Testing and Debugging

- Would be great if our code always worked properly the first time we run it!
- But life ain't perfect, so we need:
  - Testing methods
    - Ways of trying code on examples to determine if running correctly
  - Debugging methods
    - Ways of fixing a program that you know does not work as intended

When are you ready to test?

- Ensure that code will actually run
  - Remove syntax errors
  - Remove static semantic errors
  - Both of these are typically handled by Python interpreter
- Have a set of expected results (i.e. input-output pairings) ready

When should you test and debug?

- Design your code for ease of testing and debugging
  - Break program into components that can be tested and debugged independently
  - Document constraints on modules
    - Expectations on inputs, on outputs
    - Even if code does not enforce constraints, valuable for debugging to have description
  - Document assumptions behind code design

Testing

- Goal:
  - Show that bugs exist
  - Would be great to prove code is bug free, but generally hard
    - Usually can't run on all possible inputs to check
    - Formal methods sometimes help, but usually only on simpler code

Test suite

- Want to find a collection of inputs that has high likelihood of revealing bugs, yet is efficient
  - Partition space of inputs into subsets that provide equivalent information about correctness
    - Partition divides a set into group of subsets such that each element of set is in exactly one subset
  - Construct test suite that contains one input from each element of partition
  - Run test suite

Why this partition?

- Lots of other choices
  - E.g., x prime, y not; y prime, x not; both prime; both not
- Space of inputs often have natural boundaries
  - Integers are positive, negative or zero
  - From this perspective, have 9 subsets
    - Split x = 0, y != 0 into x = 0, y positive and x =0, y negative
    - Same for x != 0, y = 0

Example of partition

```
def isBigger(x, y):
  """Assumes x and y are ints
     returns True if x is less than y
     else False"""
```

- Input space is all pairs of integers
- Possible partition
  - x positive, y positive
  - x negative, y negative
  - x positive, y negative
  - x negative, y positive
  - x = 0, y = 0
  - x = 0, y != 0
  - x != 0, y = 0

Partitioning

- What if no natural partition to input space?
  - Random testing – probability that code is correct increases with number of trials; but should be able to use code to do better
  - Use heuristics based on exploring paths through the specifications – **black-box testing**
  - Use heuristics based on exploring paths through the code – **glass-box testing**

Black-box testing

- Test suite designed without looking at code
  - Can be done by someone other than implementer
  - Will avoid inherent biases of implementer, exposing potential bugs more easily
  - Testing designed without knowledge of implementation, thus can be reused even if implementation changed

Paths through a specification

- Also good to consider boundary cases
  - For lists: empty list, singleton list, many element list
  - For numbers, very small, very large, "typical"

Paths through a specification

```
def sqrt(x, eps):
    """Assumes x, eps floats
            x >= 0
            eps > 0
      returns res such that
            x-eps <= res*res <= x+eps"""
```

- Paths through specification:
  - x = 0
  - x > 0
- But clearly not enough

Example

- For our sqrt case, try these:
  - First four are typical
    - Perfect square
    - Irrational square root
    - Example less than 1
  - Last five test extremes
    - If bug, might be code, or might be spec (e.g. don't try to find root if eps tiny)

x	eps
0.0	0.0001
25.0	0.0001
.05	0.0001
2.0	0.0001
2.0	1.0/2.0**64.0
1.0/2.0**64.0	1.0/2.0**64.0
2.0**64.0	1.0/2.0**64.0
1.0/2.0**64.0	2.0**64.0
2.0**64.0	2.0**64.0

Glass-box Testing

- Use code directly to guide design of test cases
- Glass-box test suite is **path-complete** if every potential path through the code is tested at least once
  - Not always possible if loop can be exercised arbitrary times, or recursion can be arbitrarily deep
- Even path-complete suite can miss a bug, depending on choice of examples

Rules of thumb for glass-box testing

- Exercise both branches of all if statements
- Ensure each except clause is executed
- For each for loop, have tests where:
  - Loop is not entered
  - Body of loop executed exactly once
  - Body of loop executed more than once
- For each while loop,
  - Same cases as for loops
  - Cases that catch all ways to exit loop
- For recursive functions, test with no recursive calls, one recursive call, and more than one recursive call

Example

```
def abs(x):
   """Assumes x is an int
     returns x if x>=0 and –x otherwise"""
   if x < -1:
      return –x
   else:
      return x
```

- Test suite of {-2, 2} will be path complete
- But will miss abs(-1) which incorrectly returns -1
  - Testing boundary cases and typical cases would catch this {-2 -1, 2}

Conducting tests

- Start with **unit testing**
  - Check that each module (e.g. function) works correctly
- Move to **integration testing**
  - Check that system as whole works correctly
- Cycle between these phases

