TESTING, DEBUGGING

PROGRAMMING CHALLENGES

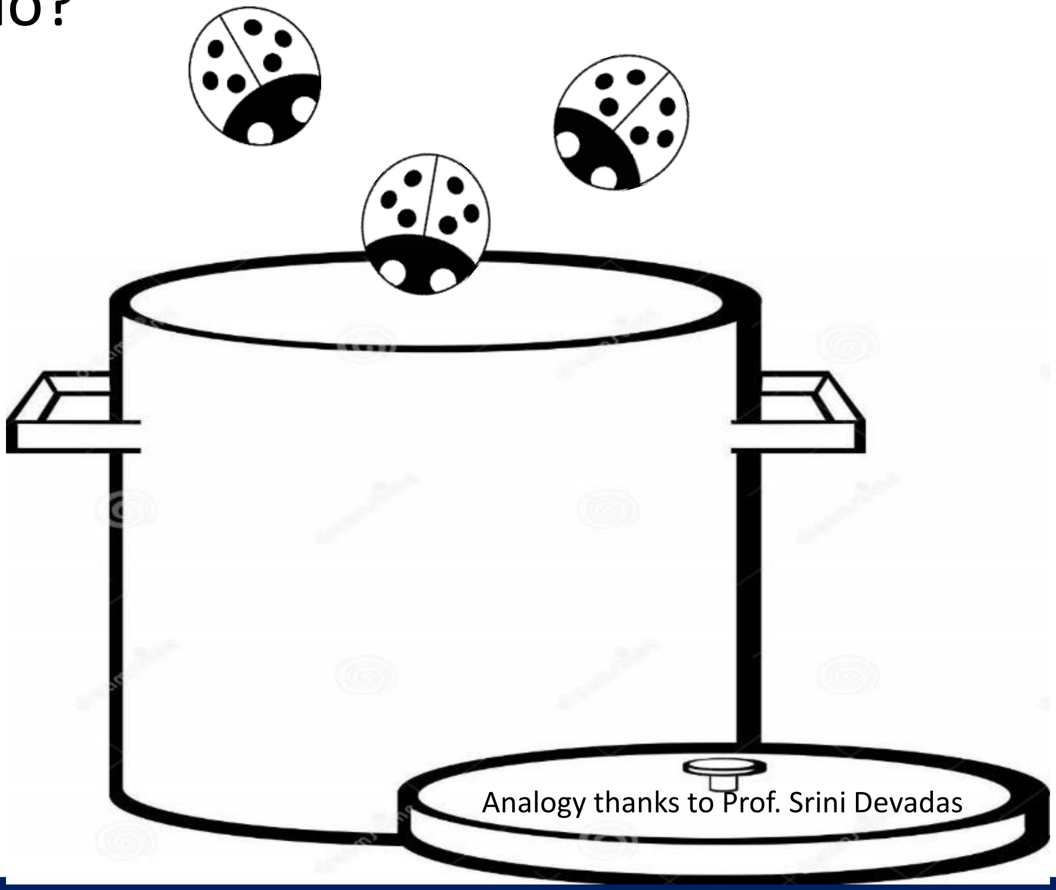
EXPECTATION | **REALITY**

What you want the program to do | **What the program actually does**

WE AIM FOR HIGH QUALITY – AN ANALOGY WITH SOUP

You are making soup but bugs keep falling in from the ceiling. What do you do?

- check soup for bugs
  - testing
- keep lid closed
  - defensive programming
- clean kitchen
  - eliminate source of bugs - debugging



Analogy thanks to Prof. Srini Devadas

DEFENSIVE PROGRAMMING

- Write **specifications** for functions
- **Modularize** programs
- Check **conditions** on inputs/outputs (assertions)

TESTING/VALIDATION

- **Compare** input/output pairs to specification
- “It’s not working!”
- “How can I break my program?”

DEBUGGING

- **Study events** leading up to an error
- “Why is it not working?”
- “How can I fix my program?”

