This 90-minute closed-book, closed-notes exam has 7 questions worth a total of roughly 90 points (some point-total adjustment may occur during grading). Pace yourself accordingly. You may separate the pages while working on the exam; we have a stapler available.

It is a violation of the Academic Integrity Code to look at any exam other than your own, to look at any reference material besides the reference provided in the exam itself, or to otherwise give or receive unauthorized help. We also ask that you not discuss this exam with students who are scheduled to take a later makeup.

Academic Integrity is expected of all students of Cornell University at all times, whether in the presence or absence of members of the faculty. Understanding this, I declare I shall not give, use or receive unauthorized aid in this examination.

Signature: ___________________________ Date ____________

Name (First Last): ____________________________

Cornell NetID, all caps: ___________________
This is a comprehensive reference sheet that might include functions or methods not needed for your exam.

### String methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>s[i:j]</code></td>
<td>Returns: if i and j are non-negative indices and i ≤ j-1, a new string containing the characters in s from index i to index j-1, or the substring of s starting at i if j ≥ len(s)</td>
</tr>
<tr>
<td><code>s.count(s1)</code></td>
<td>Returns: the number of times s1 occurs in string s</td>
</tr>
<tr>
<td><code>s.find(s1)</code></td>
<td>Returns: index of first occurrence of string s1 in string s ( -1 if not found)</td>
</tr>
<tr>
<td><code>s.find(s1,n)</code></td>
<td>Returns: index of first occurrence of string s1 in string s STARTING at position n. (-1 if s1 not found in s from this position)</td>
</tr>
<tr>
<td><code>s.index(s1)</code></td>
<td>Returns: index of first occurrence of string s1 in string s; raises an error if s1 is not found in s.</td>
</tr>
<tr>
<td><code>s.index(s1,n)</code></td>
<td>Returns: index of first occurrence of string s1 in string s STARTING at position n; raises an error if s1 is not found in s from this position</td>
</tr>
<tr>
<td><code>s.isalpha()</code></td>
<td>Returns: True if s is not empty and its elements are all letters; it returns False otherwise.</td>
</tr>
<tr>
<td><code>s.isdigit()</code></td>
<td>Returns: True if s is not empty and its elements are all numbers; it returns False otherwise.</td>
</tr>
<tr>
<td><code>s.islower()</code></td>
<td>Returns: True if s is has at least one letter and all letters are lower case; returns False otherwise (e.g., 'a123' is True but '123' is False).</td>
</tr>
<tr>
<td><code>s.isupper()</code></td>
<td>Returns: True if s is has at least one letter and all letters are upper case; returns False otherwise (e.g., 'A123' is True but '123' is False).</td>
</tr>
<tr>
<td><code>s.lower()</code></td>
<td>Returns: a copy of s, all letters converted to lower case.</td>
</tr>
<tr>
<td><code>s.join(slist)</code></td>
<td>Returns: a string that is the concatenation of the strings in list slist separated by string s</td>
</tr>
<tr>
<td><code>s.replace(a,b)</code></td>
<td>Returns: a copy of s where all instances of a are replaced with b</td>
</tr>
<tr>
<td><code>s.split(sep)</code></td>
<td>Returns: a list of the “words” in string s, using sep as the word delimiter (whitespace if sep not given)</td>
</tr>
<tr>
<td><code>s.strip()</code></td>
<td>Returns: copy of string s where all whitespace has been removed from the beginning and the end of s. (Whitespace not at the ends is preserved.)</td>
</tr>
<tr>
<td><code>s.upper()</code></td>
<td>Returns: a copy of s, all letters converted to upper case.</td>
</tr>
</tbody>
</table>

