Programming Principles in Python (CSCI 503/490)

Debugging & Testing

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Dealing with Errors

- Can explicitly check for errors at each step
  - Check for division by zero
  - Check for invalid parameter value (e.g. string instead of int)
- Sometimes all of this gets in the way and can't be addressed succinctly
  - Too many potential errors to check
  - Cannot handle groups of the same type of errors together
- Allow programmer to determine when and how to handle issues
  - Allow things to go wrong and handle them instead
  - Allow errors to be propagated and addressed once

Advantages of Exceptions

- Separate error-handling code from "regular" code
- Allows propagation of errors up the call stack
- Errors can be grouped and differentiated

[Java Tutorial, Oracle]

Try-Except

- The `try` statement has the following form:

```
try:
   <body>
except <ErrorType>*:
   <handler>
```

- When Python encounters a `try` statement, it attempts to execute the statements inside the body.
- If there is no error, control passes to the next statement after the `try`… `except` (unless `else` or `finally` clauses)
- Note: **except** not catch

Exception Granularity

- If you catch any exception using a base class near the top of the hierarchy, you may be **masking** code errors
- ```
  try:
      c, d = a / b
  except Exception:
      c, d = 0, 0
  ```
- Remember `Exception` catches any exception is an instance of Exception
- Catches `TypeError: cannot unpack non-iterable float object`
- Better to have more **granular** (specific) exceptions!
- We don't want to catch the TypeError because this is a **programming error** not a runtime error
  ```

Exception Locality

- ```
  try:
      fname = 'missing-file.dat'
      with open(fname) as f:
          lines = f.readlines()
  except OSError:
      print(f"An error occurred reading {fname}")
  try:
      out_fname = 'output-file.dat'
      with open('output-file.dat', 'w') as fout:
          fout.write("Testing")
  except OSError:
      print(f"An error occurred writing {out_fname}")
  ```
  ```

Multiple Except Clauses

- Function like an if/elif sequence
- Checked in order so put more granular exceptions earlier!
- ```
  try:
      fname = 'missing-file.dat'
      with open(fname) as f:
          lines = f.readlines()
      out_fname = 'output-file.dat'
      with open('output-file.dat', 'w') as fout:
          fout.write("Testing")
  except FileNotFoundError:
      print(f"File {fname} does not exist")
  except OSError:
      print("An error occurred processing files")
  ```
  ```

Handling Multiple Exceptions at Once

- Can process multiple exceptions with one clause, use **tuple** of classes
- Allows some specificity but without repeating
- ```
  try:
      fname = 'missing-file.dat'
      with open(fname) as f:
          lines = f.readlines()
      out_fname = 'output-file.dat'
      with open('output-file.dat', 'w') as fout:
          fout.write("Testing")
  except (FileNotFoundError, PermissionError):
      print("An error occurred processing files")
  ```
  ```

Exception Objects

- Exceptions themselves are a type of object.
- If you follow the error type with an identifier in an except clause, Python will assign that identifier the actual exception object.
- Sometimes exceptions encode information that is useful for handling
- ```
  try:
      fname = 'missing-file.dat'
      with open(fname) as f:
          lines = f.readlines()
      out_fname = 'output-file.dat'
      with open('output-file.dat', 'w') as fout:
          fout.write("Testing")
  except OSError as e:
      print(e.errno, e.filename, e)
  ```
  ```

Assignment 6

- Upcoming
- Object-Oriented Programming

Else Clause

- Code that executes if no exception occurs
- ```
  b = 3
  a = 2
  try:
      c = b / a
  except ZeroDivisionError:
      print("Division failed")
      c = 0
  else:
      print("Division successful:", c)
  ```
  ```

Finally

- Code that always runs, **regardless** of whether there is an exception
- ```
  b = 3
  a = 0
  try:
      c = b / a
  except ZeroDivisionError:
      print("Division failed")
      c = 0
  finally:
      print("This always runs")
  ```
  ```

Finally

- Code that always runs, **regardless** of whether there is an exception
- …even if the exception isn't handled!
- ```
  b = 3
  a = 0
  try:
      c = b / a
  finally:
      print("This always runs, even if we crash")
  ```
- Remember that context managers (e.g. for files) have built-in cleanup clauses
  ```

