[kwol-i-tee] • 1250–1300; ME qualite < OF < L quālitās
[uh-shoor-uhns, -shur-] • 1325–75; ME ass(e)ura(u)nce < MF ass(e)urance
dictionary.com

CSE403: Software Engineering

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Software quality assurance

- What are we assuring?
- Why are we assuring it?
- How do we assure it?
- How do we know we have assured it?

What are we assuring?

- Validation: building right system?
- Verification: building system right?

- Presence of good properties?
- Absence of bad properties?

- Identifying errors?
- Confidence in the absence of errors?

- Robust? Safe? Available? Reliable? Understandable? Modifiable? Cost-effective? Usable? …

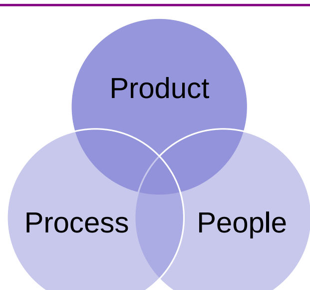
The answer matters

Why are we assuring it?

- Business reasons
- Ethical reasons
- Professional reasons
- Personal satisfaction
- Legal reasons
- Social reasons
- Economic reasons
- …

The answer matters

How do we assure it?



How do we know we have assured it?

- Depends on "it"
- Depends on what we mean by "assurance"
- …

Our focus

- Primarily on the product – testing, verification, etc.
  - And primarily on "built the system right?"
- Some on the process – walkthroughs, code reviews, etc.

Foundation: program correctness

- Relatively few programs are proven correct
  - Hard, expensive, and usually uni-dimensional
- The language and "way of thinking" is important, and many recent testing and anomaly checking technologies are heavily reliant on this foundation

Basics of program correctness

- Make precise the meaning of programs
- In a logic, write down (this is often called the specification)
  - the effect of the computation that the program is required to perform (the postcondition **Q**)
  - any constraints on the input environment to allow this computation (the precondition **P**)
- Associate precise (logical) meaning to each construct in the programming language (this is done per-language, not per-program)
- Reason (usually backwards) that the logical conditions are satisfied by the program **S**
- A Hoare triple is a predicate **{P}S{Q}** that is true whenever **P** holds and the execution of **S** guarantees that **Q** holds

Examples

```
• {true}
    y := x * x;
  {y >= 0}

• {x <> 0}
    y := x * x;
  {y > 0}

• {x > 0}
    x := x + 1;
  {x > 1}
```


More examples

```
• {x = k}
    if (x < 0) x := -x endif;
  {    ?    }


• {    ?    }
    x := 3;
  { x = 8 }
```


Strongest postconditions

[example from Aldrich and perhaps from Leino]

The following are all valid Hoare triples

```
• {x = 5} x := x * 2 { true }
• {x = 5} x := x * 2 { x > 0 }
• {x = 5} x := x * 2 { x = 10 || x = 5 }
• {x = 5} x := x * 2 { x = 10 }
```

- Which is the most useful, interesting, valuable? Why?

Weakest preconditions
[example from Aldrich and perhaps from Leino]

Here are a number of valid Hoare Triples
- `{x = 5 && y = 10} z := x / y { z < 1 }`
- `{x < y && y > 0} z := x / y { z < 1 }`
- `{y ≠ 0 && x / y < 1} z := x / y { z < 1 }`

- The last one is the most useful because it allows us to invoke the program in the most general condition
- It is called the *weakest precondition*, `wp(S,Q)` of `S` with respect to `Q`
  - If `{P} S {Q}` and for all `P'` such that `P' => P`, then `P` is `wp(S,Q)`

Sequential execution

- What if there are multiple statements
  - `{P} S1;S2 {Q}`
- We create an intermediate assertion
  - `{P} S1 {A} S2 {Q}`
- We reason (usually) backwards to prove the Hoare triples
- A formalization of this approach essential defines the ; operator in most programming languages

```
– {x > 0}
    y := x*2;
    z := y/2
  {z > 0}

– {x > 0}
    y := x*2;
  {y > 0}
    z := y/2
  {z > 0}
```


Conditional execution

```
• {P}
    if C then S1
         else S2
    endif
  {Q}
```

- Must consider both branches
- Ex: compute the maximum of two variables `x` and `y`

```
{true}
  if x >= y then
    max := x
  else
    max := y
  fi
{(max >= x ∧ max >= y)}
```


Hoare logic rule: conditional

```
{P} if C then S1 else S2 {Q}
  ≡
{P ∧ C}S1{Q} ∧ {P ∧ ¬ C}S2{Q}
```


Be careful!

- ```
  {true}
    max := abs(x)+abs(y);
  {max >= x ∧ max >= y}
  ```
- This predicate holds, but we don't "want" it to
  - The postcondition is written in a way that permits satisfying programs that don't compute the maximum
  - In essence, every specification is satisfied by an infinite number of programs and vice versa
- The "right" postcondition is
  - ```
    {(max = x ∨ max = y)
     ∧ (max >= x ∧ max >= y)}
    ```


Assignment statements

- We've been highly informal in dealing with assignment statements
- What does the statement `x := E` mean?
  - `{Q(E)} x := E {Q(x)}`
  - If we knew something to be true about `E` before the assignment, then we know it to be true about `x` after the assignment (assuming no side-effects)

Examples

```
{y > 0}
  x := y
{x > 0}

{x > 0}    [Q(E) ≡ x + 1 > 1 ≡ x > 0 ]
  x := x + 1;
{x > 1}    [Q(x) ≡ x > 1]
```


More examples