### List methods

<table>
<thead>
<tr>
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<tr>
<td><code>lt[i:j]</code></td>
<td>Returns: if i and j are non-negative indices and i ≤ j-1, a new list containing the elements in lt from index i to index j-1, or the sublist of lt starting at i if j ≥ len(lt)</td>
</tr>
<tr>
<td><code>lt.append(item)</code></td>
<td>Adds item to the end of list lt</td>
</tr>
<tr>
<td><code>lt.count(item)</code></td>
<td>Returns: count of how many times item occurs in list lt</td>
</tr>
<tr>
<td><code>lt.index(item)</code></td>
<td>Returns: index of first occurrence of item in list lt; raises an error if item is not found. (There’s no “find()” for lists.)</td>
</tr>
<tr>
<td><code>lt.index(y, n)</code></td>
<td>Returns: index of first occurrence of item in list lt STARTING at position n; raises an error if item does not occur in lt.</td>
</tr>
<tr>
<td><code>lt.insert(i,item)</code></td>
<td>Insert item into list lt at position i</td>
</tr>
<tr>
<td><code>lt.pop(i)</code></td>
<td>Returns: element of list lt at index i and also removes that element from the list lt. Raises an error if i is an invalid index.</td>
</tr>
<tr>
<td><code>lt.reverse()</code></td>
<td>Reverses the list lt in place (so, lt is modified)</td>
</tr>
<tr>
<td><code>lt.sort()</code></td>
<td>Rearranges the elements of x to be in ascending order.</td>
</tr>
</tbody>
</table>

### Dictionary Operations

<table>
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<tbody>
<tr>
<td><code>d[k] = v</code></td>
<td>Assigns value v to the key k in d.</td>
</tr>
<tr>
<td><code>d[k]</code></td>
<td>If value v was assigned to the key k in d, d[k] evaluates to v.</td>
</tr>
<tr>
<td><code>del d[k]</code></td>
<td>Deletes the key k (and its value) from the dictionary d.</td>
</tr>
<tr>
<td><code>d.keys()</code></td>
<td>Returns: an iterator of all the keys in dictionary d.</td>
</tr>
<tr>
<td><code>d.values()</code></td>
<td>Returns: an iterator of all the values in dictionary d.</td>
</tr>
</tbody>
</table>

### Other useful functions

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td><code>s1 in s</code></td>
<td>Returns: True if the substring s1 is in string s; False otherwise.</td>
</tr>
<tr>
<td><code>elem in lt</code></td>
<td>Returns: True if the element elem is in list lt; False otherwise.</td>
</tr>
<tr>
<td><code>y in d</code></td>
<td>Returns: True if y is a key in dictionary d; False otherwise.</td>
</tr>
<tr>
<td><code>y in d.values()</code></td>
<td>Returns: True if y is a value in dictionary d; False otherwise.</td>
</tr>
<tr>
<td><code>input(s)</code></td>
<td>Prompts user for a response using string s; returns the user’s response as a string.</td>
</tr>
<tr>
<td><code>isinstance(o, c)</code></td>
<td>Returns: True if o is an instance of class c; False otherwise.</td>
</tr>
<tr>
<td><code>len(s)</code></td>
<td>Returns: number of characters in string s; it can be 0.</td>
</tr>
<tr>
<td><code>len(lt)</code></td>
<td>Returns: number of items in list lt; it can be 0.</td>
</tr>
<tr>
<td><code>len(d)</code></td>
<td>Returns: number of keys in dictionary d; it can be 0.</td>
</tr>
<tr>
<td><code>list(range(n))</code></td>
<td>Returns: the list [0 .. n-1]</td>
</tr>
</tbody>
</table>
1. [8 points] **Iteration over lists.** Implement this function, making effective use of for-loops.

```python
def floor_divide_lists(numerators, denominators):
    """Performs floor division across two lists of ints.
    Returns a new list. Each element of this new list is the string of the
    floor division result of dividing each int in the numerators (numerators)
    list by its corresponding int in the denominators (denominators) list.

    Recall that floor division -- `//` -- is an integer operation that
    yields the integer that is less than or equal to the standard
division -- `/` -- result.
    Examples: 1/2 --> 0, 2/2 --> 1, 3/2 --> 1, 4/2 --> 2

    Note:
    - The new list should be a list of STRINGS; each string is the
      string representation of the int resulting from the floor division
    - In case of dividing by 0, put 'E' (for 'Error') at the corresponding
      position in the resulting list.

    Return: a (possibly empty) list of str
    
    | Example 1 | Example 2 | Example 3 |
    |-----------|-----------|-----------|
    | numerators is [0, 12, 4] | numerators is [9, 1, 6] | numerators is [] |
    | denominators is [7, 3, 3] | denominators is [0, 3, 3] | denominators is [] |
    | return ['0', '4', '1'] | return ['E', '0', '2'] | return [] |

    Preconditions:
    - numerators: a (possibly empty) list of int
    - denominators: a (possibly empty) list of int
    - len(numerators) == len(denominators), length can be 0

    """
```

