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SICP

God's Programming Book

Lecture-11 Trees

Trees

Slides Adapted from cs61a of UC Berkeley

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Box-and-Pointer Notation

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The Closure Property of Data Types

- A method for combining data values satisfies the closure property if: The result of combination can itself be combined using the same method
- Closure is powerful because it permits us to create hierarchical structures
- Hierarchical structures are made up of parts, which themselves are made up of parts, and so on

Lists can contain lists as elements (in addition to anything else)

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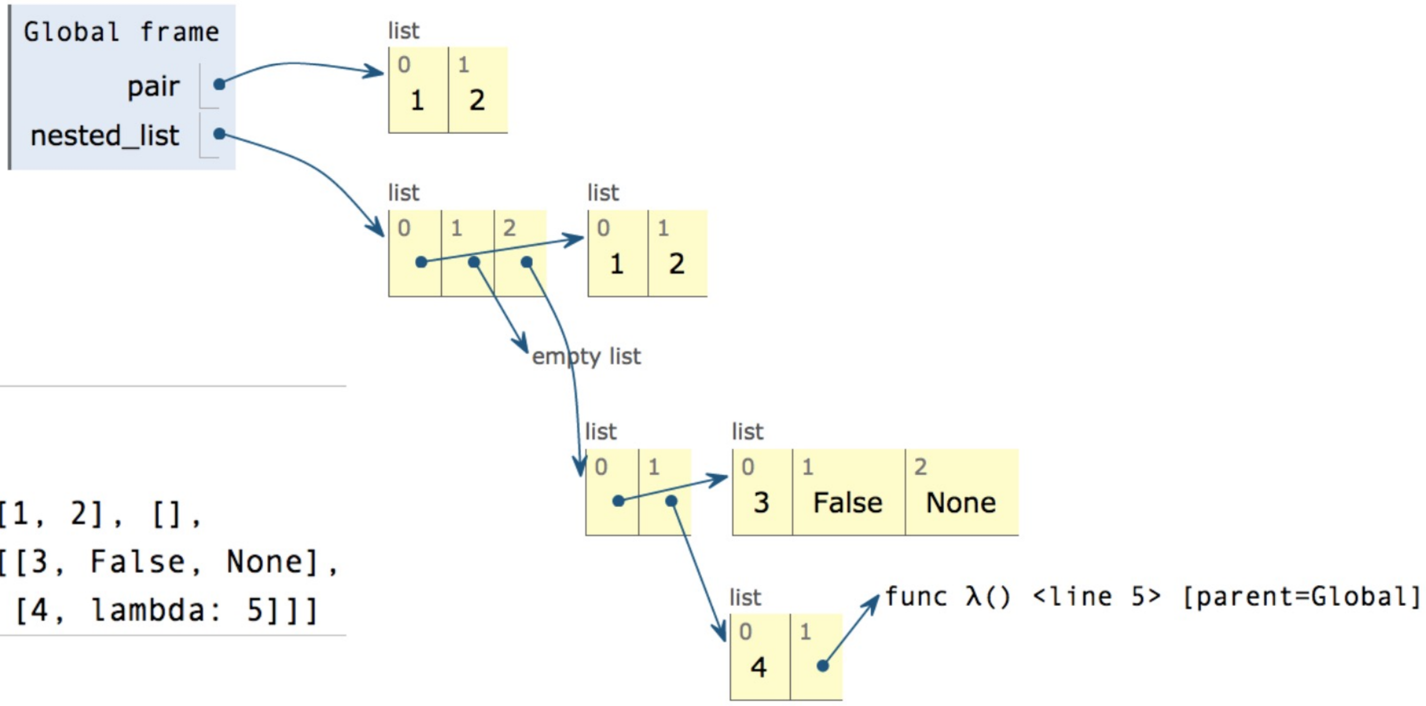
Box-and-Pointer Notation in Environment Diagrams

Lists are represented as a row of index-labeled adjacent boxes, one per element
Each box either contains a primitive value or points to a compound value




```
pair = [1, 2]

nested_list = [[1, 2], [],
               [[3, False, None],
                [4, lambda: 5]]]
```

Slicing

(Demo)

