Object-Oriented Python

Recall: Programming Paradigms

Procedural

Sequence of instructions that inform the computer what to do with the program's input

Examples
C
Pascal
Unix (sh)

Declarative

Specification describes the problem to be solved, and language implementation figures out the details

Examples
SQL
Prolog

Multi-Paradigm

Supports several different paradigms, to be combined freely

Examples
Scala
C++
Python

Object-Oriented

Deal with collections of objects which maintain internal state and support methods that query or modify this internal state in some way.

Examples
Java
Smalltalk

Functional

…composes into a set of functions, each of which solely takes inputs and produces outputs with no internal state.

Examples
Haskell
OCaml
ML

Objects, Names, Attributes

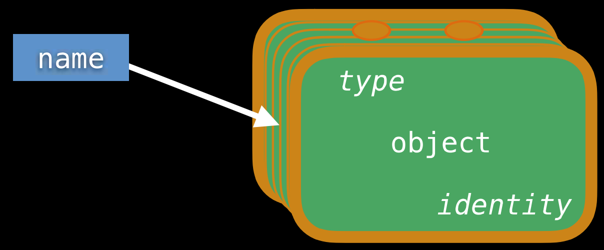
Recall: Some Definitions

An *object* has identity

A *name* is a reference to an object

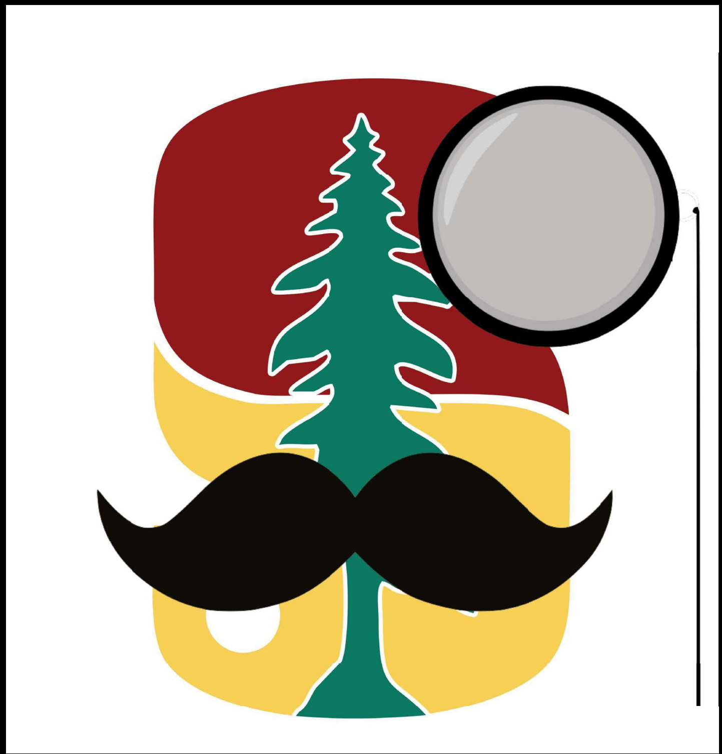
A *namespace* is an associative mapping from names to objects

An *attribute* is any name following a dot (`'.'`)



Classes

First Look at Classes



- New Syntax
- Class Objects
- Instance Objects
- Methods vs. Functions

Who says Python isn't classy?

Class Definition Syntax

The `class` keyword introduces a new class defintion

```
class ClassName:
    <statement>
    <statement>
    ...
```

Must be executed to have effect (like def)

Class Definitions

- Statements are usually assignments or function definitions
- Entering a class definition creates a new "namespace"-ish
  - Really, a special `__dict__` attribute where others live
- Exiting a class definition creates a class object
  - Defining a class `==` creating a class object (like `int`, `str`)
  - Defining a class `!=` instantiating a class

Wait, What?