# STUDENTS: assume preconditions are met. No need to assert them.
2. [12 points] **Iteration over dictionaries.** Implement this function, using for-loops effectively.

```python
def invert_dict(input_dict):
    """ Given:
    `input_dict` with the following properties:
    - the keys are characters a-z and ' '
    - values are ints

    Returns: the inverse of input_dict
    a new dictionary with the following properties:
    - the keys are the int values found in `input_dict`
    - the values are lists of letters that correspond to that int in `input_dict`
      (the letters in the lists can be in any order)

    EXAMPLES:
    {'a': 2, 'b': 1, 'c': 3, ' ': 5} → {2: ['a'], 1: ['b'], 3: ['c'], 5: [' ']}  
    {'a': 2, 'b': 2, 'c': 3, ' ': 5} → {2: ['a', 'b'], 3: ['c'], 5: [' ']}  
    {'a': 2, 'b': 2, 'c': 2, ' ': 2} → {2: ['a', 'b', 'c', ' ']}  
    {} → {}

    Precondition: input_dict is a possibly empty dictionary that will only have:
    - characters a-z or space as keys
    - ints as values
    """
    # STUDENTS: assume preconditions are met. No need to assert them.
```
3. **Lists and indexing** The variable `mylist` is successfully initialized as follows:

```
mylist = [ [ [ [ 1 ], 1, 2, 3 ] ], [2, 5, 6], [7] ]
```

After this initialization, what do the following Python expressions evaluate to? Write ERROR if evaluating the expression causes Python to throw an error. Assume each expression is evaluated independently.

(a) [2 points] `mylist[0][0].index(1)` evaluates to

(b) [2 points] `mylist[1][2]` evaluates to

(c) [2 points] `mylist[1][1][1]` evaluates to
4. [14 points] **Recursion.** Let `Worker` be a class whose objects have the following two attributes:

```
    name     [str] - unique non-empty name of worker
    reports  [list of Worker] - (possibly empty) workers who report directly
to this worker instance, who acts as the manager for these reports.
```

A. Implement the following function (not a class method), making effective use of recursion. For-loops are allowed as long as your solution is fundamentally recursive.

```python
def calculate_salary(w):
    """Returns: the salary of worker `w` where workers make $50,000 by default,
    and managers make $10,000 more than the best paid worker that reports to them.
    
    Parameter w: the worker whose salary is to be calculated
    Precondition: w is an Worker object
    
    Example:
    Carlos
       / \
   w1 = Worker("Ricky", []) Rene Draco
   w2 = Worker("Johnny", [w1])        | Johnny
   w3 = Worker("Rene", [w2])         | Ricky
   w4 = Worker("Draco", [])          |
   w5 = Worker("Carlos", [w3, w4])
    
    calculate_salary(w1) and calculate_salary(w4) Returns 50000
    because these 2 workers do not manage anyone (they have no reports)
    calculate_salary(w2) Returns 60000
    calculate_salary(w3) Returns 70000
    calculate_salary(w5) Returns 80000
    because Rene is the best paid of Carlos' 2 reports,
    so Carlos makes 10000 more than Rene
    """
```

# STUDENTS: assume preconditions are met. No need to assert them.
5. [20 points] **Simulating Python Execution.** Diagram the execution of each line of code until Python reaches the comment `# STOP HERE` which would stop the code in the middle of the first iteration of the for loop. Draw the memory diagram as seen in class and Assignment 5. (As usual, do not draw the objects/folders for imported modules or for function definitions.) Include global variables, class folders, object folders and call frames. Pay attention to what goes in the **Global Space** / Call Stack / Heap. If a value changes, cross out the old value so that it remains legible. (Do not erase the old value.) This code runs without error. We have provided a skeleton of a Class and Object folder for you to use. Please use them.

```python
class A:
    x = 1
    y = 10

    def __init__(self, x, y):
        self.x = y + 1
        A.y = x - 1
        z = self.y

    def g(self):
        silly = [self]
        for s in silly:
            # STOP HERE
            s.x = y
        return s.y

x = 6
y = 4
e = A(y, x)
e.y = A.x
w = e.g()
```
6. **Classes.** Consider the following class, defined as follows:

```python
class LapTime:
    """Represents a runner’s time for a single lap around a track.
    Each runner has at most one LapTime object for each lap they complete.

    Attributes: name: [string] the name of the runner
    lap: [int] >= 0, representing the lap number
    time: [float] >= 0.0, time taken to complete the lap in seconds
    ""
    def __init__(self, name, lap_num, time):
        """Initializes a LapTime object
        Preconditions: name is a string,
        lap_num is an int >= 0
        time is a float >= 0.0"
        self.name = name
        self.lap = lap_num
        self.time = time

(a) [5 points] Override the following special method of LapTime according to its specification.

def __lt__(self, other):
    """Compares two LapTimes of the same lap around the track
    (LapTimes of the same lap have the same value for their lap attribute)

    Returns True if this LapTime is less than (i.e., faster than) the other
    LapTime or if the other LapTime is None. Otherwise returns False.

    Precondition: other is either a LapTime object representing the same
    lap around the track as as self or None"
    # STUDENTS: assume preconditions are met. No need to assert them.
```

