CS 134 Lecture 12: More Mutability

Announcements & Logistics

- **HW 5** due Mon March 4 at 10 pm on GLOW
- **Lab 4** Part 1 autograded feedback and Lab 3 feedback will be released today
- Reminder that Midterm is **March 14**
  - Two exam slots: 6-7.30 pm, 8-9.30 pm
  - Room: Bronfman auditorium
- Midterm review Monday March 11 evening 7-9 pm in Bronfman
- How to study: review lectures
  - Practice past HW and labs on pencil and paper
  - Additional POGIL worksheets posted on course website (resources)

Do You Have Any Questions?

Last Time

- New iteration statement: the **`while`** loop
  - "Conditional" looping statement
  - Useful when we don't know a sequence or stopping condition ahead of time

Today's Plan

- Mutability and its consequences: **aliasing**

Mutability

Lists are Mutable

- Lists are a **mutable** data type in Python:
    - After a list is created, we can **change** its value
- There are **many ways** to mutate a list, we will only discuss two of these
    - Direct assignment (e.g., `lst[index] = item`)
    - Appending to list using `.append(item)` notation

Direct Assignment

- An assignment operation on an **existing index** of a list changes the value stored at that index

```
Syntax:  my_list[index] = item
```

```
>>> my_list = ['cat', 'dog']
>>> my_list[1] = 'fish'
>>> my_list
['cat', 'fish']
>>> my_list[7] = 'oops'
IndexError: list assignment index out of range
>>>
```

`my_list` has changed!

Can only assign to **existing** indices

Using .append(item)

Appending to a list places a new item ***after*** the current end of the list, increasing the list's length by one.

Syntax: `my_list.append(item)`

Important:
No [] around item!

Example.

```
my_list = [1, 7, 3, 4]

my_list.append(5)  # insert 5 after the end of list
```

`my_list` Before	`my_list` After
[1, 7, 3, 4]	[1, 7, 3, 4, 5]

Sneaky Appending

- We've often updated "accumulator lists" by "appending" items in loops
- So far we have been using **+=** (**concatenation**)
  - `var += val` normally is a shorthand for `var = var + val`
  - But when `var` is a list, Python **secretly** calls `var.append(val)`

```
>>> my_list = ['cat', 'dog']
>>> my_list += ['fish']
>>> my_list
['cat', 'dog', 'fish']
```

Python actually replaces += with append without telling us!

Explicit Appending

- If we instead explicitly use the `.append(item)` syntax, then the code **we execute** is the code that **we actually wrote**
- This also avoids one of the recurring errors that we've been running into in our labs! (Type mismatches with **+=**)

```
>>> my_list = ['cat', 'dog']
>>> my_list += ['fish']
>>> my_list
['cat', 'dog', 'fish']
```

Brackets are needed here because we are adding (+) a list (`my_list`) to another list (['fish'])

```
>>> my_list = ['cat', 'dog']
>>> my_list.append('fish')
>>> my_list
['cat', 'dog', 'fish']
```

NO brackets needed here because we are passing the item we want to append ('fish') as an argument to the append method (special type of function)

Appending to Accumulate in a List

- We need to be careful about the the type of item we provide to append

```
Syntax:   my_list.append(item)
```

If item is a `list`, then the entire list is **appended**

```
>>> my
>>> my
>>> my
['ap  ', 'orange', 'banana', ['peach']]
```

You may use `.append()` instead of **+=** in **Lab 4** because they are equivalent in Python, but no other list/string "dot methods"

[Aside] Objects, Types and Methods

- We have discussed the following types in class:
    - `int, float, Boolean, string, list, range()`
- Python is an object-oriented language
    - Everything in Python is an **object** and has a **type**
- Each type has ***methods*** you can call on objects of that type, e.g.,
    - string objects have `.find()`, `.format()`, `.split()`, ...
    - list objects have `.append()`, `.extend()`, ...
- We have intentionally not discussed these in class so far (will do so later)
- For lists, we are introducing `.append()` method as this is already being used "behind the scenes" with **+=**

Strings are Immutable

- Other data types we have seen are **immutable**
  - Strings, ints, floats, range() are immutable data types
- Once created, we **cannot** change the value of an immutable data type

Will this let us change `my_string` to `'bat'`?

```
>>> my_string = 'cat'
>>> my_string[0] = 'b'
```

```
---------------------------------------------------------------------------
TypeError                                 Traceback (most recent call last)
Cell In[25], line 2
      1 my_string = 'cat'
----> 2 my_string[0] = 'b'

TypeError: 'str' object does not support item assignment
```

Cannot change a string!

