DICTIONARIES, DEBUGGING, EXCEPTIONS

(download slides and .py files to follow along)

6.0001 LECTURE 6

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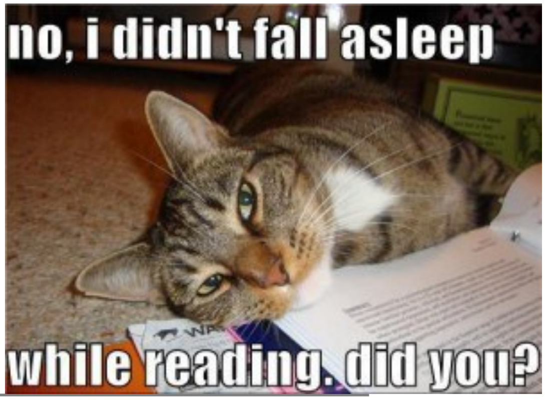
LAST TIME

- indexable, ordered data types
- tuples – immutable object type
- lists – mutable object type
  - aliasing, cloning
  - mutability side effects
- iteration or recursion over lists and tuples

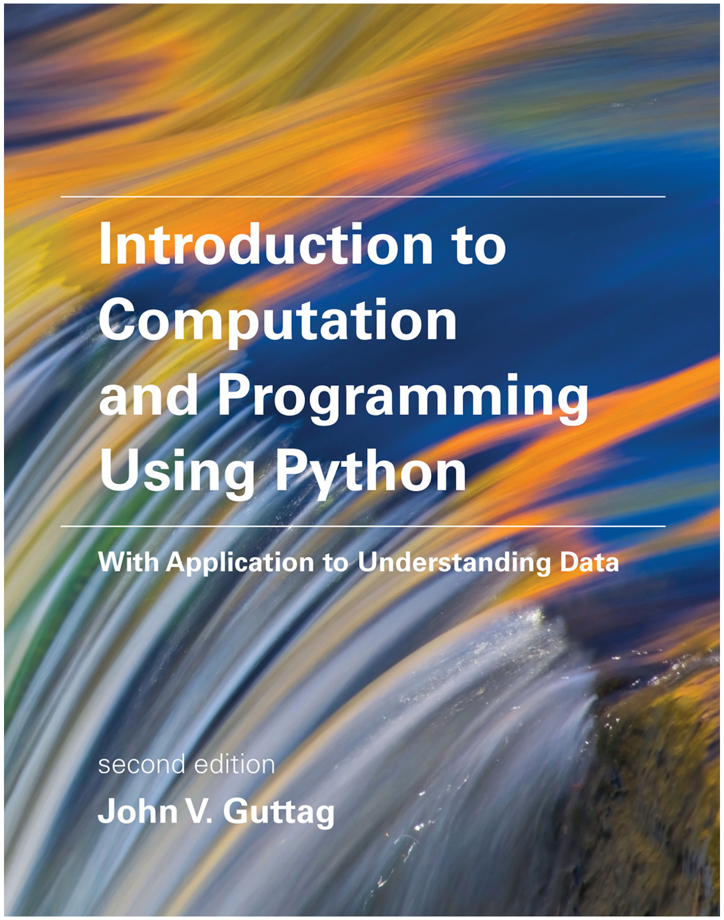
TODAY

- dictionaries – another mutable object type
- debugging
- exceptions
- assertions



Assigned Reading

- Today
  - Section 5.6
  - Chapter 6
  - Chapter 7
- Next lecture
  - Sections 8.1-8.2



https://mitpress.mit.edu/sites/default/files/Guttag_errata_revised_083117.pdf

DICTIONARIES

HOW TO STORE STUDENT INFO

- could store using separate lists for each kind of information

```
names = ['Ana', 'John', 'Matt', 'Katy']
grades = ['B',   'A+',    'A',    'A']
microquizzes = ...
psets = ...
```

- a **separate list** for each item
- each list must have the **same length**
- info stored across lists at **same index**, each index refers to information for a different person
- indirectly access information by finding location in lists corresponding to a person, then extract

HOW TO ACCESS STUDENT INFO

```
def get_grade(student, name_list, grade_list):
    i = name_list.index(student)
    grade = grade_list[i]
    return (student, grade)
```

find location in list for person

Use location to access other info

Remember the "." notation for methods associated with types of objects

- **messy** if have a lot of different info of which to keep track, e.g., a separate list for microquiz scores, for pset scores, etc.
- must maintain **many lists** and pass them as arguments
  - could store a list of lists for each student, but then need to remember which sublist corresponds to each part of the grade
- must **always index** using integers
- must remember to change multiple lists, when adding or updating information

