CME 211: Lecture 7

Topics

- Python object model
- Python modules
- Python exceptions

Python object model

Let's review and elaborate on Python's object model. Key things to always keep in mind:

- everything in Python is an object
- variables in Python are references to objects

Starting example

```python
a = [42, 19, 73]
b = a
print(a)
print(b)
```

```python
b[0] = 7    # (1.)
print(b)    # (2.)
print(a)    # (2.)
```

1. Item `b[0]` is modified
2. This action affects the object referenced by both `a` and `b`

In this example, `a` is a reference to the list object initially set to `[42, 19, 73]`. The variable `b` also references the same list.

Analogy

- This room is like an object
- "Geology Corner Auditorium" is an identifier that references this room
- "320-105" is also an identifier that references this same room

Objects and references

- Names or identifiers point to or reference an object
- Identifiers are untyped and dynamic (an identifier can reference an integer, and then reference a string)

```python
a = 5
a = 'hi'
```

- But Python is also strongly typed: you can't add a number and a string because that doesn't make sense
- Everything in Python is an object: numbers, strings, functions, etc. are all objects

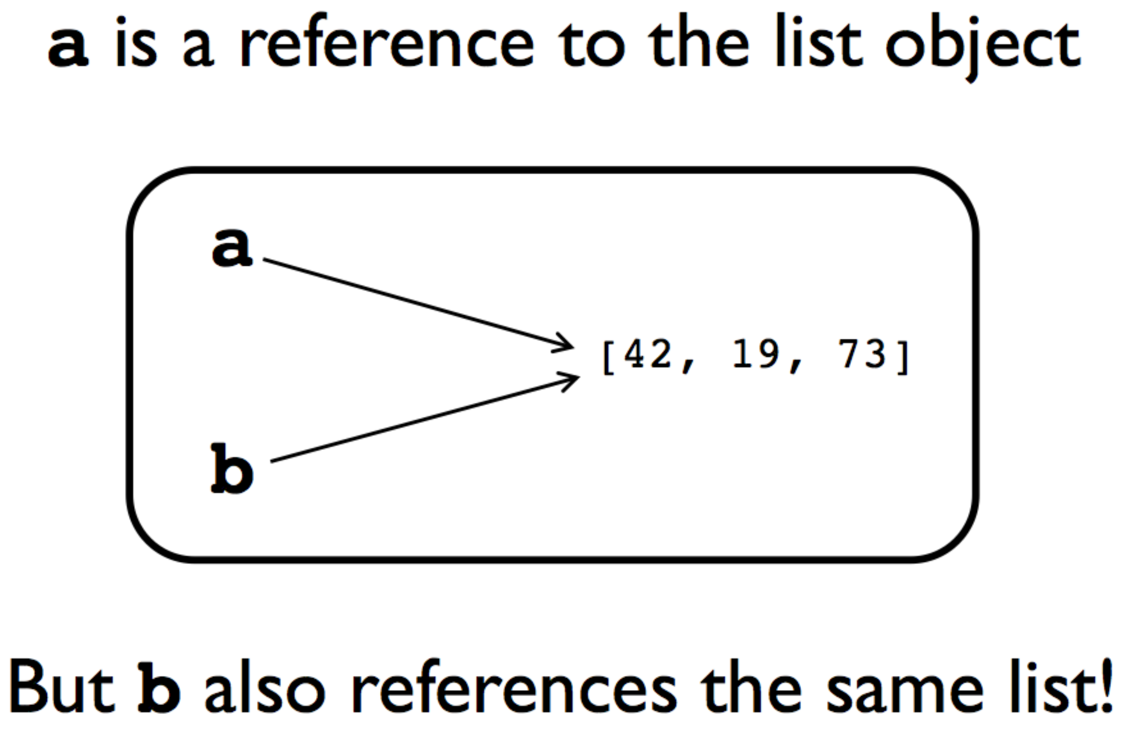

a is a reference to the list object
a
b
[42, 19, 73]
But b also references the same list!

