INSTRUCTIONS

- You have 3 hours 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 official CS 61A midterm 1, midterm 2, and final 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>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>First name</td>
<td></td>
</tr>
<tr>
<td>Student ID number</td>
<td></td>
</tr>
<tr>
<td>CalCentral email (<a href="mailto:_@berkeley.edu">_@berkeley.edu</a>)</td>
<td></td>
</tr>
<tr>
<td>TA</td>
<td></td>
</tr>
<tr>
<td>Name of the person to your left</td>
<td></td>
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<tr>
<td>Name of the person to your right</td>
<td></td>
</tr>
</tbody>
</table>

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 \texttt{min}, \texttt{max}, \texttt{pow}, \texttt{len}, \texttt{abs}, \texttt{sum}, \texttt{next}, \texttt{iter}, \texttt{list}, \texttt{tuple}, \texttt{map}, \texttt{filter}, \texttt{zip}, \texttt{all}, and \texttt{any}.
- You may not use example functions defined on your study guides 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 \texttt{Tree}, \texttt{Link}, and \texttt{BTree} classes defined on Page 2 (left column) of the Midterm 2 Study Guide.
1. (12 points) High Quality Air

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. The first row is completed for you.

- If an error occurs, write **ERROR**, but include all output displayed before the error.
- To display a function value, write **FUNCTION**.
- To display an iterator value, write **ITERATOR**.
- If an expression would take forever to evaluate, write **FOREVER**.

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 started **python3** and executed the code shown on the left first, then you evaluate each expression on the right in the order shown. Expressions evaluated by the interpreter have a cumulative effect.

<table>
<thead>
<tr>
<th>Expression</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>print(None)</code></td>
<td>None</td>
</tr>
<tr>
<td><code>print(print(None), print)</code></td>
<td>None Function</td>
</tr>
<tr>
<td><code>z(4)</code></td>
<td>2</td>
</tr>
<tr>
<td><code>breath(breath(sub))(5, 3)</code></td>
<td>4</td>
</tr>
<tr>
<td><code>[Day().aqi, m.aqi]</code></td>
<td>[140, 140]</td>
</tr>
<tr>
<td><code>[Week.aqi, t.aqi]</code></td>
<td>[50, 160]</td>
</tr>
<tr>
<td><code>t.n</code></td>
<td>[50, 10]</td>
</tr>
</tbody>
</table>
2. (8 points) Diagram Horror

```python
def get(out):
    out.pop()
    out = scary(lambda movie: out)
    return lambda: [out]

def scary(movie):
    out.append(movie)
    return movie(5)[:1]

out = [6]
get([7, 8])()
```

Fill in the environment diagram that results from executing the code on the left until the entire program is finished, an error occurs, or all frames are filled. 
You may not need to use all of the spaces or frames.

A complete answer will:

- Add all missing names and parent annotations to all local frames.
- Add all missing values created or referenced during execution.
- Show the return value for each local frame.
- Use box-and-pointer diagrams for lists and tuples.
3. (16 points) Gainz

**Definition.** A sequence is near increasing if each element beyond the second is larger than all elements preceding its previous element. That is, element $i$ must be larger than elements $i - 2$, $i - 3$, $i - 4$, etc.

(a) (3 pt) Implement `is_near`, which takes a sequence $s$ and returns whether its elements form a near increasing sequence.

```python
def is_near(s):
    """Return whether $s$ is a near increasing sequence."

    >>> is_near([]) and is_near([1]) and is_near([1, 2]) and is_near(range(10))
    True
    >>> is_near([4, 2]) and is_near([1, 4, 2, 5]) and is_near((1, 2, 4, 3))
    True
    >>> is_near((3, 2, 1))  # 1 <= 3
    False
    >>> is_near([1, 4, 2, 3, 5])  # 3 <= 4
    False
    >>> is_near([1, 4, 2, 5, 3])  # 3 <= 4
    False
    >>> is_near([1, 2, 4, 2, 5])  # 2 <= 2
    False
    ""

    return all([s[i] > max(s[:i-1]) for i in range(2, len(s))])
```

(b) (6 pt) Implement `fast_near`, which takes an iterable value and returns whether its elements form a near increasing sequence. `fast_near` must run in $\Theta(n)$ time and $\Theta(1)$ space (not including the input itself) for an iterable input with $n$ elements. Assume that $s$ has a finite number of elements. You may not call `is_near`.

```python
def fast_near(s):
    """Return whether $s$ is a near increasing sequence."

    >>> fast_near([2, 5, 3, 6, 6, 7, 7, 9, 8])
    True
    ""

    t, s = iter(s), None  # Do not refer to s below this line.
    try:
        largest, last = next(t), next(t)
    except StopIteration:
        return True
    for x in t:
        if x <= largest:
            return False
        largest, last = max(largest, last), x
    return True
```
Alternative Definition. (Equivalent to the one on the previous page, but stated in a more useful way for the problem below.) A sequence is near increasing if each element but the last two is smaller than all elements following its subsequent element. That is, element $i$ must be smaller than elements $i + 2$, $i + 3$, $i + 4$, etc.

