



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)
-
- ```
graph TD; A[DEFENSIVE PROGRAMMING] --> B[TESTING/VALIDATION]; A --> C[DEBUGGING];
```

### 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

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- 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?

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- 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

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## ■ 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

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- **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

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- **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

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```
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

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- 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

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- 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

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- **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

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- 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`

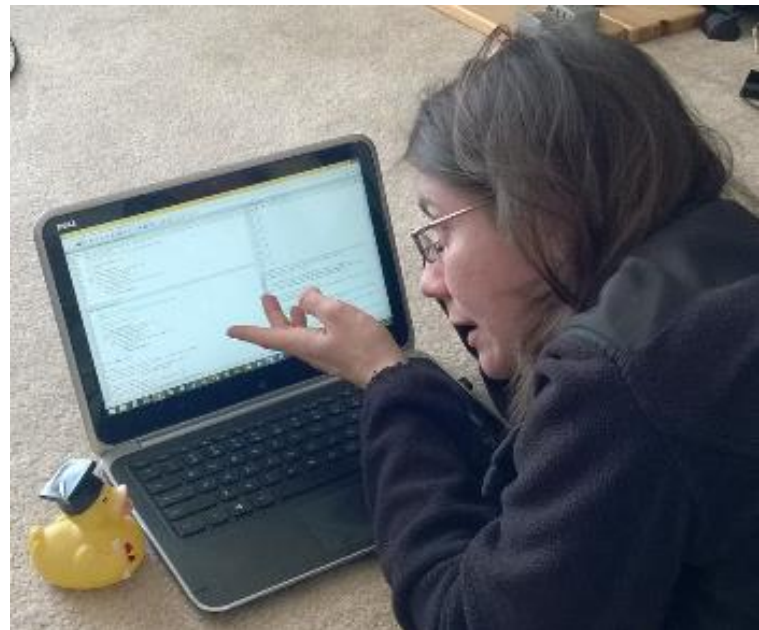
- forgetting to close parenthesis, quotation, etc.

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

# LOGIC ERRORS - HARD

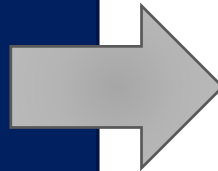
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- **think** before writing new code
- **draw** pictures, take a break
- **explain** the code to
  - someone else
  - a rubber ducky



# DON'T

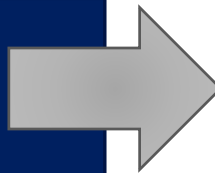
- Write entire program
- Test entire program
- Debug entire program



# 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

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- 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

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- 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

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- 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
```

*flagged the error*

```
[[['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]]
```

*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
```

*still flag the error*

```
[[['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]]
```

*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

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- 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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