Figure 1: fig/references.png

- An object is a location in memory with a type and a value

Assignment

The assignment operation, `=`, can be interpreted as setting up a reference.

We can interpret the code:

```
a = 'hello'
```

as:

1. creating a string object containing `'hello'`
2. setting the identifier `a` to refer to the newly created string object

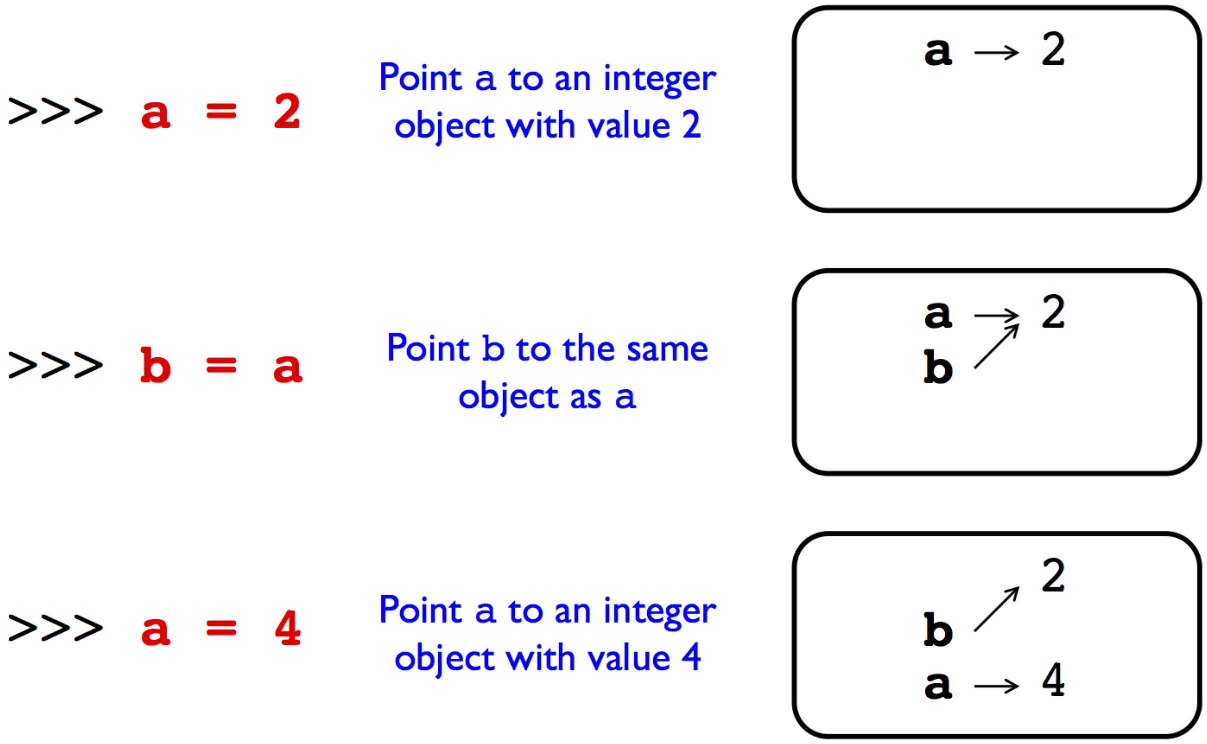
Example

Example

Checking references

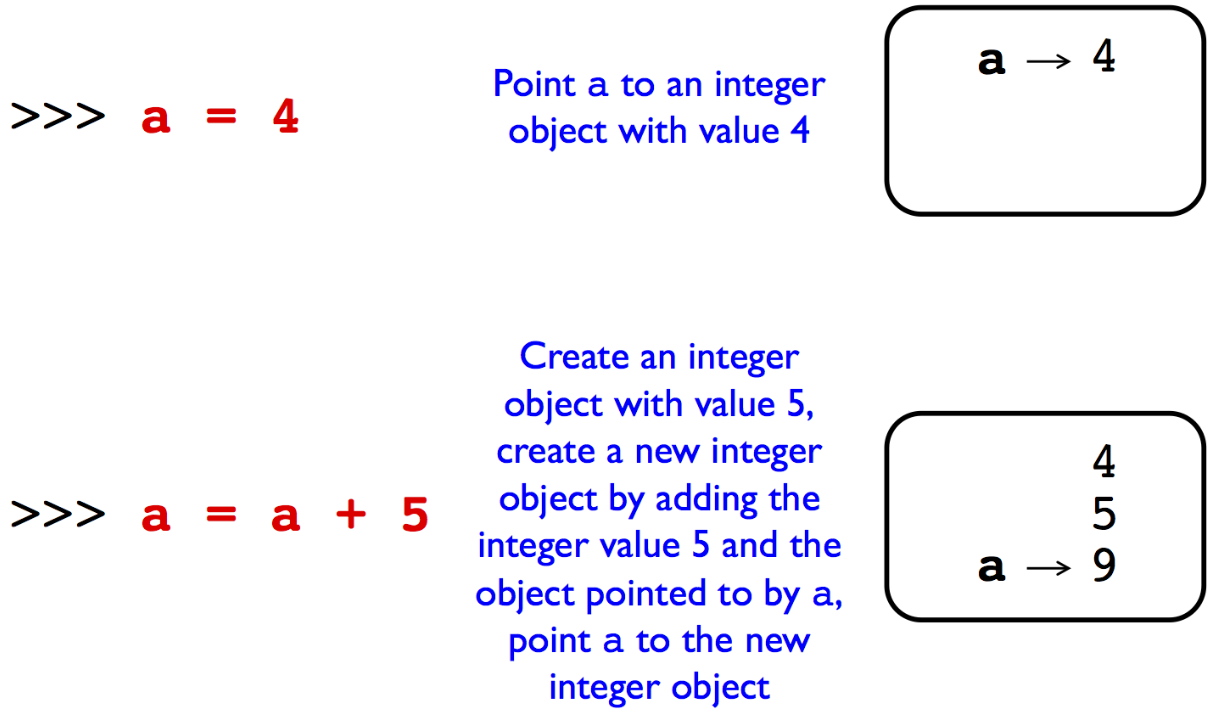
We can check if two names (variables) reference the same object with the `is` operator:

```
a = [42, 19, 73]
b = a
print(a is b)
```



>>> a = 2