A BETTER AND CLEANER WAY – A DICTIONARY

- nice to **index item of interest directly** (not always int)
- nice to use **one data structure**, no separate lists

A list

0	Elem 1
1	Elem 2
2	Elem 3
3	Elem 4
…	…

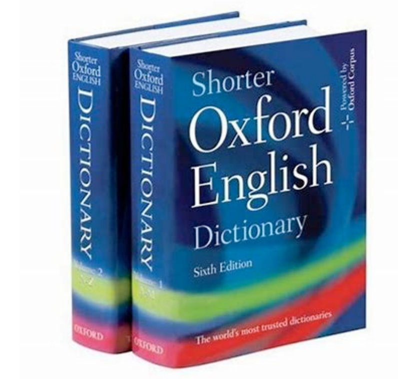
index — element

A dictionary

Key 1	Val 1
Key 2	Val 2
Key 3	Val 3
Key 4	Val 4
…	…

custom index by label — element

A PYTHON DICTIONARY



- store pairs of data
  - key
  - value (any data object)

'Ana'	'B'
'Matt'	'A'
'John'	'A+'
'Katy'	'A'

custom index by label

element

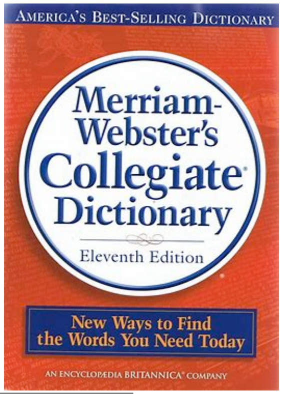
```
my_dict = {}
grades = {'Ana':'B', 'Matt':'A', 'John':'A+', 'Katy':'A'}
```

empty dictionary

key1 val1 key2 val2 key3 val3 key4 val4

Note: values could be arbitrary structure

DICTIONARY LOOKUP



- similar to indexing into a list
- **looks up** the **key**
- **returns** the **value** associated with the key
- if key isn't found, get an error

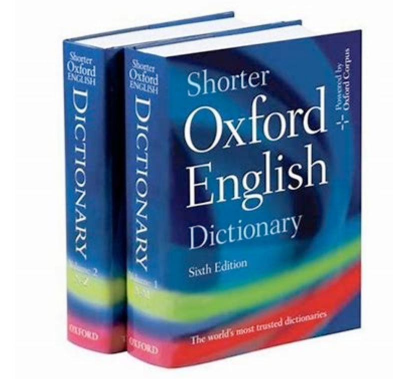
'Ana'	'B'
'Matt'	'A'
'John'	'A+'
'Katy'	'A'

```
grades = {'Ana':'B', 'Matt':'A', 'John':'A+', 'Katy':'A'}
```

`grades['John']` → evaluates to `'A+'`

`grades['Sylvan']` → gives a `KeyError`

A PYTHON DICTIONARY



- while we are going to demonstrate just using final grade, one can easily see advantage of storing more complex structures, such as another dictionary

- access parts by key, don't need to remember order

'Ana'	'mq'	[5,2,4]
	'ps'	[10,8,4]
	'fin'	'B'

```
grades = {'Ana':{'mq':[5,2,4], 'ps': [10,8,4], 'fin': 'B'}
```

`grades['Ana'][ 'mq'][0]` returns `5`

DICTIONARY OPERATIONS

'Ana'	'B'
'Matt'	'A'
'John'	'A+'
'Katy'	'A'
'Sylvan'	'B'

```
grades = {'Ana':'B', 'Matt':'A', 'John':'A+', 'Katy':'A'}
```

- **add** an entry

```
grades['Sylvan'] = 'C'
```

- **test** if key in dictionary

```
'John' in grades      → returns True
'Daniel' in grades    → returns False
```

- **delete** entry

```
del(grades['Ana'])
```

- **change** entry

```
grades['Sylvan'] = 'B'
```

DICTIONARY OPERATIONS

'Ana'	'B'
'Matt'	'A'
'John'	'A+'
'Katy'	'A'

```
grades = {'Ana':'B', 'Matt':'A', 'John':'A+', 'Katy':'A'}
```

- get an **iterable that acts like a tuple of all keys**

  can loop over iterable; no guaranteed order

```
grades.keys()
```

  → returns `dict_keys(['Denise','Katy','John','Ana'])`

- get an **iterable that acts like a tuple of all values**

```
grades.values()
```

