Debugging

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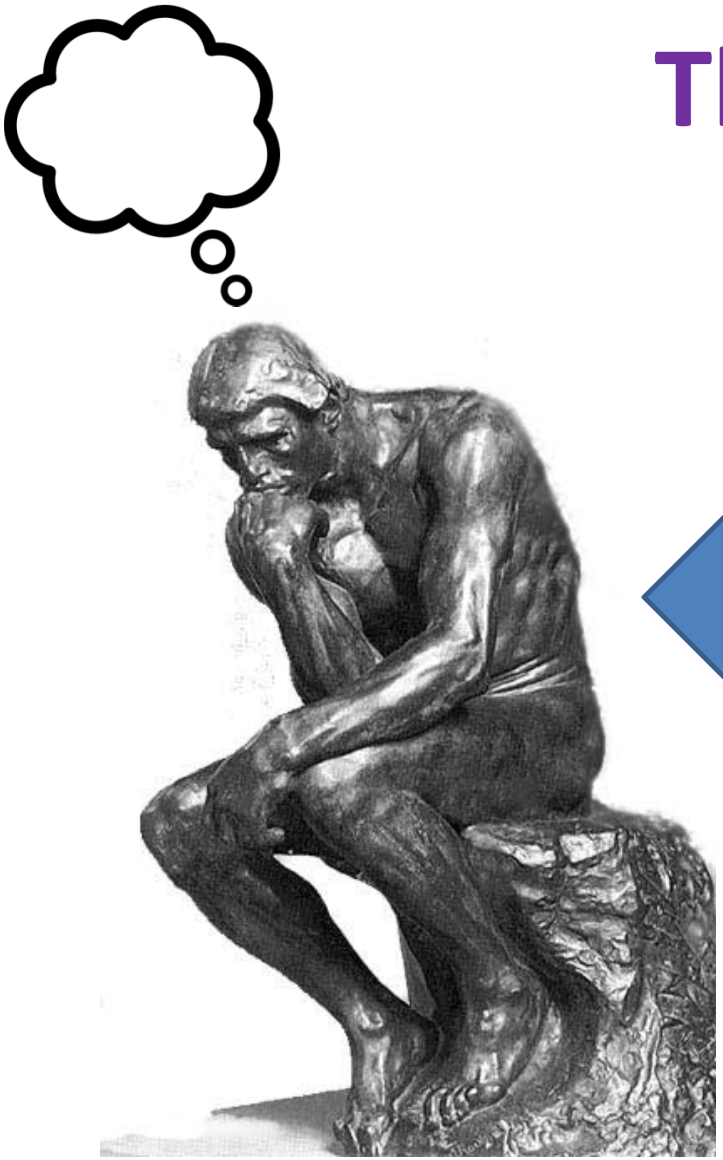
The problem



Not the same!

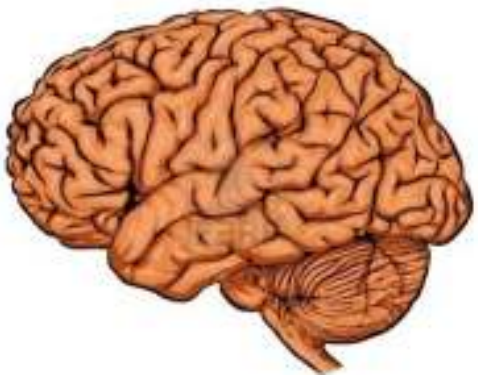
☹

What you want your program to do

What your program does

Debugging tools

- Python error message
- **`assert`**
- **`print`**
- Python interpreter
- Python Tutor (http://pythontutor.com)
- Python debugger
- Best tool:



Two key ideas

1. The scientific method
2. Divide and conquer

If you master those, you will find debugging easy, and possibly enjoyable

The scientific method

1. Create a hypothesis
2. Design an experiment to test that hypothesis
   - Ensure that it yields insight
3. Understand the result of your experiment
   - If you don't understand, then possibly suspend your main line of work to understand that

Tips:

- Be systematic
  - Never do anything if you don't have a reason
  - Don't just flail
    - Random guessing is likely to dig you into a deeper hole
- Don't make assumptions (verify them)

Example experiments

1. An alternate implementation of a function
   - Run all your test cases afterward
2. A new, simpler test case
   - Examples: smaller input, or test a function in isolation
   - Can help you understand the reason for a failure

Your scientific notebook

Record everything you do

- Specific inputs and outputs (both expected and actual)
- Specific versions of the program
  - If you get stuck, you can return to something that works
  - You can write multiple implementations of a function
- What you have already tried
- What you are in the middle of doing now
  - This may look like a stack!
- What you are sure of, and why

Your notebook also helps if you need to get help or reproduce your results

Read the error message

```
Traceback (most recent call last):
  File "nx_error.py", line 41, in <module>
    print friends_of_friends(rj, myval)
  File "nx_error.py", line 30, in friends_of_friends
    f = friends(graph, user)
  File "nx_error.py", line 25, in friends
    return set(graph.neighbors(user))#
  File "/Library/Frameworks/…/graph.py", line 978, in neighbors
     return list(self.adj[n])
TypeError: unhashable type: 'list'
```

First function that was called (**<module>** means the interpreter)

Second function that was called

Call stack or traceback

Last function that was called (this one suffered an error)

The error message: daunting but useful.

