CSE 4313
Software Engineering: Testing

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What is testing?

A technical investigation done to expose quality-related information about the product under test

Defining Testing

- **A technical**
  - Logic, mathematics, models, tools
- **investigation**
  - An organized and thorough search for information.
  - We ask hard questions (aka run hard test cases) and look carefully at the results.
- **done to expose quality-related information**
  - see the next slide
- **about the product under test.**

Information Objectives

- Find important bugs, to get them fixed
- Check interoperability with other products
- Help managers make ship/no-ship decisions
- Block premature product releases
- Minimize technical support costs
- Assess conformance to specification
- Conform to regulations
- Minimize safety-related lawsuit risk
- Find safe scenarios for use of the product

Different objectives require different testing strategies and will yield different tests, different test documentation and different test results.

Our goal

- Learn testing techniques and the situations in which they apply
- Practice with real testing tools and frameworks
- Learn how to produce quality problem reports
- Study special issues for object-oriented systems
- Understand the importance of systematic testing

Tools - Eclipse

- IDE for Java development
- Works seamlessly with Junit for unit testing
- Open source – Download from www.eclipse.org
- In the lab, do: `eclipse`
- Try it with your own Java code

Tools - Junit

- A framework for automated unit testing of Java code
- Written by Erich Gamma (of Design Patterns fame) and Kent Beck (creator of XP methodology)
- Uses Java 5 features such as annotations and static imports
- Download from www.junit.org

A first example

- Test ADDER:
  - Adds two numbers that the user enters
  - Each number should be one or two digits
  - The program echoes the entries, then prints the sum.
  - Press <ENTER> after each number
- Screen for a test run

```
? 2
? 3
5

?
```

Immediate issues

- Nothing shows what this program is. You don't even know you run the right program.
- No on-screen instructions.
- How do you stop the program?
- The 5 should probably line up with the 2 and 3.

A first set of test cases

99 + 99	-99 + -99
99 + 56	56 + 99
99 + -14	-14 + 99
38 + -99	-99 + 38
-99 + -43	-43 + -99
9 + 9	0 + 0
0 + 23	-23 + 0

Choosing test cases

- Not all test cases are significant.
- Impossible to test everything (this simple program has 39,601 possible different test cases).
- If you expect the same result from two tests, they belong to the same class. Use only one of them.
- When you choose representatives of a class for testing, pick the ones most likely to fail.

Further test cases

100 + 100

<Enter> + <Enter>

123456 + 0

1.2 + 5

A + b

<CTRL-C> + <CTRL-D>

<F1> + <Esc>

Other things to consider

- Storage for the two inputs or the sum
  - 127 or 128 can be an important boundary case
- Test cases with extra whitespace
- Test cases involving <Backspace>
- The order of the test cases might matter
  - E.g. <Enter> + <Enter>

An object-oriented example

- Input: Three integers, a, b, c, the lengths of the side of a triangle
- Output: Scalene, isosceles, equilateral, invalid

Test case classes

- Valid scalene, isosceles, equilateral triangle
- All permutations of two equal sides
- Zero or negative lengths
- All permutations of a + b < c
- All permutations of a + b = c
- All permutations of a = b and a + b = c
- MAXINT values
- Non-integer inputs

Example implementation

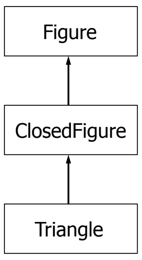
```
class Triangle{
  public Triangle(LineSegment a, LineSegment b,
                                 LineSegment c)
  public boolean is_isosceles()
  public boolean is_scalene()
  public boolean is_equilateral()
  public void draw()
  public void erase()
}
class LineSegment {
  public LineSegment(int x1, int y1,
                     int x2, int y2)
}
```

Extra Tests

- Is the constructor correct?
- Is only one of the **`is_*`** methods true in every case?
- Do results repeat, e.g. when running **`is_scalene`** twice or more?
- Results change after **`draw`** or **`erase`**?
- Segments that do not intersect or form an interior triangle

Inheritance tests

- Tests that apply to all Figure objects must still work for Triangle objects
- Tests that apply to all ClosedFigure objects must still work for Triangle objects



Testing limits

- Dijkstra: “Program Testing can be used to show the presence of defects, but never their absence”.
- It is impossible to fully test a software system in a reasonable amount of time or money
- “When is testing complete? When you run out of time or money.”

Complete testing

- What do we mean by "complete testing"?
  - Complete "coverage": Tested every line/path?
  - Testers not finding new bugs?
  - Test plan complete?
- Complete testing must mean that, at the end of testing, you know there are no remaining unknown bugs.
- After all, if there are more bugs, you can find them if you do more testing. So testing couldn't yet be "complete."

Complete coverage?

- What is coverage?
  - Extent of testing of certain attributes or pieces of the program, such as statement coverage or branch coverage or condition coverage.
  - Extent of testing completed, compared to a population of possible tests.
- Why is complete coverage impossible?
  - Domain of possible inputs is too large.
  - Too many possible paths through the program.