Mutability has Consequences!

- Mutability of data types can have **unintended consequences**
- Consider the Python code on the left (involving **strings** which are **immutable**) vs right (involving **lists** which are **mutable**)

```
>>> word = "hello"
>>> copy = word
>>> word = word + "world"
>>> copy
"hello"
```

Changing `word` does not change `copy`

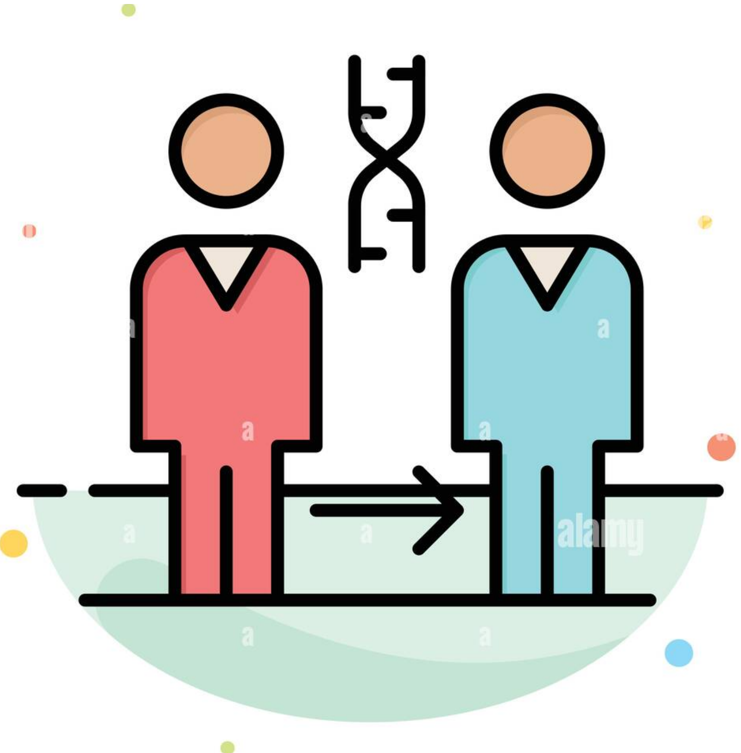
```
>>> word_list = ["hello"]
>>> copy = word_list
>>> word_list.append("world")
>>> copy
['hello', 'world']
```

Changing `word_list` **also changes** `copy`

Aliasing:
Side-effect of Mutability

Clone vs Alias

- What is the difference between a **clone** and an **alias** ?
- Clones appear the same but are actually ***different objects***
- Alias is another name for the ***same object***
- To define whether something is a clone or alias in Python, we need to revisit variables and how their values are stored "under the hood"



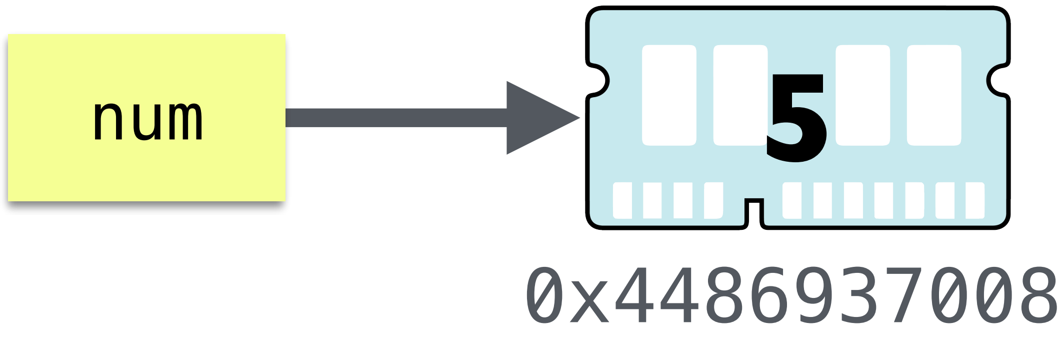
An identical copy

Alternate name

Name, Value and Identity

- Consider an assignment operation such as `num = 5`
- The variable **name** `num` is a way to refer to a unique address in memory where the **value** 5 is stored
  - This address is called the **identity** of this object

```
>>> num = 5
```



