CSc 120
Introduction to Computer Programming II

Adapted from slides by
Dr. Saumya Debray

05: Testing
Why test?

• Mars Climate Orbiter
  – Purpose: to study the Martian climate and to serve as a relay for the Mars Polar Lander
  
  – Disaster: Bad trajectory caused it to disintegrate in the upper atmosphere of Mars
  
  – Why: Software bug - failure to convert English units to metric values (pound-seconds vs. newton-seconds) as specified in the contract
Why test?

• THERAC-25 Radiation Therapy
  – 1985 to 1987: two cancer patients at the East Texas Cancer Center in Tyler received fatal radiation overdose (a total of 6 accidents) – *massive overdose*
  – Why: Software bug - mishandled race condition (i.e., miscoordination between concurrent tasks)
Why test?

• Hive Thermostat
• February, 2016: customers were roasting at home
• the thermostat mysteriously began setting the temperature to 90 degrees F (32 C)

• Hive:
  – “We are aware of a temporary glitch…where a certain sequence of commands in the Hive iOS app can cause thermostat temperature to rise to 90 degrees F.”
Why test?

• Hive user:

Hey @hivehome @HiveHelper when are you going to stop letting skynet try to boil me alive? (2nd time now)
Purpose of testing

• Every piece of software is written with some functionality in mind

• Testing aims to identify whether the program meets its intended functionality
  – "testing can only prove the presence of bugs, not their absence"
  – the more thoroughly your software is tested, the more confidence you can have about its correctness

  – "Test until fear turns into boredom." – Kent Beck
"thoroughly" ≠ lots of test cases

def main():
    x = input()
    if x %2 == 1:  # x is odd
        do_useful_computation()
    else:
        delete_all_files()
        send_rude_email_to_boss()
        crash_computer()

It isn’t enough to simply have a lot of test cases. They have to “cover” the program adequately.
Approaches to testing

Black-box testing

• Focuses only on functionality
  – does not look at how the code actually works

• Good for identifying missing features, misunderstandings of the problem spec

White-box testing

• Focuses on the code
  – examines the code to figure out what tests to use

• Good for identifying bugs and programming errors
black-box testing
Black-box testing: what to test?

• Based purely on the desired functionality
  – shouldn’t be influenced by the particular code you wrote
    (that’s white-box testing)

• Aspects to consider:
  – expected outcome
    o normal vs error
  – characterizing values
    o edge cases vs “regular” values
Black-box testing: Outcomes

• Choose tests for both *normal* and *error* behaviors
  – assumes that we know what the error situations are

• Desired program behavior:
  – on normal inputs: produce the expected behavior
  – on error inputs:
    o detect and indicate that an error occurred
    o then behave appropriately as required by the problem spec

• Passing a test:
  – the program *passes a test* if it shows the desired behavior for that test
Black-box testing: Values

• Edge cases:
  – at or near the end(s) of the range of a value the program is supposed to operate on
  – Examples:
    o “zero-related” : 0, [], empty string, empty file, ...
    o “one-related” : 1, –1, list with one element, file with one line, ...
    o (maybe) large values

• “Regular” values:
  – not edge cases
Example:

“Read a file containing integers and print the sum of the numbers that occur on odd-numbered lines.”

Sample input file:

```
9
4
8
2
3
```
Example “Read a file containing integers and print the sum of the numbers that occur on odd-numbered lines.”

**Testing for outcome (legal vs. error):**

<table>
<thead>
<tr>
<th>Normal behavior</th>
<th>Error behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>• no. of numbers = 1</td>
<td>• input file does not exist (or is unreadable)</td>
</tr>
<tr>
<td>– 0 adds</td>
<td>• file has non-numeric characters</td>
</tr>
<tr>
<td>• no. of numbers = 3</td>
<td>• empty line</td>
</tr>
<tr>
<td>– 1 add; 1 skip in-between</td>
<td>• more than one number on a line</td>
</tr>
<tr>
<td>• no. of numbers = 4</td>
<td></td>
</tr>
<tr>
<td>– 1 add; 1 skip at end</td>
<td></td>
</tr>
<tr>
<td>• &gt; 4 numbers</td>
<td></td>
</tr>
<tr>
<td>– several add operations</td>
<td></td>
</tr>
</tbody>
</table>
**Example**

“Read a file containing integers and print the sum of the numbers that occur on odd-numbered lines.”

