INSTRUCTIONS

• You have 2 hours and 50 minutes to complete the exam.
• The exam is closed book, closed notes, closed computer, closed calculator, except three hand-written 8.5" × 11" crib sheet of your own creation and the provided CS 61A study guides.
• Mark your answers on the exam itself. We will not grade answers written on scratch paper.

<table>
<thead>
<tr>
<th>Last name</th>
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<tbody>
<tr>
<td>First name</td>
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All the work on this exam is my own.
(please sign)

POLICIES & CLARIFICATIONS

• If you need to use the restroom, bring your phone and exam to the front of the room.
• You may use built-in Python functions that do not require import, such as min, max, pow, len, abs, sum, next, iter, list, sorted, reversed, tuple, map, filter, zip, all, and any.
• You may not use example functions defined on your study guide unless a problem clearly states you can.
• For fill-in-the-blank coding problems, we will only grade work written in the provided blanks. You may only write one Python statement per blank line, and it must be indented to the level that the blank is indented.
• Unless otherwise specified, you are allowed to reference functions defined in previous parts of the same question.
• You may use the Tree and Link classes defined on Page 2 (left column) of the Midterm 2 Study Guide.
1. (11 points) What Would Python Display

For each of the expressions in the table below, write the output displayed by the interactive Python interpreter when the expression is evaluated. The output may have multiple lines. If an error occurs, write “Error”, but include all output displayed before the error. If evaluation would run forever, write “Forever”. To display a function value, write “Function”. The first two rows have been provided as examples.

The interactive interpreter displays the contents of the `repr` string of the value of a successfully evaluated expression, unless it is `None`.

Assume that you have first started `python3` and executed the statements on the left, which cause no errors. Assume that expressions on the right are executed in the order shown. Expressions evaluated by the interpreter have a cumulative effect.

<table>
<thead>
<tr>
<th>Expression</th>
<th>Interactive Output</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>pow(10, 2)</code></td>
<td>100</td>
</tr>
<tr>
<td><code>print(4, 5) + 1</code></td>
<td>4 5 Error</td>
</tr>
<tr>
<td><code>print([1].append(2))</code></td>
<td>None</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Expression</th>
<th>Interactive Output</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>n = sum([again(z) for z in range(9)])</code></td>
<td>(1 pt) n 0</td>
</tr>
<tr>
<td><code>s = [[i] for i in range(3)]</code></td>
<td>(1 pt) s[1] [1, 3, 4]</td>
</tr>
<tr>
<td><code>s.append(s)</code></td>
<td>s[1] [1, 3, 4]</td>
</tr>
<tr>
<td><code>for t in list(s):</code></td>
<td>(1 pt) len(s) 6</td>
</tr>
<tr>
<td><code>t.extend(range(3, 5))</code></td>
<td>t.extend(range(3, 5))</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Expression</th>
<th>Interactive Output</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>A = 'one'</code></td>
<td>(2 pt) A('four') ['four', 'one']</td>
</tr>
<tr>
<td><code>def __init__(self, a):</code></td>
<td>(2 pt) A('four') ['four', 'one']</td>
</tr>
<tr>
<td><code>f = self.a</code></td>
<td>(2 pt) A('four') ['four', 'one']</td>
</tr>
<tr>
<td><code>self.a = a[1:]</code></td>
<td>(2 pt) A('four') ['four', 'one']</td>
</tr>
<tr>
<td><code>self.b = 'two'</code></td>
<td>(2 pt) A('four') ['four', 'one']</td>
</tr>
<tr>
<td><code>f(a)</code></td>
<td>(2 pt) A('four') ['four', 'one']</td>
</tr>
<tr>
<td><code>def a(self, b):</code></td>
<td>(2 pt) A('four') ['four', 'one']</td>
</tr>
<tr>
<td><code>print([b, type(self).b])</code></td>
<td>(2 pt) A('four') ['four', 'one']</td>
</tr>
</tbody>
</table>
| `def __repr__(self):
| `return str(self.a)` | (2 pt) A('four') ['four', 'one'] |