Nesting

- You can nest try-except clauses inside of except clauses, too.
- Example: perhaps a file load could fail so you want to try an alternative location but want to know if that fails, too.
- Can even do this in a `finally` clause:
- ```
  try:
      c = b / a
  finally:
      try:
          print("This always runs", 3/0)
      except ZeroDivisionError:
          print("It is silly to only catch this exception")
  ```
  ```

Raising Exceptions

- Create an exception and raise it using the `raise` keyword
- Pass a string that provides some detail
- Example: `raise Exception("This did not work correctly")`
- Try to find a exception class:
  - `ValueError`: if an argument doesn't fit the function's expectations
  - `NotImplementedError`: if a method isn't implemented (e.g. abstract cls)
- Be specific in the error message, state actual values
- Can also subclass from existing exception class, but check if existing exception works first
- Some packages create their own base exception class (`RequestException`)

Re-raising and Raising From

- Sometimes, we want to detect an exception but also pass it along
- ```
  try:
      c = b / a
  except ZeroDivisionError:
      print("Division failed")
      raise
  ```
- Raising from allows exception to show specific chain of issues
- ```
  try:
      c = b / a
  except ZeroDivisionError as e:
      print("Division failed")
      raise ValueError("a cannot be zero") from e
  ```
- Usually unnecessary because Python does the right thing here (shows chain)

Making Sense of Exceptions

- When code (e.g. a cell) crashes, read the traceback:
-
```
ZeroDivisionError                 Traceback (most recent call last)
<ipython-input-58-488e97ad7d74> in <module>
      4     return divide(a+b, a-b)
      5 for i in range(4):
----> 6     process(3, i)
<ipython-input-58-488e97ad7d74> in process(a, b)
      3         return c / d
----> 4     return divide(a+b, a-b)
      5 for i in range(4):
<ipython-input-58-488e97ad7d74> in divide(c, d)
      2     def divide(c, d):
----> 3         return c / d
      4     return divide(a+b, a-b)
ZeroDivisionError: division by zero
```

Making Sense of Exceptions

- Start at the bottom: last line is the exception message
- Nesting goes outside-in: innermost scope is last, outermost scope is first
- Arrows point to the line of code that caused errors at each scope
- Surrounding lines give context

Making Sense of Exceptions

- Sometimes, exception handling can mask actual issue!
- ```
  def process(a, b):
      …
  for i in range(4):
      try:
          process(3, i)
      except ZeroDivisionError:
          raise Exception(f"Cannot process i={i}") from None
  ```
- ```
  Exception                  Traceback (most recent call last)
  <ipython-input-60-6d0289010945> in <module>
        7         process(3, i)
        8     except ZeroDivisionError:
  ----> 9         raise Exception(f"Cannot process i={i}") from None
  Exception: Cannot process i=3
  ```
- Usually, Python includes inner exception (`from None` stops the chain)

Making Sense of Exceptions

- Probably the **worst** thing is to **ignore** all exceptions:
- ```
  def process(a, b):
      …
  result = []
  for i in range(6):
      try:
          result.append(process(3, i))
      except:
          pass
  ```
- This may seem like the easy way out, don't have to worry about errors, but can mask major issues in the code!
- Be specific (granularity), try to handle cases when something goes wrong, crash **gracefully** if it is an unexpected error
  ```

How do you debug code?

Debugging

- print statements
- logging library
- pdb
- Extensions for IDEs (e.g. PyCharm)
- JupyterLab Debugger Support

Print Statements

- Just print the values or other information about identifiers:
- ```
  def my_function(a, b):
      print(a, b)
      print(b - a == 0)
      return a + b
  ```
- Note that we need to remember what is being printed
- Can add this to print call, or use f-strings with trailing = which causes the name and value of the variable to be printed
- ```
  def my_function(a, b):
      print(f"{a=} {b=} {b - a == 0}")
      return a + b
  ```

Print Problems

- Have to uncomment/comment
- Have to remember to get rid of (or comment out) debugging statements when publishing code
- Print can dump a lot of text (slows down notebooks)
- Can try to be smarter:
  - ```
    if i % 100 == 0:
        print(i, f"{current_output=}")
    ```
  - ```
    do_print = value == 42
    if do_print:
        print(f"{a=} {current_output=}")
    ```

