



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



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?”

“Why?”



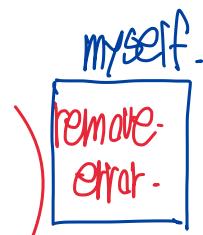
SET YOURSELF UP FOR EASY TESTING AND DEBUGGING

- 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

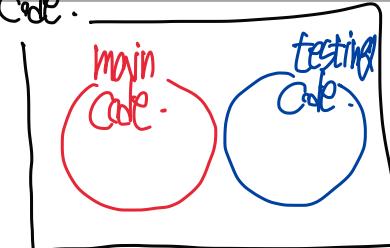


CLASSES OF TESTS

■ Unit testing

- validate each piece of program
- **testing each function separately**

function
Code.



■ 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
 - 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 $\text{abs}(-1)$ 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

next step
: fix → re-run.

- trying to access beyond the limits of a list

~~test~~ index 0 1 2 then test[4] ~~⇒ n̨, MAX index: 2.~~

→ IndexError

- trying to convert an inappropriate type

int(test) (~~= int(list type)~~)

→ TypeError

- referencing a non-existent variable

a ~~= *~~

→ NameError

- mixing data types without appropriate coercion

'3' / 4 = ~~str~~ (~~=, int~~, ~~ten~~, ~~50~~)

→ TypeError

- forgetting to close parenthesis, quotation, etc.

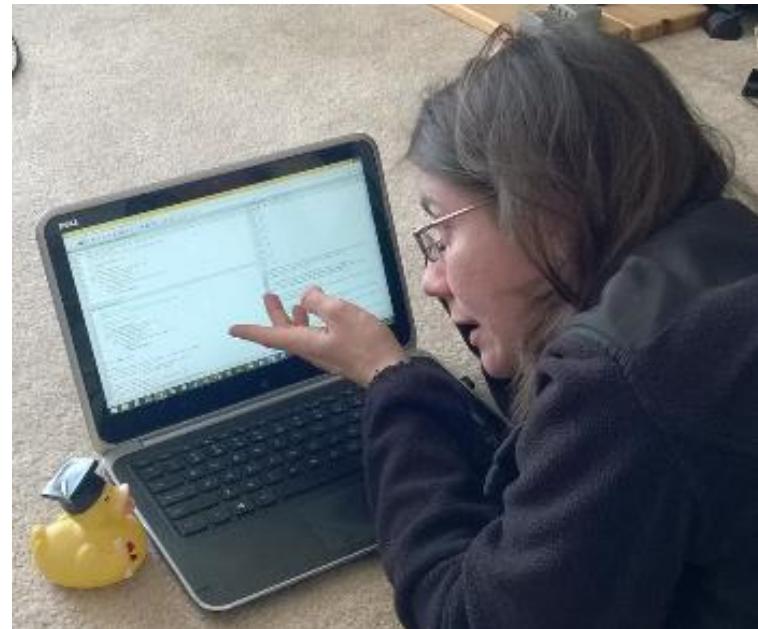
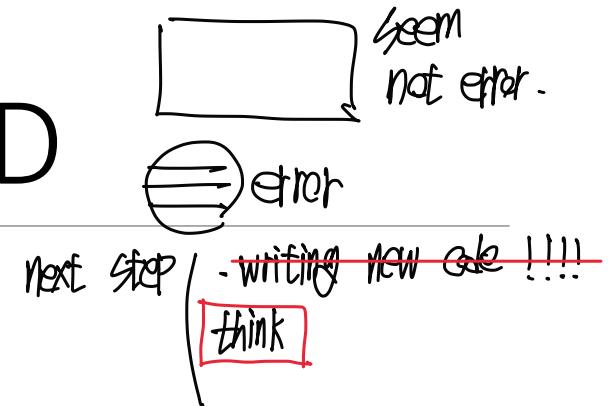
a = len([1, 2, 3])

→ SyntaxError

print(a)

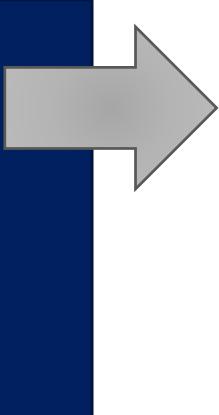
LOGIC ERRORS - HARD

- ~~**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 ***

aim for
function.

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



- Backup code *keep original ab.*
- 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 = [] ...type: list length of L1
    for index in range(len(L1)):
        try:
            ratios.append(L1[index]/L2[index])
        except ZeroDivisionError:
            ratios.append(float('nan')) #nan = not a number
    except: list name. Add new element
        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], 84.66667]]
```

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 = [] ...  
    type: list  
    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)

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6.0001 Introduction to Computer Science and Programming in Python

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