<table>
<thead>
<tr>
<th>Expression</th>
<th>Interactive Output</th>
</tr>
</thead>
</table>
| `class B(A):
| `b = 'three'` | (2 pt) B('five') ['two', 'three'] |
| `def a(self, c):
| `A.a(self, self.b)` | (2 pt) B('five') ['two', 'three'] |

<table>
<thead>
<tr>
<th>Expression</th>
<th>Interactive Output</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>f = lambda g, h: lambda p, q: h(g(q), p)</code></td>
<td>f = lambda g, h: lambda p, q: h(g(q), p)</td>
</tr>
<tr>
<td><code>g = f(lambda half: half // 2, pow)</code></td>
<td>g = f(lambda half: half // 2, pow)</td>
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</table>

```python
def again(x):
    def again(y):
        nonlocal x
        x = x - y
        return x
    return again(x) + x

n = sum([again(z) for z in range(9)])

s = [[i] for i in range(3)]
s.append(s)
for t in list(s):
    t.extend(range(3, 5))

class A:
    b = 'one'
    def __init__(self, a):
        f = self.a
        self.a = a[1:]
        self.b = 'two'
        f(a)
    def a(self, b):
        print([b, type(self).b])
    def __repr__(self):
        return str(self.a)

class B(A):
    b = 'three'
    def a(self, c):
        A.a(self, self.b)

f = lambda g, h: lambda p, q: h(g(q), p)
g = f(lambda half: half // 2, pow)
```
2. (8 points) Protect the Environment

Fill in the environment diagram that results from executing the code on the right until the entire program is finished, an error occurs, or all frames are filled. 

**Important:** You may not need to use all of the spaces or frames. Do not draw frames for calls to built-in functions, such as `len`. A complete answer will:

- Use box-and-pointer notation for lists.
- Add all missing names and parent annotations.
- Add all missing values created or referenced.
- Show the return value for each local frame.

```python
def cold(d):
    day = rain[:1]
    night = lambda: len(day)
    cold = rain.pop()
    day = d
    return night

rain = [3, 4]
d, day = [5], [lambda: d]
cold(rain + [day[0](), rain]())
```
3. (3 points) The Price is Right

Implement winner, which takes a number price and returns a function. The function takes a list of numbers guesses and returns the largest guess that is less than or equal to the price.

Important: Fill each blank with only a single name. You may use built-in functions such as min; other built-in functions are listed on the front of the exam.

```python
def winner(price):
    """Return a function that takes a list and returns the largest element not above price."
    return lambda guesses: max(filter(lambda g: g <= price, guesses))
```

4. (4 points) Big Leaf

Implement tops, a generator function that takes a Tree instance t. It yields all leaf labels in t for which the path from the root to that leaf is strictly increasing. A sequence is strictly increasing if each element is larger than the previous element. A path from the root to a leaf is a sequence of labels that includes the root label at the start and the leaf label at the end, along with all labels for nodes in between. The Tree class appears on Page 2 (left column) of the Midterm 2 study guide.

Important: You may not modify the attributes of any Tree instance or write else, and, or, [, or ].

```python
def tops(t):
    """Yield the leaf labels of Tree t at the end of increasing paths."
    if t.is_leaf():
        yield t.label
    else:
        for b in t.branches:
            if t.label < b.label:
                yield from tops(b)
```
5. (6 points) To-Do Lists