Logging Library

- Allows different levels of output (e.g. DEBUG, INFO, WARNING, ERROR CRITICAL)
- Can output to a file as well as stdout/stderr
- Can configure to suppress certain levels or filter messages
- ```
  import logging
  def my_function(a,b):
      logging.debug(f"{a=} {b=} {b-a == 0}")
      return a + b
  my_function(3, 5)
  ```
- This doesn't work in notebooks…
  ```

Logging Library

- Need to set default level (e.g. DEBUG)
- For notebooks, best to define own logger and set level
- ```
  import logging
  logger = logging.Logger('my-logger')
  logger.setLevel(logging.DEBUG)
  def my_function(a,b):
      logger.debug(f"{a=} {b=} {b-a == 0}")
      return a + b
  my_function(3, 5)
  ```
- Prints on stderr, can set to stdout via:
- ```
  import sys
  logging.basicConfig(stream=sys.stdout, level=logging.DEBUG)
  ```

Python Debugger (pdb)

- Debuggers offer the ability to inspect and interact with code as it is running
  - Define breakpoints as places to stop code and enter the debugger
  - Commands to inspect variables and step through code
  - Different types of steps (into, over, continue)
  - Can have multiple breakpoints in a piece of code
- There are a number of debuggers like those built into IDEs (e.g. PyCharm)
- pdb is standard Python, also an ipdb variant for IPython/notebooks

Python Debugger

- Post-mortem inspection:
  - In the notebook, use `%debug` in a new cell to inspect at the line that raised the exception
    - Can have this happen all the time using `%pdb` magic
    - Brings up a new panel that allows debugging interactions
  - In a script, run the script using pdb:
    - `python -m pdb my_script.py`

Python Debugger

- Breakpoints
  - To set a breakpoint, simply add a `breakpoint()` call in the code
  - Before Python 3.7, this required `import pdb; pdb.set_trace()`
  - Run the cell/script as normal and pdb will start when it hits the breakpoint

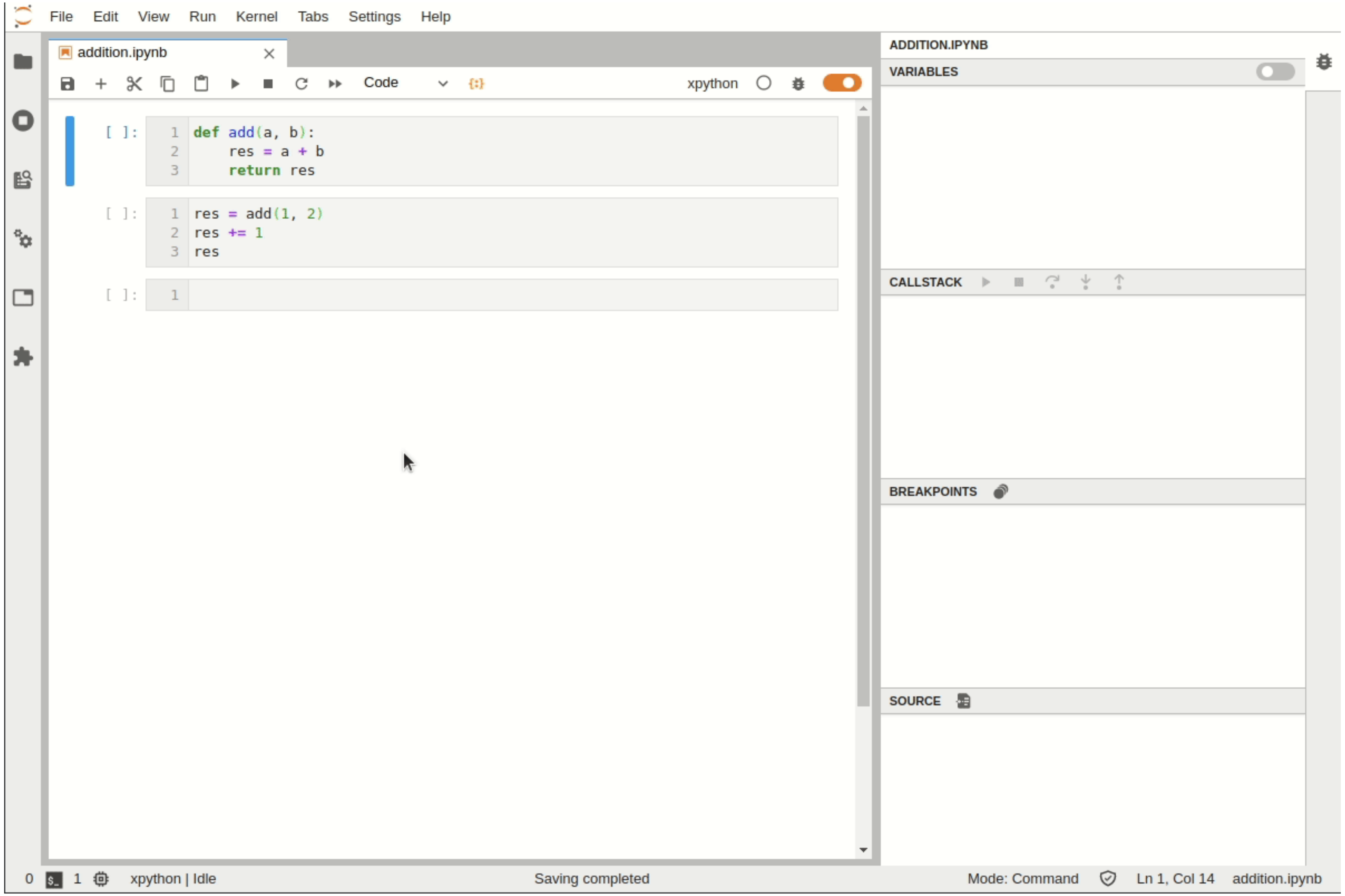
```
> <ipython-input-1-792bb5fe2598>(3)divide()
      1 def process(a, b):
      2     def divide(c, d):
----> 3         return c / d
      4     return divide(a+b, a-b)
      5 result = []