SET YOURSELF UP FOR EASY TESTING AND DEBUGGING

- from the **start**, design code to ease this part
- break program into **modules** that can be tested and debugged individually
- **document constraints** on modules
  - what do you expect the input to be? the output to be?
- **document assumptions** behind code design

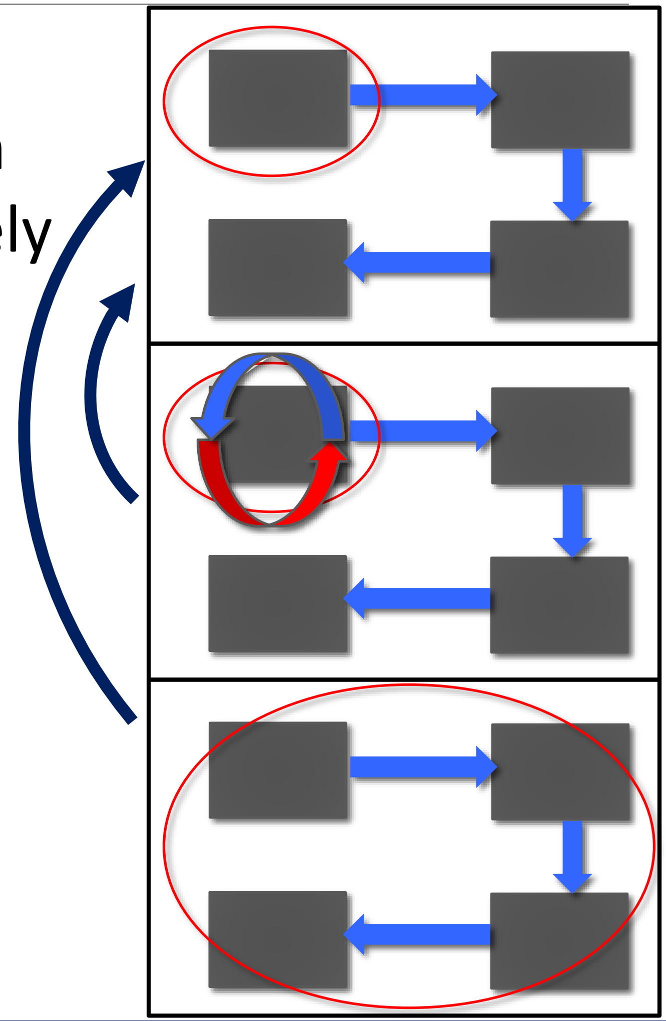
"Motherhood and apple pie" approach:
Something that cannot be questioned because it appeals to universally-held, wholesome values

WHEN ARE YOU READY TO TEST?

- ensure **code runs**
  - remove syntax errors
  - remove static semantic errors
  - Python interpreter can usually find these for you
- have a **set of expected results**
  - an input set
  - for each input, the expected output

CLASSES OF TESTS

- **Unit testing**
  - validate each piece of program
  - **testing each function** separately
- **Regression testing**
  - add test for bugs as you find them in a function
  - **catch reintroduced** errors that were previously fixed
- **Integration testing**
  - does **overall program** work?
  - tend to rush to do this



TESTING APPROACHES

- **intuition** about natural boundaries to the problem

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

  - can you come up with some natural partitions?

- if no natural partitions, might do **random testing**
  - probability that code is correct increases with more tests
  - better options below

- **black box testing**
  - explore paths through specification

- **glass box testing**
  - explore paths through code

BLACK BOX TESTING

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

- designed **without looking** at the code
- can be done by someone other than the implementer to avoid some implementer **biases**
- testing can be **reused** if implementation changes
- **paths** through specification
  - build test cases in different natural space partitions
  - also consider boundary conditions (empty lists, singleton list, large numbers, small numbers)

explore paths through specifications

BLACK BOX TESTING

```
def sqrt(x, eps):
    """ Assumes x, eps floats, x >= 0, eps > 0

    Returns res such that x-eps <= res*res <= x+eps """
```

CASE	x	eps
boundary	0	0.0001
Perfect square	25	0.0001
Less than 1	0.05	0.0001
Irrational square root	2	0.0001
extremes	2	1.0/2.0**64.0
extremes	1.0/2.0**64.0	1.0/2.0**64.0
extremes	2.0**64.0	1.0/2.0**64.0
extremes	1.0/2.0**64.0	2.0**64.0
extremes	2.0**64.0	2.0**64.0

GLASS BOX TESTING

- **use code** directly to guide design of test cases
- called **path-complete** if every potential path through code is tested at least once
- what are some **drawbacks** of this type of testing?
  - can go through loops arbitrarily many times
  - missing paths
- guidelines
  - branches
  - for loops
  - while loops

exercise all parts of a conditional

loop not entered
body of loop executed exactly once
body of loop executed more than once

