FINAL EXAM REVIEW Meta

COMPUTER SCIENCE MENTORS 61A

December 9 – December 13, 2024

Recommended Timeline:

- Environment Diagrams: 10 minutes
- Iterators: 13 minutes
- Data Abstraction: 12 minutes
- Efficiency: 15 minutes
- OOP: 10 minutes
- Trees: 12 minutes
- Scheme Lists: 8 minutes
  Note: This is our last worksheet for the semester. We want to express our heartfelt gratitude to everyone who has been part of CSM- 61A for their incredible work and contributions throughout this semester .

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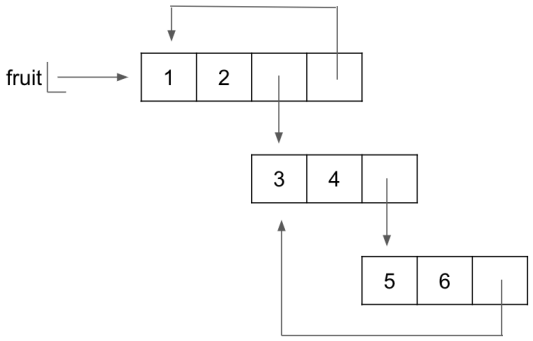
1 Environment Diagrams

1. Fill in each blank in the code example below so that its environment diagram is the following. You do not need to use all the blanks.

```
fruit = [1, 2, [3, 4]]
fruit._____________________________
fruit[3][2]._____________________
fruit[2][2]._____________________
fruit[3][3][2][2][2][1] = ____
```




```
fruit = [1, 2, [3, 4]]
fruit.append(fruit)
fruit[3][2].append([5, 6])
fruit[2][2].append(fruit[2])
fruit[3][3][2][2][2][1] = 4
```

Teaching Tips

- So many nested lists!! Be very clear when you are explaining these concepts to your students and when you are drawing as it's very easy to get confused.
- Review with students how to use arrows in list diagrams, such as shallow and deep copies, values vs. references.
- The best way to approach this problem is to just go line by line, counting the indices as you go. Remember to make the distinction between reassigning what an arrow in a box points to and updating the value of the box itself (to a value or to another arrow). (This is also good practice for 61B)
- If your students get stuck, a good hint would be to tell them that they do indeed need all the blanks. Do not try to squeeze too many operations into one line.

2 Iterators

2. Define a **non-decreasing path** as a path from the root where each node's label is greater than or equal to the previous node along the path. A **subpath** is a path between nodes X and Y, where Y must be a descendent of X (ex: Y is a branch of a branch of X).

(a) Write a generator function `root_to_leaf` that takes in a tree `t` and yields all non-decreasing paths from the root to a leaf node, in any order. Assume that `t` has at least one node.

```
def root_to_leaf(t):
    """
    >>> t1 = Tree(3, [Tree(5), Tree(4)])
    >>> list(root_to_leaf(t1))
    [[3, 5], [3, 4]]
    >>> t2 = Tree(5, [Tree(2, [Tree(7), Tree(8)]), Tree(5, [Tree(6)])])
    [[5, 5, 6]]
    """

    if _____________________:

        ___________________________

    for ___________________________:

        if ___________________________:

            for ___________________________:

                ___________________________________
```

```
def root_to_leaf(t):
    if t.is_leaf():
        yield [t.label]
    for b in t.branches:
        if t.label <= b.label:
            for path in root_to_leaf(b):
                yield [t.label] + path
```

The easiest way to approach this is to notice the two blocks of code that are provided: first an if statement, probably referring to a base case, and a for loop, which will probably be the recursive case. From the doctests, we can see that giving the function a tree that just has one node, or in other words `is_leaf()`, returns a list containing just that node.

In our recursive case we want to do two things. First, we want to check if the next branch value really is non-decreasing. Then, if it is, we want to append the result of calling `root_to_leaf` on the branch to the value of our current tree to create a complete path. So we recurse through each of the branches in `t` (`for b in t.branches`), then check if it is nondecreasing (`t.label <= b.label`), then yield our tree's label appended to the recursive call (the last two lines).

(b) Write a generator function `subpaths` that takes in a tree `t` and yields all non-decreasing subpaths that end with a leaf node, in any order. You may use the `root_to_leaf` function above, and assume again that `t` has at least one node.

```
def subpaths(t):

    yield from _____________________________

    for b in t.branches:

        ___________________________________
```

```
def subpaths(t):
    yield from root_to_leaf(t)
    for b in t.branches:
        yield from subpaths(b)
```

We can split this problem into two steps – yielding all subpaths for the current tree that we have, then yielding all subpaths for all other trees within this tree. It is important to realize that each node in the tree is merely a subtree of the original tree to solve this problem.