ipdb>
```

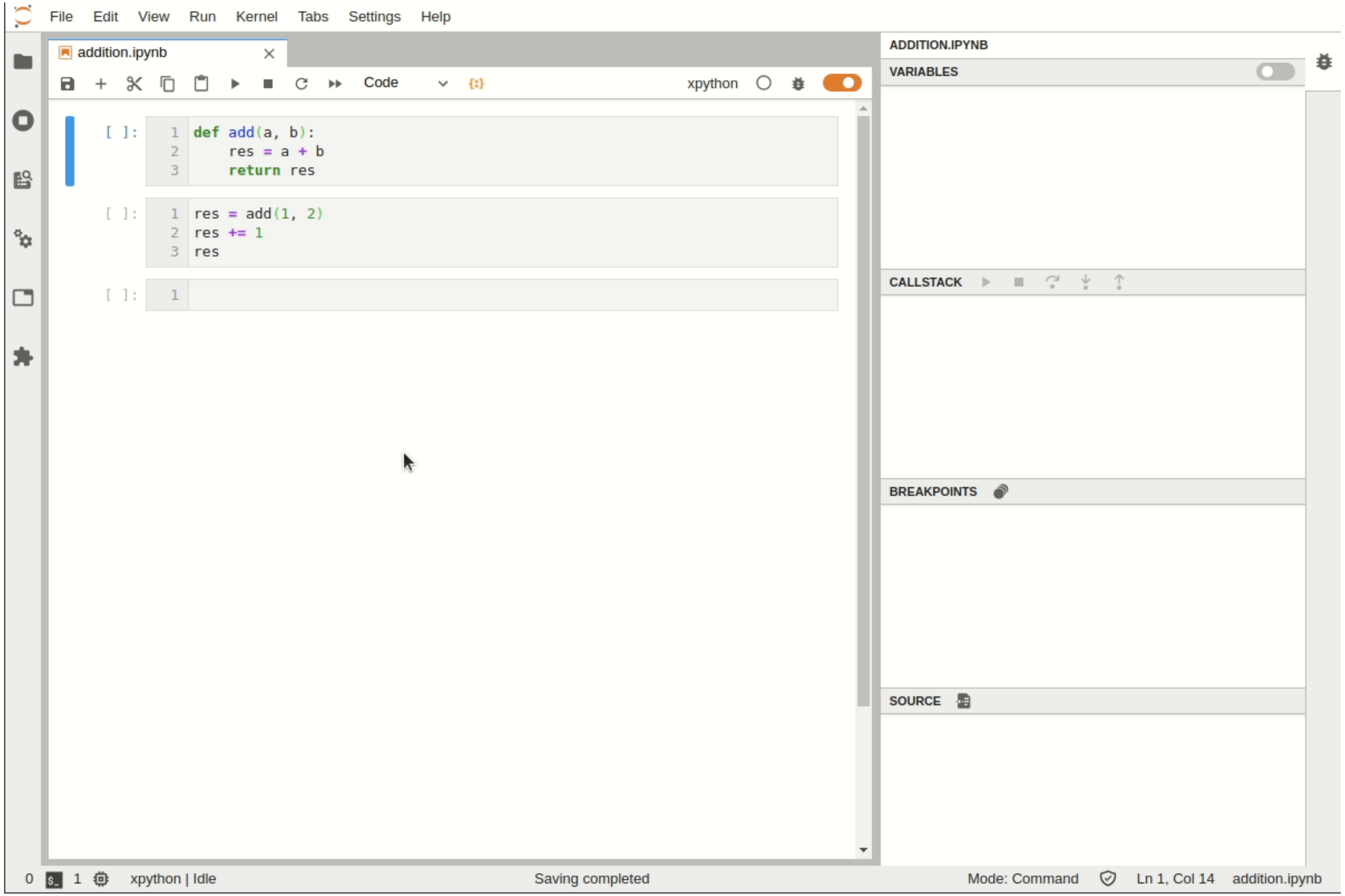
Python Debugger Commands

- `p` [print expressions]: Print expressions, comma separated
- `n` [step over]: continue until next line in **current function**
- `s` [step into]: stop at next line of code (same function or one being called)
- `c` [continue]: continue execution until next breakpoint
- `l` [list code]: list source code (ipdb does this already), also `ll` (fewer lines)
- `b` [breakpoints]: list or set new breakpoint (with line number)
- `w` [print stack trace]: Prints the stack (like what notebook shows during traceback), `u` and `d` commands move up/down the stack
- `q` [quit]: quit
- `h` [help]: help (there are many other commands)

Jupyter Debugging Support



Jupyter Debugging Support



How do you test code?

Testing

- If statements
- Assert statements
- Unit Testing
- Integration Testing

Testing via Print/If Statements

- Can make sure that types or values satisfy expectations
- ```
  if not isinstance(a, str):
      raise Exception("a is not a string")
  ```
- ```
  if 3 < a <= 7:
      raise Exception("a should not be in (3,7]")
  ```
- These may not be something we need to always check during runtime

Assertions

- Shortcut for the manual if statements
- Have python throw an exception if a particular condition is not met
- `assert` is a keyword, part of a statement, not a function
- `assert a == 1, "a is not 1"`
- Raises `AssertionError` if the condition is not met, otherwise continues
- Can be caught in an except clause or made to crash the code
- Problem: first failure ends error checks

Unit Tests