  → returns `dict_values(['A', 'A', 'A+', 'B'])`

DICTIONARY KEYS & VALUES

- values
  - any type (**immutable and mutable**)
  - can be **duplicates**
  - dictionary values can be lists, even other dictionaries!
- keys
  - must be **unique**
  - **immutable** type (`int`, `float`, `string`, `tuple`,`bool`)
    - actually need an object that is **hashable,** but think of as immutable as all immutable types are hashable
  - be careful using `float` type as a key
- **no order** to keys or values!

```
d = {4:{1:0}, (1,3):"twelve", 'const':[3.14,2.7,8.44]}
```

`list` vs `dict`

- **ordered** sequence of elements
- look up elements by an integer index
- indices have an **order**
- index is an **integer**

- **matches** "keys" to "values"
- look up one item by another item
- **no order** is guaranteed
- key can be any **immutable** type

EXAMPLE: THREE FUNCTIONS TO ANALYZE SONG LYRICS

1) create a **frequency dictionary** mapping `str:int`

2) find **word that occurs most often** and how many times

- use a list, in case more than one word with same number
- return a tuple `(list,int)` for (words_list, highest_freq)

3) find the **words that occur at least X times**

- let user choose "at least X times", so allow as parameter
- return a list of tuples, each tuple is a `(list, int)` containing the list of words ordered by their frequency
- IDEA: From song dictionary, find most frequent word. Delete most common word. Repeat. It works because you are mutating the song dictionary.

CREATING A DICTIONARY

```
def generate_word_dict(song):
    song_words = song.lower()
    words_list = song_words.split()
    word_dict = {}
    for w in words_list:
        if w in word_dict:
            word_dict[w] += 1
        else:
            word_dict[w] = 1
    return word_dict
```

convert string to list of words; divides based on spaces

can iterate over list of words in song

if word in dict (as a key), increase # times you've seen it, update entry

if word not in dict, seen word once, create entry

USING THE DICTIONARY


```
def find_frequent_word(word_dict):
    words = []
    highest = max(word_dict.values())
    for w in word_dict.keys():
        if word_dict[w] == highest:
            word.append(w)
    return (words, highest)
```

highest frequency in dict's values

loop over keys

create list of all words that have that freq

LEVERAGING DICT PROPERTIES


```
def occurs_often(word_dict, atleast):
    freq_list = []
    done = False
    while not done:
        word_freq_tuple = find_frequent_word(word_dict)
        if word_freq_tuple[1] < atleast:
            done = True
        else:
            freq_list.append(word_freq_tuple)
            for i in word_freq_tuple[0]:
                del(word_dict[i])
    return freq_list
```

Use Boolean as flag to stay/exit from a loop

finding freqs higher than atleast

mutate dict

```
song_dict = generate_word_dict(song)
print("***** WORDS IN SONG *****")
print(song_dict)
print("***** MOST COMMON WORD *****")
print(find_frequent_word(song_dict))
print("***** TOP MOST COMMON WORDS *****")
print(occurs_often(song_dict, 20))
```

Some observations

- conversion of string into list of words enables use of list methods
- iteration over list naturally follows from structure of lists
- ability to access all values and all keys of dictionary allows natural looping methods
- mutability of dictionary enables recursive processing