To yield all non-decreasing subpaths for our current tree (that is all non-decreasing subpaths that start at our current node and end at the leaf nodes), we can just yield from our previous function, `root_to_leaf`, called on that node. For the rest of the subpaths, we want to recursively call `subpaths` on all our child nodes. This will give us all paths that end on the leaf nodes (because `root_to_leaf` ends on the leaf nodes) that start from any child on this tree. It is important to realize that the base case in this situation is implicit. If a leaf node is passed in and reaches the for loop, the for loop finds no items in `t.branches`, and will just terminate without calling the clause inside.

Teaching Tips

- For a reminder on Tree paths, it can help to start with the all paths function:

```
def all_paths(t):
    if t.is_leaf():
        return [[t.label]]
    paths = []
    for b in t.branches:
        for path in all_paths(b):
            paths.append([t.label] + path)
    return paths
```

- From there, it becomes a much simpler matter of modifying two things:
  - Making the function a generator so it yields paths one at a time instead of returning a list of paths
  - Only returning non-decreasing paths

3. In the following problem, we will represent a bookshelf object using dictionaries.

   In the first section, we will set up the format. Here, we will directly work with the internals of the Bookshelf, so don't worry about abstraction barriers for now. Fill in the following functions based on their descriptions (the constructor is given to you):

```
def Bookshelf(capacity):
    """ Creates an empty bookshelf with a certain max capacity. """
    return {'size': capacity, 'books': {}}

def add_book(bookshelf, author, title):
    """
    Adds a book to the bookshelf. If the bookshelf is full,
    print "Bookshelf is full!" and do not add the book.
    >>> books = Bookshelf(2)
    >>> add_book(books, 'Jane Austen', 'Pride and Prejudice')
    >>> add_book(books, 'Daniel Kleppner', 'An Introduction to Mechanics
       5th Edition')
    >>> add_book(books, 'Kurt Vonnegut', 'Galapagos')
    Bookshelf is full!
    """
    if ___________________________________:
        print('Bookshelf is full!')
    else:
        if author in bookshelf['books']:
            ___________________________________
        else:
            ___________________________________


    if len(bookshelf['books']) == bookshelf['size']:
        print('Bookshelf is full!')
    else:
        if author in bookshelf['books']:
            bookshelf['books'][author].append(title)
        else:
            bookshelf['books'][author] = [title]
```

```
def get_all_authors(bookshelf):
    """
    Returns a list of all authors who have at least one book in the
       bookshelf.
    >>> books = Bookshelf(10)
    >>> add_book(books, 'Jane Austen', 'Pride and Prejudice')
    >>> add_book(books, 'Sheldon Axler', 'Linear Algebra Done Right')
    >>> add_book(books, 'Kurt Vonnegut', 'Galapagos')
    >>> get_all_authors(books)
    ['Jane Austen', 'Sheldon Axler', 'Kurt Vonnegut']
    """
    return ____________________________________


        return list(bookshelf['books'].keys())
```

Now, complete the function `most_popular_author` **without breaking the abstraction barrier**. In other words, you are not allowed to assume anything about the implementation of a Bookshelf object, or use the fact that it is a dictionary. You can only use the methods above and their stated return values.

```
def most_popular_author(bookshelf):
    """
    Returns the author with the greatest number of books on this bookshelf.
    You can assume that the bookshelf is not empty.
    >>> books = Bookshelf(100)
    >>> add_book(books, 'Orson Scott Card', 'Xenocide')
    >>> add_book(books, 'Orson Scott Card', 'Children of the Mind')
    >>> add_book(books, 'J.R.R. Tolkien', 'The Hobbit')
    >>> most_popular_author(bookshelf)
    'Orson Scott Card'
    """
    return max(____________________________________________________,

        key=_____________________________________________________________)


        return max(get_all_authors(bookshelf), key=lambda x:
            len(get_author_books(x))
```

This is a hard question! Only do it if your students are absolutely assured in their definition of data abstraction and the abstraction barrier.

Feel free to spend even more time on this. Lists are more important for students generally, but understanding data abstraction deeply is a great setup for OOP!

4. Find the $\Theta(\cdot)$ runtime bound for `hiya(n)`. Remember that Python strings are immutable: when we add two strings together, we need to make a copy.

```
def hiii(m):
    word = "h"
    for i in range(m):
        word += "i"
    return word

def hiya(n):
    i = 1
    while i < n:
        print(hiii(i))
        i *= 2
```

$\Theta(n^2)$.