Point a to an integer object with value 2
a → 2
>>> b = a
Point b to the same object as a
a → 2
b
>>> a = 4
Point a to an integer object with value 4
2
b
a → 4

Figure 2: fig/references-example.png



>>> a = 4
Point a to an integer object with value 4
a → 4
>>> a = a + 5
Create an integer object with value 5, create a new integer object by adding the integer value 5 and the object pointed to by a, point a to the new integer object
4
5
a → 9

Figure 3: fig/references-example-2.png

In memory we have:

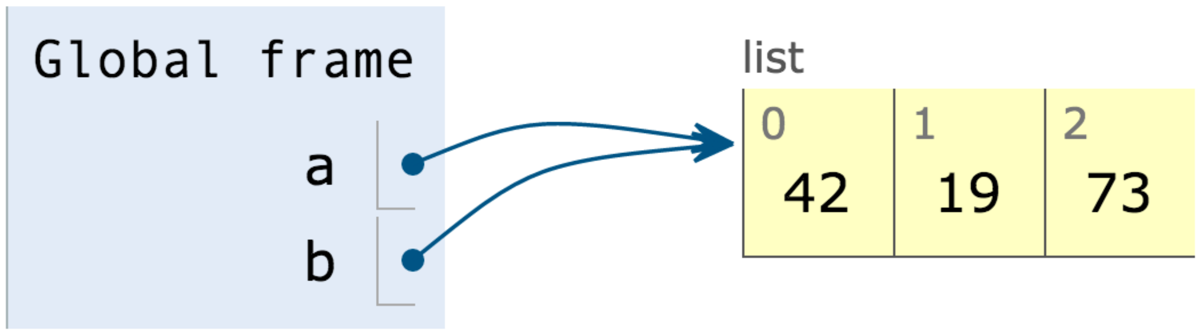


Figure 4: list-1

```
b = [42, 19, 73]
print(a is b)
```

In memory we have:

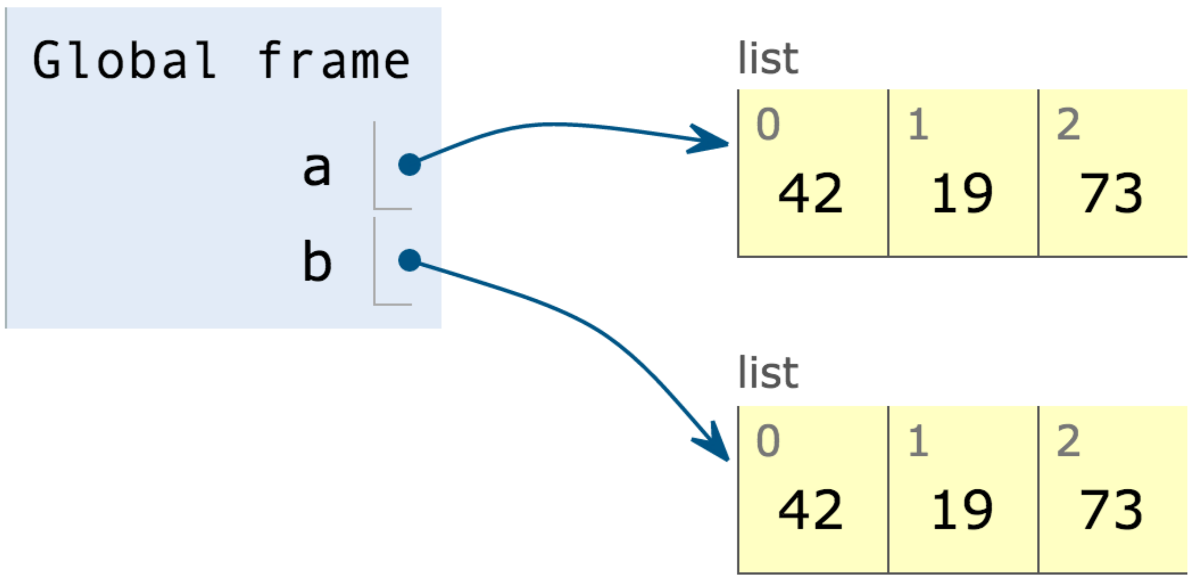


Figure 5: list-2

Check it out in Python Tutor.

Integers and references

Integers are objects also and need to be created in memory. Let's explore this a bit.

```
a = 1024
b = a
a is b
```

```
a = 1024
b = 1024
a is b
```

```
a = 16
b = 16
a is b
```

In the last code block, `a` and `b` point to the same object, because Python preallocates some integers.

Preallocated integers

- For interactive usage, Python preallocates permanent integer objects for the values `-5` to `256`
- Instead of constantly creating / destroying these objects they are permanently maintained
- Integers outside this range are created / destroyed as needed

```
a = -6
b = -6
a is b
```

```
a = -5
b = -5
a is b
```

```
a = 256
b = 256
a is b
```

```
a = 257
b = 257
a is b
```

String reuse

String objects may be "reused" internally:

```
a = 'hello'
b = 'hello'
a is b
```

Why immutables?