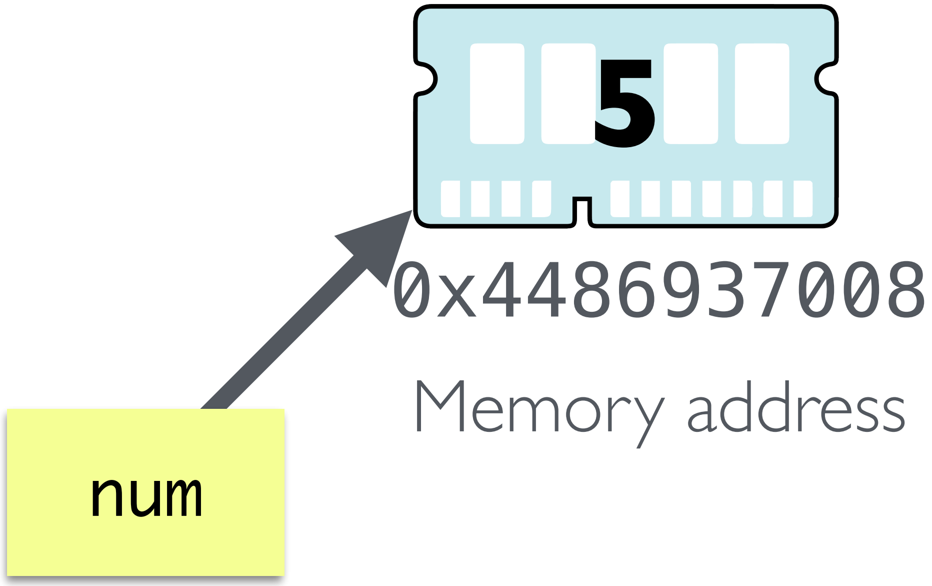
Identity of num: memory address where **5** is stored (e.g., 0x4486937008)

Value of num: 5

Value vs Identity

- An **object's identity** never changes once it has been created
- On the other hand, an **object's value** may be changeable
  - Objects whose values can change are called **mutable**
  - Objects whose values cannot change are called **immutable**

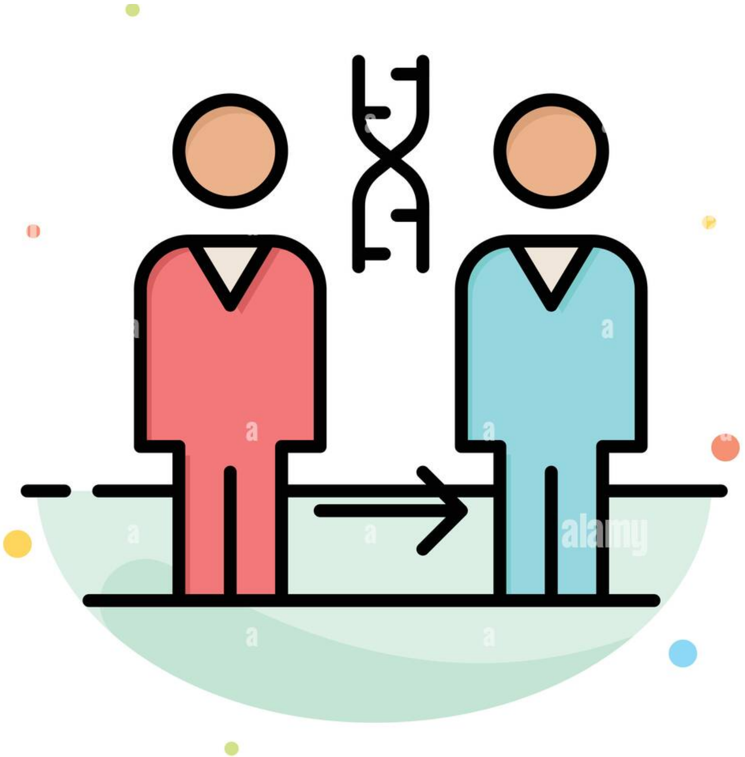
```
>>> num = 5
```



Variable names like `num` point to memory addresses of stored value

Clone and Alias in Python

- A **clone** of an object has the ***same value*** but **different identities**
  - Mutating a clone does not change the original object
- An **alias** of an object has the ***same value*** and the **same identity**
  - Mutating an alias also mutates the original object



Different identities (locations in memory)

Same identity (same location in memory)

