TESTING, DEBUGGING, EXCEPTIONS, ASSERTIONS

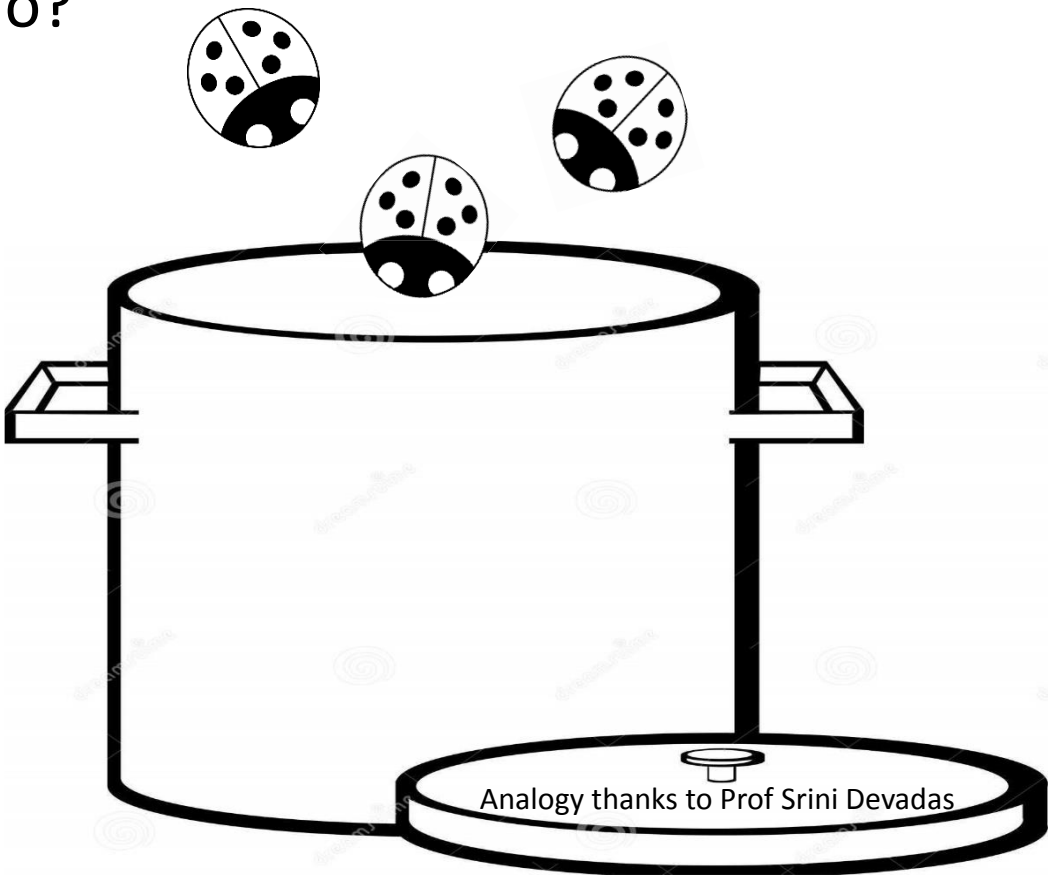
(download slides and .py files and follow along!)

6.0001 LECTURE 7

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



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?"

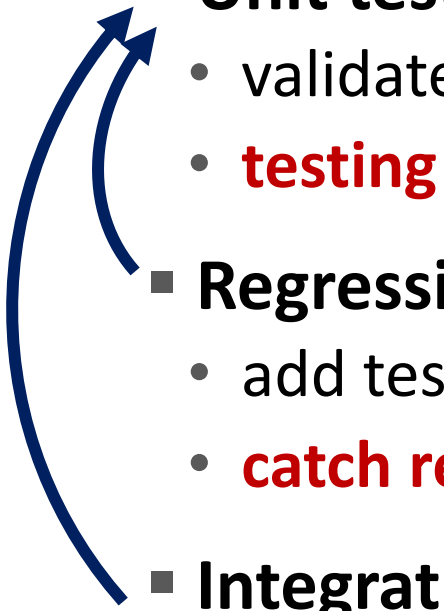
SET YOURSELF UP FOR EASY TESTING AND DEBUGGING

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

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
  - **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