Test Drivers and Stubs

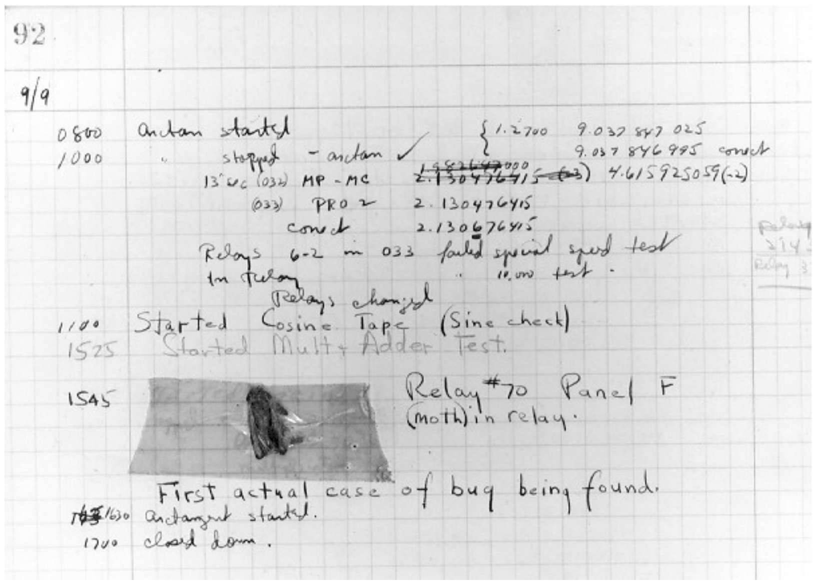
- **Drivers** are code that
  - Set up environment needed to run code
  - Invoke code on predefined sequence of inputs
  - Save results, and
  - Report
- Drivers simulate parts of program that use unit being tested
- **Stubs** simulate parts of program used by unit being tested
  - Allow you to test units that depend on software not yet written

Debugging

- The "history" of debugging
  - Often claimed that first bug was found by team at Harvard that was working on the Mark II Aiken Relay Calculator
  - A set of tests on a module had failed; when staff inspected the actually machinery (in this case vacuum tubes and relays), they discovered this:

Good testing practice

- Start with unit testing
- Move to integration testing
- After code is corrected, be sure to do **regression testing**:
  - Check that program still passes all the tests it used to pass, i.e., that your code fix hasn't broken something that used to work



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```
0800  Arctan started
1000    "   stopped - arctan ✓        { 1.2700   9.037 847 025
                                      {          9.037 846 995 correct
      13"uc (032) MP - MC   ~~1.982147000~~
                            ~~2.130476415 (-3)~~) 4.615925059(-2)
            (033) PRO 2     2.130476415
                  correct   2.130676415
          Relays 6-2 in 033 failed special speed test
          In relay            "   10,000 test.
              Relays changed
1100  Started Cosine Tape (Sine check)
1525  Started Mult + Adder Test.
1545                        Relay #70 Panel F
                            (moth) in relay.
         First actual case of bug being found.
1630  Antangent started.
1700  closed down.
```

A real bug!

- However, the term bug dates back even earlier:
  - *Hawkin's New Catechism of Electricity, 1896*
    - "The term 'bug' is used to a limited extent to designate any fault or trouble in the connections or working of electrical apparatus."

Categories of bugs

- Overt and persistent
  - Obvious to detect
  - Good programmers use **defensive programming** to try to ensure that if error is made, bug will fall into this category
- Overt and intermittent
  - More frustrating, can be harder to debug, but if conditions that prompt bug can be reproduced, can be handled
- Covert
  - Highly dangerous, as users may not realize answers are incorrect until code has been run for long period

Runtime bugs

- **Overt vs. covert:**
  - **Overt** has an obvious manifestation – code crashes or runs forever
  - **Covert** has no obvious manifestation – code returns a value, which may be incorrect but hard to determine
- **Persistent vs. intermittent:**
  - **Persistent** occurs every time code is run
  - **Intermittent** only occurs some times, even if run on same input

Debugging skills

- Treat as a search problem: looking for explanation for incorrect behavior
  - Study available data – both correct test cases and incorrect ones
  - Form an hypothesis consistent with the data
  - Design and run a repeatable experiment with potential to refute the hypothesis
  - Keep record of experiments performed: use narrow range of hypotheses

Debugging as search

- Want to narrow down space of possible sources of error
- Design experiments that expose intermediate stages of computation (use print statements!), and use results to further narrow search
- Binary search can be a powerful tool for this