Class Objects vs. Instance Objects

Defining a class creates a *class object*

- Supports attribute reference and instantiation

Instantiating a class object creates an *instance object*

- Only supports attribute reference

Class Objects

Support (1) attribute references and (2) instantation

Class Attribute References

Class Attribute References

```python
class MyClass:
    """A simple example class"""
    num = 12345
    def greet(self):
        return "Hello world!"

# Attribute References
MyClass.num    # => 12345          (int object)
MyClass.greet  # => <function f> (function object)
```

Warning! Class attributes can be written to by the client

Class Instantiation

Class Instantiation

No `new`

Classes are instantiated using parentheses and an optional argument list

```
x = MyClass(args)
```

"Instantiating" a class constructs an instance object of that class object.
In this case, `x` is an instance object of the `MyClass` class object

Custom Constructor using `__init__`

```python
class Complex:
    def __init__(self, realpart=0, imagpart=0):
        self.real = realpart
        self.imag = imagpart
```

Class instantiation calls the special method `__init__` if it exists

```python
# Make an instance object `c`!
c = Complex(3.0, -4.5)
c.real, c.imag  # => (3.0, -4.5)
```

You can't overload `__init__`!
Use keyword arguments or factory methods

Instance Objects

Only support attribute references

Data Attributes

= "instance variables"
= "data members"

```
c = Complex(3.0, -4.5)

# Get attributes
c.real, c.imag  # => (3.0, -4.5)

# Set attributes
c.real = -9.2
c.imag = 4.1
```

Instance Attribute Reference Resolution

```python
class MyOtherClass():
    num = 12345
    def __init__(self):
        self.num = 0

x = MyOtherClass()
print(x.num)  # 0 or 12345?
del x.num
print(x.num)  # 0 or 12345?
```

Attribute references first search the instance's `__dict__` attribute, then the class object's

Setting Data Attributes

```
# You can set attributes on instance (and class) objects
# on the fly (we used this in the constructor!)
c.counter = 1
while c.counter < 10:
    c.counter = x.counter * 2
    print(c.counter)
del c.counter  # Leaves no trace

# prints 1, 2, 4, 8
```

Setting attributes actually inserts into the instance object's `__dict__` attribute

Recall: A Sample Class

```python
class MyClass:
    """A simple example class"""
    num = 12345
    def greet(self):
        return "Hello world!"
```

Calling Methods

```python
x = MyClass()
x.greet()  # 'Hello world!'
# Weird... doesn't `greet` accept an argument?

print(type(x.greet))         # method
print(type(MyClass.greet))  # function

print(x.num is MyClass.num)  # True
print(x.greet is MyClass.greet)  # False
```

Methods vs. Functions

Methods vs. Functions

A *method* is a function bound to an object

```
method ≈ (object, function)
```

Methods calls invoke special semantics

```
object.method(arguments) = function(object, arguments)
```

Example: 🍕🍕🍕

Pizza

```python
class Pizza:
    def __init__(self, radius, toppings, slices=8):
        self.radius = radius
        self.toppings = toppings
        self.slices_left = slices

    def eat_slice(self):
        if self.slices_left > 0:
            self.slices_left -= 1
        else:
            print("Oh no! Out of pizza")

    def __repr__(self):
        return '{}" pizza'.format(self.radius)
```

Pizza

```python
p = Pizza(14, ("Pepperoni", "Olives"), slices=12)
print(Pizza.eat_slice)
# => <function Pizza.eat_slice>

print(p.eat_slice)
# => <bound method Pizza.eat_slice of 14" Pizza>

method = p.eat_slice
method.__self__  # => 14" Pizza
method.__func__  # => <function Pizza.eat_slice>

p.eat_slice()  # Implicitly calls Pizza.eat_slice(p)
```

Class and Instance Attributes

Class and Instance Variables

```
class Dog:
    kind = 'Canine'         # class variable shared by all instances

    def __init__(self, name):
        self.name = name    # instance variable unique to each instance

a = Dog('Astro')
pb = Dog('Mr. Peanut Butter')

a.kind   # 'Canine' (shared by all dogs)
pb.kind  # 'Canine' (shared by all dogs)
a.name   # 'Astro' (unique to a)
pb.name  # 'Mr. Peanut Butter' (unique to pb)
```

Warning

```python
class Dog:
    tricks = []

    def __init__(self, name):
        self.name = name

    def add_trick(self, trick):
        self.tricks.append(trick)
```

What could go wrong?