(c) (6 pt) Implement near, which takes a non-negative integer $n$ and returns the largest near increasing sequence of digits within $n$ as an integer. The arguments smallest and $d$ are part of the implementation; you must determine their purpose. You may not call is_near or fast_near. You may not use any values except integers and booleans (True and False) in your solution (no lists, strings, etc.).

```python
def near(n, smallest=10, d=10):
    """Return the longest sequence of near-increasing digits in n."

    >>> near(123)
    123
    >>> near(153)
    153
    >>> near(1523)
    153
    >>> near(15123)
    1123
    >>> near(11111111)
    11
    >>> near(985357)
    557
    >>> near(14735476)
    143576
    >>> near(812348567)
    1234567
    ""
    if n == 0:
        return 0

    no = near(n//10, smallest, d)

    if smallest > n % 10:
        yes = 10 * near(n//10, d, min(d, n%10)) + n%10
        # OR yes = 10 * near(n//10, min(smallest, d), n%10) + n%10
        return max(yes, no)

    return no
```

(d) (1 pt) What is the largest possible integer that could ever be returned from the near function? Note: In general, integers in Python can be arbitrarily large.

1122334455667788999
4. (11 points) Tree Time

Definition. A runt node is a node in a tree whose label is smaller than all of the labels of its siblings. A sibling is another node that shares the same parent. A node with no siblings is a runt node.

(a) (7 pt) Implement runts, which takes a Tree instance \( t \) in which every label is different and returns a list of the labels of all runt nodes in \( t \), in any order. Also implement apply_to_nodes, which returns nothing and is part of the implementation. Do not mutate any tree. The Tree class is on the Midterm 2 Guide.

```python
def runts(t):
    """Return a list of the labels of all smallest siblings in any order."
    result = []
    def g(node):
        if not node.is_leaf():
            result.append(min([b.label for b in node.branches]))
    apply_to_nodes(g, t)
    return [t.label] + result
```

```python
def apply_to_nodes(f, t):
    """Apply a function f to each node in a Tree instance t."""
    f(t)
    for b in t.branches:
        apply_to_nodes(f, b)
```

(b) (4 pt) Implement max_label, which takes a Tree \( t \) and returns its largest label. Do not mutate any tree.

```python
def max_label(t):
    """Return the largest label in t."
    def f(node):
        nonlocal t
        t = max(t, node, key=lambda n: n.label)
    apply_to_nodes(f, t)
    return t.label
```
5. (9 points) Run, Program, Run

Implement runs, a Scheme procedure that takes a list of integers $s$ and returns a list of non-empty lists of integers $t$. Together, the lists in $t$ should contain all elements of $s$ in order. The first element in each list in $t$ must be less than the last element in the previous list, if there is one. The rest of the elements in each list in $t$ must be greater than or equal to the previous element.

Also implement and use next-run in your solution, which takes a non-empty list of integers $s$ and returns a pair of lists: the longest non-decreasing prefix of $s$ and the rest of $s$. Use the provided pair data abstraction. Your implementation should be correct even if the pair implementation were to change.

```
;; Return a list of non-decreasing lists that together contain the elements of s.
;; scm> (runs '(3 4 7 6 6 8 1 2 5 5 4))
;; ((3 4 7) (6 6 8) (1 2 5 5) (4))
;; scm> (runs '(4 3 2 3))
;; ((4) (3) (2 3))
(define (runs s)

  (if (null? s) nil

    (let ((p (next-run s)))

      (cons (first p) (runs (rest p))))))

;; A data abstraction for a pair of a first run and the rest of a list.
(define (pair a b) (lambda (c) (if c a b)))
(define (first p) (p #t))
(define (rest p) (p #f))

;; Return a pair containing the first run in s (a list) and the rest of s (another list).
;; scm> (first (next-run '(4 5 1 3 2)))
;; (4 5)
;; scm> (rest (next-run '(4 5 1 3 2)))
;; (1 3 2)
(define (next-run s)

  (if (or (null? (cdr s))

    (< (car (cdr s)) (car s)))

    (pair (list (car s)) (cdr s))

    (begin

      (define p (next-run (cdr s)))

      (pair (cons (car s) (first p)) (rest p)))))
```
6. (9 points) Generation Z