Testing for values (edge cases vs. regular values):

<table>
<thead>
<tr>
<th>Edge cases</th>
<th>Regular values</th>
</tr>
</thead>
<tbody>
<tr>
<td>empty file</td>
<td>a file with several numbers, one per line</td>
</tr>
<tr>
<td>file with one number</td>
<td></td>
</tr>
</tbody>
</table>
Example

“Read a file containing integers and print the sum of the numbers that occur on odd-numbered lines.”

Putting these together:

<table>
<thead>
<tr>
<th>Normal behavior</th>
<th>Error behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>• empty file</td>
<td>• input file does not exist (or is unreadable)</td>
</tr>
<tr>
<td>• file with one number</td>
<td>• file has non-numeric characters</td>
</tr>
<tr>
<td>• a file with several numbers, one per line</td>
<td>• empty line</td>
</tr>
<tr>
<td></td>
<td>• more than one number on a line</td>
</tr>
</tbody>
</table>

edge

regular
Consider this program specification:

Write a program that reads a file name and computes (and prints out) the length of the longest line in that file.

Specify input files that exemplify each of the following:

a) two error cases

b) two edge cases

c) one regular (normal) case
Consider this program specification:

Write a program that reads a file name and computes (and prints out) the length of the longest line in that file.

Specify input files that exemplify each of the following:

a) two error cases
   - the file does not exist
   - the file is readable but not organized into lines (it’s a JPEG,…)

a) two edge cases
   - the file has one line
   - the file is empty

a) one regular (normal) case
   - the file has many lines, each line containing readable values
Consider the rhyming words assignment. Specify input files that exemplify each of the following:

a) one error cases

b) one edge cases

c) one regular (normal) case
Consider the rhyming words assignment. Specify input files that exemplify each of the following:

a) two error cases
An input file that has more than one pronunciation per line
An empty input file

b) one edge case
An input file that has two words where the pronunciation of each has no sound that precedes the primary phoneme

c) one regular (normal) case
An input file that has two words, where the pronunciation of each has phonemes meet the rules for rhyming
Consider this program specification:

Write a program that reads a (possibly empty) file containing only numbers (and whitespace) and prints out the difference between the smallest and largest numbers. An empty input file should generate no output.

Specify input files that exemplify each of the following:

a) two error cases

b) two edge cases

c) one regular (normal) case
white-box testing
White-box testing: what to test?

• Ideally, that every path through the code works correctly
  – but this can be prohibitively difficult and expensive

• Instead, what we often do is:
  – check that the individual pieces of the program work properly
  – use asserts of pre/postconditions to check that the pieces interact properly
Unit testing

• Tests individual units of code, e.g., functions, methods, or classes
  – e.g.: given specific test inputs, does the function behave correctly?
    ○ CloudCoder!
  – useful for making programmers focus on the exact behavior of the function being tested
    ○ e.g., preconditions, postconditions, invariants
  – helps find problems early

• Isolate a unit and validate its correctness
• Often automated, but can be done manually
Unit testing

# grid_is_square(arglist) – returns True if arglist
# has the shape of a square grid, i.e.,
# the length of each element ("row") of arglist is
# equal to the number of rows of arglist

def grid_is_square(arglist):
    num_rows = len(arglist)
    for row in arglist:
        if len(row) != num_rows:
            return False
    return True
Unit testing

# grid_is_square(arglist) – returns True if arglist
# has the shape of a square grid, i.e.,
# the length of each element ("row") of arglist is
# equal to the number of rows of arglist

def grid_is_square(arglist):
    num_rows = len(arglist)
    for row in arglist:
        if len(row) != num_rows:
            return False
    return True

• Write three white box test cases (inputs) for this.
• (I.e., give the specific arglist that would be passed in to test the function.)
Code coverage

• Code coverage refers to how much of the code is executed ("covered") by a set of tests
  – want to be at (or close to) 100%
  – coverage tools report which parts of the program were executed, and how much
    o e.g., Coverage.py

• Figuring out how to increase coverage often leads to testing edge cases
Unit testing: practical heuristics

• Check both normal and error behaviors
• edge-case inputs:
  – zero values (0, empty list/string/tuple/file, ...)
  – singleton values (1, list/string/tuple/file of length 1, ...)
  – large values
• if statements: make sure each outcome (True/False) is taken
• Loops: test 0, 1, >1 iterations
Unit testing: what to check?

• Not just “output is what we expect”
  – remember “accidental” success

• Check that invariants hold at key points
Unit testing: what to check?

• Not just “output is what we expect”
  – remember “accidental” success

• Check that invariants hold at key points
Unit testing: what to check?

• Check that invariants hold at key points
Unit testing: what to check?

• Check that invariants hold at key points

① Check that nothing breaks if the loop does not execute at all
Unit testing: what to check?