Implement the TodoList and Todo classes. When a Todo is complete, it is removed from all the TodoList instances to which it was ever added. Track both the number of completed Todo instances in each list and overall so that printing a TodoList instance matches the behavior of the doctests below. Assume the complete method of a Todo instance is never invoked more than once.

```python
class TodoList:
    """A to-do list that tracks the number of completed items in the list and overall."
    >>> a, b = TodoList(), TodoList()
    >>> a.add(Todo('Laundry'))
    >>> t = Todo('Shopping')
    >>> a.add(t)
    >>> b.add(t)
    >>> print(a)
    Remaining: ['Laundry', 'Shopping'] ; Completed in list: 0 ; Completed overall: 0
    >>> print(b)
    Remaining: ['Shopping'] ; Completed in list: 0 ; Completed overall: 0
    >>> t.complete()
    >>> print(a)
    Remaining: ['Laundry'] ; Completed in list: 1 ; Completed overall: 1
    >>> print(b)
    Remaining: [] ; Completed in list: 0 ; Completed overall: 0
    >>> Todo('Homework').complete()
    >>> print(a)
    Remaining: ['Laundry'] ; Completed in list: 1 ; Completed overall: 2
    """
    def __init__(self):
        self.items, self.complete = [], 0
    def add(self, item):
        self.items.append(item)
        item.lists.append(self)
    def remove(self, item):
        self.complete += 1
        self.items.remove(item)
    def __str__(self):
        return ('Remaining: ' + str([t.task for t in self.items]) +
                '; Completed in list: ' + str(self.complete) +
                '; Completed overall: ' + str(Todo.done))

class Todo:
    done = 0
    def __init__(self, task):
        self.task, self.lists = task, []
    def complete(self):
        Todo.done += 1
        for t in self.lists:
            t.remove(self)
```

class TodoList:
    """A to-do list that tracks the number of completed items in the list and overall."
    >>> a, b = TodoList(), TodoList()
    >>> a.add(Todo('Laundry'))
    >>> t = Todo('Shopping')
    >>> a.add(t)
    >>> b.add(t)
    >>> print(a)
    Remaining: ['Laundry', 'Shopping'] ; Completed in list: 0 ; Completed overall: 0
    >>> print(b)
    Remaining: ['Shopping'] ; Completed in list: 0 ; Completed overall: 0
    >>> t.complete()
    >>> print(a)
    Remaining: ['Laundry'] ; Completed in list: 1 ; Completed overall: 1
    >>> print(b)
    Remaining: [] ; Completed in list: 0 ; Completed overall: 0
    >>> Todo('Homework').complete()
    >>> print(a)
    Remaining: ['Laundry'] ; Completed in list: 1 ; Completed overall: 2
    """
    def __init__(self):
        self.items, self.complete = [], 0
    def add(self, item):
        self.items.append(item)
        item.lists.append(self)
    def remove(self, item):
        self.complete += 1
        self.items.remove(item)
    def __str__(self):
        return ('Remaining: ' + str([t.task for t in self.items]) +
                '; Completed in list: ' + str(self.complete) +
                '; Completed overall: ' + str(Todo.done))

class Todo:
    done = 0
    def __init__(self, task):
        self.task, self.lists = task, []
    def complete(self):
        Todo.done += 1
        for t in self.lists:
            t.remove(self)
6. (20 points)  Palindromes

Definition.  A palindrome is a sequence that has the same elements in normal and reverse order.

(a) (3 pt)  Implement `pal`, which takes a positive integer `n` and returns a positive integer with the digits of `n` followed by the digits of `n` in reverse order.

   Important:  You may not write `str, repr, list, tuple, [, or ]`.

   ```python
def pal(n):
    """Return a palindrome starting with n."

    >>> pal(12430)
    1243003421
    """
    m = n

    while m:
        n, m = n * 10 + m % 10, m // 10

    return n
```

(b) (4 pt)  Implement `contains`, which takes non-negative integers `a` and `b`. It returns whether all of the digits of `a` also appear in order among the digits of `b`.

   Important:  You may not write `str, repr, list, tuple, [, or ]`.