same as for loops, cases that catch all ways to exit loop

GLASS BOX TESTING

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

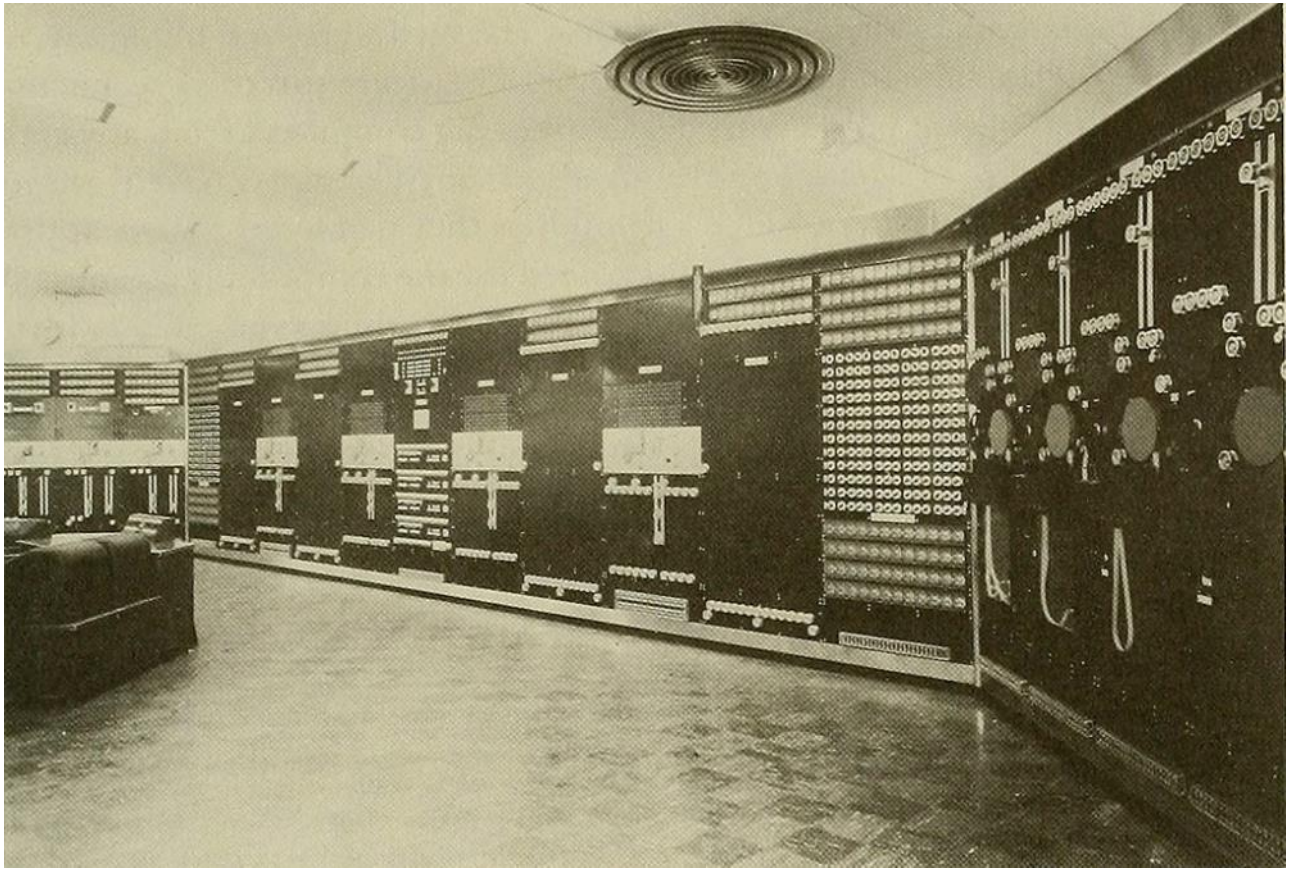
- a path-complete test suite could **miss a bug**
- path-complete test suite: 2 and -2
- but abs(-1) incorrectly returns -1
- should still test boundary cases

