INSTRUCTIONS

- You have 2 hours and 50 minutes to complete the exam.
- The exam is closed book, closed notes, closed computer, closed calculator, except two 8.5” × 11” cheat sheets of your own creation.
- Mark your answers on the exam itself. We will not grade answers written on scratch paper.

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All the work on this exam is my own.
(please sign)
1. (6 points) Does Jack Like Jackfruits?

For each of the statements below, write the output displayed by the interactive Python interpreter when the statement is executed. The output may have multiple lines. **No answer requires more than three lines.** If executing a statement results in an error, write ‘Error’, but include all lines displayed before the error occurs. The first two have been provided as examples.

Assume that you have started `python3` and executed the following statements:

```python
class Fruit:
    ripe = False
    def __init__(self, taste, size):
        self.taste = taste
        self.size = size
        self.ripe = True
    def eat(self, eater):
        print(eater, 'eats the', self.name)
        if not self.ripe:
            print(' But it is not ripe!')
        else:
            print(' What a', self.taste, 'and', self.size, 'fruit!')

class Tomato(Fruit):
    name = 'tomato'
    def eat(self, eater):
        print(' Adding some sugar first')
        self.taste = 'sweet'
        Fruit.eat(self, eater)

mystery = Fruit('tart', 'small')
tommy = Tomato('plain', 'normal')

>>> mystery.taste
'tart'

>>> mystery.name
Error

>>> mystery.ripe
>>> Tomato.ripe

>>> Tommy.eat(mystery, 'Marvin')

>>> mystery.ripe

>>> Fruit.eat(tommy, 'Brian')

>>> tommy.eat('Brian')

>>> tommy.name = 'sweet tomato'
>>> Fruit.eat = lambda self, own: print(  ...
...        self.name, 'is too sweet!')

>>> tommy.eat('Marvin')
```
2. (12 points) Marsalists Have Mutant Powers

(a) (6 pt) Fill in the environment diagram that results from executing the code below 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 frames.
- Add all missing values created or referenced during execution.
- Show the return value for each local frame.

```python
def iter(iterable):
    def iterator(msg):
        nonlocal iterable
        if msg == 'next':
            next = iterable[0]
            iterable = iterable[1:]
            return next
        elif msg == 'stop':
            raise StopIteration
        return iterator
    return iterator

def next(iterator):
    return iterator('next')

def stop(iterator):
    iterator('stop')

lst = [1, 2, 3]
iterator = iter(lst)
elem = next(iterator)
```

Global

```
iter
next
stop
lst
```

func iter(iterable) [parent=Global]  
func next(iterator) [parent=Global]  
func stop(iterator) [parent=Global]  

f1: _______ [parent=_______]

```
Return Value
```

f2: _______ [parent=_______]

```
Return Value
```

f3: _______ [parent=_______]

```
Return Value
```

f4: _______ [parent=_______]

```
Return Value
```
(b) (6 pt) Fill in the environment diagram that results from executing the code below 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 frames.
- Add all missing values created or referenced during execution.
- Show the return value for each local frame.

```python
def filter(pred, lst):
    i = 0
    while i < len(lst):
        elem = lst[i]
        if not pred(lst[i]):
            elem = 'X'
        i += 1
    j = 0
    while j < len(lst):
        if lst[j] == 'X':
            lst.pop(j)
        else:
            j += 1
    return elem

filter(lambda x: x < 2, [1, 2, 3])
```

---

**Environment Diagram**

- **Global Frame**
  - `filter` (parent=Global)
  - `func filter(pred, lst) [parent=Global]`

- **Local Frame 1**
  - `filter` (parent=Global)
  - `return Value`

- **Local Frame 2**
  - `filter` (parent=Local Frame 1)
  - `return Value`

- **Local Frame 3**
  - `filter` (parent=Local Frame 2)
  - `return Value`

- **Local Frame 4**
  - `filter` (parent=Local Frame 3)
  - `return Value`
3. (8 points) The Pair of Pair-ic and Pair-ome

(a) (6 pt) Define the function `combine_pairs` that takes a two-argument function `func` and returns a new function that takes in a list `lst`. When called, the new function should combine the elements in `lst` two by two using `func`, and return a new list of the results. If the length of `lst` is odd, the last element should be included in the return value without being combined with anything. See the doctests for details.

