Lecture #14: Mutable Data, Lists, and Dictionaries

Local, Global, and Nonlocal

- By default, an assignment in Python (including = and `for...in`), binds a name in the current environment frame (creating an entry if needed).
- But within any function, one may declare particular variables to be *nonlocal* or *global*:

```
>>> x0, y0 = 0, 0
>>> def f1(x1):
...     y1 = 0
...     def f2(x2):
...         nonlocal x1
...         global x0
...         x0, x1 = 1, 2
...         y0, y1 = 1, 2
...         print(x0, x1, y0, y1)
...     f2(0)
...     print(x0, x1, y0, y1)
...
>>> f1(0)
1, 2, 1, 2
1, 2, 0, 0
>>> print(x0, y0)
1, 0
```

Local, Global, and Nonlocal (II)

- **global** marks names assigned to in the function as referring to variables in the global scope, not new local variables. These variables need not previously exist, and should not already have been used in the function.
- nonlocal marks names assigned to in function as referring to variables in some enclosing function. These variables must previously exist, and may not be local.
- **global** is an old feature of Python. **nonlocal** was introduced in version 3 and immediate predecessors.
- Neither declaration affects variables in nested functions:

```
>>>def f():
...     global x
...     def g():  x = 3  # Local x
...     g()
...     return x
>>> x = 0
>>> f()
0
```

State

- The term *state* applied to an object or system refers to the current information content of that object or system.
- In the case of functions, this includes 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 expect that both objects continue to have the same value.

Immutable Data Structures from Functions

- Back in lecture 10, saw how to build immutable objects from functions. Here's how we might implement pairs:

```
>>> def make_pair(left, right):
...     def result(key):
...         if key == 0:
...             return left
...         else:
...             return right
...     return result
>>> p = make_pair(4, 7)
>>> p(0)
4
>>> p(1)
7
```

- Results of make_pair are immutable, since left and right are inaccessible outside make_pair and result.

Mutable Data Structures from Functions

- Using nonlocal, we can make mutable data types as well.
- Example: a counter that increments on each call.

```
>>> def make_counter(value):
...     """A counter that increments and returns its value on each
...     call, starting with VALUE."""
...     def result():
...         nonlocal value
...         value += 1
...         return value
...     return result
>>> c = make_counter(0)
>>> c()
1
>>> c()
2
```

Another Example

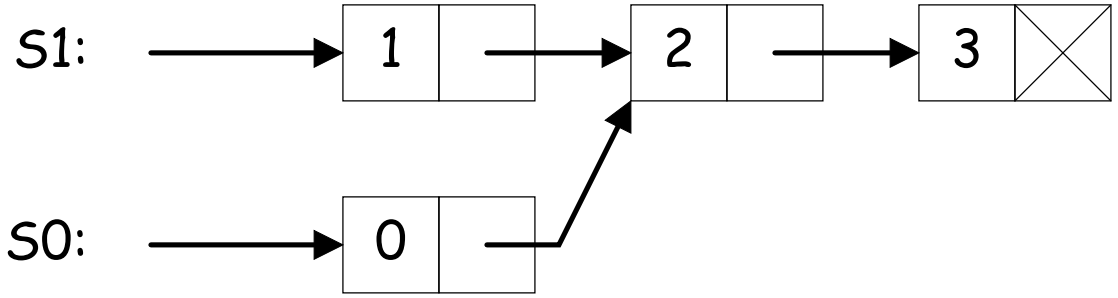
- Likewise, we could use the dispatching idea to implement *mutable rlists:*

```
>>> def mut_rlist(head, rest):
...     def result(key, newval=None):
...         nonlocal head, rest
...         if key == 0: return head
...         if key == 1: return rest
...         if key == 2: head = newval;
...         if key == 3: rest = newval;
...     return result
>>> def first(r): return r(0)
>>> def rest(r): return r(1)
>>> def set_first(r, v): return r(2, v)
>>> def set_rest(r, v): return r(3, v)
>>> r = mut_rlist(1, None)
>>> rest(r)  # None
>>> set_rest(r, mut_rlist(2, None))
>>> first(r)
1
>>> first(rest(r))
2
```