BUGS

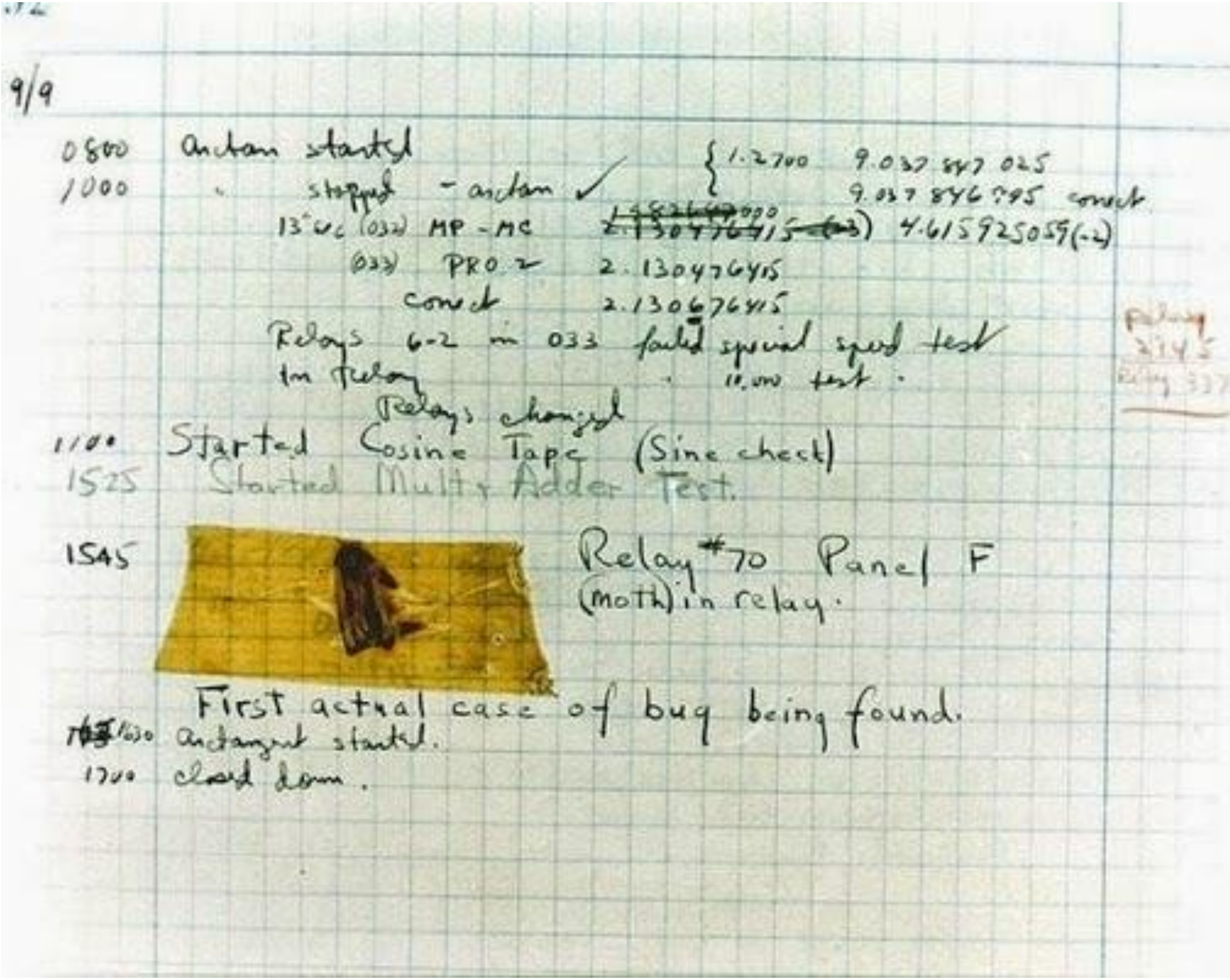
- once you have discovered that your code does not run properly, you want to:
  - isolate the bug(s)
  - eradicate the bug(s)
  - retest until code runs correctly

September 9, 1947

- Mark II Aiken Relay Computer



Admiral Grace Murray Hopper



9/9

0800 Anctan started

1000 stopped - anctan ✓ {1.2700 9.037 847 025
9.037 846 995 correct

13" uc (032) MP - MC ~~2.130476415~~ 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.

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

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

DEBUGGING

- steep learning curve
- goal is to have a bug-free program
- tools
  - **built in** to IDLE and Anaconda
  - **Python Tutor**
  - **`print`** statement
  - use your brain, be **systematic** in your hunt

PRINT STATEMENTS

- good way to **test hypothesis**
- when to print
  - enter function
  - parameters
  - function results
- use **bisection method**
  - put print halfway in code
  - decide where bug may be depending on values

ERROR MESSAGES - EASY

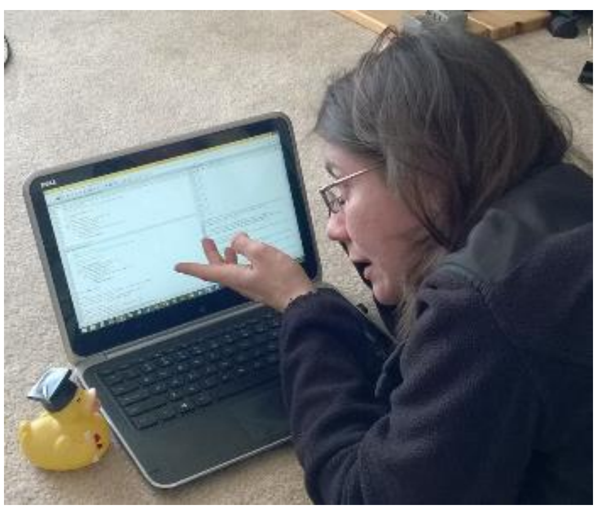
- trying to access beyond the limits of a list
  `test = [1,2,3]` then `test[4]` → `IndexError`
- trying to convert an inappropriate type
  `int(test)` → `TypeError`
- referencing a non-existent variable
  `a` → `NameError`
- mixing data types without appropriate coercion
  `'3'/4` → `TypeError`
- forgetting to close parenthesis, quotation, etc.