   ```python
def contains(a, b):
    """Return whether the digits of a are contained in the digits of b."

    >>> contains(357, 12345678)
    True
    >>> contains(753, 12345678)
    False
    >>> contains(357, 37)
    False
    """
    if a == b:
        return True

    if a > b:
        return False

    if a % 10 == b % 10:
        return contains(a // 10, b // 10)

    else:
        return contains(a, b // 10)
(c) (6 pt) Implement big, a helper function for biggest_palindrome. The biggest_palindrome function takes a non-negative integer n and returns the largest palindrome integer with an even number of digits that appear among the digits of n in order. If there is no even-length palindrome among the digits of n, then biggest_palindrome(n) returns 0. You may call pal and contains.

Important: You may not write str, repr, list, tuple, [ , or ].

def biggest_palindrome(n):
    """Return the largest even-length palindrome in n.
    >>> biggest_palindrome(3425534)
    4554
    >>> biggest_palindrome(126130450234125)
    21300312
    """
    return big(n, 0)

def big(n, k):
    """A helper function for biggest_palindrome."""
    if n == 0:
        return 0

    choices = [big(n // 10, k), big(n // 10, 10 * k + n % 10)]

    if contains(k, n):
        choices.append(pal(k))

    return max(choices)

(d) (1 pt) Circle the term that fills in the blank: the is_palindrome function defined below runs in _____ time in the length of its input.

Constant  Logarithmic  Linear  Quadratic  Exponential  None of these

def is_palindrome(s):
    """Return whether a list of numbers s is a palindrome."""
    return all([s[i] == s[len(s) - i - 1] for i in range(len(s))])

Assume that len runs in constant time and all runs in linear time in the length of its input. Selecting an element of a list by its index requires constant time. Constructing a range requires constant time.
(e) (6 pt) Implement outer, a helper function for palindrome. The palindrome function takes a positive integer n and returns a one-argument function that, when called repeatedly n times, returns a Link containing the sequence of arguments to the repeated calls followed by that sequence in reverse order. The Link class appears on Page 2 (left column) of the Midterm 2 study guide.

```python
from link import *

def palindrome(n):
    """Return a function that returns a palindrome starting with the args of n repeated calls."

    >>> print(palindrome(3)(5)(6)(7))
    <5 6 7 6 5>
    >>> print(palindrome(1)(4))
    <4 4>
    """
    return outer(Link.empty, n)

def outer(r, n):
    def inner(k):
        s = Link(k, r)

        if n == 1:
            t = s

            while s is not Link.empty:
                t, s = Link(s.first, t), s.rest

            return t

        else:
            return outer(s, n - 1)

    return inner
```
7. (10 points) Mull It Over

Uh oh! Someone evaluated (define * +). Now (* 3 2) evaluates to 5 instead of 6! Let’s fix it.

**Important:** Answer all questions on this page without calling the built-in multiplication procedure.

(a) (3 pt) Implement mulxy, which multiplies integers x and y. **Hint:** (- 2) evaluates to -2.

;; multiply x by y (without using the * operator).
;; (mulxy 3 4) -> 12 ; 12 = 3 + 3 + 3 + 3
;; (mulxy (- 3) (- 4)) -> 12 ; 12 = - (-3 + -3 + -3 + -3)
(define (mulxy x y)
  (cond ((< y 0) (- (mulxy x (- y))))
        ((= y 0) 0)
        (else (+ x (mulxy x (- y 1))))))

(b) (2 pt) Implement mul-expr, which takes an expression e that contains only calls to * and numbers. It returns the normal value of e under a Scheme interpreter with an unmodified * operator that multiplies. You may call the mul procedure defined below.

**Important:** Fill each blank with only a single symbol.

;; Multiply together a list of numbers.
;; (mul (2 3 4 2)) -> 48
(define (mul s) (reduce mulxy s))

;; Evaluate an expression with only calls to * and numbers.
;; (mul-expr (* (* 1 2) (* 3 (* 4 1 1) 2))) -> 48
(define (mul-expr e)
  (if (number? e) e
      (mul (map mul-expr (cdr e)))))

(c) (5 pt) Implement *-to-mul, which takes any expression e. It returns an expression like e, but with all calls to * replaced with calls to mul. Note that * takes an arbitrary number of arguments, while mul always takes exactly one argument: a list of numbers. You should account for this difference.

;; Convert all calls to * to calls to mul in expression e.
;; (eval (*-to-mul '(* 1 (+ 2 3) (+ 4 5 (* 6 1)))))) -> 75
(define (*-to-mul e)
  (if (not (list? e)) e
      (let ((op (*-to-mul (car e))) (rest (map *-to-mul (cdr e))))
        (if (equal? op '*)
            (list 'mul (cons 'list rest))
            (cons op rest))))))
8. (4 points) Live Stream

Implement \texttt{up}, which takes an infinite stream \texttt{s} with no largest element. (That means for every element there is some larger element later in the stream.) It returns a stream of all elements of \texttt{s} that are larger than every previous element in \texttt{s}.

\begin{verbatim}
;; Scale all elements of a stream by \texttt{k}.
(define (scale s k) (cons-stream (* (car s) k) (scale (cdr-stream s) k)))

;; A stream of 1 -2 4 -8 16 -32 64 -128 256 -512 ...
(define twos (cons-stream 1 (scale twos -2)))

;; Return a stream of all elements in \texttt{s} larger than all previous elements.
;; \texttt{(up twos)} \rightarrow \texttt{a stream of 1 4 16 64 256 ...}
(define (up s)
  (define (rest t)
    (if (> (car t) (car s))
      (up t)
      (rest (cdr-stream t))))

  (cons-stream (car s) (rest s)))
\end{verbatim}

9. (3 points) Macro Lens

Implement \texttt{partial}, a macro that takes a call expression that is missing its last operand. A call to \texttt{partial} evaluates to a one-argument procedure that takes a value \texttt{y} and returns the result of evaluating call extended to include an additional operand \texttt{y} at the end.

\begin{verbatim}
;; A macro that creates a procedure from a partial call expression missing the last operand.
;; (define add-two (partial (+ 1 1))) \rightarrow \texttt{(lambda (y) (* 1 1 y))}
;; (add-two 3) \rightarrow \texttt{5} by evaluating \texttt{(+ 1 1 3)}

;; (define eq-5 (partial (equal? (+ 2 3)))) \rightarrow \texttt{(lambda (y) (equal? (+ 2 3) y))}
;; (eq-5 (+ 3 2)) \rightarrow \texttt{#t} by evaluating \texttt{(equal? (+ 2 3) 5)}

;; ((partial (append '(1 2))) '(3 4)) \rightarrow \texttt{(1 2 3 4)}
(define-macro (partial call)
  `'(lambda (y) ,(append call (list 'y)))))
\end{verbatim}
10. (6 points) Big Game

The **scoring** table has three columns, a **player** column of strings, a **points** column of integers, and a **quarter** column of integers. The **players** table has two columns, a **name** column of strings and a **team** column of strings. Complete the SQL statements below so that they would compute the correct result even if the rows in these tables were different than those shown.

**Important:** You may write anything in the blanks including keywords such as **WHERE** or **ORDER BY**.

**CREATE TABLE scoring AS**