Measuring and achieving high coverage

- Coverage measurement is a good tool to show **how far** you are from complete testing.
- But it’s a lousy tool for investigating how close you are to completion.

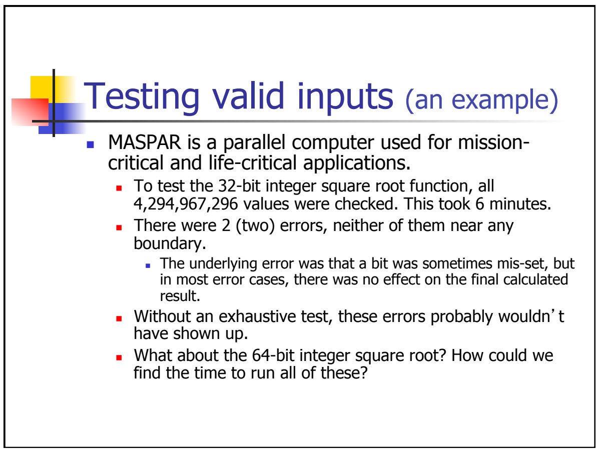
Testers live and breathe tradeoffs

- The time needed for test-related tasks is infinitely larger than the time available.
- Example: Time you spend on
  - Analyzing, troubleshooting, and effectively describing a failure
- Is time no longer available for

Designing tests	Documenting tests
Executing tests	Automating tests
Reviews, inspections	Training other staff

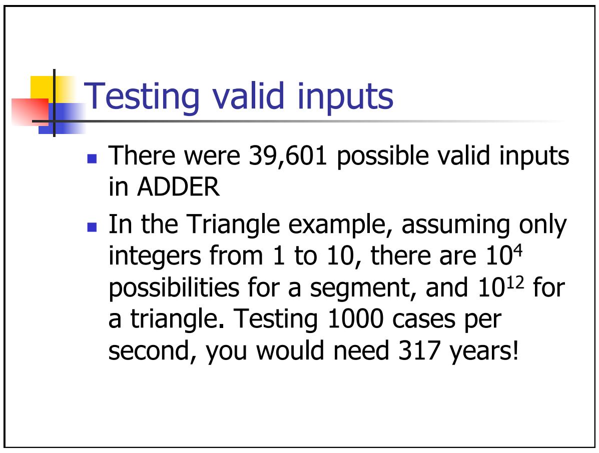
The infinite set of tests

- There are enormous numbers of possible tests. To test everything, you would have to:
  - Test every possible input to every variable.
  - Test every possible combination of inputs to every combination of variables.
  - Test every possible sequence through the program.
  - Test every hardware / software configuration, including configurations of servers not under your control.
  - Test every way in which any user might try to use the program.



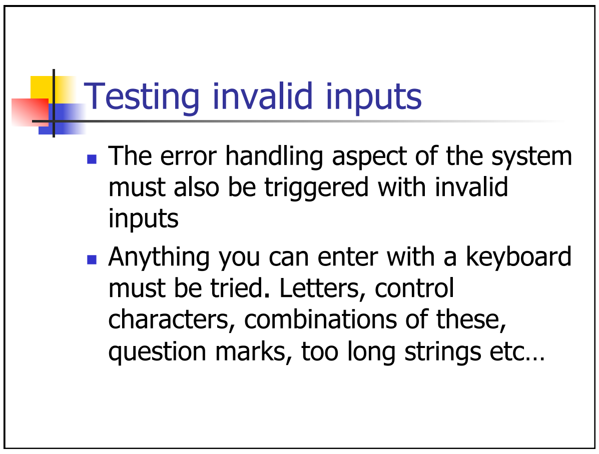
Testing valid inputs (an example)

- MASPAR is a parallel computer used for mission-critical and life-critical applications.
  - To test the 32-bit integer square root function, all 4,294,967,296 values were checked. This took 6 minutes.
  - There were 2 (two) errors, neither of them near any boundary.
    - The underlying error was that a bit was sometimes mis-set, but in most error cases, there was no effect on the final calculated result.
  - Without an exhaustive test, these errors probably wouldn' t have shown up.
  - What about the 64-bit integer square root? How could we find the time to run all of these?



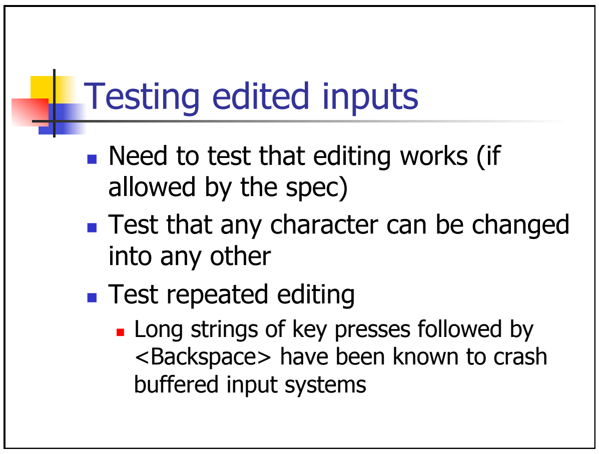
Testing valid inputs

- There were 39,601 possible valid inputs in ADDER
- In the Triangle example, assuming only integers from 1 to 10, there are 10^4 possibilities for a segment, and 10^{12} for a triangle. Testing 1000 cases per second, you would need 317 years!