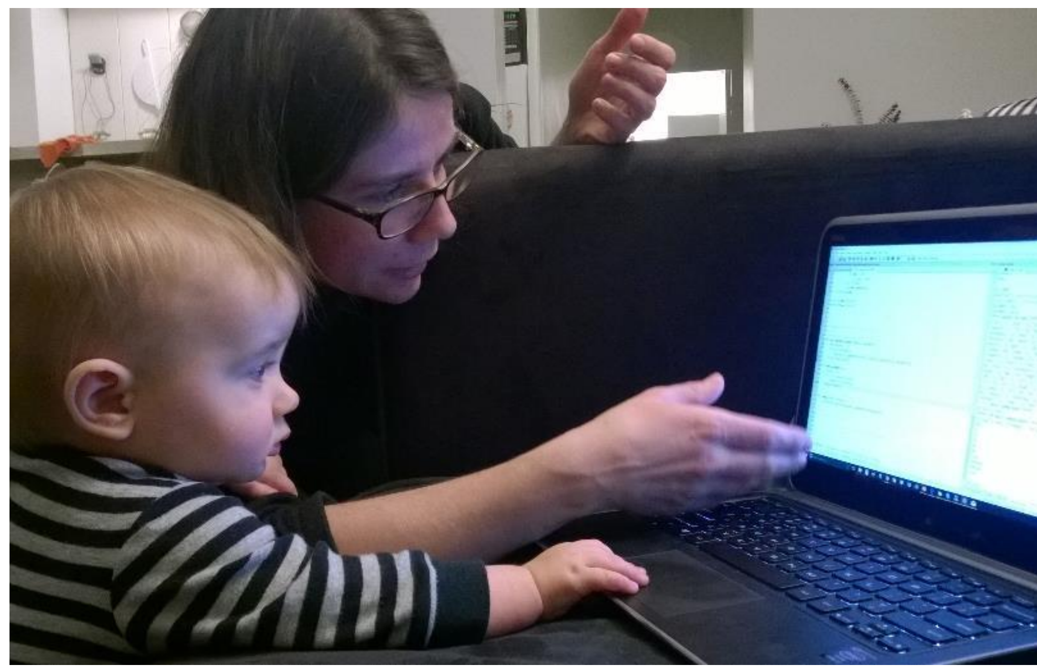
```
a = len([1,2,3]
print a
```

→ `SyntaxError`

LOGIC ERRORS - HARD

- **think** before writing new code
- **draw** pictures, take a break
- **explain** the code to
  - someone else
  - a rubber ducky





DEBUGGING STEPS

- **study** program code
  - ask how did I get the unexpected result
  - don’t ask what is wrong
  - is it part of a family?

- **scientific method**
  - study available data
  - form hypothesis
  - repeatable experiments
  - pick simplest input to test with

DON'T

- Write entire program
- Test entire program
- Debug entire program

- Change code
- Remember where bug was
- Test code
- Forget where bug was or what change you made
- Panic

DO

- Write a function
- Test the function, debug the function
- Write a function
- Test the function, debug the function
- *** Do integration testing ***

- Backup code
- Change code
- Write down potential bug in a comment
- Test code
- Compare new version with old version

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

```python
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 = 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

```python
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 = 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, this time inside the loop

```python
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 = 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

```python
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 = input('Enter element: ')
        result.append(elem)
        print(result)
    if isPal(result):
        print('Yes')
    else:
        print('No')
```

STEPPING THROUGH

- 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; remove the earlier print statement

```python
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 = 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('before reverse', temp, x)
    temp.reverse
    print('after reverser', temp, x)
    if temp == x:
        return True
    else:
        return False

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

STEPPING THROUGH

- 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('before reverse', temp, x)
    temp.reverse()
    print('after reverse', temp, x)
    if temp == x:
        return True
    else:
        return False

def silly(n):
    result = []
    for i in range(n):
        elem = 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

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

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

STEPPING THROUGH

- 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