Referential Transparency and Immutable Structures

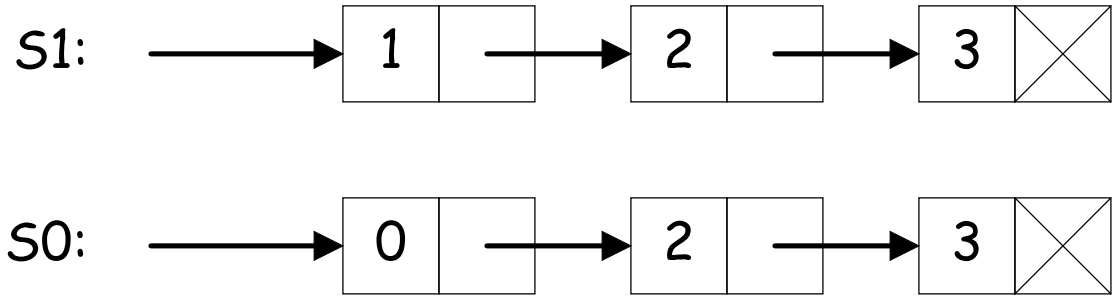
- Immutable values are generally *interchangeable:* one can *"substitute equals for equals."*
- The term *referential transparency* refers to this ability to refer to values by any equivalent expression anywhere.
- For our original (immutable) rlists, we can freely represent the two sequences [1, 2, 3] and [0, 2, 3] like this:

```
S2 = rlist(2, rlist(3, None))
S1 = rlist(1, S2)
S0 = rlist(0, S2)
```




```
   # or like this, substituting for S2:

S2 = rlist(2, rlist(3, None))
S1 = rlist(1,
           rlist(2, rlist(3, None))
S0 = rlist(0,
           rlist(2, rlist(3, None))
```