Warning

```
d = Dog('Fido')
e = Dog('Buddy')
d.add_trick('roll over')
e.add_trick('play dead')
d.tricks  # => ['roll over', 'play dead'] (shared value)
```

Did we Solve It?

```python
class Dog:
    # Let's try a default argument!
    def __init__(self, name='', tricks=[]):
        self.name = name
        self.tricks = tricks

    def add_trick(self, trick):
        self.tricks.append(trick)
```

Hmm...

```
d = Dog('Fido')
e = Dog('Buddy')
d.add_trick('roll over')
e.add_trick('play dead')
d.tricks  # => ['roll over', 'play dead'] (shared value)
```

Solution

```python
class Dog:
    def __init__(self, name):
        self.name = name
        self.tricks = []  # New list for each dog

    def add_trick(self, trick):
        self.tricks.append(trick)
```

Solution

```python
d = Dog('Fido')
e = Dog('Buddy')
d.add_trick('roll over')
e.add_trick('play dead')
d.tricks  # => ['roll over']
e.tricks  # => ['play dead']
```

Privacy and Style

Keep an Eye Out!

Nothing is truly private!

Clients can modify *anything*

"With great power…"

Stylistic Conventions

- A method's first parameter should always be **`self`**
    - Why? Explicitly differentiate instance and local variables
    - Method calls already provide the calling object as the first argument to the class function
- Attribute names prefixed with a leading underscore are intended to be private (e.g. _spam)
- Use verbs for methods and nouns for data attributes

Inheritance

Parentheses indicate inheritance

```
class DerivedClassName(BaseClassName):
    pass
```

Any expression is valid

Facts about Single Inheritance

- A class object 'remembers' its base class
- Python 3 class objects inherit from `object` (by default)
- Method and attribute lookup begins in the derived class
  - Proceeds down the chain of base classes
- Derived methods override (shadow) base methods
  - Like `virtual` in C++

Multiple Inheritance

"The Dreaded Diamond Pattern"

Multiple Inheritance

Base classes are separated by commas

```
class Derived(Base1, Base2, …, BaseN):
    pass
```

Order matters!

Attribute Resolution

- Attribute lookup is (almost) depth-first, left-to-right
  - Officially, "C3 superclass linearization" (Wikipedia)

- Class objects have a (hidden) function attribute `.mro()`
  - Shows linearization of base classes

Attribute Resolution In Action

```python
class A: pass
class B: pass
class C: pass
class D: pass
class E: pass
class K1(A, B, C): pass
class K2(D, B, E): pass
class K3(D, A): pass
class Z(K1, K2, K3): pass

Z.mro()  # [Z, K1, K2, K3, D, A, B, C, E, object]
```

Magic Methods

Magic Methods

- Python uses `__init__` to build classes
  - Overriding `__init__` lets us hook into the language
- What else can we do? Can we define classes that act like:
  - iterators? lists?
  - sets? dictionaries?
  - numbers?
  - comparables?

Implementing Magic Methods

```python
class MagicClass:
    def __init__(self): ...
    def __contains__(self, key): ...
    def __add__(self, other): ...
    def __iter__(self): ...
    def __next__(self): ...
    def __getitem__(self, key): ...
    def __len__(self): ...
    def __lt__(self, other): ...
    def __eq__(self, other): ...
    def __str__(self): ...
    def __repr__(self): ...  # And even more...
```

Some Magic Methods

```python
x = MagicClass()
y = MagicClass()
str(x)    # => x.__str__()
x == y    # => x.__eq__(y)

x < y     # => x.__lt__(y)
x + y     # => x.__add__(y)
iter(x)   # => x.__iter__()
next(x)   # => x.__next__()
len(x)    # => x.__len__()
el in x   # => x.__contains__(el)
```