- It's a design decision not uncommon in other languages (e.g. strings are immutable in Java)
- Allows for performance optimizations
- Can setup storage for a string once because it never changes
- Dictionary keys required to be immutable for performance optimizations to quickly locate keys

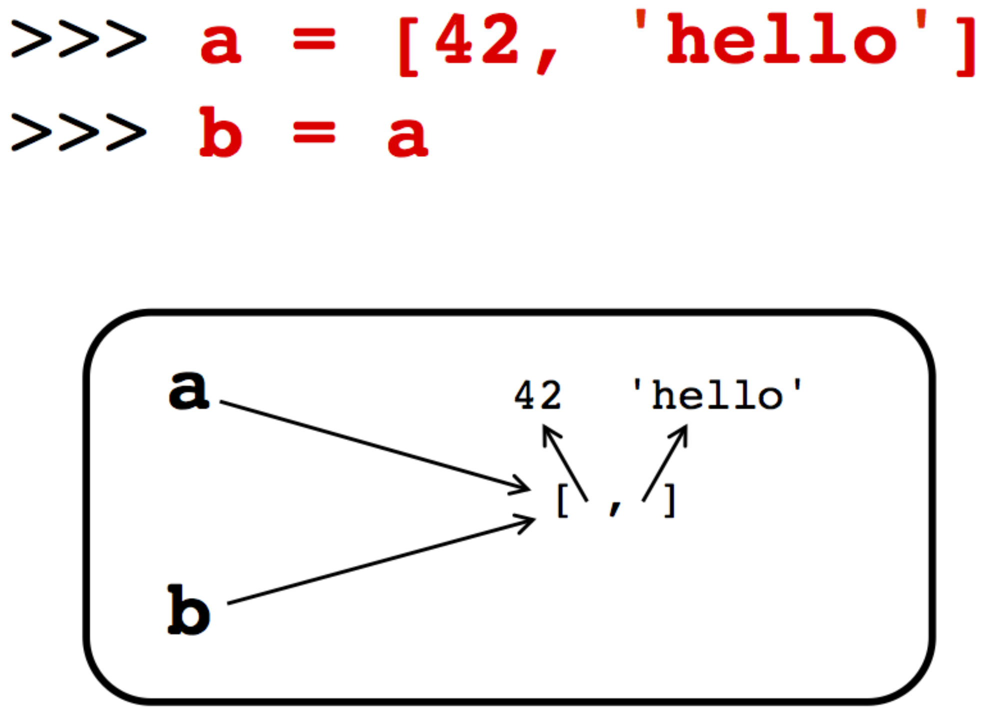
Containers and element references

- The elements in a list, or the key and value pairs in a dictionary, contain references to objects
- Those references can be to "simple" data types like a number or string, or more complicated data types like other containers

- There are some restrictions, for example the key objects in a dictionary must be immutable (e.g. numbers, strings, or tuples)

Containers and element references

```
a = [42, 'hello']
b = a
```



```
>>> a = [42, 'hello']
>>> b = a
```