(b) [5 points] Complete the following test which asserts a case for which your implementation of `__lt__` should return `True`.

```python
t1 = LapTime(_________________________________________)  
t2 = LapTime(_________________________________________)  
expected = True  
assert_equals(expected, __________________________________)  ```
Now we introduce a second class, defined as follows:

class Tracker:
    """Records the best lap times of runners in a training session.
    Attributes:
    runner_times: dictionary whose keys are names of runners (string) and
    values are lists of LapTime objects. Each LapTime object
    corresponds to the runner's performance for a certain lap.
    best_times: a list with one entry per lap. The element at index i contains
    either None or the LapTime object of the best performance for
    Lap i (across all runners) that have been added to the Tracker.
    """
    def __init__(self, max_laps):
        """Initializes Tracker object self.
        runner_times: set to an empty dictionary
        best_times: a list of length max_laps, containing all Nones
        Precondition: max_laps is an int > 0
        """
        self.runner_times = {}
        self.best_times = []
        for i in range(max_laps):
            self.best_times.append(None)

(c) [12 points] Override the following class method of Tracker according to its specification.

def add_laptime(self, t):
    """Modifies this Tracker given a LapTime object t

    Adds t to the end of the corresponding runner's list in
    runner_times, or creates a new entry and list if necessary.
    If t represents a faster performance for its lap than the current
    entry for that lap in best_times, t should be added to best_times
    at the appropriate index

    Precondition: t is a LapTime object
    """
    # STUDENTS: assume preconditions are met. No need to assert them.
7. Debugging. Consider the following two classes and 3 lines of code that use them:

class Course:
    def __init__(self, name, n_credit):
        name = name
        n_credit = n_credit

class Student:
    max_credit = 20

    def __init__(self, netID, courses=None):
        self.netID = netID
        self.courses = courses if courses is not None else []
        # this line has no error and is also not important to the question
        for one_course in self.courses:
            self.n_credit += one_course.n_credit  # Add up all the credits

    def enroll(new_course):
        if new_course.n_credit + self.max_credit <= Student.n_credit:
            self.courses.append(new_course)
            self.n_credit += new_course.n_credit

c1 = Course("CS 1110", 4)
s1 = Student("mep1")
s1.enroll(c1)
When the given code is run in Python, the following error is reported:

```
Traceback (most recent call last):
  File "college.py", line 23, in <module>
    s1.enroll(c1)
TypeError: enroll() takes 1 positional argument but 2 were given
```

(a) [2 points] What are the 2 positional arguments that were given?

first argument:

second argument:

(b) [2 points] Fix the code to remove only the above error. **Fix only the code that directly leads to the above error message.** Mark your fix(es) with the label **FIX1.**

Now that you have fixed the error, you rerun the code and now a new error is reported:

```
Traceback (most recent call last):
  File "college.py", line 23, in <module>
    s1.enroll(c1)
  File "college.py", line 17, in enroll
    if new_course.n_credit + self.max_credit <= Student.n_credit:
AttributeError: 'Course' object has no attribute 'n_credit'
```

(c) [2 points] Fix the above code to remove only this new error. **Fix only the code that directly leads to the new error message.** Mark your fix(es) with the label **FIX2.**

(d) [2 points] Will your fixed code now run to completion without any reported Python errors?

Circle One: Yes No

If you answered No, circle or underline the source(s) of the next error that Python will report in the code. Label this as **ERR3.**