Lecture #12: Mutable Data
Using Mutability For Construction: map_rlist Revisited

• Even if we never change a data structure once it is constructed, mutation may be useful during its construction.

• Example: constructing a recursive list. In lecture #9, I said that iterative construction of the result of map_rlist was not as easy as for getitem_rlist, compared to recursive version.

• But it's reasonably easy if we mutate items during construction:

```python
def map_rlist(f, s):
    """The rlist of values F(x) for each x in rlist S (in the same order.)""
    if (isempty(s)):
        return s
    result = last = make_rlist(f(first(s)))
    s = rest(s)
    while not isempty(s):
        set_rest(last,
            make_rlist(f(first(s))))
        last, s = rest(last), rest(s)
    return result
```
map_rlist Illustrated

```python
def map_rlist(f, s):
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        set_rest(last,
            make_rlist(f(first(s))))
        last, s = rest(last), rest(s)
    return result

L = make_rlist(-1,
               make_rlist(-2,
                          make_rlist(-3)))
Q = map_rlist(abs, L)
```

L: \[ L = [\text{rlist}(-1, \text{rlist}(-2, \text{rlist}(-3)))] \]

s: \[ s = [\text{rlist}(-1, -2, -3)] \]

result: \[ \text{rlist}(-1, -2, -3) \]

last: \[ \text{rlist}(-1, -2, -3) \]
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L = make_rlist(-1, make_rlist(-2, make_rlist(-3)))
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```

L:
(1)
-1
-2
-3

s:
(result:
 1

last: -
def map_rlist(f, s):
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    s = rest(s) ←
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        set_rest(last,
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        last, s = rest(last), rest(s)
    return result

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map_rlist Illustrated (IV)

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        return s
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    s = rest(s)
    while not isempty(s):
        set_rest(last,
            make_rlist(f(first(s)))) ←
        last, s = rest(last), rest(s)
    return result

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        set_rest(last,
            make_rlist(f(first(s))))  ⇐
        last, s = rest(last), rest(s)
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        last, s = rest(last), rest(s)
    return result

L = make_rlist(-1, make_rlist(-2, make_rlist(-3)))
Q = map_rlist(abs, L)
```

\[ L: -1 \rightarrow -2 \rightarrow -3 \]
\[ s: \]
\[ \text{result}: 1 \rightarrow 2 \rightarrow 3 \]
\[ \text{last}: \]

\[ Q = \text{map_rlist}(\text{abs}, L) \]
map_rlist Illustrated (VIII)

```python
def map_rlist(f, s):
    """The rlist of values F(x) for each x in rlist S (in the same order.)""
    if (isempty(s)):
        return s
    result = last = make_rlist(f(first(s)))
    s = rest(s)
    while not isempty(s):
        set_rest(last,
            make_rlist(f(first(s))))
        last, s = rest(last), rest(s)
    return result
```

L = make_rlist(-1,
    make_rlist(-2,
        make_rlist(-3)))
Q = map_rlist(abs, L) ⇐

L: -1 -2 -3
Q: 1 2 3

• In building Q, we modified rlists we had previously created,…
• … but map_rlist is non-destructive; the original list is intact.
We've seen functions as immutable data items.

For example, in lecture #8, we defined

```python
def cons(left, right):
    return lambda which: left if which else right

def left(pair): return pair(True)
def right(pair): return pair(False)
```

Can one do `set_left` and `set_right` with this representation?
Mutation By Assignment?

- Why not use assignment?

```python
def cons(left, right):
    def data(which, value=None):
        if which == 0: return left
        elif which == 1: return right
        elif which == 2: left = value
        else: right = value
    return data

def left(pair): return pair(0)
def right(pair): return pair(1)
def set_left(pair, v): return pair(2, v)
def set_right(pair, v): return pair(3, v)
```

- This does not work. Why not?
Assignment Up Until Now

• By default, an assignment in Python (including = and for...in), binds a name in the current environment frame.

• Not always what you want. E.g.,

```python
def cons(left, right):
    def data(which, value=None):
        if which == 0: return left
        elif which == 1: return right
        elif which == 2: left = value  # Doesn't work
        else: right = value  # Doesn't work
    return data
A = cons(1, 2)
A(2, 4)  # Try to assign 4 to left
```

• The attempt to assign to `left` creates a new local (uninitialized) variable on each call to `A`, which vanishes when the call returns.
The nonlocal Declaration

• To fix this problem, we introduce a new declaration: `nonlocal`:

```python
def cons(left, right):
    def data(which, value=None):
        nonlocal left, right
        if which == 0: return left
        elif which == 1: return right
        elif which == 2: left = value  # Assigns to enclosing left
        else: right = value  # Assigns to enclosing right
        return data
A = cons(1, 2)
A(2, 4)  # Try to assign 4 to left
```

• The effect of `nonlocal` is that all references `left` and `right` immediately within `data` refer to the ordinary local variable or parameter in the smallest enclosing function definition, rather than to any local variable in `data`.

• [Any `nonlocal` declarations in functions enclosing `data` would have no effect.]
Global Declaration

- *nonlocal* does not refer to *global variables*—those defined outside of any function.

- Instead, Python has a *global* declaration that marks names assigned in the function as referring to variables in the global scope.

- These variables need not previously exist, and must not already be local in the function.

```python
>>> def f():
    ...   global x, y
    ...   x = 4  # Sets global x
    ...   y = 2  # Creates and sets global y
    ...   g()
>>> x = 1
>>> f()
>>> print(x, y)
4 2
```
Neither `global` nor `nonlocal` affects variables in more deeply nested functions:

```python
>>> def f():
...     global x
...     def g():
...         x = 3  # Local x
...         g()
...         return x

>>> x = 0
>>> f()
0  # global declaration does not apply to outer x
```
More on Building Objects With State

• The term *state* applied to an object or system refers to the current information content of that object or system.

• Include values of attributes and, in the case of functions, the values of variables in the environment frames they link to.

• Some objects are *immutable*, e.g., integers, booleans, floats, strings, and tuples that contain only immutable objects. Their state does not vary over time, and so objects with identical state may be substituted freely.

• Other objects in Python are (at least partially) *mutable*, and substituting one object for another with identical state may not work as expected if you incorrectly expect that both objects will continue to have the same value.

• Have just seen that we can build mutable objects from functions.
Mutable Objects With Functions (continued)

- How about dice?

```python
import time
def make_dice(sides = 6, seed = None):
    """A new 'sides'-sided die.""
    if seed == None:
        seed = int(time.time() * 100000)
    a, c, m = 25214903917, 11, 2**48  # From Java
    def die():
        nonlocal seed
        seed = (a*seed + c) % m
        return seed % sides + 1
    return die

>>> d = make_dice(6, 10002)
>>> d()
6
>>> d()
5
```
Truth: We Don’t Usually Do It This Way!

• Usually, if we want an object with mutable state, we use one of Python’s mutable object types,

• Let’s look at a couple of standard ones.
Tuples and Lists

- Python tuples are a kind of function, mapping non-negative integers (indices) in a finite range to values.

- One cannot change the value at a given index, but can only create a new tuple:

```python
>>> A = B = (1, 2, 3, 4, 5, 6)
>>> B = A[:2] + (42,) + A[3:] + (7, 8)
>>> A
(1, 2, 3, 4, 5, 6)
>>> B
(1, 2, 42, 4, 5, 6, 7, 8)
```

- Lists are a kind of *mutable function*, where the value at an index may be changed, and new items added.

```python
>>> A = B = [1, 2, 3, 4, 5, 6]
>>> A
[1, 2, 42, 4, 5, 6, 7, 8]
>>> B
[1, 2, 42, 4, 5, 6, 7, 8]
```
Dictionaries

- **Dictionaries** *(type dict)* are mutable mappings from one set of values (called *keys*) to another.

**Constructors:**

```python
>>> {}  # A new, empty dictionary
>>> { 'brian': 29, 'erik': 27, 'zack': 18, 'dana': 25 }  
{'brian': 29, 'erik': 27, 'dana': 25, 'zack': 18}
>>> L = ('aardvark', 'axolotl', 'gnu', 'hartebeest', 'wombat')
>>> successors = { L[i-1] : L[i] for i in range(1, len(L)) }  
>>> successors
{'aardvark': 'axolotl', 'hartebeest': 'wombat',  
'aardvark': 'axolotl', 'hartebeest': 'wombat',  
'axolotl': 'gnu', 'hartebeest': 'wartebeest'}
```

**Queries:**

```python
>>> len(successors)  
4
>>> 'gnu' in successors
True
>>> 'wombat' in successors
False
```
Dictionary Selection and Mutation

- Selection and Mutation

```python
>>> ages = { 'brian': 29, 'erik': 27, 'zack': 18, 'dana': 25 }
>>> ages['erik']
27
>>> ages['paul']
...
KeyError: 'paul'
>>> ages.get('paul', '?')  # Supply default value
'?'
```

- Mutation:

```python
>>> ages['erik'] += 1; ages['john'] = 56
ages
{'brian': 29, 'john': 56, 'erik': 28, 'dana': 25, 'zack': 18}
```
Dictionary Keys

• Unlike sequences, ordering is not defined.

• Keys must typically have immutable types that contain only immutable data [can you guess why?] that have a \_hash\_ method. Take CS61B to find out what’s going on here.

• When converted into a sequence, get the sequence of keys:

```python
>>> ages = { 'brian' : 29, 'erik': 27, 'zack': 18, 'dana': 25 }
>>> list(ages)
[‘brian’, ‘erik’, ‘dana’, ‘zack’]
>>> for name in ages: print(ages[name], end=",")
29, 27, 25, 18,
```
def frequencies(L):
    """A dictionary giving, for each w in L, the number of times w appears in L.
    >>> frequencies(['the', 'name', 'of', 'the', 'name', 'of', 'the',
                    ... 'song'])
    {'of': 2, 'the': 3, 'name': 2, 'song': 1}
    """
def frequencies(L):
    """A dictionary giving, for each w in L, the number of times w appears in L.
    >>> frequencies(['the', 'name', 'of', 'the', 'name', 'of', 'the', ...
    'song'])
    {'of': 2, 'the': 3, 'name': 2, 'song': 1}
    """

    for ________________:
        __________________________

    return ______________________
A Dictionary Problem (III)

```python
def frequencies(L):
    """A dictionary giving, for each w in L, the number of times w appears in L.
    >>> frequencies(['the', 'name', 'of', 'the', 'name', 'of', 'the', ...
    'song'])
    {'of': 2, 'the': 3, 'name': 2, 'song': 1}
    """
    result = {}
    for w in L:
        result[w] = result.get(w, 0) + 1
    return result
```

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def frequencies(L):
    """A dictionary giving, for each w in L, the number of times w appears in L.
    >>> frequencies(['the', 'name', 'of', 'the', 'name', 'of', 'the', ...
                    'song'])
    {'of': 2, 'the': 3, 'name': 2, 'song': 1}
    """
    result = {}

    for w in L:
        result[w] = result.get(w, 0) + 1

    return result
def frequencies(L):
    """A dictionary giving, for each w in L, the number of times w appears in L."
    >>> frequencies(['the', 'name', 'of', 'the', 'name', 'of', 'the',
                    ...             'song'])
    {'of': 2, 'the': 3, 'name': 2, 'song': 1}
    """

    result = {}

    for w in L:
        result[w] = result.get(w, 0) + 1

    return result

Challenge: Do this in one line (I used 51 characters, including the return).
Using Only Keys

• Suppose that all we need are the keys (values are irrelevant):

```python
def is_duplicate(L):
    """True iff L contains a duplicated item.""
    items = {}
    for x in L:
        if x in items: return True
        items[x] = True    # Or any value
    return False

def common_keys(D0, D1):
    """Return dictionary containing the keys common to D0 and D1.""
    result = {}
    for x in D0:
        if x in D1: result[x] = True
    return result
```

• These dictionaries function as sets of values.
Sets

Rather than force us to use dictionaries like this ("wasting" the values), Python supplies *sets*:

```python
>>> rainbow = {'Red', 'Orange', 'Yellow', 'Green', 'Blue', 'Indigo', 'Violet'}
>>> nothing = set()  # Empty set (sorry; {} was already taken)
>>> from_list = set([1, 2, 3])  # Same as { 1, 2, 3 }
>>> A = { -2, -1, 0, 1, 2, 3, 4, 5 }
>>> B = { 0, 2, 4, 6, 8 }
>>> A.add(-3)  # Mutable
>>> A | B     # Union
{0, 1, 2, 3, 4, 5, 6, 8, -2, -3, -1}  # Order undefined
>>> A & B    # Intersection
{0, 2, 4}
>>> A - B    # Set difference
{1, 3, 5, -1, -3, -2}
>>> A ^ B    # Symmetric difference
{1, 3, 5, 6, 8, -1, -3, -2}
>>> 1 in B   # Membership ( 1 ∈ B )
False
>>> A |= { 42 }  # Updating assignment (also \&, -, etc.)
>>> A
{0, 1, 2, 3, 4, 5, 42, -2, -3, -1}
```
Using Sets

- Can improve on previous use of dictionaries:

  ```python
def is_duplicate(L):
    """True iff L contains a duplicated item."""
    return len(L) != len(set(L))

def common_keys(D0, D1):
    """Return set containing the keys common to D0 and D1."""
    return D0.keys() & D1.keys()
```

- When a dictionary is iterated over in a for loop, or turned into a list or set, the values it provides are its keys, so we can write the last line above as

  ```python
  return set(D0) & set(D1)
  ```