You may only use the lines provided. You may not need to fill all the lines.

```python
def combine_pairs(func):
    """
    >>> from operator import add
    >>> add_pairs = combine_pairs(add)
    >>> add_pairs([1, 2, 3, 4])
    [3, 7]
    >>> add_pairs([1, 2, 3, 4, 5])
    [3, 7, 5]
    >>> group_pairs = combine_pairs(lambda x, y: [x, y])
    >>> group_pairs(['hi', 'there', 'bye', 'now'])
    [['hi', 'there'], ['bye', 'now']]
    """

def pairer(lst):
    result = ________________________________
    for i in ________________________________
        try:
            ________________________________
        except IndexError:
            ________________________________
    return ________________________________
    return _______________________________
```

(b) (2 pt) Assuming the function `combine_pairs` works correctly, fill in the following line of code to correctly define the function `sum`, which takes in a non-empty list of numbers and returns the sum of the numbers. Use only one line of code. If you need more space, you can continue your line of code on the second blank. The `add` function has been imported for you; you may find it to be useful.

*Hint:* You may need the ternary operator `<expr1> if <cond> else <expr2>`.

```python
>>> from operator import add

>>> sum = _______________________________________________________
___________________________________________________________

>>> sum([1, 2, 3])
6
>>> sum([2, 0, 1, 6])
9```
4. (9 points) Caught Ya!

Implement the function catch_up, which takes in two linked lists of integers lnk1 and lnk2 and mutates the linked list with the lower sum by repeatedly inserting 1 at the end until the sums are equal. See the doctests for details. You may assume that the two linked lists that are passed in are non-empty and have the same length. The Link class is provided for your reference.

You may only use the lines provided. You may not need to fill all the lines. You may not use methods that are not implemented in the Link class below.

Hint: You may need the ternary operator <expr1> if <cond> else <expr2>.

def catch_up(lnk1, lnk2):
    ""
    >>> odds = Link(1, Link(3, Link(5, Link(7))))
    >>> evens = Link(2, Link(4, Link(6, Link(8))))
    >>> catch_up(odds, evens)
    ""
    def catcher(lnk1, lnk2, sum1, sum2):
        sum1 = _________________________________________________________
        sum2 = _________________________________________________________
        if _____________________________________________________________
            lower = ____________________________________________________
            for ________________________________________________________
                ________________________________________________________
                ________________________________________________________
                ________________________________________________________
        else:
            catcher(____________________________________________________)
            catcher(____________________________________________________)

class Link:
    empty = ()
    def __init__(self, first, rest=empty):
        self.first, self.rest = first, rest

    def __str__(self):
        string = '<'
        while self.rest is not Link.empty:
            string += str(self.first) + ' ',
            self = self.rest
        return string + str(self.first) + '>'
5. (9 points) The Tree-o of Tam-tree, Tree-tas, and Tree-il

(a) (3 pt) Define the function `min_leaf_depth`, which takes in a tree `t` and returns the minimum depth of any of the leaves in `t`. Recall that the depth of a node is defined as how far away that node is from the root. See the doctests for details. The `Tree` class is provided for your reference.

You may only use the lines provided. You may not need to fill all the lines. You may not use methods that are not implemented in the `Tree` class below.

*Hint:* You may find the built-in `min` function useful.

```python
def min_leaf_depth(t):
    
    >>> t1 = Tree(2)
    >>> min_leaf_depth(t1)
    0
    >>> t2 = Tree(2, [Tree(0), Tree(1), Tree(6)])
    >>> min_leaf_depth(t2)
    1
    >>> t3 = Tree(2, [Tree(0), t2])
    >>> min_leaf_depth(t3)
    1
    >>> t4 = Tree(2, [t2, t3])
    >>> min_leaf_depth(t4)
    2
    
    if t.is_leaf():
        
    else:
        
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
```
(b) (6 pt) Define the function `find_path`, which takes in a binary search tree `bst` and a number `n` and returns a list representing the path through `bst` starting from the root and ending at `n`. You may assume that `n` exists in `bst` exactly once. See the doctests for details. The `BST` class is provided for your reference.

You may only use the lines provided. You may not need to fill all the lines. You may not use methods that are not implemented in the `BST` class below.