Figure 6: fig/list-ref.png

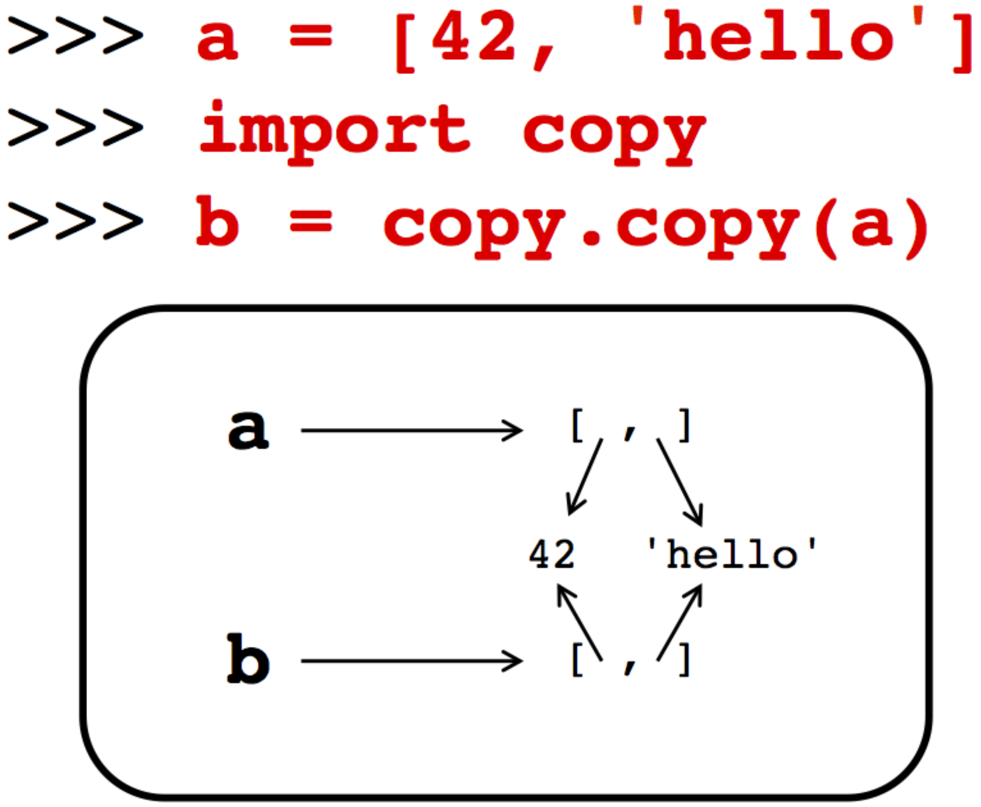
Copying a list

- Simple assignment does not give us a copy of a list, only an additional reference to the same list
- What if we really want an additional copy that can be modified without changing the original?

Shallow copy

```
a = [42, 'hello']
import copy
b = copy.copy(a)
```

A shallow copy (`copy.copy`) constructs a new list and inserts references to the objects referenced in the original.



```
>>> a = [42, 'hello']
>>> import copy
>>> b = copy.copy(a)
```

Figure 7: fig/shallow-copy.png

Shallow copies and mutables

```
a = [19, {'grade':92}]
b = copy.copy(a)
print(a)
print(b)
```

```
a[0] = 42
a[1]['grade'] = 97
print(a)
print(b)
```

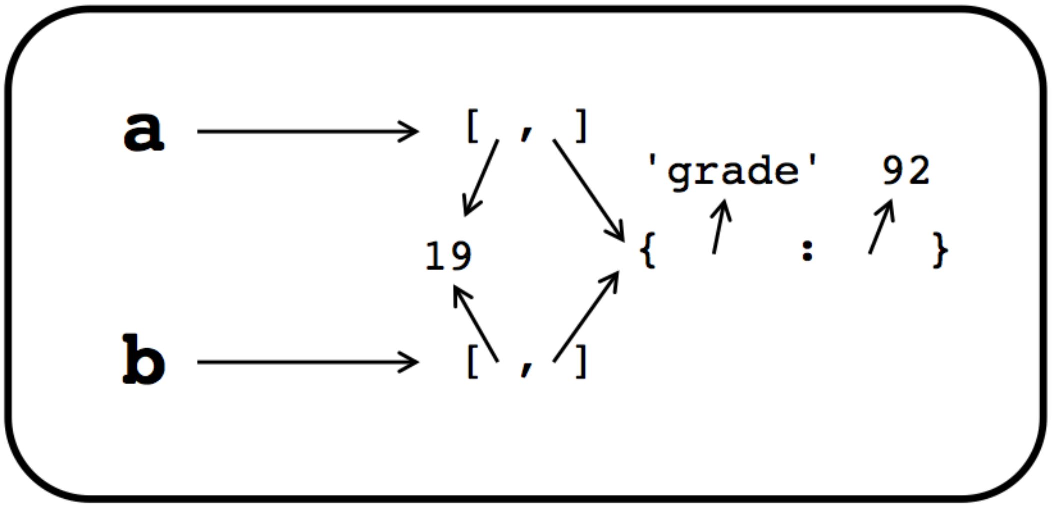


Figure 8: fig/shallow-copy-mutables.png

Deep copy

```
a = [19, {'grade':92}]
b = copy.deepcopy(a)
print(a)
print(b)
```

```
a[0] = 42
a[1]['grade'] = 97
print(a)
print(b)
```

A deep copy (`copy.deepcopy`) constructs a new list and inserts copies of the objects referenced in the original. It will copy all nested data structures.