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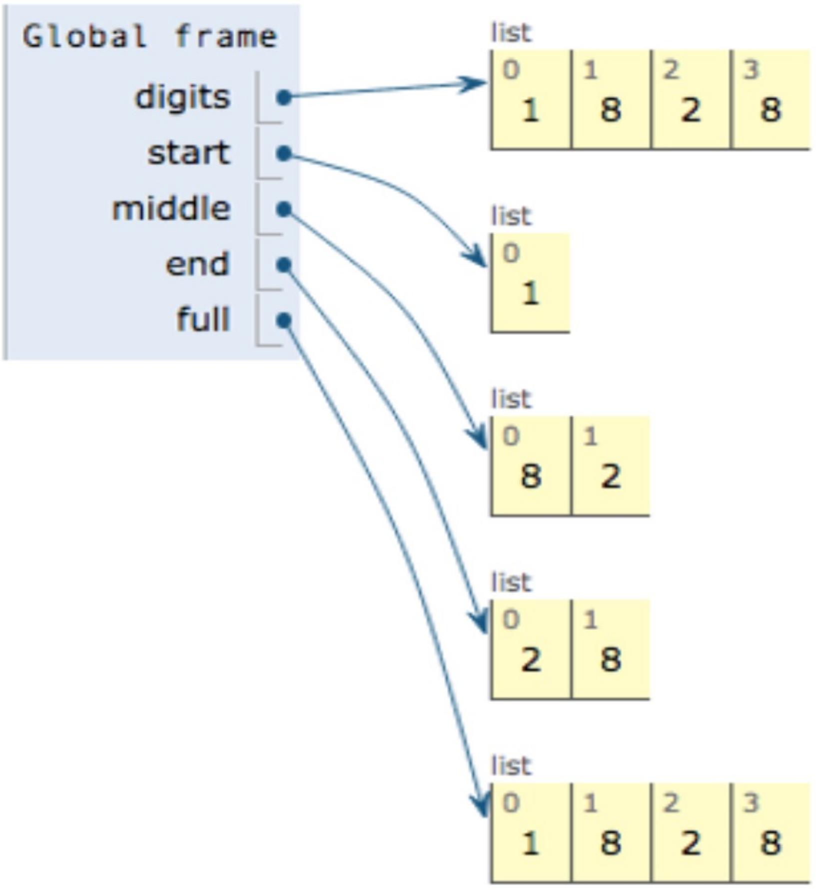
Slicing Creates New Values

```
digits = [1, 8, 2, 8]
start = digits[:1]
middle = digits[1:3]
end = digits[2:]
full = digits[:]
```



Processing Container Values

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Sequence Aggregation

Several built-in functions take iterable arguments and aggregate them into a value

- sum(iterable[, start]) -> value

  Return the sum of a 'start' value (default: 0) plus an iterable of numbers.

- max(iterable[, key=func]) -> value

  max(a, b, c, ...[, key=func]) -> value

  With a single iterable argument, return its largest item.

  With two or more arguments, return the largest argument.

- all(iterable) -> bool

  Return True if bool(x) is True for all values x in the iterable. If the iterable is empty, return True.

Trees

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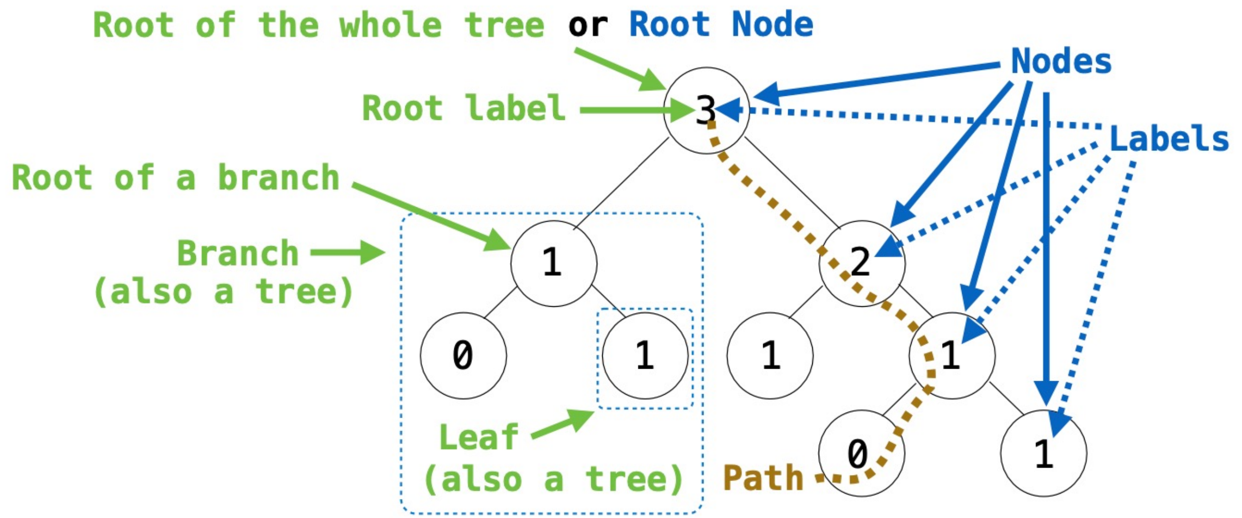
Tree Abstraction



