1 Nonlocal

Until now, you’ve been able to access names in parent frames, but you have not been able to modify them. The nonlocal keyword can be used to modify a binding in a parent frame. For example, consider stepper, which uses nonlocal to modify num:

```python
def stepper(num):
    def step():
        nonlocal num  # declares num as a nonlocal name
        num = num + 1  # modifies num in the stepper frame
        return num
    return step
```

```python
>>> step1 = stepper(10)
>>> step1()  # Modifies and returns num
11
>>> step1()  # num is maintained across separate calls to step
12
>>> step2 = stepper(10)  # Each returned step function keeps its own state
>>> step2()
11
```

As illustrated in this example, nonlocal is useful for maintaining state across different calls to the same function.

However, there are two important caveats with nonlocal names:

- **Global names** cannot be modified using the nonlocal keyword.
- **Names in the current frame** cannot be overridden using the nonlocal keyword. This means we cannot have both a local and nonlocal binding with the same name in a single frame.

Because nonlocal lets you modify bindings in parent frames, we call functions that use it **mutable functions**.
Questions

1.1 Draw the environment diagram for the following code.

```python
def stepper(num):
    def step():
        nonlocal num
        num = num + 1
        return num
    return step

s = stepper(3)
s()
s()
```

Video walkthrough
1.2 Write a function that takes in no arguments and returns two functions, `prepend` and `get`, which represent the “add to front of list” and “get the ith item” operations, respectively. Do not use any python built-in data structures like lists or dictionaries. You do not necessarily need to use all the lines.

*This question is more difficult than the average discussion problem; it is an exam level problem.*

```python
def nonlocalist():
    """
    >>> prepend, get = nonlocalist()
    >>> prepend(2)
    >>> prepend(3)
    >>> prepend(4)
    >>> get(0)
    4
    >>> get(1)
    3
    >>> get(2)
    2
    >>> prepend(8)
    >>> get(2)
    3
    """
    get = lambda x: "Index out of range!"

def prepend(value):
    ________________________________
    f = ________________________________

def get(i):
    if i == 0:
        return value
    ________________________________

    return ________________________________, ________________________________
```

```python
def nonlocalist():
    """
    >>> prepend, get = nonlocalist()
    >>> prepend(2)
    >>> prepend(3)
    >>> prepend(4)
    >>> get(0)
    4
    >>> get(1)
    3
    >>> get(2)
    2
    >>> prepend(8)
    >>> get(2)
    3
    """
    get = lambda x: "Index out of range!"

def prepend(value):
    ________________________________
    f = ________________________________

def get(i):
    if i == 0:
        return value
    ________________________________

    return ________________________________, ________________________________
```

return prepend, lambda x: get(x)
2 Object Oriented Programming

In a previous lecture, you were introduced to the programming paradigm known as Object-Oriented Programming (OOP). OOP allows us to treat data as objects - like we do in real life.

For example, consider the class `Student`. Each of you as individuals is an instance of this class. So, a student Angela would be an instance of the class `Student`.

Details that all CS 61A students have, such as `name`, `year`, and `major`, are called instance attributes. Every student has these attributes, but their values differ from student to student. An attribute that is shared among all instances of `Student` is known as a class attribute. An example would be the `instructors` attribute; the instructor for CS 61A, Professor DeNero, is the same for every student in CS 61A.

All students are able to do homework, attend lecture, and go to office hours. When functions belong to a specific object, they are said to be methods. In this case, these actions would be bound methods of `Student` objects.

Here is a recap of what we discussed above:

- **class**: a template for creating objects
- **instance**: a single object created from a class
- **instance attribute**: a property of an object, specific to an instance
- **class attribute**: a property of an object, shared by all instances of a class
- **method**: an action (function) that all instances of a class may perform
Questions

2.1 Below we have defined the classes Professor and Student, implementing some of what was described above. Remember that we pass the self argument implicitly to instance methods when using dot-notation. There are more questions on the next page.

class Student:
    students = 0 # this is a class attribute
    def __init__(self, name, ta):
        self.name = name # this is an instance attribute
        self.understanding = 0
        Student.students += 1
        print("There are now", Student.students, "students")
        ta.add_student(self)
        
    def visit_office_hours(self, staff):
        staff.assist(self)
        print("Thanks, " + staff.name)

class Professor:
    def __init__(self, name):
        self.name = name
        self.students = {}
        
    def add_student(self, student):
        self.students[student.name] = student
        
    def assist(self, student):
        student.understanding += 1
What will the following lines output?

```python
>>> snape = Professor("Snape")
>>> harry = Student("Harry", snape)

There are now 1 students

>>> harry.visit_office_hours(snape)

Thanks, Snape

>>> harry.visit_office_hours(Professor("Hagrid"))

Thanks, Hagrid

>>> harry.understanding

2

>>> [name for name in snape.students]

['Harry']

>>> x = Student("Hermione", Professor("McGonagall")).name

There are now 2 students

>>> x

'Hermione'

>>> [name for name in snape.students]

['Harry']
We now want to write three different classes, `Server`, `Client`, and `Email` to simulate email. Fill in the definitions below to finish the implementation! There are more methods to fill out on the next page.

We suggest that you approach this problem by first filling out the `Email` class, then fill out the `register_client` method of `Server`, then implement the `Client` class, and lastly fill out the `send` method of the `Server` class.