FIBONACCI RECURSIVE CODE

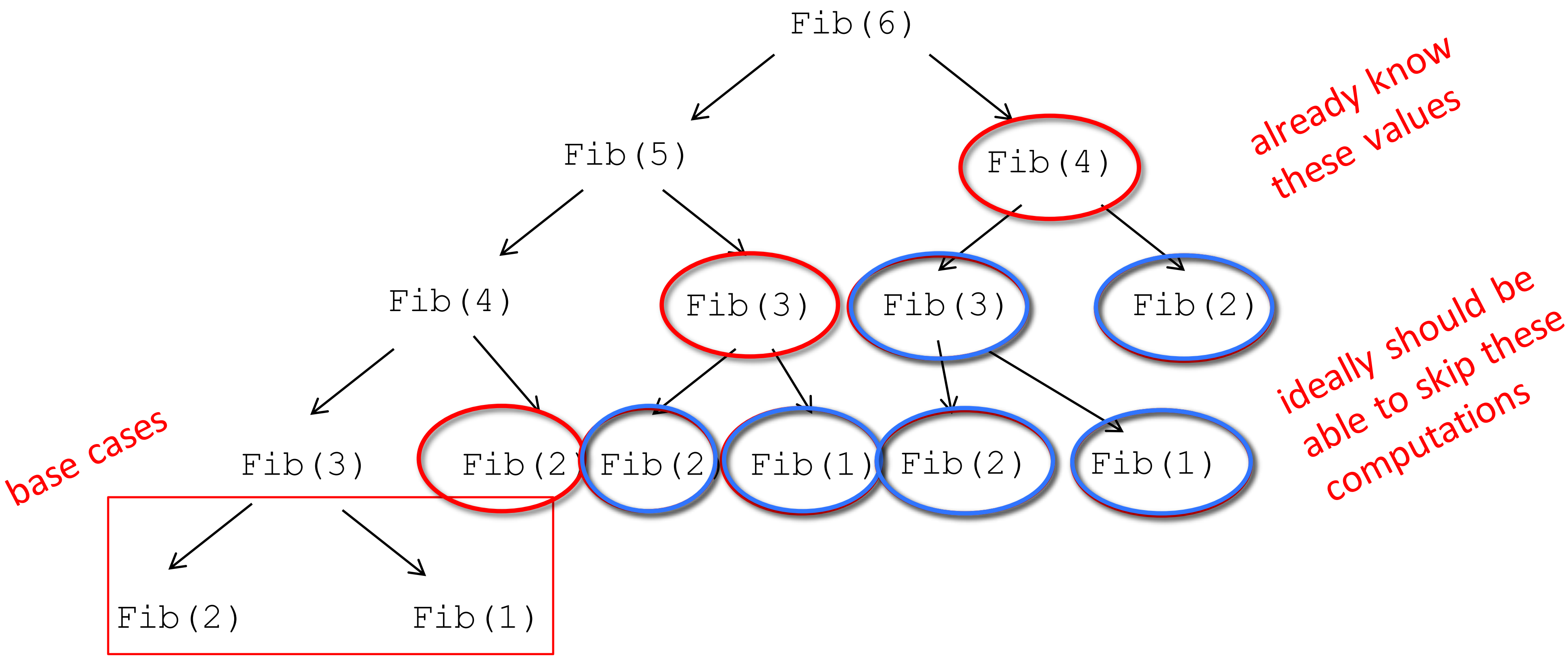
```
def fib(n):
    if n == 1:
        return 1
    elif n == 2:
        return 2
    else:
        return fib(n-1) + fib(n-2)
```

Leonardo Bonacci,
aka Fibonacci

- two base cases
- calls itself twice
- this code is inefficient

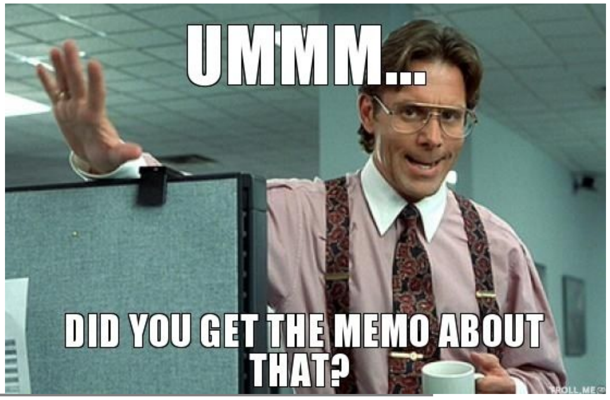
INEFFICIENT FIBONACCI

`fib(n) = fib(n-1) + fib(n-2)`



- **recalculating** the same values many times!
- could keep **track** of already calculated values

FIBONACCI WITH MEMOIZATION




```
def fib_efficient(n, d):
    if n in d:
        return d[n]
    else:
        ans = fib_efficient(n-1, d) + fib_efficient(n-2, d)
        d[n] = ans
        return ans

d = {1:1, 2:2}
print(fib_efficient(6, d))
```

Checking in keys

Method sometimes called "**memoization**"

Initialize dictionary with base cases

- do a **lookup first** in case already calculated the value
- **modify dictionary** as progress through function calls

EFFICIENCY GAINS

- Calling fib(34) results in **11,405,773** recursive calls to the procedure
- Calling fib_efficient(34) results in **65** recursive calls to the procedure
- Using dictionaries to capture intermediate results can be very efficient
- But note that this only works **for procedures without side effects** (i.e., the procedure will always produce the same result for a specific argument independent of any other computations between calls)

TESTING, DEBUGGING, EXCEPTIONS, ASSERTIONS

PROGRAMMING CHALLENGES

EXPECTATION

What you want the program to do

REALITY

What the program actually does

DEFENSIVE PROGRAMMING

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

Prevent bugs from occurring

TESTING/VALIDATION

- **Compare** input/output pairs to specification
- "Is it working?"
- "How can I break my program?"

