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)
```
```

Else & Finally

- else: Code that executes if no exception occurs
- 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
  else:
      print("Division succeeded", c)
  finally:
      print("This always runs")
  ```
  ```

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 functions 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`)

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
```

Assignment 6

- Object-oriented Programming
- Track University Enrollment
- Methods for checking conflicts (e.g. disallow student to have overlapping courses, take too many credits)
- [503] Methods for changing course time (check the new time works for everyone)
- Sample code is meant to be run in different cells!
- Due Tuesday, Nov. 2

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

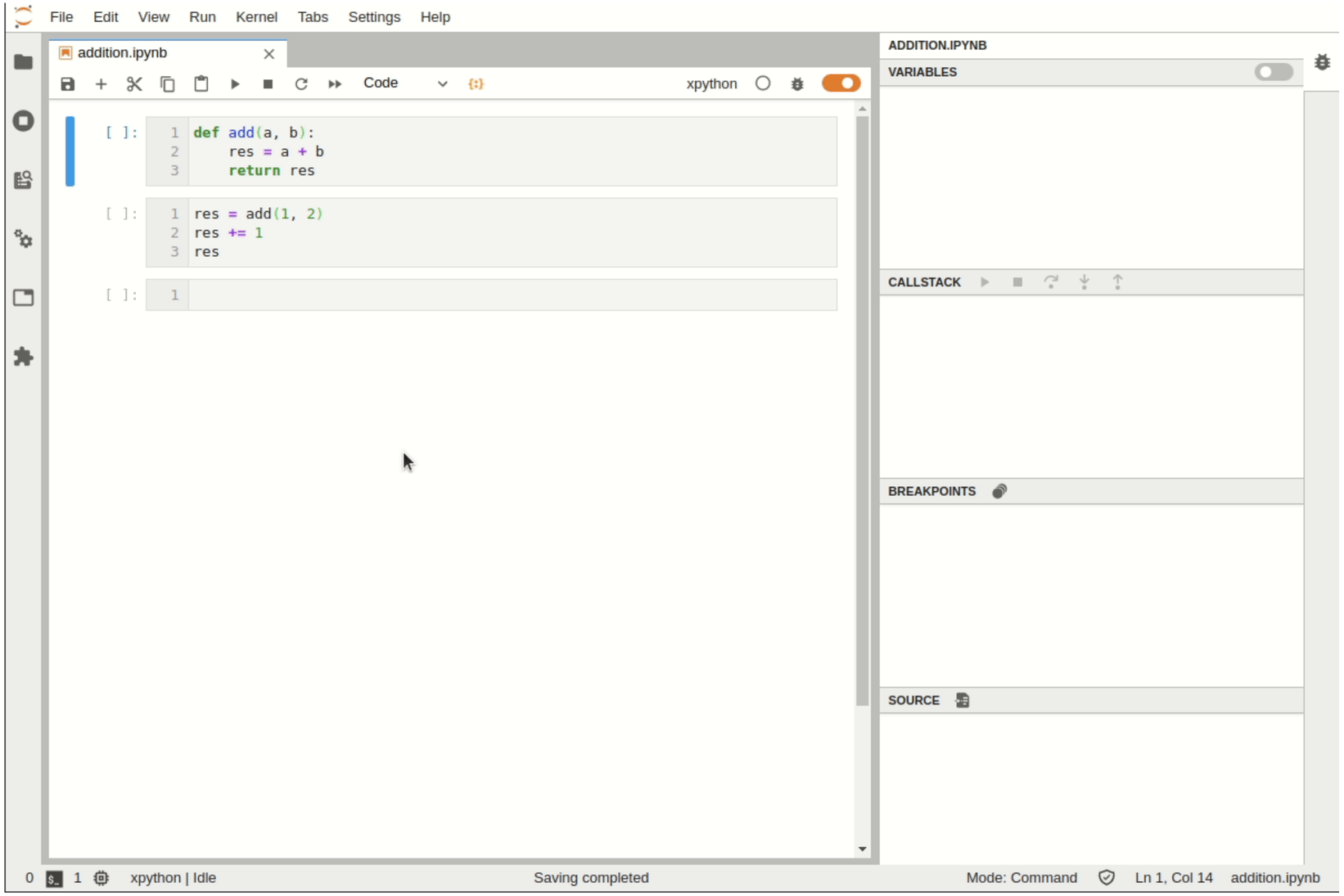
```
> <ipython-input-1-792bb5fe2598>(3)divide()
      1 def process(a, b):
      2     def divide(c, d):
----> 3         return c / d
      4     return divide(a+b, a-b)
      5 result = []