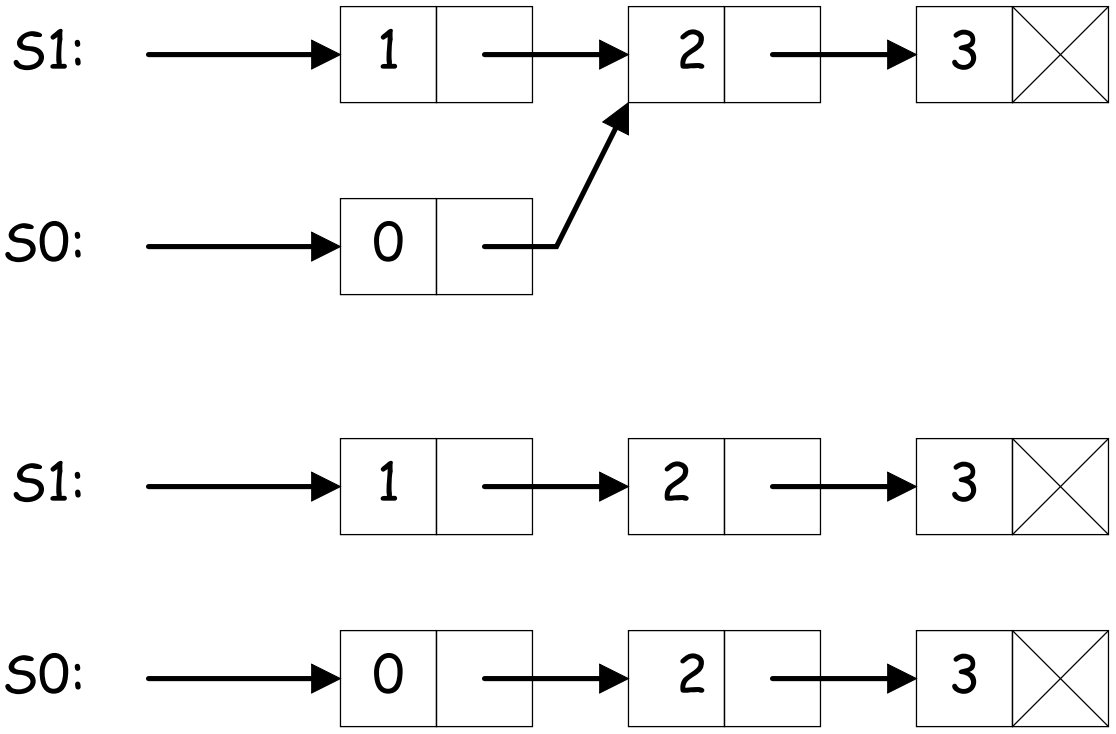


Mutable Structures are not Referentially Transparent

- Now consider mutable rlists:

```
>>> S2 = mut_rlist(2, rlist(3, None))
>>> S1 = mut_rlist(1, S2)
>>> S0 = mut_rlist(0, S2)
>>> set_first(rest(S0), 42)
>>> first(rest(S0))
42
>>> first(rest(S1))
42
```

```
S2 = mut_rlist(2, rlist(3, None))
S1 = mut_rlist(1,
        mut_rlist(2, rlist(3, None))
S0 = mut_rlist(0,
        mut_rlist(2, rlist(3, None))
>>> set_first(rest(S0), 42)
>>> first(rest(S0))
42
>>> first(rest(S1))
2
```



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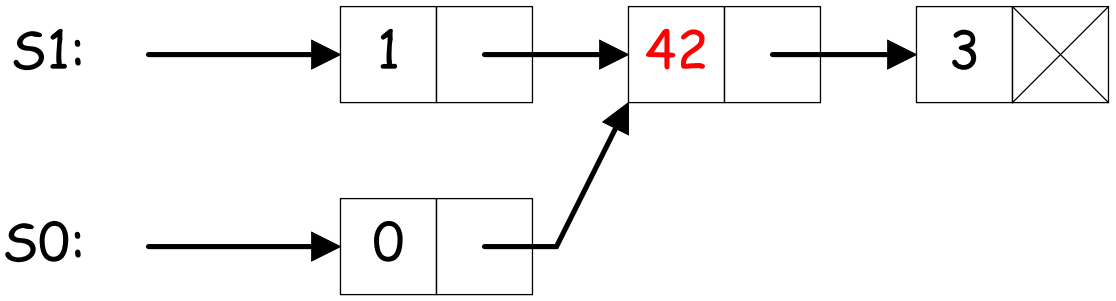


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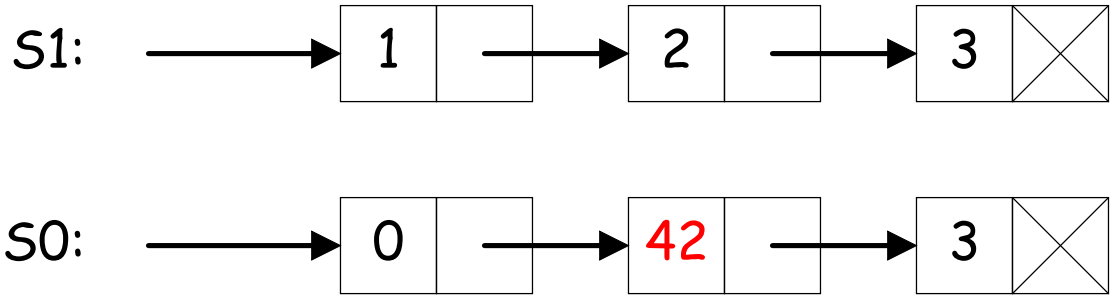
S1 = mut_rlist(1,
        mut_rlist(2, rlist(3, None))
S0 = mut_rlist(0,
        mut_rlist(2, rlist(3, None))
>>> set_first(rest(S0), 42)
>>> first(rest(S0))
42
>>> first(rest(S1))
2
```



So we *cannot* freely use either way of creating the lists and expect the same results.

Truth: We Don't Usually Build Structures This Way!

- Usually, if we want an object with mutable state, we use one of Python's mutable object types.
- We'll see soon how to create such types.
- But for now, let's look at some standard ones.

Lists

- Lists are mutable tuples, syntactically distinguished by `[...]`.
- Generally like tuples, but unlike tuples, we can assign to elements:

```
>>> x = [1, 2, 3]
>>> x[1] = 0
>>> x
[1, 0, 3]
```

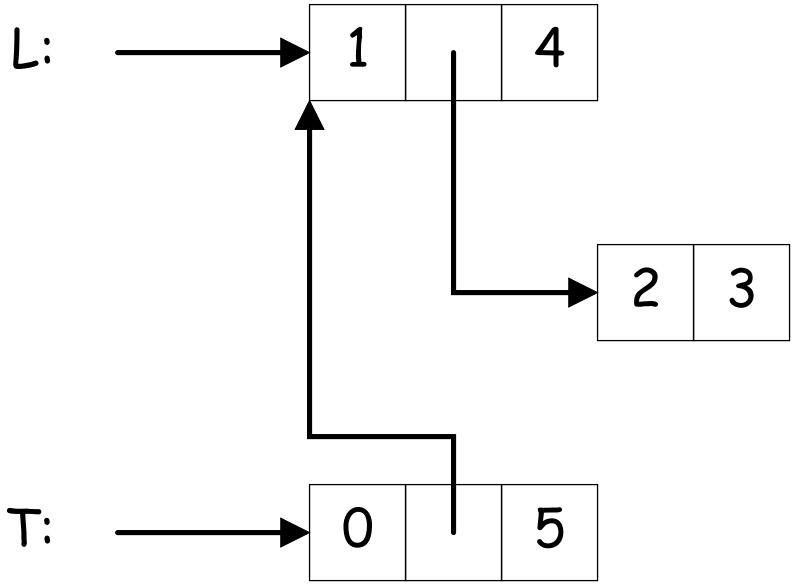
- And can also assign to slices:

```
>>> x = [1, 2, 3]
>>> x[1:2] = [6, 7, 8]  # Replace 2nd item
>>> x
[1, 6, 7, 8, 3]
>>> x[0:2] = []         # Remove first 2
>>> x
[7, 8, 3]
```

In Pictures

- Like rlists, Python lists and tuples are *referenced* entities.

```
L = [1, [2, 3], 4]
T = (0, L, 5)
```



- The values of L and T, as well as those of L[1] and T[1] are *references* (aka *pointers*), which we typically depict as arrows.
- Assignments, parameter passing, function returns, and list or tuple constructors all deal with references.
- In our interpreter, just about *all* Python values are references, even integers, but for immutable values, we can usually ignore the fact.

Object Identity Versus Equality

- The == operator is intended to test for *equality of content* or *equivalence of state*. Two separate entities (tuples, strings, lists) can therefore be ==.
- Sometimes (*BUT NOT OFTEN*) we need to see if two expressions in fact denote the same object.
- For this purpose, Python uses the operators `is` and `is not`.
- The `is` operator tests *equality of arrows*, whereas == tests *equality of what's at the ends of the arrows*.

```
>>> x = 1000000
>>> x == x + 1 - 1
True
>>> x is x + 1 - 1
False
>>> x = 100
>>> x == x + 1 - 1
True
>>> x is x + 1 - 1
True
```

```
>>> (1,) == (1,)
True
>>> (1,) is (1,)
False
>>> () == ()
True
>>> () is ()
True
```

```
>>> "a"*100 == "a"*100
True
>>> "a"*100 is "a"*100
False
>>> "a"*10 is "a"*10
True
```

WHAT'S GOING ON??

Object Identity Usually Irrelevant for Immutable Data

- The examples where `is` and `==` differ can differ from Python implementation to Python implementation.
- Runtime implementor is free to choose whether two expressions of literals that produce equal (==) values do so by producing identical (is) objects.
- This freedom results from the fact that, once equal, immutable values continue to be indistinguishable under equality, and other operations.
- Again, this is *Referential transparency.*
- So when we write

```
>>> x = (2, 3)
>>> L = (1, x)
```

  it doesn't matter whether we create a new copy of `x` to put into `L`, or use the same one.

- . . . *Unless* we use `is` (which is why we generally don't!).

Object Identity Is Important in Lists

```
>>> x = [1, 2]
>>> y = [0, x]
>>> x[0] = 5
>>> y
[0, [5, 2]]
>>> x = []
>>> y
?
```

Object Identity Is Important in Lists

```
>>> x = [1, 2]
>>> y = [0, x]
>>> x[0] = 5
>>> y
[0, [5, 2]]
>>> x = []
>>> y
[0, [5, 2]]  # Why doesn't y change?
```

Shared Structure

- Can make 2D lists, just as with tuples.
- What's the difference between the following ways to create an all-0 3x3 array?