Check for bugs

DEBUGGING

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

Remove bugs

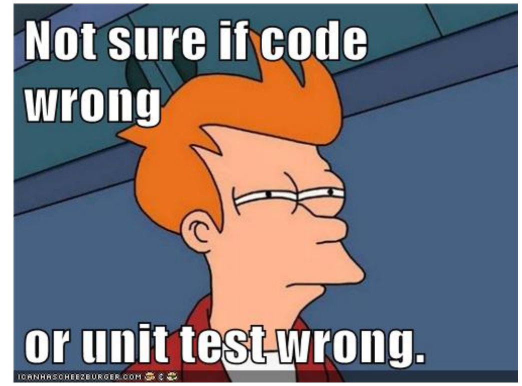
SET YOURSELF UP FOR EASY TESTING AND DEBUGGING

- 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

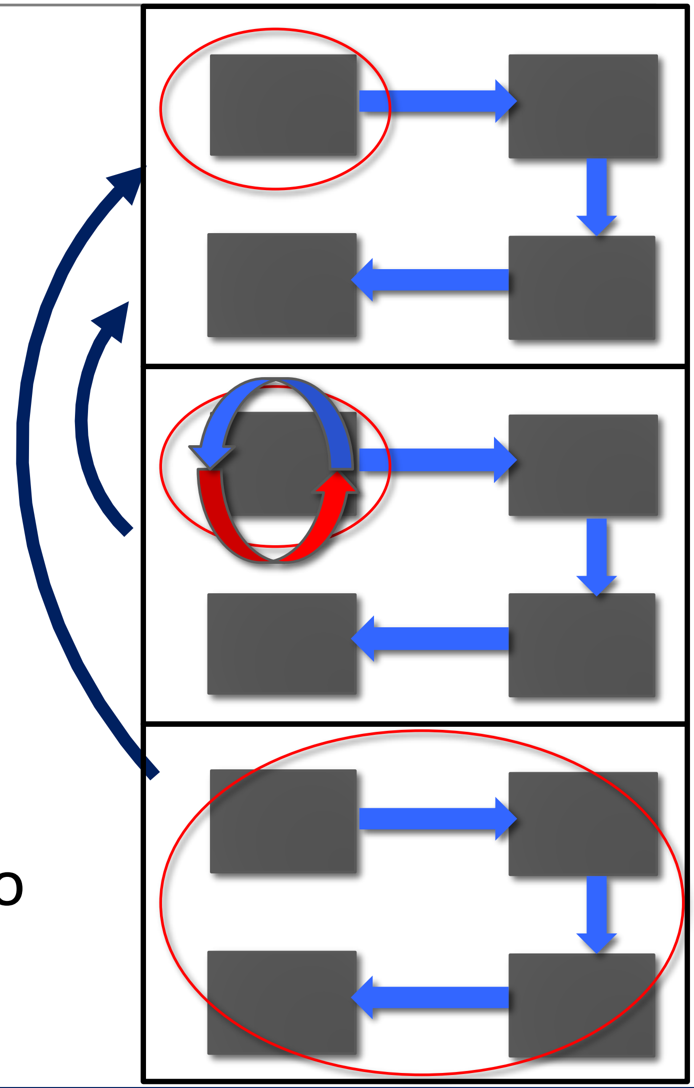
WHEN ARE YOU READY TO TEST?

- 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

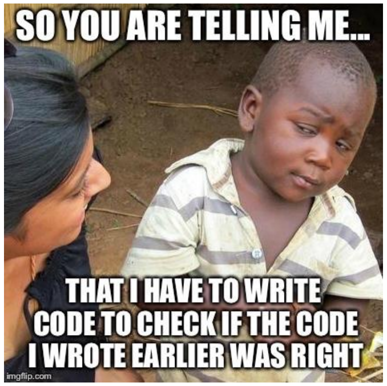


CLASSES OF TESTS

- **Unit testing**
  - validate each piece of program
  - **testing each function** separately
- **Regression testing**
  - fixing a bug might introduce new ones, so add test for bugs as you find them in a function
  - **catch reintroduced** errors that were previously fixed
- **Integration testing**
  - does **overall program** work?
  - most programmers 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