```
{    ?     }
  x := y + 5
{x > 0}

{x = A ∧ y = B }
  t := x;
  x := y;
  y := t
{x = B ∧ y = A }
```


Loops

- **`{P} while B do S {Q}`**
- We can try to unroll this into
  - `{P ∧ ¬ B} S {Q} ∨`
    `{P ∧ B} S {Q ∧ ¬B} ∨`
    `{P ∧ B} S {Q ∧ B} S {Q ∧ ¬B} ∨ …`
- But we don't know how far to unroll, since we don't know how many times the loop can execute
- The most common approach to this is to find a loop invariant, which is a predicate that
  - is true each time the loop head is reached (on entry and after each iteration)
  - and helps us prove the postcondition of the loop
  - It approximates the fixed point of the loop

Loop invariant for `{P} while B do S {Q}`

- Find `I` such that
  - `P ⇒ I` –Invariant is correct on entry
  - `{B ∧ I} S {I}` –Invariant is maintained
  - `{¬B ∧ I} ⇒ Q` –Loop termination proves Q
- Example

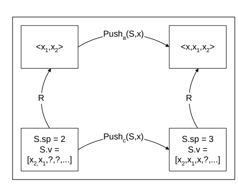
```
{n > 0}
  x := a[1];
  i := 2;
  while i <= n do
    if a[i] > x then x := a[i];
    i := i + 1;
  end;
{x = max(a[1],…,a[n])}
```


Termination

- Proofs with loop invariants do not guarantee that the loop terminates, only that it does produce the proper postcondition **if** it terminates – this is called *weak correctness*
- A Hoare triple for which termination has been proven is *strongly correct*
- Proofs of termination are usually performed separately from proofs of correctness, and they are usually performed through well-founded sets
  - In this example it's easy, since `i` is bounded by `n`, and `i` increases at each iteration
- Historically, the interest has been in proving that a program does terminate: but many important programs now are intended not to terminate

Correctness of data structures

- Primarily due to Hoare; figures from Wulf *et al*.
- Prove the specifications on the abstract operations (e.g., $\mathtt{Push}_a$)
- Prove the specifications on the concrete operations (e.g., $\mathtt{Push}_c$)
- Prove the relation between abstract and concrete operations (e.g., `R`), the representation mapping



Example

$\{\neg \mathtt{full}(S_a)\}$	$\{\neg \mathtt{full}(R(S_c))\}$
$\mathtt{Push}_a(S_a, x)$	$\mathtt{Push}_c(S_c, x)$
$\{S_a = \langle x \rangle \| S'_a\}$	$\{R(S_c) = \langle x \rangle \| R(S'_c)\}$

So what?

- It lays a foundation for
  - Thinking about programs more precisely
  - Applying techniques like these in limited, critical situations
  - Development of some modern design, specification and analysis approaches that seem to have value in more situations
  - Basis for many testing and analysis approaches

Testing vs. proving

- Dynamic
- Builds confidence
  - Can only show the presence of bugs, not their absence
- Used widely in practice
- Costly

- Static
- It's a proof
  - Proofs are human processes that aren't foolproof
- Applicability is practically limited
- Extremely costly

Brief (and informal) aside

- Dynamic techniques are unattractive because they are "unsound" — you can believe something is true when it's not
- Static techniques are unattractive because they are often very costly — and they may lead you to confuse the checked property for other desirable properties
- The truth is that they should be considered to be complementary, not competitive

Testing

- In any case, testing is by far the dominant approach to assessing software products

Two kinds of improvements

- One goal is to improve testing to increase the quality of the software that is produced
- Another goal is to reduce the costs of testing while maintaining the current quality of the software that is produced

Terminology

- A *failure* occurs when a program doesn't satisfy its specification
- A *fault* occurs when a program's internal state is inconsistent with what is expected (usually an informal notion)
- A *defect* is the code that leads to a fault (and perhaps to a failure)
- An *error* is the mistake the programmer made in creating the defect

More terminology

- A test case is a specific set of data that exercises the program
- A test suite is a set of test cases
- Old terminology
  - A test case (suite) fails if it demonstrates a problem
- New terminology
  - A test case (suite) succeeds if it demonstrates a problem

Root cause analysis

- Tries to track a failure to an error
- Identifying errors is important because it can
  - help identify and remove other related defects
  - help a programmer (and perhaps a team) avoid making the same or a similar error again

Kinds of testing

- Unit
- White-box
- Black-box
- Gray-box
- Bottom-up
- Top-down
- Boundary condition
- Syntax-driven
- Big bang
- Integration
- Acceptance
- Stress
- Regression
- Alpha
- Beta
- Fuzz

In groups

- The program reads three integer values. The three values are interpreted as representing the lengths of the sides of a triangle. The program prints a message that states whether the triangle is isosceles, equilateral, or scalene.
- Write a set of test cases that you feel would adequately test this program

In practice

- 13 kinds of errors were found in actual programs
- When highly experienced programmers are given this example, on the average they figure out about half of the kinds of errors

The lucky thirteen...

- Valid scalene triangle
- Valid equilateral triangle
- Valid isosceles triangle
- Three cases that represent valid isosceles triangles in all permutations
- One side is zero
- One side is negative
- 3 positive integers where two sum to the third
- All permutations of the previous case

The remaining ones

- 3 positive integers where two sum to less than the third
- 3 permutations of the previous case
- All sides are zero
- A non-integer side
- An incorrect number of inputs

Questions?