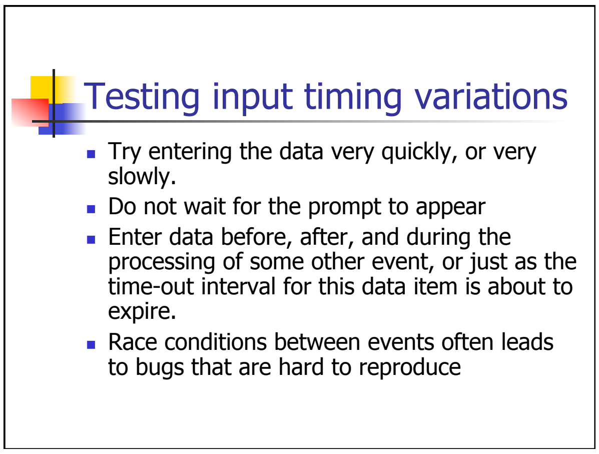
Testing invalid inputs

- The error handling aspect of the system must also be triggered with invalid inputs
- Anything you can enter with a keyboard must be tried. Letters, control characters, combinations of these, question marks, too long strings etc…



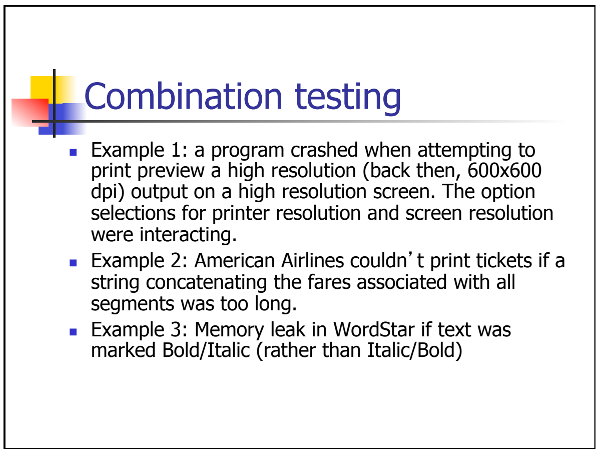
Testing edited inputs

- Need to test that editing works (if allowed by the spec)
- Test that any character can be changed into any other
- Test repeated editing
  - Long strings of key presses followed by <Backspace> have been known to crash buffered input systems



Testing input timing variations

- Try entering the data very quickly, or very slowly.
- Do not wait for the prompt to appear
- Enter data before, after, and during the processing of some other event, or just as the time-out interval for this data item is about to expire.
- Race conditions between events often leads to bugs that are hard to reproduce



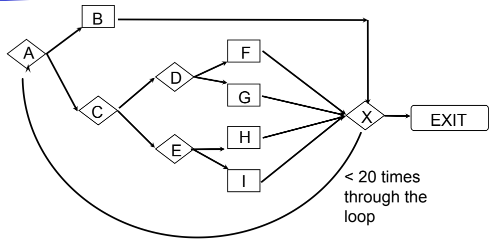
Combination testing

- Example 1: a program crashed when attempting to print preview a high resolution (back then, 600x600 dpi) output on a high resolution screen. The option selections for printer resolution and screen resolution were interacting.
- Example 2: American Airlines couldn' t print tickets if a string concatenating the fares associated with all segments was too long.
- Example 3: Memory leak in WordStar if text was marked Bold/Italic (rather than Italic/Bold)

What if you don’t test all possible inputs?

- Based on the test cases chosen, an implementation that passes all tests but fails on a missed test case can be created.
- If it can be done on purpose, it can be done accidentally too.
  - A word processor had trouble with large files that were fragmented on the disk (would suddenly lose whole paragraphs)

Testing all paths in the system



Here’s an example that shows that there are too many paths to test in even a fairly simple program. This is from Myers, *The Art of Software Testing*.

Number of paths

- One path is ABX-Exit. There are 5 ways to get to X and then to the EXIT in one pass.
- Another path is ABXACDFX-Exit. There are 5 ways to get to X the first time, 5 more to get back to X the second time, so there are 5 x 5 = 25 cases like this.
- There are $5^1 + 5^2 + ... + 5^{19} + 5^{20} = 10^{14} = 100$ trillion paths through the program.
- It would take only a billion years to test every path (if one could write, execute and verify a test case every five minutes).

Further difficulties for testers

- Testing cannot verify requirements. Incorrect or incomplete requirements may lead to spurious tests
- Bugs in test design or test drivers are equally hard to find
- Expected output for certain test cases might be hard to determine

Conclusion

- Complete testing is impossible
  - *There is no simple answer for this.*
  - *There is no simple, easily automated, comprehensive oracle to deal with it.*
  - *Therefore testers live and breathe tradeoffs.*