Many, many more

Link 1

Link 2

Link 3

Example: Point

```python
class Point:
    def __init__(self, x=0, y=0):
        self.x = x
        self.y = y

    def rotate_90_CC(self):
        self.x, self.y = -self.y, self.x

    def __add__(self, other):
        return Point(self.x + other.x, self.y + other.y)

    def __str__(self):
        return "Point({0}, {1})".format(self.x, self.y)
```

Example

```python
o = Point()
print(o)          # Point(0, 0)

p1 = Point(3, 5)
p2 = Point(4, 6)
print(p1, p2)     # Point(3, 5) Point(4, 6)

p1.rotate_90_CC()
print(p1)         # Point(-5, 3)

print(p1 + p2)    # Point(-1, 9)
```

OOP Case Study: Errors and Exceptions

Syntax Errors

"Errors before execution"

```
>>> while True print('Hello world')
  File "<stdin>", line 1
    while True print('Hello world')
                   ^
SyntaxError: invalid syntax
```

Error is detected at the token preceding the arrow

Exceptions

"Errors during execution"

```
>>> 10 * (1/0)
Traceback (most recent call last):
    File "<stdin>", line 1
ZeroDivisionError: division by zero

>>> 4 + spam*3
Traceback (most recent call last):
    File "<stdin>", line 1
NameError: name 'spam' is not defined

>>> '2' + 2
Traceback (most recent call last):
    File "<stdin>", line 1
TypeError: Can't convert 'int' object to str implicitly
```

And More

`KeyboardInterrupt`

`UnboundLocalError`

`SystemExit`

`StopIteration`

`SyntaxError`

`ZeroDivisionError`

`AttributeError`

`KeyError`

`IndexError`

`NotImplementedError`

`TypeError`

`OSError`

`NameError`

And Even More

Inheritance in Action!

```
BaseException
├── SystemExit
├── KeyboardInterrupt
├── GeneratorExit
└── Exception
    ├── StopIteration
    ├── ArithmeticError
    │   ├── FloatingPointError
    │   ├── OverflowError
    │   └── ZeroDivisionError
    ├── AssertionError
    ├── AttributeError
    ├── BufferError
    ├── EOFError
    ├── ImportError
    ├── LookupError
    │   ├── IndexError
    │   └── KeyError
    ├── MemoryError
    ├── NameError
    │   └── UnboundLocalError
    ├── OSError
    │   ├── BlockingIOError
    │   ├── ChildProcessError
    │   ├── ConnectionError
    │   │   ├── BrokenPipeError
    │   │   ├── ConnectionAbortedError
    │   │   ├── ConnectionRefusedError
    │   │   └── ConnectionResetError
    │   ├── FileExistsError
    │   ├── FileNotFoundError
    │   ├── InterruptedError
    │   ├── IsADirectoryError
    │   ├── NotADirectoryError
    │   ├── PermissionError
    │   ├── ProcessLookupError
    │   └── TimeoutError
    ├── ReferenceError
    ├── RuntimeError
    │   └── NotImplementedError
    ├── SyntaxError
    │   └── IndentationError
    │       └── TabError
    ├── SystemError
    ├── TypeError
    ├── ValueError
    │   └── UnicodeError
    │       ├── UnicodeDecodeError
    │       ├── UnicodeEncodeError
    │       └── UnicodeTranslateError
    └── Warning
        ├── DeprecationWarning
        ├── PendingDeprecationWarning
        ├── RuntimeWarning
        ├── SyntaxWarning
        ├── UserWarning
        ├── FutureWarning
        ├── ImportWarning
        ├── UnicodeWarning
        ├── BytesWarning
        └── ResourceWarning
```

Handling Exceptions

What's Wrong?

```python
def read_int():
    """Reads an integer from the user (broken)"""
    return int(input("Please enter a number: "))
```

What happens if the user enters a nonnumeric input?