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

DEBUGGING STEPS

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

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

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`

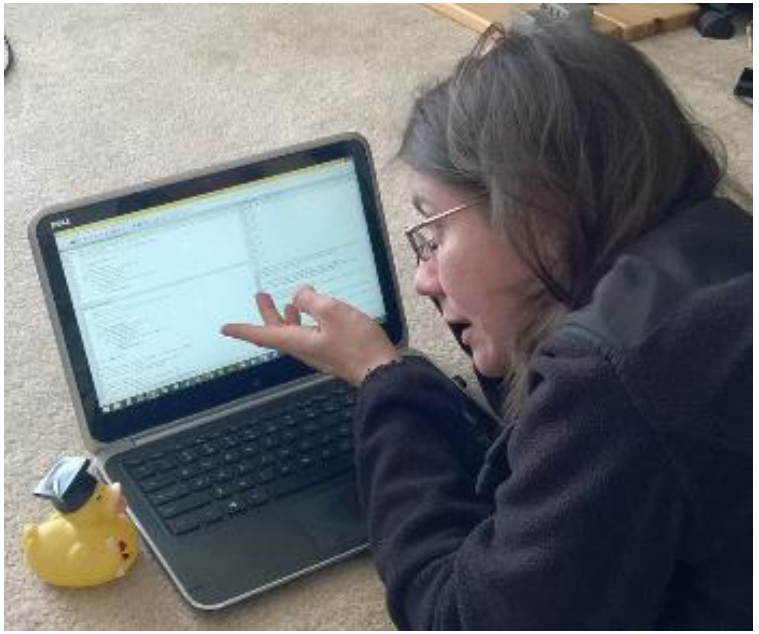
- forgetting to close parenthesis, quotation, etc.

```
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



DON'T

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

DO

- 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

EXCEPTIONS AND ASSERTIONS

- what happens when procedure execution hits an **unexpected condition**?
- get an **exception**… to what was expected
  - trying to access beyond list limits

```
test = [1,7,4]
test[4]
```
→ `IndexError`

  - trying to convert an inappropriate type

```
int(test)
```
→ `TypeError`

  - referencing a non-existing variable

```
a
```
→ `NameError`

  - mixing data types without coercion

```
'a'/4
```
→ `TypeError`

OTHER TYPES OF EXCEPTIONS

- already seen common error types:
  - `SyntaxError`: Python can't parse program
  - `NameError`: local or global name not found
  - `AttributeError`: attribute reference fails
  - `TypeError`: operand doesn't have correct type
  - `ValueError`: operand type okay, but value is illegal
  - `IOError`: IO system reports malfunction (e.g. file not found)

DEALING WITH EXCEPTIONS

- Python code can provide **handlers** for exceptions

```
try:
    a = int(input("Tell me one number:"))
    b = int(input("Tell me another number:"))
    print(a/b)
except:
    print("Bug in user input.")
```

- exceptions **raised** by any statement in body of **`try`** are **handled** by the **`except`** statement and execution continues with the body of the `except` statement

HANDLING SPECIFIC EXCEPTIONS

- have **separate `except` clauses** to deal with a particular type of exception

```
try:
    a = int(input("Tell me one number: "))
    b = int(input("Tell me another number: "))
    print("a/b = ", a/b)
    print("a+b = ", a+b)
except ValueError:
    print("Could not convert to a number.")
except ZeroDivisionError:
    print("Can't divide by zero")
except:
    print("Something went very wrong.")
```

only execute if these errors come up

for all other errors

OTHER EXCEPTIONS

- `else:`
  - body of this is executed when execution of associated `try` body **completes with no exceptions**
- `finally`:
  - body of this is **always executed** after `try`, `else` and `except` clauses, even if they raised another error or executed a `break`, `continue` or `return`
  - useful for clean-up code that should be run no matter what else happened (e.g. close a file)

WHAT TO DO WITH EXCEPTIONS?

- what to do when encounter an error?
- **fail silently**:
  - substitute default values or just continue
  - bad idea! user gets no warning
- return an **"error" value**
  - what value to choose?
  - complicates code having to check for a special value
- stop execution, **signal error** condition
  - in Python: **raise an exception**

```
raise Exception("descriptive string")
```

EXCEPTIONS AS CONTROL FLOW

- don't return special values when an error occurred and then check whether 'error value' was returned
- instead, **raise an exception** when unable to produce a result consistent with function's specification

```
raise <exceptionName>(<arguments>)
```

```
raise ValueError("something is wrong")
```

keyword

name of error you want to raise

optional, but typically a string with a message

EXAMPLE: RAISING AN EXCEPTION