Clones and Aliases in Python

- Giving a new name to an existing ***immutable object*** creates a **clone**
- Giving a new name to an existing ***mutable object*** creates an **alias**

```
>>> word = "hello"
>>> copy = word
>>> word = word + "world"
>>> copy
"hello"
```

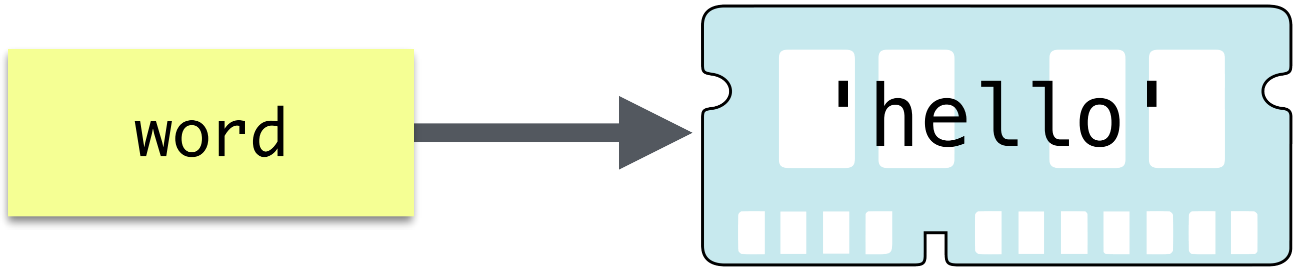
`copy` is a **clone** of `word`, changing word does not change `copy`

```
>>> word_list = ["hello"]
>>> copy = word_list
>>> word_list.append("world")
>>> copy
['hello', 'world']
```

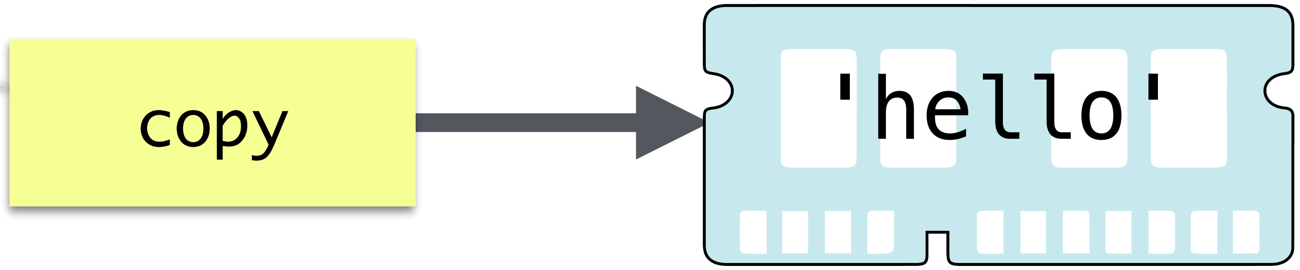
`copy` is an **alias** of `word_list`, changing word changes `copy`

