

RECURSIVE OBJECTS 9

COMPUTER SCIENCE 61A

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1 Linked Lists in OOP

1.1 A New Implementation

Linked lists are data abstractions that can have multiple implementations. Previously, we saw linked lists implemented using Python lists. Today, we will look at linked lists implemented using Object-Oriented Programming. Here it is:

```
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 __getitem__(self, i):
        if i == 0:
            return self.first
        return self.rest[i-1]
    def __len__(self):
        return 1 + len(self.rest)
```

When we implemented linked lists using Python lists, we called `first(lnk)` and `rest(lnk)` to access the `first` and `rest` elements. This time, we can write `lnk.first` and `lnk.rest` instead. In the former, we could access the elements, but we could not modify them. In the latter, we can access and also modify the elements. In other words, linked lists implemented using OOP is mutable.

In addition to the constructor `__init__`, we have the special Python methods `__getitem__` and `__len__`. Note that any method that begins and ends with two underscores is a special Python method. Special Python methods may be invoked using built-in functions and special notation. The built-in Python element selection operator, as in `lst[i]`, invokes `lst.__getitem__(i)`. Likewise, the built-in Python function `len`, as in `len(lst)`, invokes `lst.__len__()`.

1.2 Questions

1. Write `sum_nums`, which takes in a linked list `lnk` and sums up all elements in `lnk`. You may assume all elements in `lnk` are integers. `sum_nums` should return the sum, an integer.

```
def sum_nums(lnk):  
    """  
    >>> a = Link(1, Link(6, Link(7)))  
    >>> sum_nums(a)  
    14  
    """
```

Solution:

```
if lnk == Link.empty:  
    return 0  
return lnk.first + sum_nums(lnk.rest)
```

2. Write `multiply_links`, which takes in a Python list of `Link` objects and multiplies them element-wise. It should return a new linked list. If not all of the `Link` objects are of equal length, return a linked list whose length is that of the shortest linked list given. You may assume the `Link` objects are shallow linked lists, and that `lst_of_links` contains at least one linked list.

```
def multiply_links(lst_of_links):
    """
    >>> a = Link(2, Link(3, Link(5)))
    >>> b = Link(6, Link(4, Link(2)))
    >>> c = Link(4, Link(1, Link(0, Link(2))))
    >>> p = multiply_links([a, b, c])
    >>> p.first
    48
    >>> p.rest.first
    12
    >>> p.rest.rest.rest
    ()
    """
```

Solution:

```
product = 1
for lnk in lst_of_links:
    if lnk == Link.empty:
        return Link.empty
    product *= lnk.first
lst_of_links_rests = [lnk.rest for lnk in lst_of_links]
return Link(product, multiply_links(lst_of_links_rests))
```

1.3 Extra Questions

1. Define `reverse`, which takes in a linked list and reverses the order of the links. The function may *not* return a new list; it must mutate the original list. Return a pointer to the head of the reversed list.

```
def reverse(lnk):
    """
    >>> a = Link(1, Link(2, Link(3)))
    >>> r = reverse(a)
    >>> r.first
    3
    >>> r.rest.first
    2
    """
```

Solution:

```
if lnk == Link.empty or lnk.rest == Link.empty:
    return lnk
rest_rev = reverse(lnk.rest)
lnk.rest.rest = lnk
lnk.rest = Link.empty
return rest_rev
```

2. Write a function `remove_duplicates` that takes as input a sorted linked list of integers, `lnk`, and mutates `lnk` so that all duplicates are removed.

```
def remove_duplicates(lnk):
    """
    >>> lnk = Link(1, Link(1, Link(1, Link(1, Link(5)))))
    >>> unique = remove_duplicates(lnk)
    >>> len(unique)
    2
    >>> len(lnk)
    2
    """
```

Solution:

```
if lnk == Link.empty:
    return
seen = {lnk.first}
current = lnk
```

```
while current.rest != Link.empty:
    if current.rest.first not in seen:
        seen.add(current.rest.first)
        current = current.rest
    else:
        current.rest = current.rest.rest
return lnk
```

2 Trees in OOP

2.1 Another New Implementation

Trees are also data abstractions that can have multiple implementations. Previously, we implemented the tree abstraction using Python lists. Let's look at another implementation using objects instead. With this implementation, we can easily specify specialized tree types, such as binary trees, using inheritance.

```
class Tree:
    def __init__(self, entry, children=[]):
        for c in children:
            assert isinstance(c, Tree)
        self.entry = entry
        self.children = children

    def is_leaf(self):
        return not self.children
```

Notice that with this implementation we can mutate the entry of a tree by reassigning `tree.entry`. In the previous implementation using lists, this was not possible, because the abstraction barrier prevented us from seeing how the tree was implemented.

