TESTING, DEBUGGING

PROGRAMMING CHALLENGES

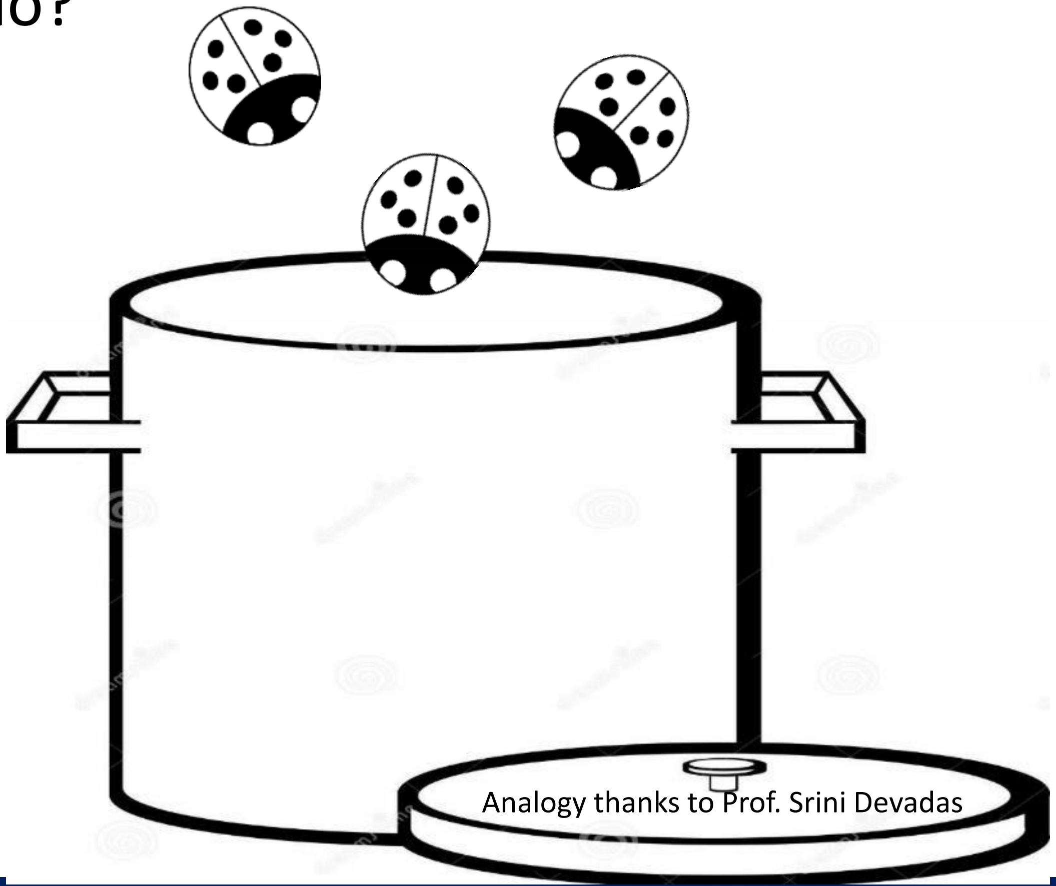
EXPECTATION	**REALITY**

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

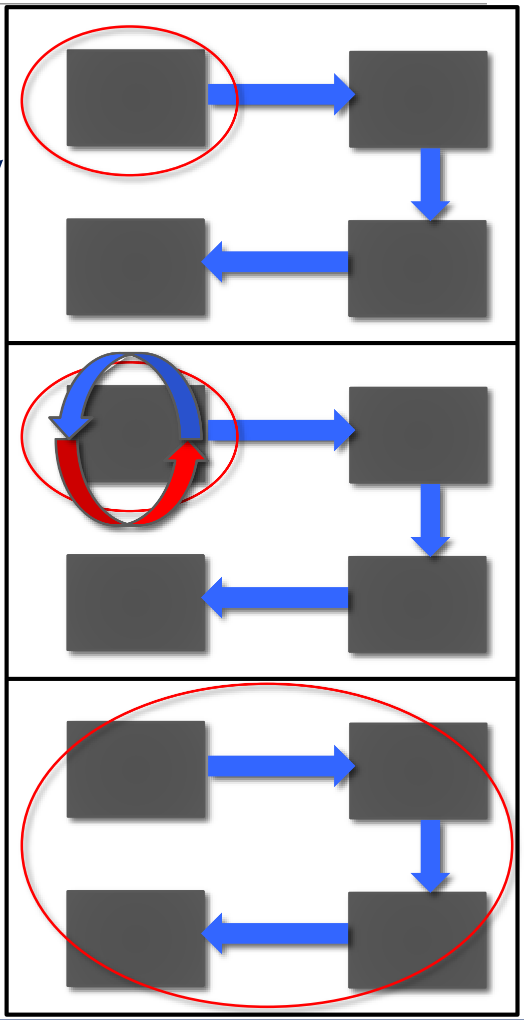
"Motherhood and apple pie" approach:
Something that cannot be questioned because it appeals to universally-held, wholesome values