ipdb>
```

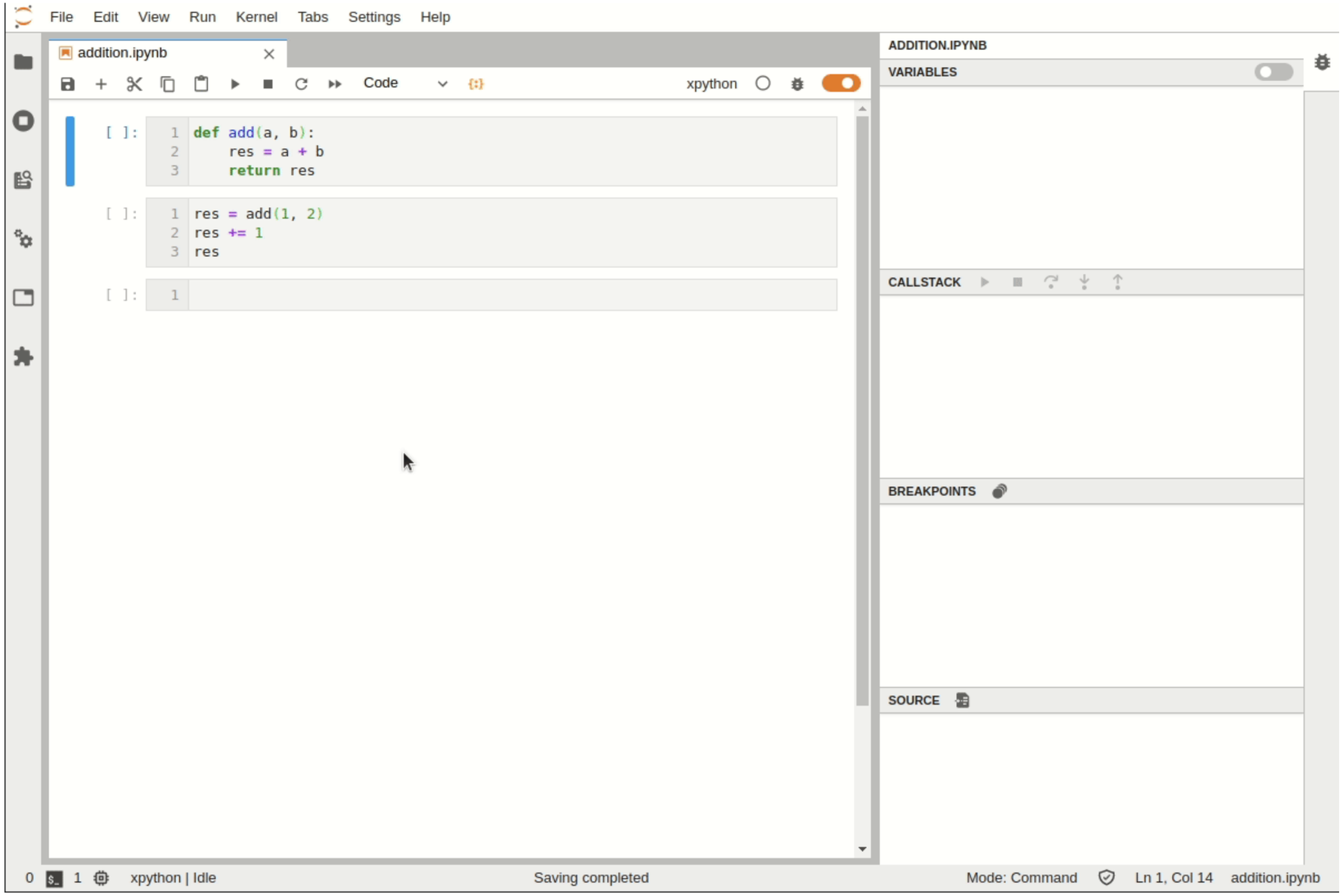
Python Debugger Commands

- `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

Test Options

- Run only certain tests
  - `argv=['']` # run default set of tests
  - `argv=['', 'TestLists']` # run all test* methods in TestLists
  - `argv=['', 'TestAdd.test_add']` # run test_add in TestAdd
- Show more detailed output
  - By default, one character per test plus listing at end
    - `F.`
    - `.` indicates success, `F` indicates failed, `E` indicates error
  - `verbosity=2`
    - `test_add (__main__.TestAdd) ... FAIL`
      `test_add_op (__main__.TestAdd) ... ok`

Startup and Cleanup for Tests

- `setUp`: instantiate particular objects, read data, etc.
- `tearDown`: get rid of unnecessary objects
- Example: set up a GUI widget that will be tested

```
- def setUp(self):
      self.widget = Widget(some_params)
  def tearDown(self):
      self.widget.dispose()
```

- Also functions for setting up classes and modules

[Python Documentation]

Mock Testing

- Sometimes we don't want to actually execute all of the code that may be triggered by a particular test
- Examples: code that posts to Twitter, code that deletes files
- We can mock this behavior by substituting the actual methods with mockers
- Can even simulate side effects like having the function being mocked raise an exception signifying the network is done

Mock Examples

- Can check whether/how many times the mocked function was called
- ```
  from unittest.mock import MagicMock
  thing = ProductionClass()
  thing.method = MagicMock(return_value=3)
  thing.method(3, 4, 5, key='value')
  thing.method.assert_called_with(3, 4, 5, key='value')
  ```

- ```
  from unittest.mock import patch
  with patch.object(ProductionClass, 'method',
                    return_value=None) as mock_method:
      thing = ProductionClass()
      thing.method(1, 2, 3)
  mock_method.assert_called_once_with(1, 2, 3)
  ```

[Python Documentation]