You need to understand:

- the literal meaning of the error
- the underlying problems certain errors tend to suggest

List of all exceptions (errors):
http://docs.python.org/2/library/exceptions.html#bltin-exceptions

Two other resources, with more details about a few of the errors:
http://inventwithpython.com/appendixd.html
http://www.cs.arizona.edu/people/mccann/errors-python

Common Error Types

- AssertionError
  - Raised when an assert statement fails.
- IndexError
  - Raised when a sequence subscript is out of range.
- KeyError
  - Raised when a mapping (dictionary) key is not found in the set of existing keys.
- KeyboardInterrupt
  - Raised when the user hits the interrupt key (normally Control-C or Delete).
- NameError
  - Raised when a local or global name is not found.
- SyntaxError
  - Raised when the parser encounters a syntax error.
- IndentationError
  - Base class for syntax errors related to incorrect indentation.
- TypeError
  - Raised when an operation or function is applied to an object of inappropriate type.

Divide and conquer

- Where is the defect (or “bug”)?
- Your goal is to find the one place that it is
- Finding a defect is often harder than fixing it

- Initially, the defect might be anywhere in your program
  - It is impractical to find it if you have to look everywhere
- Idea: bit by bit reduce the scope of your search
- Eventually, the defect is localized to a few lines or one line
  - Then you can understand and fix it

- 4 ways to divide and conquer:
  - In the program code
  - In test cases
  - During the program execution
  - During the development history

Divide and conquer in the program code

- Localize the defect to part of the program
  - e.g., one function, or one part of a function
- Code that isn't executed cannot contain the defect

3 approaches:

- Test one function at a time
- Add assertions or print statements
  - The defect is executed before the failing assertion (and maybe after a succeeding assertion)
- Split complex expressions into simpler ones

  Example: Failure in

  ```
  result = set({graph.neighbors(user)})
  ```

  Change it to

  ```
  nbors = graph.neighbors(user)
  nbors_set = {nbors}
  result = set(nbors_set)
  ```

  The error occurs on the "nbors_set = {nbors}" line

Divide and conquer in test cases

- Your program fails when run on some large input
  - It's hard to comprehend the error message
  - The log of print statement output is overwhelming
- Try a smaller input
  - Choose an input with some but not all characteristics of the large input
  - Example: Unicode characters, duplicates, zeroes in data, …

Divide and conquer in execution time via print (or "logging") statements

- A sequence of **`print`** statements is a record of the execution of your program
- The **`print`** statements let you see and search multiple moments in time
- Print statements are a useful technique, in moderation
- Be disciplined
  - Too much output is overwhelming rather than informative
  - Remember the scientific method: have a reason (a hypothesis to be tested) for each print statement
  - Don't *only* use print statements

Divide and conquer in development history

- The code used to work (for some test case)
- The code now fails
- The defect is related to some line you changed

- This is useful only if you kept a version of the code that worked (use good names!)
- This is most useful if you have made few changes
- Moral: test often!
  - Fewer lines to compare
  - You remember what you were thinking/doing recently

A metaphor about debugging

If your code doesn't work as expected, then by definition you don't understand what is going on.

- You're lost in the woods.
- You're behind enemy lines.
- All bets are off.
- Don't trust anyone or anything.

Don't press on into unexplored territory -- go back the way you came!
(and leave breadcrumbs!)

You're trying to "advance the front lines," not "trailblaze"

My Favorite Time-Saving Trick: Make Sure you're Debugging the Right Problem

- The game is to go from "working to working"
- When something doesn't work, STOP!
  - It's wild out there!
- FIRST: go back to the last situation that worked properly.
  - Rollback your recent changes and verify that everything still works as expected.
  - Don't make assumptions – by definition, you don't understand the code when something goes wrong, so you can't trust your assumptions.
  - You may find that even what previously worked now doesn't
  - Perhaps you forgot to consider some "innocent" or unintentional change, and now even tested code is broken

A bad timeline

- A works, so celebrate a little
- Now try B
- B doesn’t work
- Change B and try again
- Change B and try again
- Change B and try again

…

A better timeline

- A works, so celebrate a little
- Now try B
- B doesn't work
- *Rollback to A*
- Does A still work?
  - Yes: Find A' that is somewhere between A and B
  - No: You have unintentionally changed something else, and there's no point futzing with B at all!

These "innocent" and unnoticed changes happen more than you would think!

- You add a comment, and the indentation changes.
- You add a print statement, and a function is evaluated twice.
- You move a file, and the wrong one is being read
- You're on a different computer, and the library is a different version

Once you're on solid ground you can set out again

- Once you have something that works and something that doesn't work, it's only a matter of time
- You just need to incrementally change the working code into the non-working code, and the problem will reveal itself.
- Variation: Perhaps your code works with one input, but fails with another. Incrementally change the good input into the bad input to expose the problem.

Simple Debugging Tools

print

- shows what's happening whether there's a problem or not
- does not stop execution

assert

- Raises an exception if some condition is not met
- Does nothing if everything works
- Example: `assert len(rj.edges()) == 16`
- Use this liberally! Not just for debugging!

raw_input

- Stops execution
- (Designed to accept user input, but I rarely use it for this.)