Lecture #10: Sequences to Trees
Review: Sequence Comprehension

- **Syntax:**

  ```python
  [ <expr> for <var> in <sequence expr> ]
  [ <expr> for <var> in <sequence expr> if <boolean expression> ]
  ```

- **Examples:**

  ```python
  >>> [ 2**x for x in range(5) ]
  [1, 2, 4, 8, 16 ]
  >>> L = [5, 7, 8, 10, 6, 8, 7, 4, 9, 8]
  >>> [ x for x in L if x % 2 == 1 ]
  [ 5, 7, 7, 9 ]
  ```

- **In fact, the syntax is more general:**

  ```python
  >>> [(x, y) for x in range(2) for y in range(3)]
  [((0, 0), (0, 1), (0, 2), (1, 0), (1, 1), (1, 2))
  >>> # Still one-dimensional; y varies fastest
  ```
Representing Multi-Dimensional Structures

• How do we represent a two-dimensional table (like a matrix)?

  • Answer: use a **sequence of sequences** (typically a list of lists or tuple of tuples).

• The same approach is used in C, C++, and Java.

• Example:

  \[
  \begin{bmatrix}
  1 & 2 & 0 & 4 \\
  0 & 1 & 3 & -1 \\
  0 & 0 & 1 & 8
  \end{bmatrix}
  \]

  becomes

  \[
  ( ( 1, 2, 0, 4 ), ( 0, 1, 3, -1 ), (0, 0, 1, 8) )
  \]

  # or

  \[
  [ [ 1, 2, 0, 4 ], [ 0, 1, 3, -1 ], [0, 0, 1, 8] ]
  \]

  # or (for old Fortran hands):

  \[
  [ [ 1, 0, 0 ], [ 2, 1, 0 ], [ 0, 3, 1 ], [ 4, -1, 8 ]]\]
def multiplication_table(rows, cols):
    """A ROWS x COLS multiplication table where row x, column y (element [x][y]) contains xy. Example:
    >>> multiplication_table(4, 3)
    [[0, 0, 0], [0, 1, 2], [0, 2, 4], [0, 3, 6]]
    """
    return ________________________________
def multiplication_table(rows, cols):
    """A ROWS x COLS multiplication table where row x, column y
    (element [x][y]) contains xy. Example:
    >>> multiplication_table(4, 3)
    [[0, 0, 0], [0, 1, 2], [0, 2, 4], [0, 3, 6]]
    """
    return [ for row in range(rows) ]
def multiplication_table(rows, cols):
    """A ROWS x COLS multiplication table where row x, column y
    (element [x][y]) contains xy. Example:
    >>> multiplication_table(4, 3)
    [[0, 0, 0], [0, 1, 2], [0, 2, 4], [0, 3, 6]]
    """
    return [ [ row * col for col in range(cols) ]
             for row in range(rows) ]
Problem: Creating a Triangular Array

- There's no reason the rows in a 2D list must have the same length.

```python
def triangle(rows):
    """A ROWSxROWS lower-triangular array containing "*"s.
    >>> triangle(4)
    [[‘*’], [‘*’, ‘*’], [‘*’, ‘*’, ‘*’], [‘*’, ‘*’, ‘*’, ‘*’]]
    """
```
Problem: Creating a Triangular Array (II)

There's no reason the rows in a 2D list must have the same length.

```python
def triangle(rows):
    """A ROWSxROWS lower-triangular array containing "*"s.
    >>> triangle(4)
    [['*'], ['*', '*'], ['*', '*', '*'], ['*', '*', '*', '*']]
    """
    return [["*" for c in range(k+1)] for k in range(rows)]
```
**Variation: Creating a Numbered Triangular Array**

- This time, use numbers instead of asterisks.

```python
def numbered_triangle(rows):
    """A ROWSxROWS lower-triangular array whose elements
    are integers, starting at 0 going left-to-right,
    up-to-down."
    >>> numbered_triangle(3)
    [[0], [1, 2], [3, 4, 5]]"
```
Creating a Numbered Triangular Array (II)

- This time, use numbers instead of asterisks.

```python
def numbered_triangle(rows):
    """A ROWSxROWS lower-triangular array whose elements are integers, starting at 0 going left-to-right, up-to-down.
    >>> numbered_triangle(3)
    [ [ 0 ], [ 1, 2 ], [ 3, 4, 5 ] ]"
    def first(row):
        """The ROWth triangular number.""
        return (row * row + row) // 2
    return ____________________________
```
This time, use numbers instead of asterisks.