```
def get_ratios(L1, L2):
    """ Assumes: L1 and L2 are lists of equal length of numbers
        Returns: a list containing L1[i]/L2[i] """
    ratios = []
    for index in range(len(L1)):
        try:
            ratios.append(L1[index]/L2[index])
        except ZeroDivisionError:
            ratios.append(float('nan')) #nan = not a number
        except:
            raise ValueError('get_ratios called with bad arg')
    return ratios
```

manage flow of program by raising own error

EXAMPLE OF EXCEPTIONS

- assume we are **given a class list** for a subject: each entry is a list of two parts
  - a list of first and last name for a student
  - a list of grades on assignments

```
test_grades = [[['peter', 'parker'], [80.0, 70.0, 85.0]],
               [['bruce', 'wayne'], [100.0, 80.0, 74.0]]]
```

- create a **new class list**, with name, grades, and an average

```
[[['peter', 'parker'], [80.0, 70.0, 85.0], 78.33333],
[['bruce', 'wayne'], [100.0, 80.0, 74.0], 84.666667]]
```

EXAMPLE CODE

```
[[['peter', 'parker'], [80.0, 70.0, 85.0]],
[['bruce', 'wayne'], [100.0, 80.0, 74.0]]]
```

```
def get_stats(class_list):
    new_stats = []
    for elt in class_list:
        new_stats.append([elt[0], elt[1], avg(elt[1])])
    return new_stats

def avg(grades):
    return sum(grades)/len(grades)
```

ERROR IF NO GRADE FOR A STUDENT

- if one or more students **don't have any grades**, get an error

```
test_grades = [[['peter', 'parker'], [10.0, 5.0, 85.0]],
               [['bruce', 'wayne'], [10.0, 8.0, 74.0]],
               [['captain', 'america'], [8.0,10.0,96.0]],
               [['deadpool'], []]]
```

- get `ZeroDivisionError: float division by zero` because try to

```
return sum(grades)/len(grades)
```

length is 0

OPTION 1: FLAG THE ERROR BY PRINTING A MESSAGE

- decide to **notify** that something went wrong with a msg

```
def avg(grades):
    try:
        return sum(grades)/len(grades)
    except ZeroDivisionError:
        print('warning: no grades data')
```

- running on some test data gives

```
warning: no grades data
[['peter', 'parker'], [10.0, 5.0, 85.0], 15.41666666],
[['bruce', 'wayne'], [10.0, 8.0, 74.0], 13.83333334],
[['captain', 'america'], [8.0, 10.0, 96.0], 17.5],
[['deadpool'], [], None]]
```

flagged the error

because `avg` did not return anything in the except

OPTION 2: CHANGE THE POLICY

- decide that a student with no grades gets a **zero**

```
def avg(grades):
    try:
        return sum(grades)/len(grades)
    except ZeroDivisionError:
        print('warning: no grades data')
        return 0.0
```

- running on some test data gives

```
warning: no grades data
[[['peter', 'parker'], [10.0, 5.0, 85.0], 15.41666666],
[['bruce', 'wayne'], [10.0, 8.0, 74.0], 13.83333334],
[['captain', 'america'], [8.0, 10.0, 96.0], 17.5],
[['deadpool'], [], 0.0]]
```

still flag the error

now avg returns 0

ASSERTIONS

- want to be sure that **assumptions** on state of computation are as expected
- use an **`assert` statement** to raise an `AssertionError` exception if assumptions not met
- an example of good **defensive programming**

EXAMPLE

```
def avg(grades):
    assert len(grades) != 0, 'no grades data'
    return sum(grades)/len(grades)
```

function ends immediately if assertion not met

- raises an `AssertionError` if it is given an empty list for grades
- otherwise runs ok

ASSERTIONS AS DEFENSIVE PROGRAMMING

- assertions don't allow a programmer to control response to unexpected conditions
- ensure that **execution halts** whenever an expected condition is not met
- typically used to **check inputs** to functions, but can be used anywhere
- can be used to **check outputs** of a function to avoid propagating bad values
- can make it easier to locate a source of a bug

WHERE TO USE ASSERTIONS?

- goal is to spot bugs as soon as introduced and make clear where they happened
- use as a **supplement** to testing
- raise **exceptions** if users supplies **bad data input**
- use **assertions** to
  - check **types** of arguments or values
  - check that **invariants** on data structures are met
  - check **constraints** on return values
  - check for **violations** of constraints on procedure (e.g. no duplicates in a list)

6.0001 Introduction to Computer Science and Programming in Python
Fall 2016