```
def isPal(x):
    assert type(x) == list
    temp = x
    temp.reverse
    if temp == x:
        return True
    else:
        return False

def silly(n):
    for i in range(n):
        result = []
        elem = raw_input('Enter element: ')
        result.append(elem)
    if isPal(result):
        print('Yes')
    else:
        print('No')
```

Stepping through the tests

- Suppose we run this code:
  - We try the input 'abcba', which succeeds
  - We try the input 'palinnilap', which succeeds
  - But we try the input 'ab', which also 'succeeds'
- Let's use binary search to isolate bug(s)
- Pick a spot about halfway through code, and devise experiment
  - Pick a spot where easy to examine intermediate values

```
def isPal(x):
    assert type(x) == list
    temp = x
    temp.reverse
    if temp == x:
        return True
    else:
        return False

def silly(n):
    for i in range(n):
        result = []
        elem = raw_input('Enter element: ')
        result.append(elem)
    print(result)
    if isPal(result):
        print('Yes')
    else:
        print('No')
```

Stepping through the tests

- At this point in the code, we expect (for our test case of ‘ab’), that result should be a list [‘a’, ‘b’]
- We run the code, and get [‘b’].
- Because of binary search, we know that at least one bug must be present earlier in the code
- So we add a second print

```
def isPal(x):
   assert type(x) == list
   temp = x
   temp.reverse
   if temp == x:
      return True
   else:
      return False

def silly(n):
   for i in range(n):
      result = []
      elem = raw_input('Enter element: ')
      result.append(elem)
      print(result)
   if isPal(result):
      print('Yes')
   else:
      print('No')
```

Stepping through

- When we run with our example, the print statement returns
  - [‘a’]
  - [‘b’]
- This suggests that result is not keeping all elements
  - So let’s move the initialization of result outside the loop and retry

```
def isPal(x):
   assert type(x) == list
   temp = x
   temp.reverse
   if temp == x:
      return True
   else:
      return False

def silly(n):
   result = []
   for i in range(n):
      elem = raw_input('Enter element: ')
      result.append(elem)
      print(result)
   if isPal(result):
      print('Yes')
   else:
      print('No')
```

Stepping through

- So this now shows we are getting the data structure result properly set up, but we still have a bug somewhere
  - A reminder that there may be more than one problem!
  - This suggests second bug must lie below print statement; let's look at isPal
  - Pick a point in middle of code, and add print statement again

```
def isPal(x):
    assert type(x) == list
    temp = x
    temp.reverse
    print(temp, x)
    if temp == x:
        return True
    else:
        return False

def silly(n):
    result = []
    for i in range(n):
        elem = raw_input('Enter element: ')
        result.append(elem)
    if isPal(result):
        print('Yes')
    else:
        print('No')
```

Stepping through

- At this point in the code, we expect (for our example of 'ab') that x should be ['a', 'b'], but temp should be ['b', 'a'], however they both have the value ['a', 'b']
- So let's add another print statement, earlier in the code

```
def isPal(x):
    assert type(x) == list
    temp = x
    print(temp, x)
    temp.reverse
    print(temp, x)
    if temp == x:
        return True
    else:
        return False

def silly(n):
    result = []
    for i in range(n):
        elem = raw_input('Enter element: ')
        result.append(elem)
    if isPal(result):
        print('Yes')
    else:
        print('No')
```

Stepping through

- And we see that temp has the same value before and after the call to reverse
- If we look at our code, we realize we have committed a standard bug – we forgot to actually invoke the reverse method
  - Need temp.reverse()
- So let's make that change and try again

```
def isPal(x):
   assert type(x) == list
   temp = x
   print(temp, x)
   temp.reverse()
   print(temp, x)
   if temp == x:
      return True
   else:
      return False

def silly(n):
   result = []
   for i in range(n):
      elem = raw_input('Enter element: ')
      result.append(elem)
   if isPal(result):
      print('Yes')
   else:
      print('No')
```

Stepping through

- But now when we run on our simple example, both x and temp have been reversed!!
- We have also narrowed down this bug to a single line. The error must be in the reverse step
- In fact, we have an aliasing bug – reversing temp has also caused x to be reversed
  - Because they are referring to the same object

```
def isPal(x):
   assert type(x) == list
   temp = x[:]
   print(temp, x)
   temp.reverse()
   print(temp, x)
   if temp == x:
      return True
   else:
      return False

def silly(n):
   result = []
   for i in range(n):
      elem = raw_input('Enter element: ')
      result.append(elem)
   if isPal(result):
      print('Yes')
   else:
      print('No')
```

Stepping through

- And now running this shows that before the reverse step, the two variables have the same form, but afterwards only temp is reversed.
- We can now go back and check that our other tests cases still work correctly

Some pragmatic hints

- Look for the usual suspects
- Ask why the code is doing what it is, not why it is not doing what you want
- The bug is probably not where you think it is – eliminate locations
- Explain the problem to someone else
- Don’t believe the documentation
- Take a break and come back to the bug later