REPRESENTATION, MUTABLE TREES, LINKED LISTS

CSM 61A

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1 Representation

Representation Overview: `__repr__` and `__str__`

Classes can have "magic methods" that add special built-in syntax features. They start and end with double underscores, such as in `__init__`. The goal of `__str__` is to convert an object to a human-readable string. The `__str__` function is helpful for printing objects and giving us information that's more readable than `__repr__`. Whenever we call `print()` on an object, it will call the `__str__` method of that object and print whatever value the `__str__` call returned. However, if a class only defines `__repr__` but not `__str__`, the `print()` call on an object will print what `__repr__` returns instead. For example, if we had a `Person` class with a name instance variable, we can create a `__str__` method like this:

```
def __str__(self):
    return "Hello, my name is " + self.name
```

This `__str__` method gives us readable information: the person's name. Now, when we call print on a person, the following will happen:

```
>>> p = Person("John Denero")
>>> str(p)
'Hello, my name is John Denero'
>>> print(p)
Hello, my name is John Denero
```

The `__repr__` magic method returns the "official" string representation of an object. You can invoke it directly by calling `repr(<some object>)`. However, `__repr__` doesn't always return something that is easily readable, that is what `__str__` is for. Rather, `__repr__` ensures that all information about the object is present in the representation. Specifically, by convention, this should look like a valid Python expression that could be used to recreate an object with the same value. When you ask Python to represent an object in the Python interpreter, it will automatically call **repr** on that object and then print out the string that **repr** returns. If we were to continue our `Person` example from above, let's say that we added a **repr** method:

```
def __repr__(self):
    return f"Person({self.name})"
    # Note that this returns a string that is exactly the
    # same as the expression we use to construct this object.
```

Then we can write the following code:

```
# Python calls this object's repr function to see what
# to print on the line. Note, Python prints whatever
# result it gets from repr so it removes the quotes
# from the string.
>>> p
Person("John Denero")

# User is invoking the repr function directly.
# Since the function returns a string, its output
# has quotes. In the previous line, Python called
# repr and then printed the value. This line works
# like a regular function call: if a function
# returns a string, output that string with quotes.
>>> repr(p)
'Person("John Denero")'
```

1. **Musician** - What would Python display? Write the result of executing the code and the prompts below. If a function is returned, write "Function". If nothing is returned, write "Nothing". If an error occurs, write "Error".

```python
class Musician:
    popularity = 1

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

    def perform(self):
        print("a rousing " + self.instrument + " performance")
        self.popularity = self.popularity + 2

    def __repr__(self):
        return f'Musician({self.instrument})'

    def __str__(self):
        return self.instrument

class BandLeader(Musician):
    def __init__(self):
        self.band = []

    def recruit(self, musician):
        self.band.append(musician)

    def perform(self, song):
        for m in self.band:
            m.perform()
        print(song)

    def __str__(self):
        band = ""
        for m in self.band:
            band += str(m) + ", "
        return band[:-2] + " - here's the band!"

miles = Musician("trumpet")
goodman = Musician("clarinet")
ellington = BandLeader()
```

```
>>> ellington.recruit(goodman)
>>> ellington.perform()


>>> ellington.perform("sing, sing, sing")




>>> goodman.popularity, miles.popularity


>>> ellington.recruit(miles)
>>> ellington.perform("caravan")



>>> ellington.popularity, goodman.popularity, miles.popularity



>>> print(ellington)



>>> miles
```

2 Mutable Trees

For the following problems, use this definition for the Tree class:

```
class Tree:
    def __init__(self, label, branches=[]):
        self.label = label
        self.branches = list(branches)

    def is_leaf(self):
        return not self.branches

    def __repr__(self):
        if self.branches:
            branch_str = ', ' + repr(self.branches)
        else:
            branch_str = ''
        return 'Tree({0}{1})'.format(self.label, branch_str)
```

- The constructor constructs and returns a new instance of `Tree`

  `t = Tree(1)#creates a Tree instance with label 1 and no branches`
  .

- The `label` and `branches` are variables, and `is_leaf()` is a method of the class.

  `t.label #returns the label of the tree`

  `t.branches #returns the branches of the tree, which is a list of trees`

  `t.is_leaf()#returns True if the tree is a leaf`

- A tree object is mutable

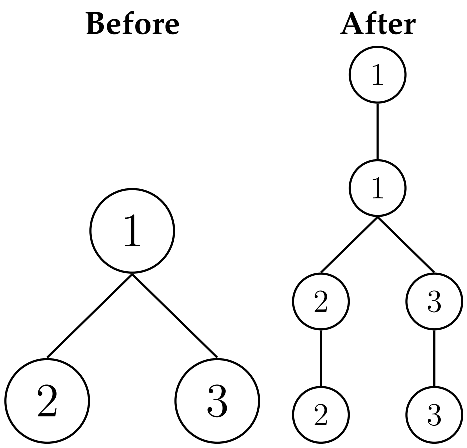
  To modify a `Tree` object, simply reassign its attributes. For example, `t.label = 2`.

