int y) { X = x; Y = y; }
}

public class Program {
    public static void Puzzle(Point p) {
        if (p.X * p.Y == 42)
            throw new Exception("Bug!");
    }
}

Propose 3 inputs: null, (0,0) and (3,14).
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Propose 3 inputs: null, (0,0) and (3,14).
```
public class Program {
    public static string Puzzle(string value) {
        Contract.Requires(value != null);
        Contract.Ensures(Contract.Result<string>() != null);
        Contract.Ensures(
            char.IsUpper(Contract.Result<string>()[0]));
        return char.ToLower(value[0]) + value.Substring(1);
    }
}

Find inputs that trigger bugs...
public class Program {
    public static string Puzzle(string value) {
        Contract.Requires(value != null);
        Contract.Requires(value == "" ||
                          char.IsLower(value[0]));
        Contract.Ensure(Contract.Result<string>() != null);
        Contract.Ensure(
            Contract.Result<string>() == "" ||
            char.IsUpper(Contract.Result<string>()[0]));
        if (value == "") return value;
        return char.ToUpper(value[0]) + value.Substring(1);
    }
}
using System;

public class Program {
    static int Fib(int x) {
        return x == 0 ? 0 : x == 1 ? 1 :
            Fib(x - 1) + Fib(x - 2);
    }
    public static void Puzzle(int x, int y) {
        if (Fib(x + 27277) + Fib(y - 27277) == 42)
            Console.WriteLine("puzzle solved");
    }
}
What if we cannot / don’t want to rely on the code?
Black box: TDD

Test driven development: write tests first, then code that passes them.
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Why do you multiply the percentage by 0.16772888172?

Otherwise the test fails.
Tests cannot replace specs, but allow to exploit it more.

Generate tests from specs:
  spec coverage, e.g., cause/consequence, clauses
Black box: randomness and stress

Randomized tests

- Quickcheck, Scalacheck (demo):
  test predicates on random input values
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- **Csmith**: compare C compilers on random code samples
  → no need for a spec (phew!)
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Stress

- Flood a server with requests
- Execution with constrained resources *(memory, disk)*
- Create latency *(network)*
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Fuzz testing

- Mainly for file formats and protocols
- Test on (partly) randomly generated/modified data
- **zzuf** *(demo)*, **LibFuzzer**, **afl-fuzz**, …
In practice
Objection

Writing tests = wasting time?
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When coding, you’re already writing tests:
  maybe in an interpreter,
  often in temporary \texttt{printf} checkes, visual verification,
  etc.

The goal is to preserve such tests, so as to fully exploit them.
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Regression test

Good practice integrating testing and debugging:
   before debugging, turn minimized bug into a test;
   the test will validate the fix and prevent future regressions.
Testing environment

Librairies to write tests more easily:
  xUnit, Scalacheck, Scalatest, etc.
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Systematic exploitation:
  - Hooks on commits
  - Continuous integration (Jenkins, Travis CI, etc.)
Objection

“That’s easy for a sorting function,
but another story for a server…”

Often, hard to test = poorly designed!

Examples

▷ Interaction with the filesystem, a database, etc.: sandboxing
▷ Graphical interface: possibility to script or capture (xnee)
  beware: testing the interface or the underlying logic?
▷ Non-functional aspects (time, space): profiling
Conclusion

Remember

- Be a humble, paranoid programmer
- Think debugging even from the design phase
- Provoke bugs

Tools are your friends (tutorials coming):

- Your programming language
- A strict compiler, linter, etc.
- Unit testing infrastructure, continuous integration
- Logging system
- Git(Hub) for code reviews and debugging