Tuples and immutability

```
a = [42, 'feed the dog', 'clean house']
import copy
b = copy.copy(a)
```

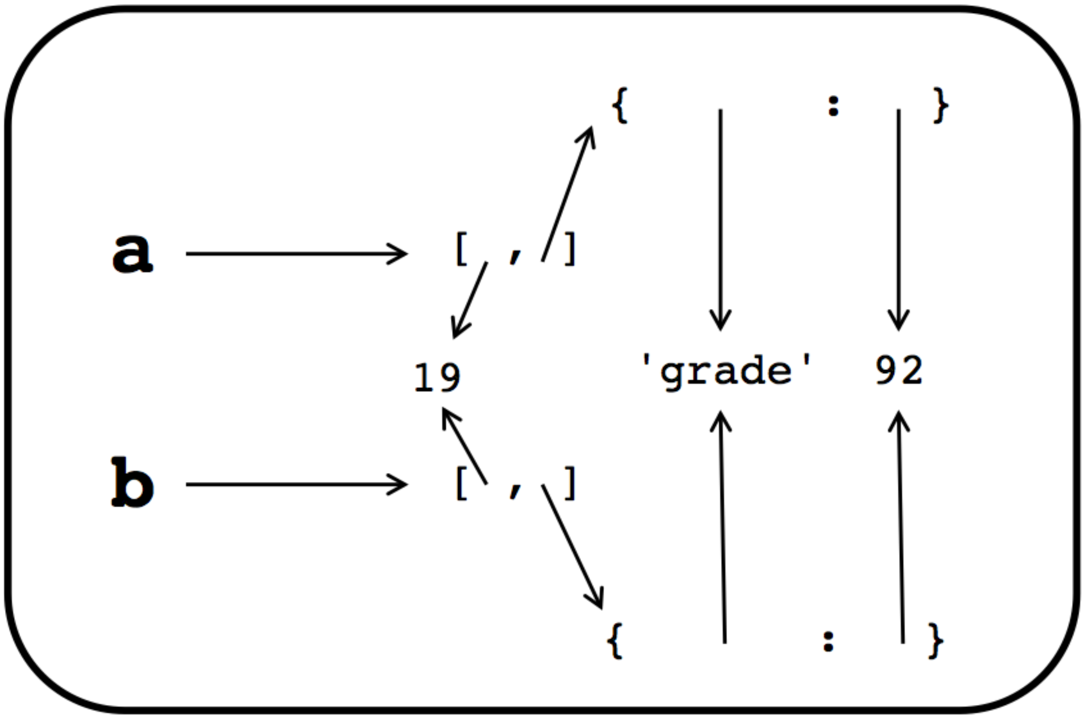


Figure 9: fig/deep-copy-mutables.png

```
c = (a,b)
c
([42, 'feed the dog', 'clean house'], [42, 'feed the dog', 'clean house'])
```

```
b[0] = 7
print(c)
c[0][0] = 7
print(c)
```

```
c[0] = [73, 'wash dishes', 'do laundry']
```