  This means we can mutate values in the tree object instead of making a new tree that we return. In other words, we can solve tree class problems non-destructively and destructively.

1. Implement `tree_sum` which takes in a Tree object and replaces the label of the tree with the sum of all the values in the tree. `tree_sum` should also return the new label.

```
def tree_sum(t):
    """
    >>> t = Tree(1, [Tree(2, [Tree(3)]), Tree(4)])
    >>> tree_sum(t)
    10
    >>> t.label
    10
    >>> t.branches[0].label
    5
    >>> t.branches[1].label
    4
    """
```

2. DoubleTree hired you to architect one of their hotel expansions! As you might expect, their floor plan can be modeled as a tree and the expansion plan requires doubling each node (the patented double tree floor plan). Here's what some sample expansions look like:



Fill in the implementation for `double_tree`.

```
def double_tree(t):
    """
    Given a tree, return a new tree where entries appear
    twice.
    >>> double_tree(Tree(1))
    Tree(1, [Tree(1)])
    >>> double_tree(Tree(1, [Tree(2), Tree(3)]))
    Tree(1, [Tree(1, [Tree(2, [Tree(2)]),
                      Tree(3, [Tree(3)])
                     ])
            ])
    """
```

3 Linked Lists

Linked lists consists of a series of links which have two attributes: `first` and `rest`. The `first` attribute contains the value of the link (which can be an integer, string, list, even another linked list!). The `rest` attribute, on the other hand, is a pointer to another link or `Link.empty`, which is just an empty linked list represented traditionally by an empty tuple (but not necessarily, so never assume that it is represented by an empty tuple otherwise you will break an abstraction barrier!).

Because each link contains another link or `Link.empty`, linked lists lend themselves to recursion (just like trees). Consider the following example, in which we double every value in linked list. We mutate the current link and then recursively double the rest.

```
def double_values(link):
     if link is not Link.empty:
        link.first *= 2 # we mutate the value inside of the link
        double_val(link.rest) # we mutate the values in the rest
                              # of the linked list
    # if the link is empty then do nothing
```

However, unlike with trees, we can also solve many linked list questions using iteration. Take the following example where we have written `double_values` using a while loop instead of using recursion:

```
def double_values_iter(link):
    while link is not Link.empty:
        link.first *= 2
        link = link.rest # Note that this does not mutate
                         # the original linked list;
                         # it changes what link the variable
                         # link is pointing to
```

Note that unlike Python lists, for a given linked list, we do not know its length immediately by calling `len()`. If we really need its length, we can calculate its manually by iteration or recursion.

For each of the following problems, assume linked lists are defined as follows:

```
class Link:
    empty = ()
    def __init__(self, first, rest=empty):
        assert rest is Link.empty or isinstance(rest, Link)
        self.first = first
        self.rest = rest

    def __repr__(self):
        if self.rest is not Link.empty:
            rest_repr = ', ' + repr(self.rest)
        else:
            rest_repr = ''
        return 'Link(' + repr(self.first) + rest_repr + ')'

    def __str__(self):
        string = '<'
        while self.rest is not Link.empty:
            string += str(self.first) + ' '
            self = self.rest
        return string + str(self.first) + '>'
```

To check if a `Link` is empty, compare it against the class attribute `Link.empty`:

```
if link is Link.empty:
    print('This linked list is empty!')
```

1. What will Python output? Draw box-and-pointer diagrams to help determine this.

```
>>> a = Link(1, Link(2, Link(3)))
>>> a.first
```

```
>>> a.first = 5
>>> a.first
```

```
>>> a.rest.first
```

```
>>> a.rest.rest.rest.rest.first
```

```
>>> a.rest.rest.rest = a
>>> a.rest.rest.rest.rest.first
```

```
>>> repr(Link(1, Link(2, Link(3, Link.empty))))
```

```
>>> Link(1, Link(2, Link(3, Link.empty)))
```

```
>>> str(Link(1, Link(2, Link(3))))
```

```
>>> print(Link(Link(1), Link(2, Link(3))))
```

2. Write a function `skip`, which takes in a `Link` and returns a new `Link` with every other element skipped.

```
def skip(lst):
    """
    >>> a = Link(1, Link(2, Link(3, Link(4))))
    >>> a
    Link(1, Link(2, Link(3, Link(4))))
    >>> b = skip(a)
    >>> b
    Link(1, Link(3))
    >>> a
    Link(1, Link(2, Link(3, Link(4)))) # Original is unchanged
    """
    if ____________________________________________:

        ____________________________________________

    elif __________________________________________:

        ____________________________________________

    ________________________________________________
```

3. Now write function `skip` by mutating the original list, instead of returning a new list. Do NOT call the `Link` constructor.

```
def skip(lst):
    """
    >>> a = Link(1, Link(2, Link(3, Link(4))))
    >>> skip(a)
    >>> a
    Link(1, Link(3))
    """
```

4. **(Optional)** Write `has_cycle` which takes in a `Link` and returns `True` if and only if there is a cycle in the `Link`. Note that the cycle may start at any node and be of any length. Try writing a solution that keeps track of all the links we've seen. Then try to write a solution that doesn't store those witnessed links (consider using two pointers!).

```
def has_cycle(s):
    """
    >>> has_cycle(Link.empty)
    False
    >>> a = Link(1, Link(2, Link(3)))
    >>> has_cycle(a)
    False
    >>> a.rest.rest.rest = a
    >>> has_cycle(a)
    True
    """
```

4 Magic Methods Extension

Magic Methods

There's so much more to magic methods than meets the eye. These functions constantly work behind scenes to make object oriented programming easier. Unfortunately, the official Python documentation is sparse and confusing, so much of this is borrowed from this blog post.