- Check that invariants hold at key points

① Check that nothing breaks if the loop does not execute at all

② Check that everything is initialized properly when the loop is first entered
Unit testing: what to check?

• Check that invariants hold at key points

① Check that nothing breaks if the loop does not execute at all

② Check that everything is initialized properly when the loop is first entered

③ Check that everything is OK after going around the loop
Unit testing: summary

• Test normal and error values, edge cases

• If statements: test all branches (if/elif/else)

• Loops: check invariants for:
  – 0 iterations
  – 1 iteration
  – >1 iteration

• Functions:
  – check return values
Example 1: buggy list-lookup

# lookup(string, lst) -- returns the
# position where the given string
# occurs in lst.

def lookup(string, lst):
    for i in range(len(lst)):
        if string == lst[i]:
            return i
Example 1: buggy list-lookup

```
# lookup(string, lst) -- returns the
# position where the given string
# occurs in lst.

def lookup(string, lst):
    for i in range(len(lst)):
        if string == lst[i]:
            return i
```

0, 1, >1 iterations \(\rightarrow\) lists of length 0, 1, 2
Example 1: (buggy) list-lookup

```python
# lookup(string, lst) -- returns the # position where the given string # occurs in lst.

def lookup(string, lst):
    for i in range(len(lst)):
        if string == lst[i]:
            return i
```

0, 1, >1 iterations ⇒ lists of length 0, 1, 2

both branches taken ⇒ string is at positions 0, 1
Example 1: (buggy) list-lookup

```python
# lookup(string, lst) -- returns the # position where the given string # occurs in lst.

def lookup(string, lst):
    for i in range(len(lst)):
        if string == lst[i]:
            return i
```

0, 1, >1 iterations ⇒ lists of length 0, 1, 2

both branches taken ⇒ string is at positions 0, 1

some possible test inputs:
- 'a', []
- 'a', ['a']
- 'a', ['b','a']

---

39
Example 1: (buggy) list-lookup

```python
# lookup(string, lst) -- returns the position where the given string occurs in lst.

def lookup(string, lst):
    for i in range(len(lst)):
        if string == lst[i]:
            return i
```

0, 1, >1 iterations ⇒ lists of length 0, 1, 2
both branches taken ⇒ string is at positions 0, 1

some possible test inputs:
- 'a', []
- 'a', ['a']
- 'a', ['b','a']

**Note:** this will catch the no-return-value bug
Example 2: (buggy) average

# average(lst) -- returns the
# average of the numbers in lst.

def average(lst):
    sum = 0
    for i in range(len(lst)):
        sum += lst[i]
    return sum/len(lst)
Example 2: (buggy) average

# average(lst) -- returns the
# average of the numbers in lst.

def average(lst):
    sum = 0
    for i in range(len(lst)):
        sum += lst[i]
    return sum/len(lst)

0, 1, >1 iterations ⇒ lists of length 0, 1, 2
Example 2: (buggy) average

# average(lst) -- returns the average of the numbers in lst.

def average(lst):
    sum = 0
    for i in range(len(lst)):
        sum += lst[i]
    return sum/len(lst)

0, 1, >1 iterations ⇒ lists of length 0, 1, 2

some possible test inputs:
    []
    [17]
    [5, 12]
Example 2: (buggy) average

```python
# average(lst) -- returns the average of the numbers in lst.
def average(lst):
    sum = 0
    for i in range(len(lst)):
        sum += lst[i]
    return sum/len(lst)
```

Note: this will catch the divide-by-zero on empty list bug

0, 1, >1 iterations ⇒ lists of length 0, 1, 2

Some possible test inputs:

- `[]`
- `[17]`
- `[5, 12]`
Write four unit tests for the function below:

# Returns a list consisting of the strings in wordlist # that end with tail.
def words_ending_with(wordlist, tail):
    outlist = []
    for item in wordlist:
        if item.endswith(tail):
            outlist.append(item)
    return outlist
Testing strategy

• Test as a part of program development
  – try out small tests even when the code is only partially developed (i.e., lots of stubs)
    o helps catch problems at function boundaries, e.g., number and types of arguments
    o can help identify bugs in the design, e.g., missing pieces

• Start with tiny test inputs (work your way up to small, then medium, then large)
  – problems found on tiny inputs are usually easier to debug
• In black-box testing, what does the tester know about the code being tested?

__________________________________________

• When black-box testing, what are some of the kinds of cases we should test?

  ○ __________
  ○ __________
  ○ __________
  ○ __________

• How does white-box testing differ from black-box testing?