- "Testing shows the presence, not the absence of bugs", E. Dijkstra
- Want to test many parts of the code
- Try to cover different functions that may or may not be called
- Write functions that test code
- ```
  def add(a, b):
      return a + b + 1
  def test_add():
      assert add(3,4) == 7, "add not working"
  def test_operator():
      assert operator.add(3,4) == 7, "__add__ not working"
  ```
- If we just call these in a program, first error stops all testing
  ```

Unit Testing Framework

- unittest: built in to Python Standard Library
- nose2: nose tests, was nose, now nose2 (some nicer filtering options)
- pytest: extra features like restarting tests from last failed test
- doctest: built-in, allows test specification in docstrings

- With the exception of doctest, the frameworks allow the same specification of tests

unittest

- Subclass from `unittest.TestCase`, write `test_*` functions
- Use `assert*` instance functions
- ```
  import unittest

  class TestOperators(unittest.TestCase):
      def test_add(self):
          self.assertEqual(add(3, 4), 7)

      def test_add_op(self):
          self.assertEqual(operator.add(3,4), 7)
  unittest.main(argv=[''], exit=False)
  ```
  ```

Lots of Assertions

- assertEqual/assertNotEqual: smart about lists/tuples/etc.
- assertLess/assertGreater/assertLessEqual/assertGreaterEqual
- assertAlmostEqual: allows for floating-point arithmetic errors
- assertTrue/assertFalse: check boolean assertions
- assertIsNone: check for `None` values
- assertIn: check containment
- assertIsInstance
- assertRegex: check that a regex matches
- assertRaises: check that a particular exception is raised