```python
class Email:
    """Every email object has 3 instance attributes: the message, the sender name, and the recipient name."
    ""
    def __init__(self, msg, sender_name, recipient_name):
        self.msg = msg
        self.sender_name = sender_name
        self.recipient_name = recipient_name

class Server:
    """Each Server has an instance attribute clients, which is a dictionary that associates client names with client objects."
    ""
    def __init__(self):
        self.clients = {}

    def send(self, email):
        """Take an email and put it in the inbox of the client it is addressed to."
        ""

        client = self.clients[email.recipient_name]
        client.receive(email)

def register_client(self, client, client_name):
    """Takes a client object and client_name and adds it to the clients instance attribute."
    ""

    self.clients[client_name] = client
```
class Client:
    """Every Client has instance attributes name (which is
    used for addressing emails to the client), server
    (which is used to send emails out to other clients), and
    inbox (a list of all emails the client has received).
    """
    def __init__(self, server, name):
        self.inbox = []
        self.server = server
        self.name = name
        self.server.register_client(self, self.name)

    def compose(self, msg, recipient_name):
        """Send an email with the given message msg to the
        given recipient client.
        """
        email = Email(msg, self.name, recipient_name)
        self.server.send(email)

    def receive(self, email):
        """Take an email and add it to the inbox of this
        client.
        """
        self.inbox.append(email)
3 Inheritance

Python classes can implement a useful abstraction technique known as **inheritance**. To illustrate this concept, consider the following Dog and Cat classes.

```python
class Dog:
    def __init__(self, name, owner):
        self.is_alive = True
        self.name = name
        self.owner = owner
    def eat(self, thing):
        print(self.name + ' ate a ' + str(thing) + '!')
    def talk(self):
        print(self.name + ' says woof!')

class Cat:
    def __init__(self, name, owner, lives=9):
        self.is_alive = True
        self.name = name
        self.owner = owner
        self.lives = lives
    def eat(self, thing):
        print(self.name + ' ate a ' + str(thing) + '!')
    def talk(self):
        print(self.name + ' says meow!')
```

Notice that because dogs and cats share a lot of similar qualities, there is a lot of repeated code! To avoid redefining attributes and methods for similar classes, we can write a single superclass from which the similar classes inherit. For example, we can write a class called Pet and redefine Dog as a subclass of Pet:

```python
class Pet:
    def __init__(self, name, owner):
        self.is_alive = True # It's alive!!!
        self.name = name
        self.owner = owner
    def eat(self, thing):
        print(self.name + ' ate a ' + str(thing) + '!')
    def talk(self):
        print(self.name)

class Dog(Pet):
    def talk(self):
        print(self.name + ' says woof!')
```

Inheritance represents a hierarchical relationship between two or more classes where one class is a more specific version of the other, e.g. a dog is a pet. Because Dog inherits from Pet, we didn’t have to redefine _init_ or eat. However, since we want Dog to talk in a way that is unique to dogs, we did **override** the talk method.
Questions

3.1 Below is a skeleton for the Cat class, which inherits from the Pet class. To complete the implementation, override the \_\_init\_\_ and talk methods and add a new lose\_life method.

*Hint:* You can call the \_\_init\_\_ method of Pet to set a cat's name and owner.

class Cat(Pet):
    def \_\_init\_\_(self, name, owner, lives=9):
        Pet.\_\_init\_\_(self, name, owner)
        self.lives = lives

def talk(self):
    """Print out a cat's greeting."
    
    >>> Cat('Thomas', 'Tammy').talk()
    Thomas says meow!
    """

    print(self.name + ' says meow!')

def lose\_\_life(self):
    """Decrements a cat's life by 1. When lives reaches zero, 'is\_alive' becomes False."
    
    if self.lives > 0:
        self.lives -= 1
        if self.lives == 0:
            self.is\_alive = False
    else:
        print("This cat has no more lives to lose :)"

Video walkthrough
3.2 More cats! Fill in this implementation of a class called NoisyCat, which is just like a normal Cat. However, NoisyCat talks a lot – twice as much as a regular Cat!

```python
class ________________: # Fill me in!
```

```python
class NoisyCat(Cat):
    
    """A Cat that repeats things twice."""
    def __init__(self, name, owner, lives=9):
        # Is this method necessary? Why or why not?
        Cat.__init__(self, name, owner, lives)

    def talk(self):
        """Talks twice as much as a regular cat."

        >>> NoisyCat('Magic', 'James').talk()
        Magic says meow!
        Magic says meow!
        """
```

No, this method is not necessary because NoisyCat already inherits Cat's `__init__` method.

```python
def talk(self):
    """Talks twice as much as a regular cat."

    >>> NoisyCat('Magic', 'James').talk()
    Magic says meow!
    Magic says meow!
    """
```

```python
Cat.talk(self)
Cat.talk(self)
```

Video walkthrough

**Extra Questions**

3.3 (Summer 2013 Final) What would Python display?

```python
class A:
    def f(self):
        return 2
    def g(self, obj, x):
        if x == 0:
            return A.f(obj)
        return obj.f() + self.g(self, x - 1)

class B(A):
    def f(self):
        return 4
```
>>> x, y = A(), B()

>>> x.f()
2

>>> B.f()
Error (missing self argument)

>>> x.g(x, 1)
4

>>> y.g(x, 2)
8

Video walkthrough

3.4 (Summer 2013 Final) Implement the Foo class so that the following interpreter session works as expected.

>>> x = Foo(1)
>>> x.g(3)
4

>>> x.g(5)
6

>>> x.bar = 5

>>> x.g(5)
10

class Foo:

    def __init__(self, bar):
        self.bar = bar
    def g(self, n):
        return self.bar + n