2.2 Questions

1. Consider the following definitions and assignments and determine what Python would output for each of the calls below *if they were evaluated in order*.

```
>>> t0 = Tree(0)
>>> t0.entry
```

Solution: 0

```
>>> t0.children
```

Solution: []

```
>>> t1 = Tree(0, [1, 2]) #Is this a valid tree?
```

Solution: AssertionError #As the child must be a Tree object

```
>>> t2 = Tree(0, [Tree(1), Tree(2, [Tree(3)])])
>>> t2.children[0]
```

Solution: <__main__.Tree object>

```
>>> t2.children[1].children[0].entry
```

Solution: 3

2. Define a function `make_even` which takes in a tree `t` whose entries are integers, and mutates the tree such that all the odd integers are increased by 1 and all the even integers remain the same.

```
def make_even(t):
    """
    >>> t = Tree(1, [Tree(2, [Tree(3)]), Tree(4), Tree(5)])
    >>> make_even(t)
    >>> t.entry
    2
    >>> t.children[0].children[0].entry
    4
    """
```

Solution:

```
if t.entry % 2 != 0:
    t.entry += 1
for child in t.children:
    make_even(child)
```


2.3 Extra Question

1. Write a function that combines the entries of two trees `t1` and `t2` together with the `combiner` function. Assume that `t1` and `t2` have identical structure. This function should return a new tree.

```
def combine_tree(t1, t2, combiner):  
    """  
    >>> a = Tree(1, [Tree(2, [Tree(3)])])  
    >>> b = Tree(4, [Tree(5, [Tree(6)])])  
    >>> combined = combine_tree(a, b, mul)  
    >>> combined.entry  
    4  
    >>> combined.children[0].entry  
    10  
    """
```

Solution:

```
combined = [combine_tree(c1, c2, combiner) for c1, c2  
             in zip(t1.children, t2.children)]  
return Tree(combiner(t1.entry, t2.entry), combined)
```

3 Binary Search Trees

3.1 Intro to Binary Search Trees

A Binary Search Tree (BST) is a special kind of tree that satisfies the following properties:

- Every node of a BST has at most two children called `left` and `right`. The children are also BST's.
- For every node, the left child's entry is less than or equal to the parent's entry.
- For every node, the right child's entry is greater than the parent's entry.

Binary Search Tree (BST) Class

```
class BST:
    empty = ()
    def __init__(self, entry, left=empty, right=empty):
        assert left is BST.empty or isinstance(left, BST)
        assert right is BST.empty or isinstance(right, BST)

        self.entry = entry
        self.left = left
        self.right = right

        if left is not BST.empty:
            assert left.max <= entry
        if right is not BST.empty:
            assert entry < right.min

    @property
    def max(self):
        if self.right is BST.empty:
            return self.entry
        return self.right.max

    @property
    def min(self):
        if self.left is BST.empty:
            return self.entry
        return self.left.min
```

3.2 Questions

1. Define a function `insert` that takes in a BST, `bst`, and a number, `n`, and mutates `bst` by inserting a new node. `insert` should place the new node as a leaf in the correct position. If `t` is the BST on the left, then calling `insert(t, 3)` will change `t` to the BST on the right. Do not return a new BST unless `bst` is empty, in which case return a BST containing only `n`.



```

def insert(bst, n):
    """
    >>> bst = BST(4, BST(2, BST(1)), BST(5))
    >>> insert(bst, 3)
    >>> bst.left.right.entry
    3
    """

```

Solution:

```

if bst == BST.empty:
    return BST(n)
if bst.entry >= n:
    if bst.left == BST.empty:
        bst.left = BST(n)
    else:
        insert(bst.left, n)
else:
    if bst.right == BST.empty:
        bst.right = BST(n)
    else:
        insert(bst.right, n)

```