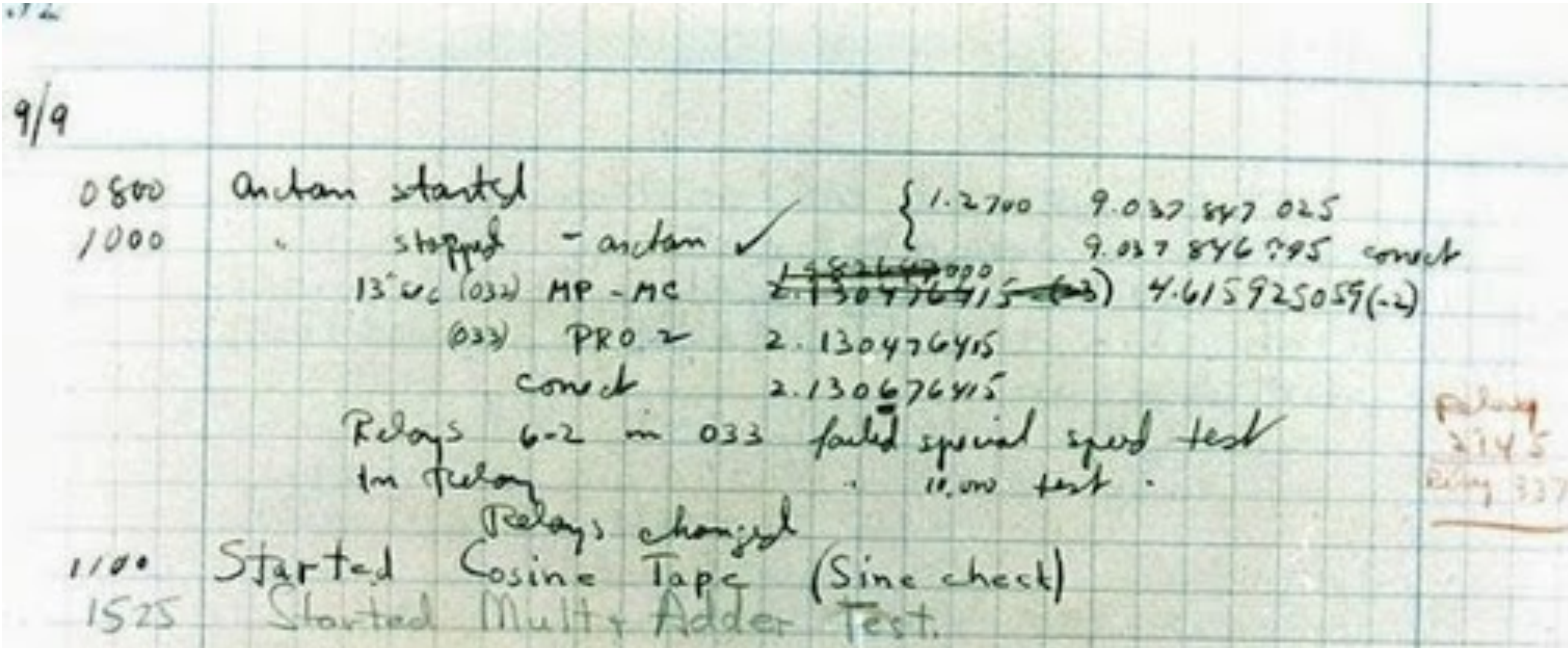
```
def abs(x):
    """ Assumes x is an int
    Returns x if x>=0 and –x otherwise """
    if x < -1:
        return –x
    else:
        return x
```

- 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 for all cases

Admiral Grace Murray Hopper


9/9
0800 Anctan started
1000 stopped - anctan ✓
13" sec (032) MP - MC
(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.

DEBUGGING

- goal is to have a bug-free program
- tools
  - **built in** to IDLE and Anaconda
    - error messages
    - stepping through code, line at a time
  - **Python Tutor**
  - **`print`** statement
  - use your brain, be **systematic** in your hunt