(a) (4 pt) Implement \texttt{rev}, a generator function that takes a \texttt{Link} instance and yields the elements of that linked list in reverse order. The \texttt{Link} class appears on Page 2 of the Midterm 2 Study Guide.

```python
def rev(s):
    """Yield the elements in Link instance s in reverse order."

    >>> list(rev(Link(1, Link(2, Link(3)))))
    [3, 2, 1]
    >>> next(rev(Link(2, Link(3))))
    3
    """
    if s is not Link.empty:
        yield from rev(s.rest)
    yield s.first
```

(b) (2 pt) Using the provided \texttt{add} procedure, define \texttt{not-three}, an infinite stream of all positive integers that are not evenly divisible by 3. The \texttt{not-three} stream is increasing and begins with 1, 2, 4, 5, 7, 8, 10, 11, 13.

```scheme
(define (add k s) (cons-stream (+ k (car s)) (add k (cdr-stream s))))
(define not-three (cons-stream 1 (cons-stream 2 (add 3 not-three))))
```

(c) (3 pt) Implement \texttt{infix}, a Scheme macro that evaluates infix expressions. An infix expression is either a number or a three-element list containing an infix expression, a procedure, and another infix expression. The value of a compound infix expression is the value of its second element applied to the values of its first and third elements. \textbf{Note:} The last line begins with a quasiquote. If you cross out the quasiquote and solve the problem without using quasiquote or unquote, you can receive up to 2 out of 3 points (not recommended).

```scheme
;; A macro to evaluate infix expressions.
;; scm> (infix (2 * 3))
;; 6
;; scm> (infix (((1 + 1) * (1 + 2))))
;; 6
;; scm> (infix (((1 + (3 - 2)) * ((2 + 3) + 2))))
;; 14
(define-macro (infix e)
    (if (number? e) e
        `((, (cadr e) (infix , (car e))) (infix , (caddr e))))))
(define (cadr x) (car (cdr x)))
(define (caddr x) (car (cdr (cdr x))))
```
7. (10 points) SQL of Course

The courses table describes the course name, start time hour (h) and minute (m), and length in minutes (len) for different lectures. For example, 61A starts at 13:00 and lasts 50 minutes. The locations table describes the course name and location (loc) of these courses. Assume that each course name appears exactly once in each table. Write your SQL statements so that they would still be correct if the table contents changed.

```sql
CREATE TABLE courses AS
SELECT "1" AS course, 14 AS h, 0 AS m, 80 AS len UNION
SELECT "2" AS course, 13 AS h, 30 AS m, 80 AS len UNION
SELECT "8" AS course, 12 AS h, 30 AS m, 50 AS len UNION
SELECT "10" AS course, 12 AS h, 30 AS m, 110 AS len UNION
SELECT "50AC" AS course, 13 AS h, 30 AS m, 45 AS len UNION
SELECT "61A" AS course, 13 AS h, 0 AS m, 50 AS len;

CREATE TABLE locations AS
SELECT "1" AS loc, "VLSB" AS loc UNION
SELECT "2" AS loc, "Dwinelle" AS loc UNION
SELECT "10" AS loc, "VLSB" AS loc UNION
SELECT "50AC" AS loc, "Wheeler" AS loc UNION
SELECT "61A" AS loc, "Wheeler" AS loc;
```

(a) (2 pt) Select a one-column table that contains the course names of all courses that start before 13:30.

```sql
SELECT course FROM courses WHERE h < 13 OR (h=13 AND m<30);
```

<table>
<thead>
<tr>
<th>course</th>
</tr>
</thead>
<tbody>
<tr>
<td>61A</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

(b) (4 pt) Select a two-column table with one row per location that contains the location, as well as the shortest length in minutes of any lecture held in that location.

```sql
SELECT loc, min(len) FROM courses, locations WHERE name=course GROUP BY loc;
```

<table>
<thead>
<tr>
<th>loc</th>
<th>len</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwinelle</td>
<td>80</td>
</tr>
<tr>
<td>VLSB</td>
<td>80</td>
</tr>
<tr>
<td>Wheeler</td>
<td>45</td>
</tr>
</tbody>
</table>

(c) (4 pt) Select a three-column table where each row describes an earlier course, a later course, and the amount of time in minutes between the end time of the earlier course and the start time of the later course. Only include pairs of courses where the lectures do not overlap in time. Note: There are 60 minutes in an hour.

```sql
SELECT a.course, b.course,
       (b.h - a.h) * 60 + b.m - a.m - a.len AS gap
FROM courses as a, courses as b WHERE gap > 0
```

<table>
<thead>
<tr>
<th>course1</th>
<th>course2</th>
<th>gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>61A</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>50AC</td>
<td>10</td>
</tr>
</tbody>
</table>
8. (0 points) **Draw!** *(Optional)* Draw a picture of some function or procedure.