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)

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 → exercise all parts of a conditional
  - for loops → loop not entered; body of loop executed exactly once; body of loop executed more than once
  - while loops → 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
```

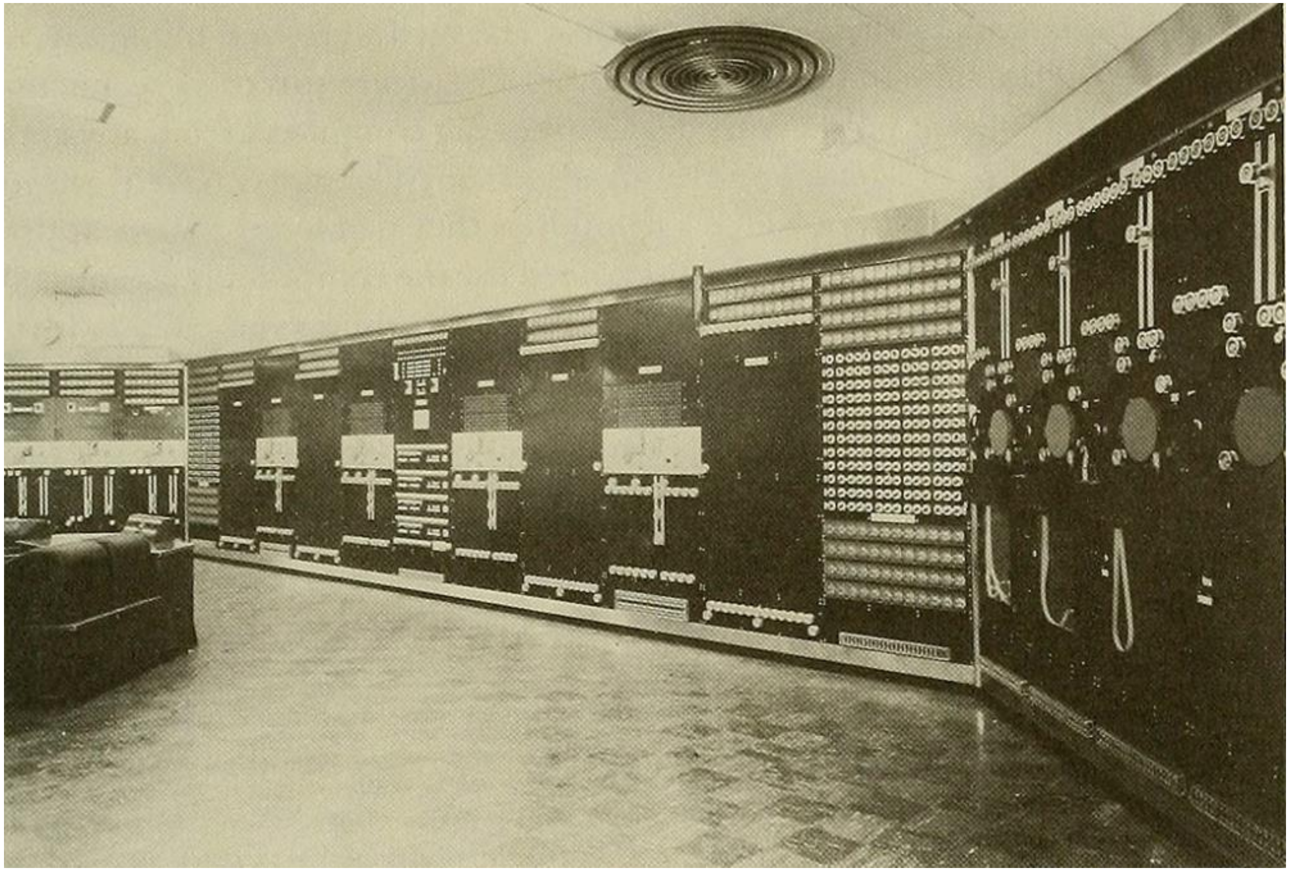
- a path-complete test suite could **miss a bug**
- path-complete test suite: 2 and -2
- but abs(-1) incorrectly returns -1
- should still test boundary cases

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