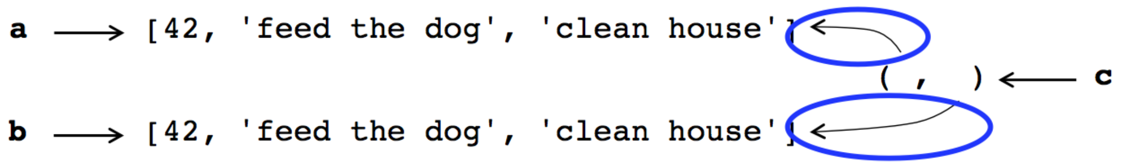
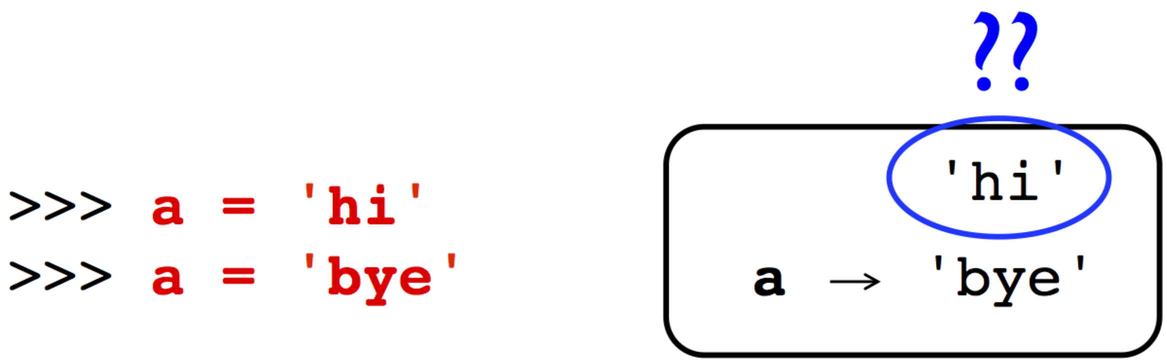

a
[42, 'feed the dog', 'clean house']
(,)
c
b
[42, 'feed the dog', 'clean house']

Figure 10: fig/tuples-and-immutability.png

The immutable property of tuples only means I can't change where the arrows point, I'm still free to change a mutable object at the arrow destination.

Memory management

- What happens to those objects that are no longer referenced?



```
>>> a = 'hi'
>>> a = 'bye'
```

Figure 11: fig/gc-1.png

Garbage collection

- Unreachable objects are garbage collected
- Garbage collection in Python is implemented with reference counting

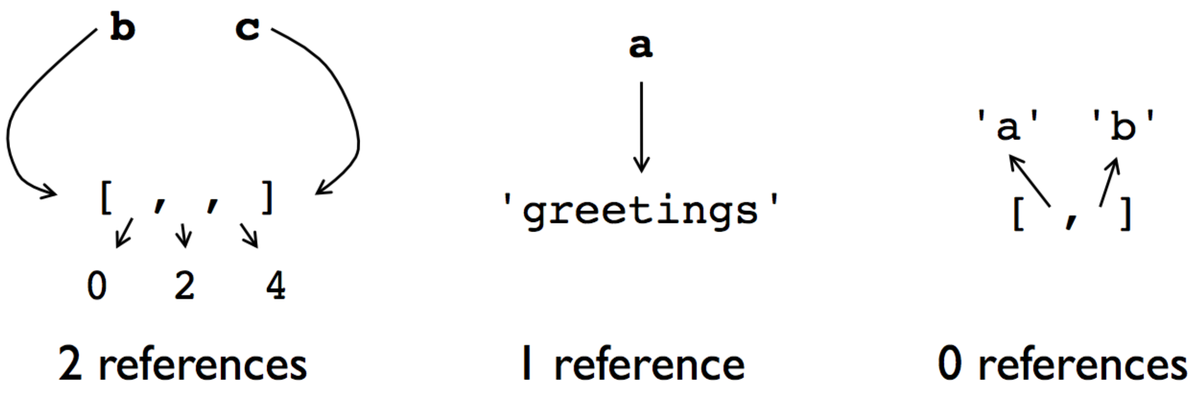


Figure 12: fig/gc-2.png

Recommended Reading

- Chapter 6: The Dynamic Typing Interlude