Software Engineering

Lecture 3: defensive programming

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Problem

What is good code / coding?
(From a software engineering perspective.)

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Debugging is twice as hard as writing the code in the first place. Therefore, if you write the code as cleverly as possible, you are, by definition, not smart enough to debug it. — Brian Kernighan

Principles

Rigor

- Think

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- Review and peer-review
- Systematize

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There ARE bugs in your code.

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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 $\rightsquigarrow$ 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 langage support: Eiffel, SpeC#
- Extension (comments): JML

Use

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

Assertions

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The `assert` function(s)

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

```
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?)

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  Consider multiple assertion levels.

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Grey zone

- 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

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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:
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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!");
  }
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Propose 3 inputs: `null`, `(0,0)` and `(3,14)`.

Pex 2 (C# + contracts)

```
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...

Pex 2 (C# + contracts) fixed

```
public class Program  {
  public static string Puzzle(string value) {
    Contract.Requires(value != null);
    Contract.Requires(value=="" ||
                      char.IsLower(value[0]));
    Contract.Ensures(Contract.Result<string>() != null);
    Contract.Ensures(
      Contract.Result<string>()=="" ||
      char.IsUpper(Contract.Result<string>()[0]));
    if (value=="") return value;
    return char.ToUpper(value[0]) + value.Substring(1);
  }
}
```

Pex 3 (C# + contracts)

```
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");
  }
}
```

Black box

What if we cannot / don't want to rely on the code?

Black box: TDD

Test driven development:
write tests first, then code
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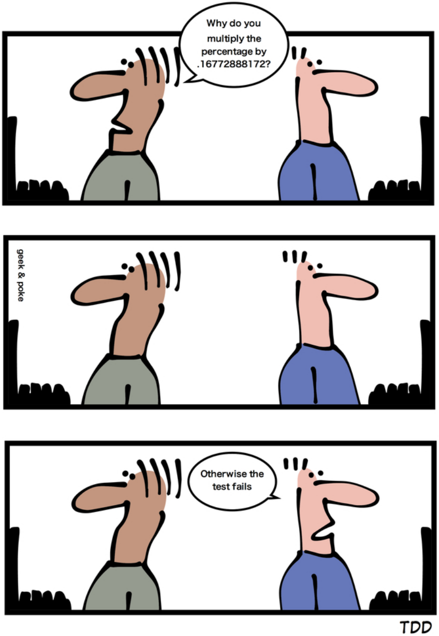

Black box: test & spec

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):
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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

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When coding, you're already writing tests:
maybe in an interpreter,
often in temporary `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