Solution: We can determine the efficiency by approximately counting the number of characters we have to store upon a call to `hiya(n)`. First, let us determine the efficiency of a call `hiii(m)`. Within `hiii`'s for loop:

- When `i` is `1`, we store the string "hi", which is 2 characters.
- When `i` is `2`, we store the string "hii", which is 3 characters.

  ...
- When `i` is `m`, we store `m + 1` characters.

Adding up these values, we see that calling `hiii(m)` causes us to store on the order of m^2 characters. (The exact value is $\frac{m(m+3)}{2} = \frac{m^2}{2} + \frac{3}{2}m$, but we really only care about the highest order term.)

Now, when we make a call `hiya(n)`, we will make calls to `hiii(1)`, `hiii(2)`, `hiii(4)`, ..., `hiii(4)`. This will store approximately $1^2 + 2^2 + 4^2 + 8^2 + ... + n^2$ characters. Calculating out the partial sums of this sequence shows that

$$1^2 = 1$$

$$1^2 + 2^2 = 5 < 2 \cdot 2^2$$

$$1^2 + 2^2 + 4^2 = 21 < 2 \cdot 4^2$$

$$1^2 + 2^2 + 4^2 + 8^2 = 85 < 2 \cdot 8^2$$

At some point, we are reasonably convinced that this pattern holds. Thus the value of $1^2 + 2^2 + 4^2 + 8^2 + ... + n^2$ is approximately n^2, within a constant factor. So we store about n^2 characters upon a call to `hiya(n)`, which means the efficiency is $\Theta(n^2)$.

Let's use OOP design to help us create a supermarket chain (think Costco)! There are many different ways to implement such a system, so there is no concrete answer.

5. What classes should we consider having? How should each of these classes interact with each other?

   There are many ways of approaching this, but one way is to have a Supermarket class to represent the entire store, an Item class to represent a certain item, a Food class to represent an item that is a food (inherits from Item), and maybe a Customer class to represent someone buying items from that store.

6. For each class, what instance and class variables would it have?

   1. Supermarket – we might have instance variables such as profit, store name, location, and a list of the items in that store along with their quantity. Note that we prefer to store the quantity inside the Supermarket, since an Item might belong to multiple Supermarkets, and each Supermarket will have a separate quantity. We might even have a price associated with each item, since specific supermarkets may mark up prices in different areas.
   2. Item – we might have instance variables such as the name and the base price.
   3. Food – we will have it inherit of all the instance variables of the Item, and also whether it is yummy, maybe the food group it is in or the expiration date.
   4. Customer – we might have some personal information, the supermarket that they're buying from, and the history of their
   5. There are some details that have been missed as well! For example, not just food items expire. Feel free to just discuss this.

7. For each class, what class methods would they have? How would they interact with each other?

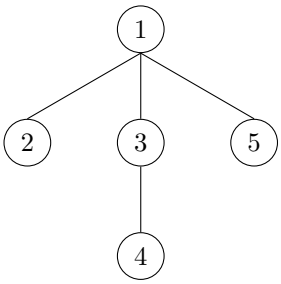
   1. Once again, these are just suggestions:
   2. Supermarket
      - `check_quantity(Item)`: looks up the available quantity of that item
      - `checkout_items(Customer)`: returns the total sum of items in a customer's shopping cart, and clears their shopping cart
   3. Item
      - `check_quantity(Supermarket)`: calls `supermarket.check_quantity(self)`
   4. Food
      - `time_to_expire()`: returns an integer representing how many days before this item expires
      - `is_yummy()`: returns a boolean value of whether this item is yummy or not!
   5. Customer
      - `enter(Supermarket)`: create a shopping cart for customer in this supermarket, if it doesn't already exist
      - `leave(Supermarket)`: clear customer's shopping cart
      - `buy_item(Item)`: add item to customer's shopping cart
      - `checkout_items()`: calls `supermarket.checkout_items(Customer)`

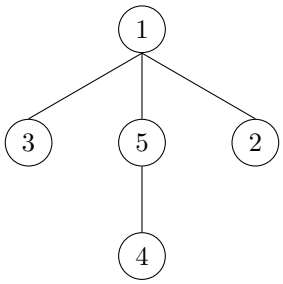
Teaching Tips

- There are many ways of designing these classes, so as long as the design is well thought out, that's all that matters. Because of this, this should be more of a discussion rather than a concrete answer.
- To guide the discussion, perhaps start with function/class headers of what functions/classes we would like to implement.
- The purpose of this question is to get students to consider what components (classes) there are in this situation, along with the interactions between various interactions and relations between each class. For example, Items are pretty general, and so maybe there is a Food class that inherits from an Item.
- Remind students to think about the assumptions that they are making when designing their classes, and whether those assumptions are valid. If they aren't, how should the class be changed?
- When thinking about the class methods, think about what each method should be able to handle. For example, `buy_item` of a Customer should be able to handle buying both Items and Food. Since Food inherits from Item, `buy_item` should generally only use methods from the Item class (since using a Food-exclusive method might cause an error if an Item is bought)