```python
def find_path(bst, n):
    ""
    >>> bst = BST(4, BST(2, BST(1)), BST(5))
    >>> find_path(bst, 1)
    [4, 2, 1]
    >>> find_path(bst, 2)
    [4, 2]
    ""
    if _________________________________________________________________
    " " "
    elif _____________________________________________________________
    " " "
    else:
    " " "

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, self.right = left, 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):  # Returns the maximum element in the tree
    if self.right is BST.empty:
        return self.entry
    return self.right.max

@property
def min(self):  # Returns the minimum element in the tree
    if self.left is BST.empty:
        return self.entry
    return self.left.min
```
6. (11 points) Dan-scheme with the Cars

(a) (3 pt) Define the procedure `digit-prod`, which takes in a non-negative integer \( n \) and returns the product of the digits of \( n \). See the example usage for more details.

You may only use the lines provided. You may not need to fill all the lines.

*Hint:* The built-in *quotient* and *modulo* procedures return the quotient and remainder, respectively, of one number divided by another.

```
(define (digit-prod n)
  ...
)
```

```
scm> (quotient 5 3)
1
scm> (modulo 5 3)
2
scm> (digit-prod 12345)
120
scm> (digit-prod 200)
0
scm> (digit-prod 2222)
16
```

(b) (5 pt) Define the procedure `merge`, which takes in two sorted lists of numbers \( \text{lst1} \) and \( \text{lst2} \) and returns a new list that contains all the elements in the two lists in sorted order. See the example usage for more details.

You may only use the lines provided. You may not need to fill all the lines.

*Hint:* The built-in *append* procedure may be useful.

```
(define (merge lst1 lst2)
  ...
)
```

```
scm> (merge '(1 3 5) '(2 4 6))
(1 2 3 4 5 6)
scm> (merge () '(2 4 6))
(2 4 6)
scm> (merge '(5 7) '(2 4 6))
(2 4 5 6 7)
```
(c) (3 pt) For each of the following Scheme expressions, circle the correct number of calls that would be made to `scheme_eval` and `scheme_apply` when evaluating the expression in our Scheme interpreter (Project 4). Assume you are not using the tail-recursive `scheme_optimized_eval`.

\begin{align*}
\text{(1) } \quad & (- (* 6 11) 2 2 2) \\
\text{Number of calls to `scheme_eval`:} & \quad 1 \quad 4 \quad 7 \quad 9 \quad 12 \\
\text{Number of calls to `scheme_apply`:} & \quad 0 \quad 1 \quad 2 \quad 3 \quad 4 \\
\text{(2) } \quad & (if (+ 0 (- 1 1)) (+ 4 5) 4) \\
\text{Number of calls to `scheme_eval`:} & \quad 1 \quad 4 \quad 7 \quad 9 \quad 12 \\
\text{Number of calls to `scheme_apply`:} & \quad 0 \quad 1 \quad 2 \quad 3 \quad 4 \\
\text{(3) } \quad & ((\lambda (x) (* x x)) 57) \\
\text{Number of calls to `scheme_eval`:} & \quad 1 \quad 4 \quad 7 \quad 9 \quad 12 \\
\text{Number of calls to `scheme_apply`:} & \quad 0 \quad 1 \quad 2 \quad 3 \quad 4
\end{align*}
7. (8 points) Let to Sam-da

In the Scheme project, you wrote a procedure `let-to-lambda` that took in a Scheme expression as a list and transformed all `let` expressions within it into equivalent `lambda` expressions. We will now do the same thing in Logic. Define the incomplete facts below to complete the `let-to-lambda` relation, which relates a Scheme expression to the equivalent expression with no `let` expressions. See the example usage on the next page for more details.

Symbolic programming is very powerful in Logic. Our `let-to-lambda` will work the exact same way as the `let-to-lambda` procedure in Scheme, with the tiny exception that we cannot use `let` as a variable name.

You may only use the lines provided. You may not need to fill all the lines.

Facts for the `equal`, `is-pair`, and `zip` relations have been defined for you, and you may find these relations useful. See the example usage for more details. **You may not assume that any other relations have been defined.**