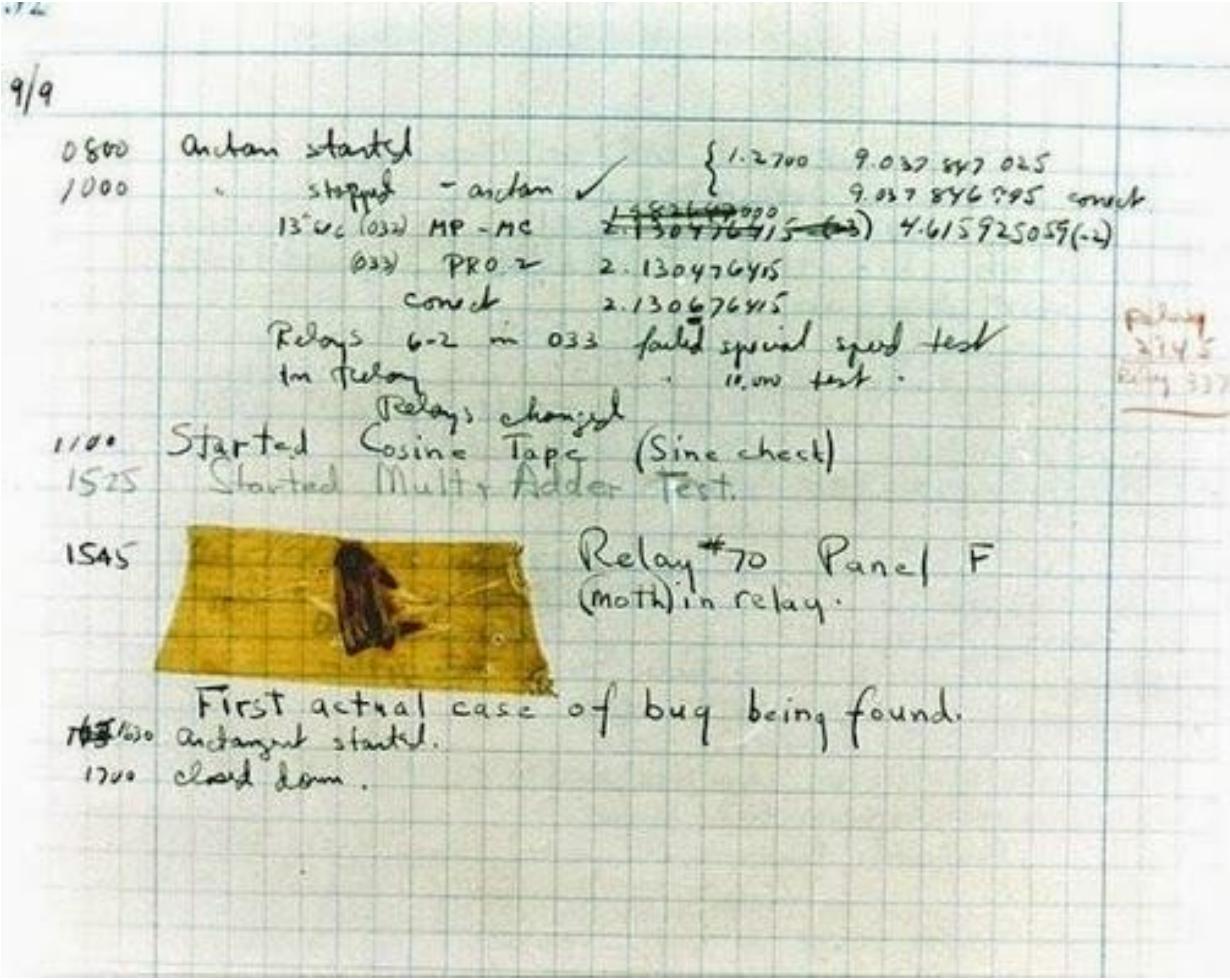
September 9, 1947

- Mark II Aiken Relay Computer




Jan Arkesteijn CC-BY 2.0

Admiral Grace Murray Hopper


9/9
0800 arctan started
1000 stopped - arctan ✓
1.2700 9.037 847 025
9.037 846 795 correct
13" uc (032) MP - MC 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 arctangent 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

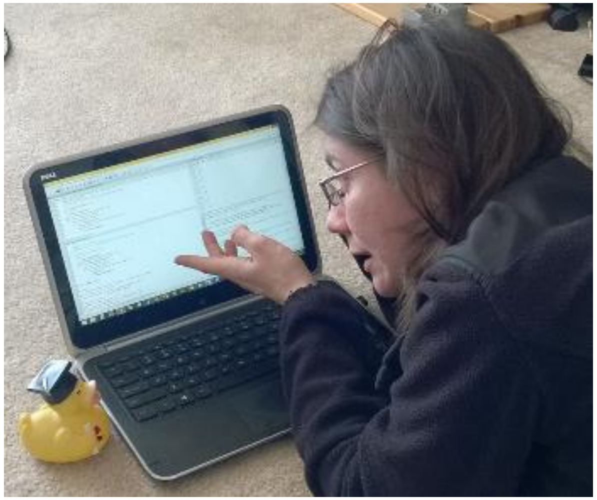
  `'3'/4` → `TypeError`

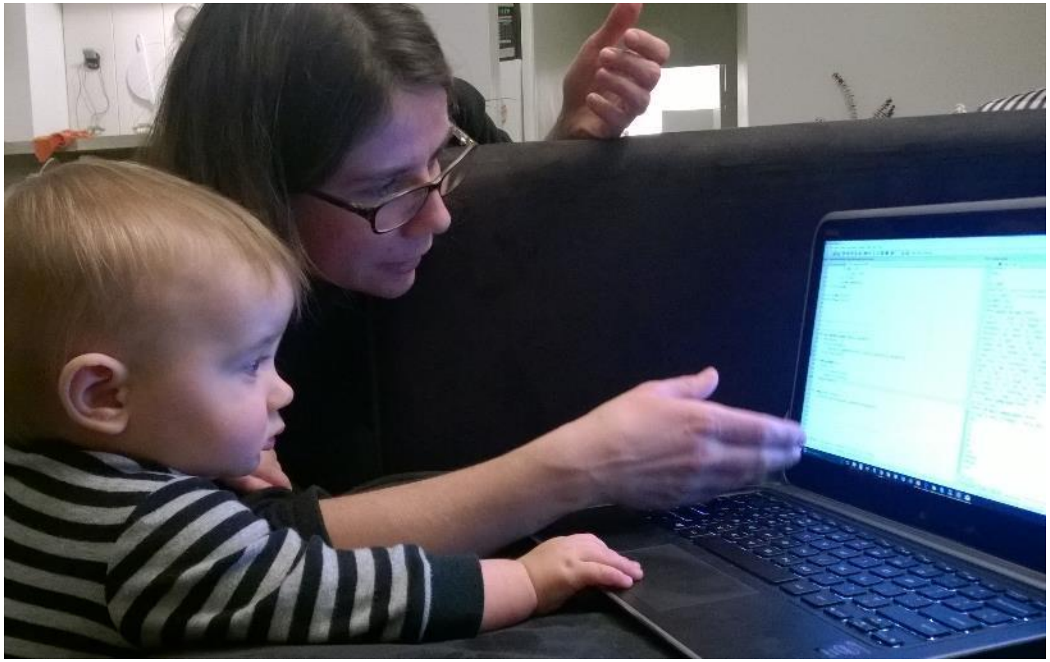
- forgetting to close parenthesis, quotation, etc.

  ```
  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	DO
• Write entire program • Test entire program • Debug entire program	• Write a function • Test the function, debug the function • Write a function • Test the function, debug the function • *** Do integration testing ***
• Change code • Remember where bug was • Test code • Forget where bug was or what change you made • Panic	• 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

```
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

```
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