8. Implement `rotate`, which takes in a tree and rotates the labels at each level of the tree by one to the left destructively. This rotation should be modular (That is, the leftmost label at a level will become the rightmost label after running rotate). You do NOT need to rotate across different branches.

   For example, given tree `t` on the left, `rotate(t)` should mutate `t` to give us the right.






```
def rotate(t):
  """
  >>> t1 = Tree(1, [Tree(2), Tree(3, [Tree(4)]), Tree(5)])
  >>> rotate(t1)
  >>> t1
  Tree(1, [Tree(3), Tree(5, [Tree(4)]), Tree(2)])
  >>> t2 = Tree(1, [Tree(2, [Tree(3), Tree(4)]),
                    Tree(5, [Tree(6)])])
  >>> rotate(t2)
  >>> t2
  Tree(1, [Tree(5, [Tree(4), Tree(3)]),
                    Tree(2, [Tree(6)])])
  """
  branch_labels = _____________________________________

  n = len(t.branches)

  for _____________________________________________:

    ____________________________________________________

    ____________________________________________________

    ____________________________________________________
```

```
def rotate(t):
  branch_labels = [b.label for b in t.branches]
  n = len(t.branches)
  for i in range(n):
    branch = t.branches[i]
    branch.label = branch_labels[(i + 1) % n]
    rotate(branch)
```

Teaching Tips

- As with most other tree problems, annotating the given examples and drawing out examples of your own will be a big help for students. Make sure they really understand the method of rotation and the rules that the problem establishes.
- Remind your students to pay close attention to the data types of whatever they are working on. For example, do they need to create a new Tree? How can they traverse across the branches? How can they access the value of a node?
- The second line in the for loop may be hard to get because of the modulo. Try to think of an example where this modulo would apply, draw it out, and see if your students catch it.
- Be sure to highlight the distinction between nondestructive and destructive recursive methods and point out the key differences in implementing each type of function.
- Since there isn't an if/else format for base cases vs. recursive case, it may be harder for students to understand what is going on in the problem. Try to break it down into several steps for them to guide them through each line.

9. Star-Lord is cruising through space and can't afford to crash into any asteroids along the way. Let his path be represented as a (possibly nested) list of integers, where an asteroid is denoted with a 0, and stars and planets otherwise. Every time Star-lord sees (visits) an asteroid (0), he merges the next planet/star with the asteroid. In other words, construct a NEW list so that all asteroids (0s) are replaced with a list containing the planet followed by the asteroid (e.g. (planet 0)). You can assume that the last object in the path is not an asteroid (0).

```
;Doctests
scm> (collision (list 1 2 3 0 4))
(1 2 3 (4 0))
scm> (collision (list 4 3 (list 0 1) 2))
(4 3 ((1 0)) 2)
scm> (collision (list 1 -2 0 -3 4 0 -5 6))
(1 -2 (-3 0) 4 (-5 0) 6)
scm> (collision (list 1 0 0 2 3))
(1 (0 0) 2 3)

;Asteroids can merge with other asteroids too

(define (collision lst)

  (cond ((_____________________) lst)

    ((_________________________________)

      ___________________________________________)

    ((_________________________________)

      (cons _____________________________

        ___________________________________________))

    (else _____________________________________________)
  )
)
```

```
(define (collision lst)
  (cond ((null? lst) nil)
    ((list? (car lst))
      (cons (collision (car lst)) (collision (cdr lst))))
    ((and (equal? (car lst) 0) (not (null? (cdr lst))))
      (cons (list (car (cdr lst)) (car lst))
        (collision (cdr (cdr lst)))))
    (else(cons (car lst) (collision (cdr lst))))
  )
)

#Alternate solution (No cond form)

(define (collision lst)
  (if (null? lst)
    lst
    (if (list? (car lst))
      (cons (collision (car lst)) (collision (cdr lst)))
      (if (equal? (car lst) 0)
        (cons (list (cadr list) (car lst)) (collision (cddr lst)))
        (cons (car lst) (collision (cdr lst)))
      )
    )
  )
)
```