```
(fact (equal ?x ?x))
(fact (is-pair (?car . ?cdr)))
(fact (zip () () ()))
(fact (zip (?f1 . ?r1) (?f2 . ?r2) ((?f1 ?f2) . ?r-zip))
  (zip ?r1 ?r2 ?r-zip))

logic> (query (is-pair (1 2 3)))
Success!
logic> (query (is-pair 1))
Failed.
logic> (query (zip ?lst1 ?lst2 ((a 1) (b 2))))
Success!
  lst1: (a b)  lst2: (1 2)
```

; atoms (expressions that are not pairs) do not need conversion
(fact (let-to-lambda ?x ?x)
  _________________________________________________________________)

; quoted expressions, even if they contain let, should not be converted
(fact (let-to-lambda (quote ?expr) (quote ?expr)))

; lets in the body of lambda expressions should be converted
(fact (let-to-lambda (lambda ?formals . ?body) (lambda ?formals . ?body-conv))
  (let-to-lambda _____________________________________________________))
; lets in the body of define expressions should be converted

(fact (let-to-lambda (define ?formals . ?body) (define ?formals . ?body-conv))
    (let-to-lambda ?body ?body-conv))

; lets like (let ((a 1)) a) should be converted into ((lambda (a) a) 1)
; remember that the bodies of lets can contain more lets
; remember that the arguments in let bindings can also contain more lets

(fact (let-to-lambda __________________________________________________)
    (zip ____________________________________________________________)
    (let-to-lambda __________________________________________________)
    (let-to-lambda _________________________________________________))

; check and convert pairs not in one of the above forms

(fact (let-to-lambda (?car1 . ?cdr1) (?car2 . ?cdr2))
    (not (equal ?car1 quote))
    (not (equal ?car1 lambda))
    (not (equal ?car1 define))
    (not (equal ?car1 let))
    (let-to-lambda ?car1 ?car2)
    (let-to-lambda ?cdr1 ?cdr2))

logic> (query (let-to-lambda (+ 1 2) ?conv))
Success!
conv: (+ 1 2)

logic> (query (let-to-lambda (let ((a 1) (b 2)) (+ a b)) ?conv))
Success!
conv: ((lambda (a b) (+ a b)) 1 2)

logic> (query (let-to-lambda (let ((a (let ((a 2)) a)) (b 2)) (+ a b)) ?conv))
Success!
conv: ((lambda (a b) (+ a b)) ((lambda (a) a) 2) 2)
8. (5 points) **Zhen-erators Produce Power**

Implement the generator function `powers_of_two` that iterates over the infinite sequence of non-negative integer powers of two, starting from 1. You must do this by selectively including elements from an infinite sequence of integers, created by calling the provided `integers` generator function.

**You may only use the lines provided. You may not need to fill all the lines.**

*Hint:* You may find the `drop` generator function useful.

```python
def integers(n):
    while True:
        yield n
        n += 1

def drop(n, s):
    for _ in range(n):
        next(s)
    for elem in s:
        yield elem

def powers_of_two(ints=integers(_______)):
    ""
    >>> p = powers_of_two()
    >>> [next(p) for _ in range(10)]
    [1, 2, 4, 8, 16, 32, 64, 128, 256, 512]
    ""
    curr = ____________________________
    yield ______________________________
    yield from __________________________
```
9. (2 points) Assorted Trivia-n

For the following four questions, choose two or more to answer. Each correct answer you provide is worth one point, but you can only earn a maximum of two points.

(a) (1 pt) What is one of the benefits that Apache Spark provides?

(b) (1 pt) In one sentence, describe a problem other than the halting problem that is undecidable.

(c) (1 pt) In one sentence, describe one reason why the Caesar cipher can be easily broken by a computer.

(d) (1 pt) In one sentence, what is a rollout in the context of reinforcement learning?

10. (0 points) We Must All Brain Together

In the box below, write a positive integer. The student who writes the lowest unique integer will receive one extra credit point. In other words, write the smallest positive integer that you think no one else will write. However, if no one’s answer is unique, then everyone receives one extra credit point. So an optimal solution would be, for example, if everyone wrote 1. Do you trust your fellow students?

11. (0 points) What a Marvelous Summer

The staff have used the letters of this exam to encode a message for you! Thank you for a fantastic semester. Write the decoded message in the box below. (This isn’t worth any extra credit.)