Strings are Immutable

```
>>> word = "hello"
>>> copy = word
```



copy is a **clone** of word



Strings are Immutable

```
>>> word = "hello"
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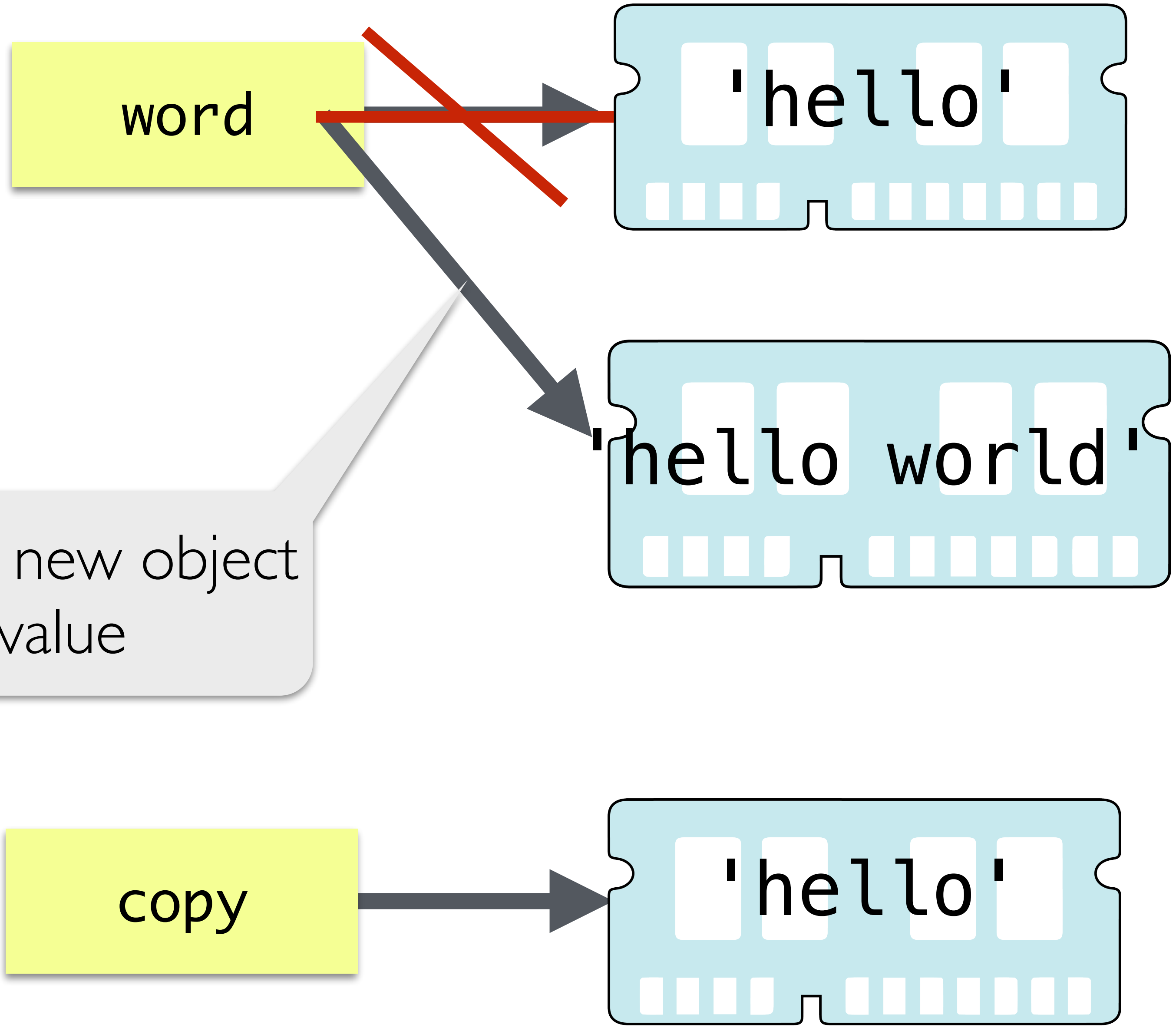
>>> word = word + "world"
>>> copy
"hello"
```



Instead of mutating `word`, create a new object with a different identity and value