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

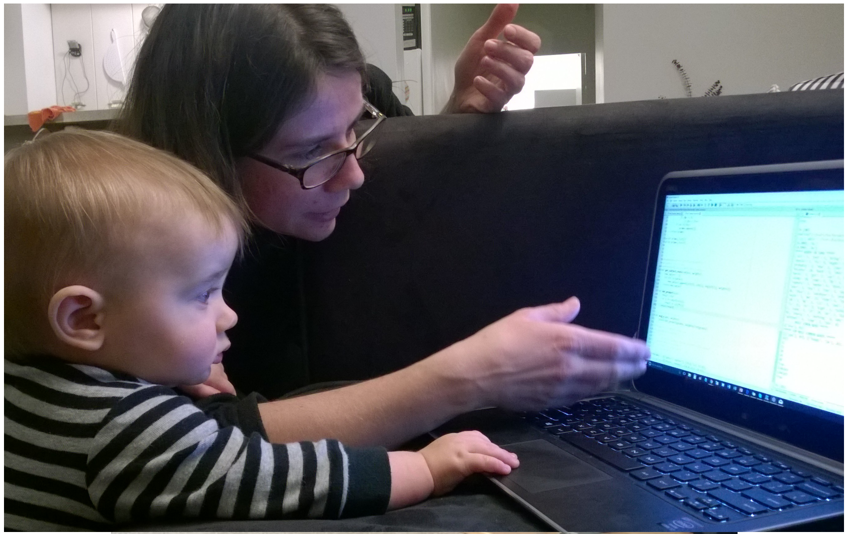
  `'3'/4` → `TypeError`

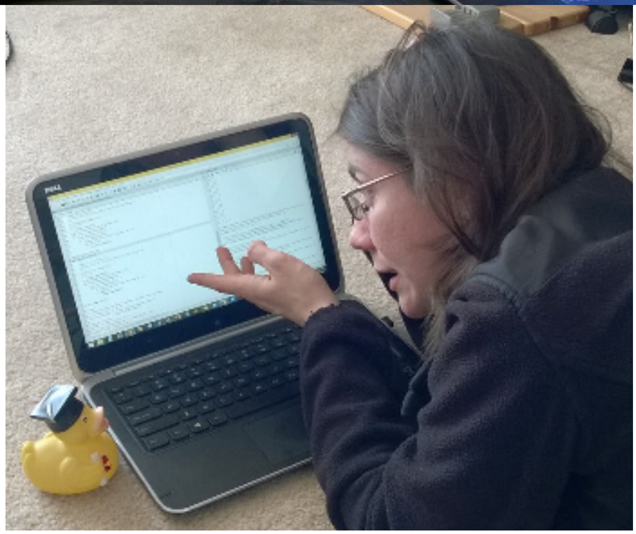
- forgetting to close parenthesis, quotation, etc.

  ```
  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

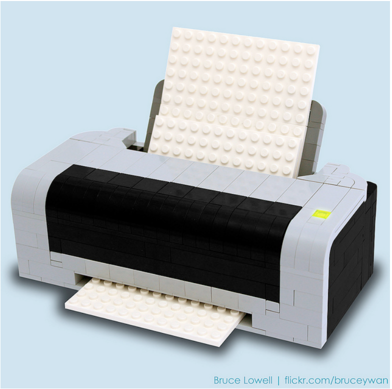




DEBUGGING STEPS: be a scientist

- **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 – 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, use simple test cases



PRINT STATEMENTS

- good way to **test hypothesis**
- when to print
  - enter function
    - show values of parameters before computation
  - function results
    - show value of computation before exiting

DEBUGGING AS SEARCH

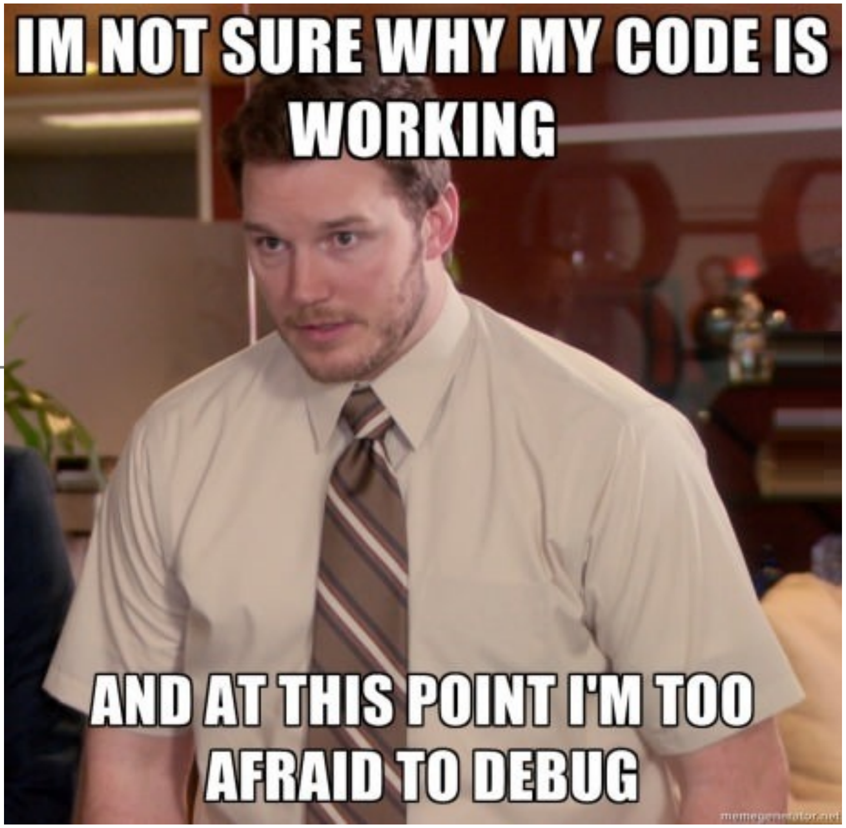
- want to narrow down space of possible sources of error
- design experiments that expose intermediate stages of computation (use print statements!), and use results to further narrow search
- **bisection search** can be a powerful tool for this
  - If reach a print statement, and intermediate results are not what expected, know there is at least one error before that point in the code; otherwise error must be restricted to code after that point

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

5 Minute Break

5 Minute Break



When my code somehow just works

EXCEPTIONS, ASSERTIONS

UNEXPECTED CONDITIONS

- 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
```

