



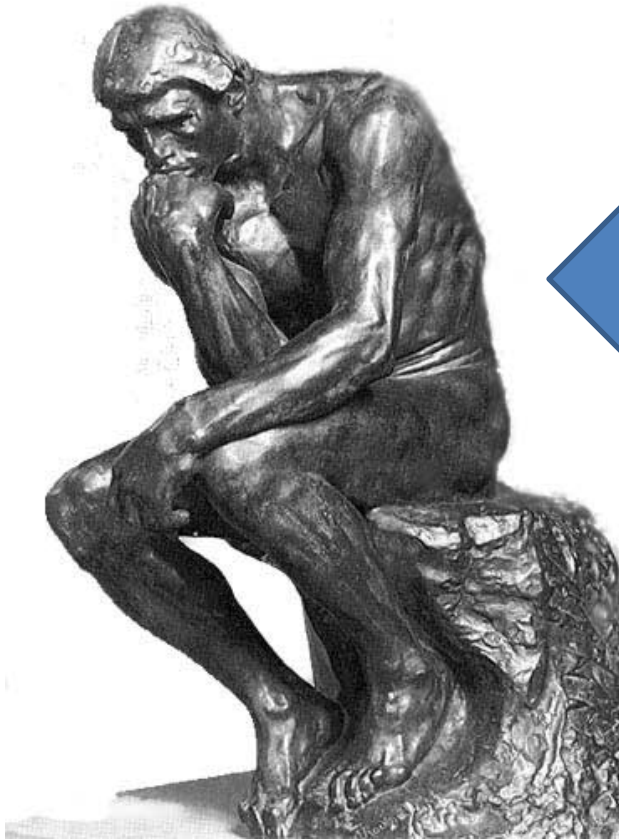
Debugging

BBM 101 - Introduction to Programming I

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The Problem



There is a bug!



What you want
your program to do

What your program does



What is Debugging?



- Grace Hopper was one of U.S.'s first programmers.
- She found a moth in the Mark I computer, which was causing errors, and called it a computer "bug"
- Thus, the word debugging is coined 😊



9/9

0800 Antan started
 1000 " stopped - antan ✓ { 1.2700 9.037 847 025
 13⁰⁰ (032) MP-MC 1.98264000 9.037 846 895 correct
 (033) PRO 2 2.130476415 (03) 4.615925059(-2)
 correct 2.130676415

Relays 6-2 in 033 failed special speed test
 in relay " 10,000 test.

1100 Started Cosine Tape (Sine check)
 Relays changed
 1525 Started Multi Adder Test.

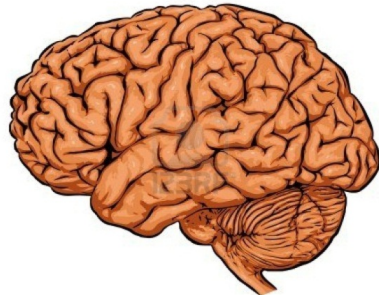
1545 Relay #70 Panel F
 (moth) in relay.

First actual case of bug being found.
 1630 Antan started.
 1700 closed down.

Relay 3145
 Relay 3376

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)

List of all exceptions (errors):

<http://docs.python.org/3/library/exceptions.html#builtin-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>

The error message: daunting but useful.

You need to understand:

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

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: 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"

Time-Saving Trick: Make Sure You are 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 are on a different computer, and the library is a different version

Once You are on Solid Ground You can Set Out Again

- Once you have **something that works** and **something that doesn't work**, it is 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 is happening whether there is 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!