```sql
SELECT "Donald Stewart" AS player, 7 AS points, 1 AS quarter UNION
SELECT "Christopher Brown Jr.", 7, 1 UNION
SELECT "Ryan Sanborn", 3, 2 UNION
SELECT "Greg Thomas", 3, 2 UNION
SELECT "Cameron Scarlett", 7, 3 UNION
SELECT "Nikko Remigio", 7, 4 UNION
SELECT "Ryan Sanborn", 3, 4 UNION
SELECT "Chase Garbers", 7, 4;
```

**CREATE TABLE players AS**

```sql
SELECT "Ryan Sanborn" AS name, "Stanford" AS team UNION
SELECT "Donald Stewart", "Stanford" UNION
SELECT "Cameron Scarlett", "Stanford" UNION
SELECT "Greg Thomas", "Cal" UNION
SELECT "Christopher Brown Jr.", "Cal" UNION
SELECT "Nikko Remigio", "Cal" UNION
SELECT "Chase Garbers", "Cal";
```

(a) (3 pt) Complete the SQL statement below to select a one-column table of quarters in which more than 10 total points were scored.

```sql
SELECT quarter FROM scoring
GROUP BY quarter HAVING SUM(points) > 10;
```

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

(b) (3 pt) Complete the SQL statement below to select a two-column table of the points scored by each team. Assume that no two players have the same name.

```sql
SELECT team, SUM(points) FROM scoring, players
WHERE player=name GROUP BY team;
```

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cal</td>
<td>24</td>
</tr>
<tr>
<td>Stanford</td>
<td>20</td>
</tr>
</tbody>
</table>

(The statement below is not part of any question on the exam.)

```sql
SELECT "Thank you, " || name FROM players WHERE SUBSTR(name, 5) = "Chase";
```
11. (0 points)  *Optional Final Thought*

Write a SQL statement that describes your thoughts or feelings about CS 61A.