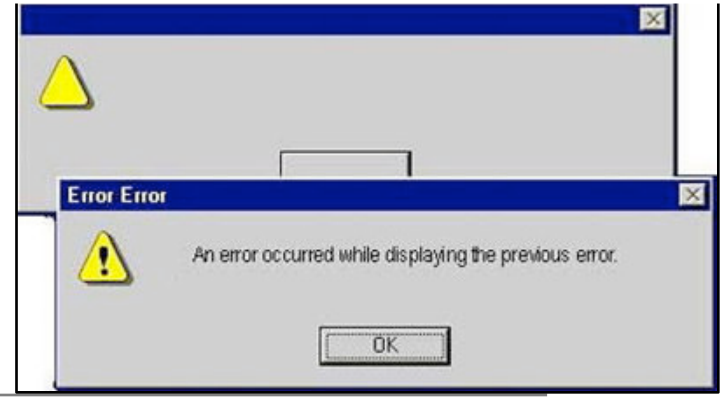
  - referencing a non-existing variable

```
a                          → NameError
```

  - mixing data types without coercion

```
'a'/4                      → TypeError
```

OTHER 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)

HANDLING 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 particular types of exceptions

```
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?

- **fail silently** – substitute default values or just continue
  - **bad idea!** user gets no warning
- return an **"error" value**
  - complicates code having to check for a special value
- stop execution, **signal error** condition

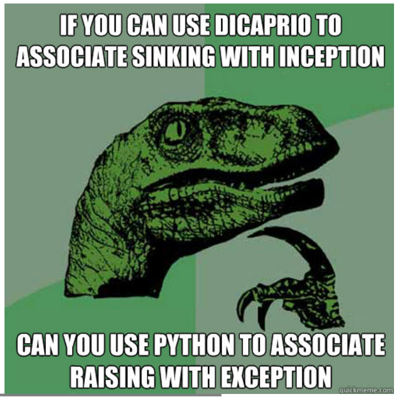
```
raise <exceptionName>(<arguments>)
raise ValueError("something is wrong")
```

keyword

name of error you want to raise

optional, usually a string message

EXAMPLE: RAISING AN EXCEPTION




```
def get_ratios(L1, L2):
    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')
        else:
            print("success")
        finally:
            print("executed no matter whats)
    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'], [10.0, 5.0, 85.0]],
               [['bruce', 'wayne'], [10.0, 8.0, 74.0]]]
```

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

```
[[['peter', 'parker'], [10.0, 5.0, 85.0], 33.33333],
[['bruce', 'wayne'], [10.0, 8.0, 74.0], 30.666667]]]
```

EXAMPLE CODE

```
[[['peter', 'parker'], [10.0, 5.0, 85.0]],
[['bruce', 'wayne'], [10.0, 8.0, 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]],
               [['thor'], []]]
```

- 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], 33.3333333],
[['bruce', 'wayne'], [10.0, 8.0, 74.0], 30.6666666],
[['captain', 'america'], [8.0, 10.0, 96.0], 38.0],
[['thor'], [], 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

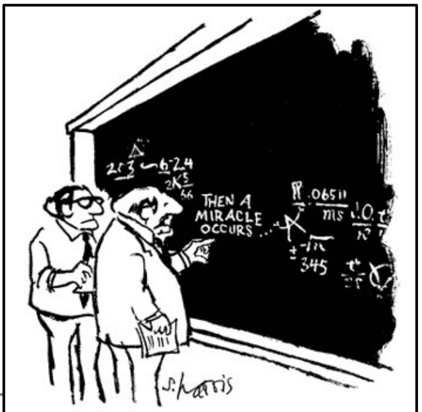
```
warning: no grades data
```

still flag the error

```
[[['peter', 'parker'], [10.0, 5.0, 85.0], 33.333333],
[['bruce', 'wayne'], [10.0, 8.0, 74.0], 30.666666],
[['captain', 'america'], [8.0, 10.0, 96.0], 38.0],
[['thor'], [], 0.0]]
```

now avg returns 0

ASSERTIONS



"I think you should be more explicit here in step two."

- want to be sure that **assumptions** on state of computation are what we 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 user 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)

TAKE HOME MESSAGE

- Dictionaries are a powerful data structure for associating values with complex keys
- Good code creation requires defensive programming, thoughtful testing, and disciplined debugging
- Exceptions provide the coder with a way of handling unexpected input
- Assertions are one way of enforcing conditions on a "contract" between a coder and a user