Let's start with one you're already familiar with, `__init__`. Consider the `Book` class below.

```
class Book:
        def __init__(self, title):
                self.title = title
```

We know that `Book("Dr. Suess")` somehow calls `__init__` with the supplied `title` argument, but where does `self` come from? In fact, when instantiating a new object, the *first* method that gets called is `__new__` which returns an instance of the object (the `self`) and *then* calls `__init__`. This makes it useful for subclassing immutable types like strings and numbers.

If `__new__` is the constructor, `__del__` is the destructor. It handles the process for ”cleaning up” and object. Suppose we want to remove a `Book` from our database. We might need to delete some files as well, in which case we may need to override `__del__` and implement a custom delete procedure. The process is called **garbage collection**, which is an interesting topic in its own right.

Next, let's consider comparisons. We're familiar with numeric comparisons like `6 > 4`, and maybe some other ones too, like `"cat"\leq "dog"` (alphabetical ordering). But suppose we wanted to compare two `Book`s to see which one was longer. Here, we can use magic to methods to specify behavior for comparisons, each of which compares the `self` to some `other` object:

```
class Book:
        def __init__(self, title, pages=0):
                self.title = title
                self.pages = pages
        def __eq__(self, other):
                return self.pages == other.pages
        def __ne__(self, other):
                return self.pages != other.pages
        def __lt__(self, other):
                return self.pages < other.pages
        def __gt__(self, other):
                return self.pages > other.pages
```

```
        def __le__(self, other):
                return self.pages <= other.pages
        def __ge__(self, other):
                return self.pages >= other.pages
```

Other numeric operations are also implement this way. For example, we've seen before how to use + for numbers, strings, and lists. But we're only able to specify behaviors for +, -, *, and so on through their corresponding magic methods: `__add__`, `__sub__`, `__mul__`, and so on. And so we could support "adding" two books together by combining titles and pages:

```
class Book:
        def __init__(self, title, pages=0):
                self.title = title
                self.pages = pages
        def __add__(self, other):
                return Book(self.title += " and " + other.title,
                   self.pages + other.pages)
```

Other binary operators include `__floordiv__` (//), `__div__` (/), `__mod__` (%), `__pow__` (**), and more. Likewise, magic methods also implement the logic for unary operators like `__abs__` (**abs**), conversions like `__int__` (**int**), and representations like `__str__` (**str**).

At this point, you might be wondering about the += we used earlier. Does it also use `__add__`? No, as it turns out. These methods are called **augmented assignments**, and they use a similar set of magic methods, except they are prepended with an "i" (so `__iadd__` instead of `__add__`). They also don't have a **return** statement, instead mutating the object itself.

```
class Book:
        def __init__(self, title, pages=0):
                self.title = title
                self.pages = pages
        def __iadd__(self, other):
                self.title += " " + other.title
                self.pages += other.pages
```

Let's use this knowledge to revisit an old puzzle. Recall that when concatenating two lists `l1 = [1, 2, 3]` and `l2 = [4, 5, 6]`, using `l1 += l2` is mutative/destructive while using `l1 = l1 + l2` creates a new list. The reason is that the **list** class' `__add__` and `__addi__` functions are implemented differently, so that the former is non-mutative and the latter is mutative. Now it makes sense! — + and += are not the same.

A final word on magic methods and containers. Have you ever stopped to think how `l1[1]` ”gets” the second element of `l1`? Or how Python knows that `1 in l1`? Here’s how magic methods implement each of these operations:

- `__getitem__` and `__setitem__` control what happens when an item is accessed or assigned, e.g. in `l1[1] = 2`.
- `__len__` returns the count of items.
- `__contains__` defines behavior for membership testing.
- `__iter__` returns an iterator, which is used in **`for`** loops.

So if we wanted our `Book` to be a container of ”pages” of text, we could have:

```
class Book:
        def __init__(self, title, pages={}):
                self.title = title
                self.pages = pages
        def __getitem__(self, key):
                return self.pages[key]
        def __setitem__(key, value):
                self.pages[key] = value
        def __contains__(self, item):
                return item in self.pages
        def __len__(self):
                return len(pages)
        def __iter__(self):
                return iter(pages)
```

Other cool magic method topics you should check out include:

- The `with` keyword, and the associated `__enter__` and `__exit__` methods, for context management.
- The `__copy__` and `__deepcopy__` methods, the latter of which also copies the data of the object.
- The `__call__` method, which makes an object callable, behaving a function.