Solution

```python
def read_int():
    """Reads an integer from the user (fixed)"""
    while True:
        try:
            x = int(input("Please enter a number: "))
            break
        except ValueError:
            print("Oops! Invalid input. Try again...")
    return x
```

Mechanics of `try` statement

1) Attempt to execute the try clause

2a) If no exception occurs, skip the except clause. Done!

2b) If an exception occurs, skip the rest of the try clause.

2bi) If the exception's type matches (/ is a subclass of) that named by except, then execute the except clause. Done!

2bii) Otherwise, hand off the exception to any outer try statements. If unhandled, halt execution. Done!

Conveniences

```python
try:
    distance = int(input("How far? "))
    time = car.speed / distance
    car.drive(time)
except ValueError as e:
    print(e)
except ZeroDivisionError:
    print("Division by zero!")
except (NameError, AttributeError):
    print("Bad Car")
except:
    print("Car unexpectedly crashed!")
```

Bind a name to the exception instance

Catch multiple exceptions

"Wildcard" catches everything

Good Python:
Don't Be a Pokemon Trainer

Solution?

```python
def read_int():
    """Reads an integer from the user (fixed?)"""
    while True:
        try:
            x = int(input("Please enter a number: "))
            break
        except:
            print("Oops! Invalid input. Try again...")
    return x
```

"I'll just catch 'em all!"

Oops! Now we can't CTRL+C to escape

Raising Exceptions

The `raise` keyword

```
>>> raise NameError('Why hello there!')
Traceback (most recent call last):
    File "<stdin>", line 1, in <module>
NameError: Why hello there!
```

You can raise either instance objects or class objects

```
>>> raise NameError
Traceback (most recent call last):
    File "<stdin>", line 1, in <module>
NameError
```

raise within except clause

```python
try:
    raise NotImplementedError("TODO")
except NotImplementedError:
    print('Looks like an exception to me!')
    raise
# Looks like an exception to me!
# Traceback (most recent call last):
#   File "<stdin>", line 2, in <module>
# NotImplementedError: TODO
```

Re-raises the currently active exception

Good Python: Using `else`

```python
try:
    ...
except ...:
    ...
else:
    do_something()
```

Code that executes if the try clause does not raise an exception

Why? Avoid accidentally catching an exception raised by something other than the code being protected

Example: Database Transactions

```
try:
    update_the_database()
except TransactionError:
    rollback()
    raise
else:
    commit()
```

If the commit raises an exception,
we might actually *want* to crash

Aside: Python Philosophy

Coding for the Common Case

- Don't check if a file exists, then open it.
  - Just try to open it!
  - Handle exceptional cases with an except clause (or two)
  - *(avoids race conditions too)*
- Don't check if a queue is nonempty before popping
  - Just try to pop the element!

Good Python:
Custom Exceptions

Custom Exceptions

```python
class Error(Exception):
    """Base class for errors in this module."""
    pass

class BadLoginError(Error):
    """A user attempted to login with
    an incorrect password."""
    pass
```

Don't misuse existing exceptions when the real error is something else!

You can define an `__init__` method to be fancy

Clean-Up Actions

The `finally` clause

Executed upon leaving the try/except/else block

```python
try:
    raise NotImplementedError
finally:
    print('Goodbye, world!')

# Goodbye, world!
# Traceback (most recent call last):
#   File "<stdin>", line 2, in <module>
# NotImplementedError
```

How `finally` works

Always executed before leaving the try statement.

Unhandled exceptions (not caught, or raised in except) are re-raised after finally executes.

Also executed "on the way out" (break, continue, return)

Note: `with ... as ...`

```python
# This is what enables us to use with ... as ...
with open(filename) as f:
    raw = f.read()
# is (almost) equivalent to
f = open(filename)
f.__enter__()
try:
    raw = f.read()
finally:
    f.__exit__()  # Closes the file
```

Surprisingly useful and flexible!

Lab Time

Building Basic Classes

Fun with Inheritance

Magic Methods a.k.a. 007