Recursive description (wooden trees):

A **tree** has a **root label** and a list of **branches**

Each **branch** is a **tree**

A **tree** with zero **branches** is called a **leaf**

A **tree** starts at the **root**

Relative description (family trees):

Each location in a tree is called a **node**

Each **node** has a **label** that can be any value

One node can be the **parent/child** of another

The top node is the **root node**

People often refer to labels by their locations: "each parent is the sum of its children"

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Implementing the Tree Abstraction

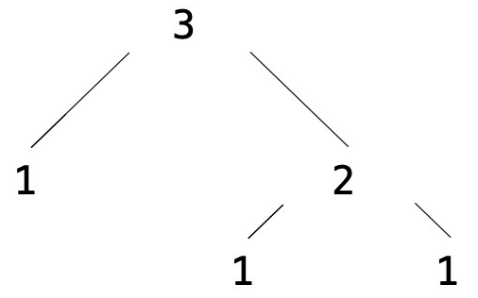
```
def tree(label, branches=[]):
    for branch in branches:
        assert is_tree(branch)
    return [label] + list(branches)

def label(tree):
    return tree[0]

def branches(tree):
    return tree[1:]

def is_tree(tree):
    if type(tree) != list or len(tree) < 1:
        return False
    for branch in branches(tree):
        if not is_tree(branch):
            return False
    return True
```

Verifies the tree definition

Creates a list from a sequence of branches

Verifies that tree is bound to a list

- A **tree** has a root **label** and a list of **branches**
- Each branch is a tree




```
>>> tree(3, [tree(1),
...          tree(2, [tree(1),
...                   tree(1)])])
[3, [1], [2, [1], [1]]]

def is_leaf(tree):
    return not branches(tree)
```

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Tree Processing

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Tree Processing Uses Recursion

Processing a leaf is often the base case of a tree processing function

The recursive case typically makes a recursive call on each branch, then aggregates

```
def count_leaves(t):
    """Count the leaves of a tree."""
    if is_leaf(t):
        return 1
    else:
        branch_counts = [count_leaves(b) for b in branches(t)]
        return sum(branch_counts)
```

Discussion Question

Implement leaves, which returns a list of the leaf labels of a tree
Hint: If you sum a list of lists, you get a list containing the elements of those lists

```
>>> sum([ [1], [2, 3], [4] ], [])
[1, 2, 3, 4]
>>> sum([ [1] ], [])
[1]
>>> sum([ [[1]], [2] ], [])
[[1], 2]
```

```
def leaves(tree):
    """Return a list containing the leaf labels of tree.

    >>> leaves(fib_tree(5))
    [1, 0, 1, 0, 1, 1, 0, 1]
    """
    if is_leaf(tree):
        return [label(tree)]
    else:
        return sum(List of leaf labels for each branch, [])
```

```
branches(tree)                          [b for b in branches(tree)]

leaves(tree)                            [s for s in leaves(tree)]

[branches(b) for b in branches(tree)]   [branches(s) for s in leaves(tree)]

[leaves(b) for b in branches(tree)]     [leaves(s) for s in leaves(tree)]
```

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Creating Trees

A function that creates a tree from another tree is typically also recursive

```
def increment_leaves(t):
    """Return a tree like t but with leaf labels incremented."""
    if is_leaf(t):
        return tree(label(t) + 1)
    else:
        bs = [increment_leaves(b) for b in branches(t)]
        return tree(label(t), bs)


def increment(t):
    """Return a tree like t but with all labels incremented."""
    return tree(label(t) + 1, [increment(b) for b in branches(t)])
```

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Example: Printing Trees

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Example: Summing Paths

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Thanks for Listening