```
Z1 = [ [0, 0, 0], [0, 0, 0], [0, 0, 0] ]
Z2 = [ [0, 0, 0] ] * 3
     # (For list expression E, E * 3 is computed by L + L + L,
     # where L is the value of E.)
Z3 = [ [0, 0, 0] for r in range(3) ]
Z4 = [ [0 for c in range(3)] for r in range(3) ]
```

Shared Structure

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     # (For list expression E, E * 3 is computed by L + L + L,
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Z3 = [ [0, 0, 0] for r in range(3) ]
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```

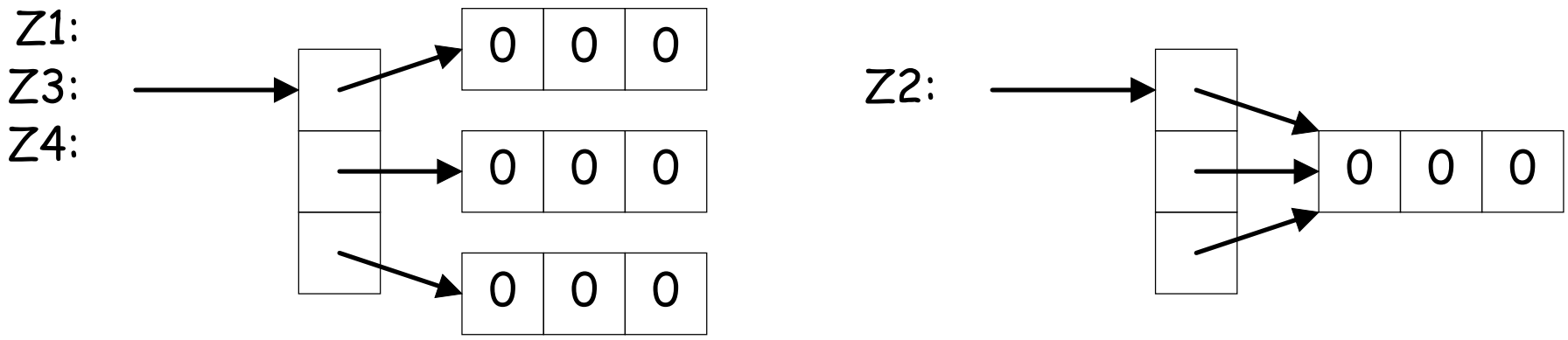

Dictionaries

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

```
>>> {}   # 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',
 'axolotl': 'gnu', 'gnu': 'hartebeest'}
```

- Queries:

```
>>> len(successors)
4
>>> 'gnu' in successors
True
>>> 'wombat' in successors
False
```

Dictionary Selection and Mutation

- Selection and Mutation

```
>>> ages = { 'brian' : 29, 'erik': 27, 'zack': 18, 'dana': 25 }
>>> ages['erik']
27
>>> 'erik' in ages
True
>>> 'paul' in ages
False
>>> ages['paul']
...
KeyError: 'paul'
>>> ages.get('paul', "?")
'?'
```

- Mutation:

```
>>> 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:

```
>>> ages = { 'brian' : 29, 'erik': 27, 'zack': 18, 'dana': 25 }
>>> list(ages)
['brian', 'erik', 'dana', 'zack']  # One possible order
>>> for name in ages: print(ages[name], end=",")
29, 27, 25, 18,
```

A Dictionary Problem

```
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 word in L:
        result[word] = _____________________________
    return result
```

A Dictionary Problem

```
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 word in L:
        result[word] = result.get(word, 0) + 1
    return result
```

Using Only Keys

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

```
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
    in both D0 and D1."""
    result = {}
    for x in D0:
         if x in D1: result[x] = True
    return result
```

- These dictionaries serve as *sets* of values.

Sets

- Python supplies a specialized set data type for slightly better syntax (and perhaps speed) than dictionaries for set-like operations.
- Operations

Set operation	Python Syntax	Modification
$\{\}$	`set()`	
$\{1, 2, 3\}$	`{ 1, 2, 3 }, set([1,2,3])`	
$\{x \in L \mid P(x)\}$	`{ x for x in L if P(x) }`	
$A \cup B$	`A | B`	`A |= B`
$A \cap B$	`A & B`	`A &= B`
$A \setminus B$	`A - B`	`A -= B`
$A \cup \{x\}$	`A | {x}`	`A.add(x)`
$A \setminus \{x\}$	`A - {x}`	`A.discard(x)`
$x \in A$	`x in A`	
$A \subseteq B$	`A <= B`	

Reworked Examples with Sets

```
def is_duplicate(L):
    """True iff L contains a duplicated item."""
    items = set()
    for x in L:
        if x in items: return True
        items.add(x)
    return False
def common_keys(D0, D1):
    """Return set containing the keys in both D0 and D1."""
    return set(D0) & set(D1)
```

- As shown in the last example, anything that can iterated over can be used to create a set.