def numbered_triangle(rows):
    """A ROWSxROWS lower-triangular array whose elements are integers, starting at 0 going left-to-right, up-to-down.
    >>> numbered_triangle(3)
    [ [ 0 ], [ 1, 2 ], [ 3, 4, 5 ] ]"

def first(row):
    """The ROWth triangular number."""
    return (row * row + row) // 2

return [ [ x for x in range(first(row), first(row) + row + 1) ]
    for row in range(rows) ]
And Why Stop There? Trees

- We can have rows of rows, and rows of rows of rows of rows, but we needn’t stop at an arbitrary limit.
- Result can be thought of as a form of tree.
- E.g: One way to see [[[3, 7, 8], 9], 10]:

![Diagram of a tree]

- The circles are called vertices or nodes, connected by edges.
- Top node is the root, bottom ones are leaves, non-leaves are inner nodes.
- Each node is itself the root of a subtree; those immediately below are its children.
Trees With Labels

• Generally, each node (not just leaves) can have additional data, known as a label:

![Tree with labels]

• How can we represent this structure?
Tree Interface

• Evidently, trees have labels and children, suggesting an API like this:

```python
def make_tree(label, branches = []):
    """A (sub)tree with given LABEL at its root, whose children are KIDS.""

def label(tree):
    """The label on TREE.""

def branches(tree):
    """The children of TREE (each a tree).""

def isleaf(tree):
    """True if TREE is a leaf node.""
```

• Representation?
def make_tree(label, kids = []):
    """A (sub)tree with given LABEL at its root, whose children are KIDS.""
    return [ label ] + kids

def label(tree):
    """The label on TREE.""
    return tree[0]

def branches(tree):
    """The children of TREE (each a tree).""
    return tree[1:]

def isleaf(tree):
    """True if TREE is a leaf node.""
    return len(tree) == 1

Alternatives?
def make_tree(label, kids = []):
    """A (sub)tree with given LABEL at its root, whose children are KIDS.""
    return (label, kids)

def label(tree):
    """The label on TREE.""
    return tree[0]

def branches(tree):
    """The children of TREE (each a tree).""
    return tree[1]

def isleaf(tree):
    """True if TREE is a leaf node.""
    return len(branches(tree)) == 0
Algorithms on Trees

- Trees have a recursive structure. A tree is:
  - A label and
  - Zero or more children, each a tree.

- Recursive structure implies recursive algorithm.
def count_leaves(tree):
    """The number of leaf nodes in TREE."""

    if ____________:
        return ____________

    else:
        return sum(______________________________)
def count_leaves(tree):
    """The number of leaf nodes in TREE."""

    if isleaf(tree):
        return 1

    else:

        return sum(_______________________________)
def count_leaves(tree):
    """The number of leaf nodes in TREE.""

    if isleaf(tree):

        return 1

    else:

        return sum(map(count_leaves, branches(tree)))

    # or
    
    return sum([ count_leaves(x) for x in branches(tree) ])
Evaluating an Expression

- Trees can represent arithmetic expressions.
- Leaf labels are numbers; other labels are operators (+, -, *, /)
- So \((3 + 4) \times (9 - 6)\) is

\[
\begin{array}{c}
\ast \\
\downarrow \\
+ \\
\downarrow \\
3 & 4 \\
\downarrow \\
- \\
\downarrow \\
9 & 6
\end{array}
\]

- Can we write a program to evaluate such an expression tree (i.e., return the value of the expression it represents)?
Evaluation

def value(expr):
    """Return the value of the expression represented by the expression tree expr
    >>> value(make_tree("*", [ make_tree("+", [make_tree(3), make_tree(4)]), ... make_tree("-", [make_tree(9), make_tree(6)])])
    36
    """
    if isleaf(expr):
        return ______________________

    elif ______________________:
        return ______________________

    ...?

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def value(expr):
    """Return the value of the expression represented by the
    expression tree expr.
    >>> value(make_tree("*", [ make_tree("+", [make_tree(3), make_tree(4)]),
                        ... make_tree("-", [make_tree(9), make_tree(6)])])
    21
    ""
    if isleaf(expr):
        return label(expr)

    elif label(expr) == '+':
        return value(branches(expr)[0]) + value(branches(expr)[1])

    ...?