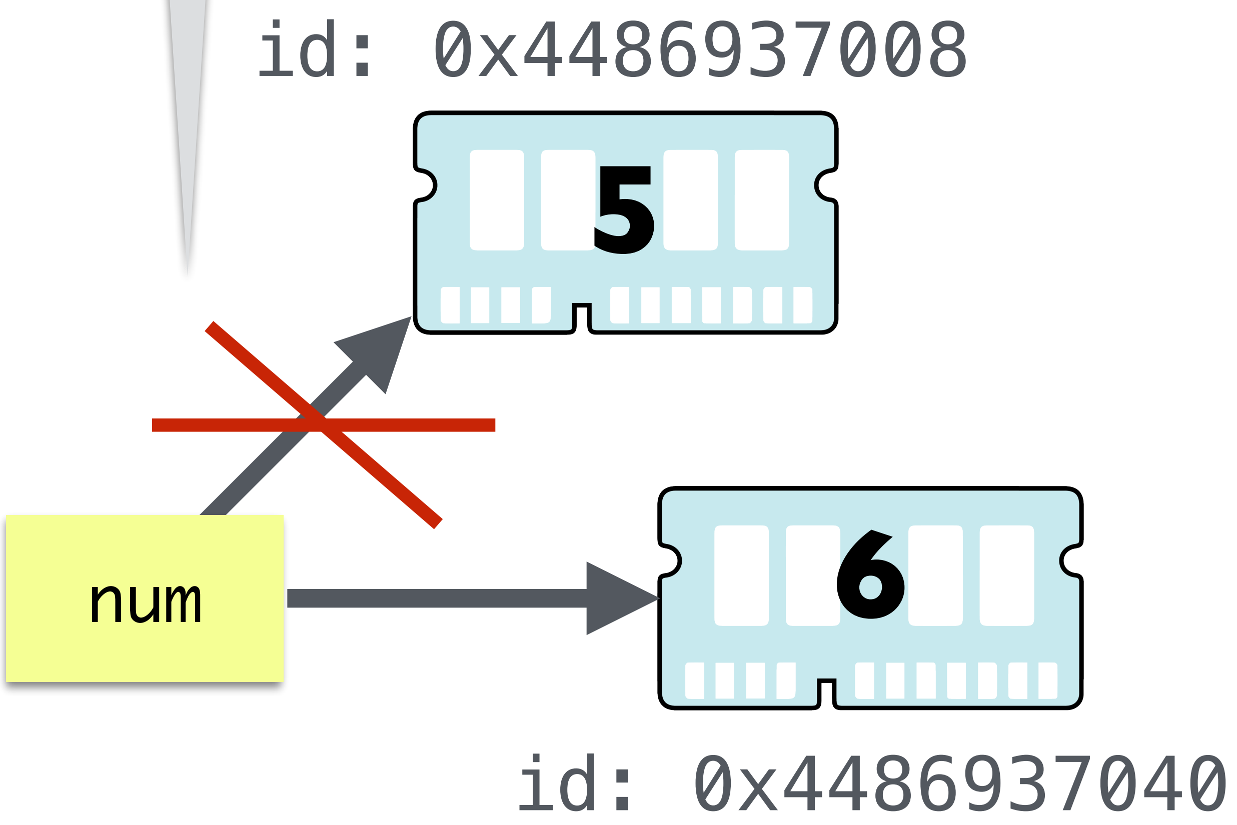
changing `word` does not change `copy`

Attempts to change an immutable object create a new object

Ints, Floats are Immutable

```
>>> num = 5
>>> num = num + 1
```

Trying to change the value of **`num`** creates a **new object** with a different identity

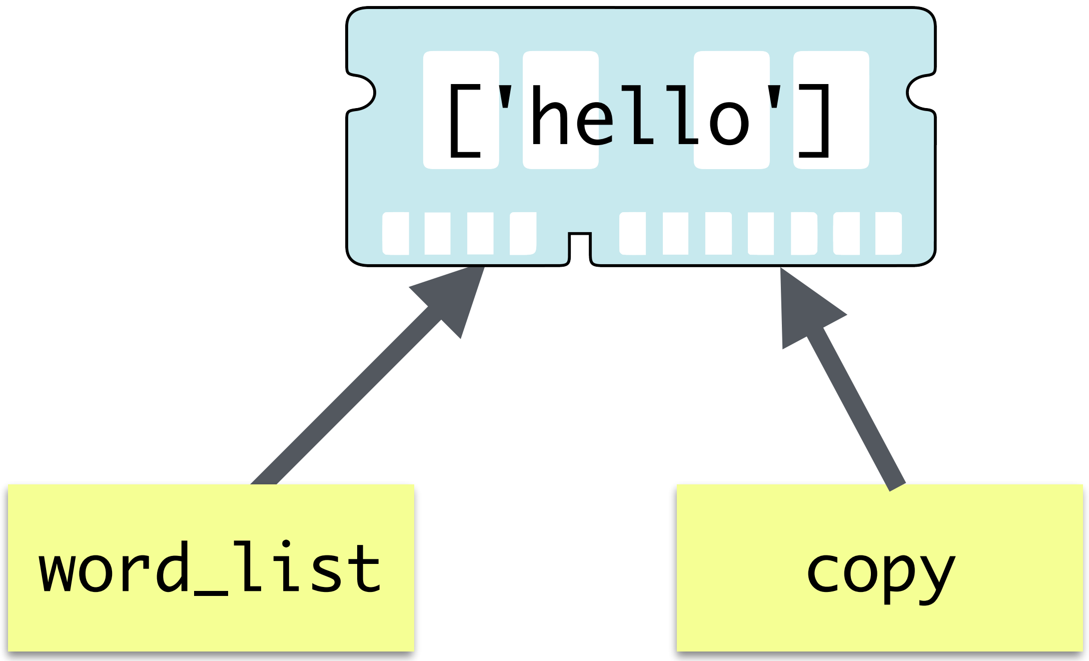


Attempts to change an immutable object create a clone

List Aliasing

- Any assignment or operation that creates a new name for an existing **mutable object** implicitly creates an ***alias***

```
>>> word_list = ["hello"]
>>> copy = word_list
```

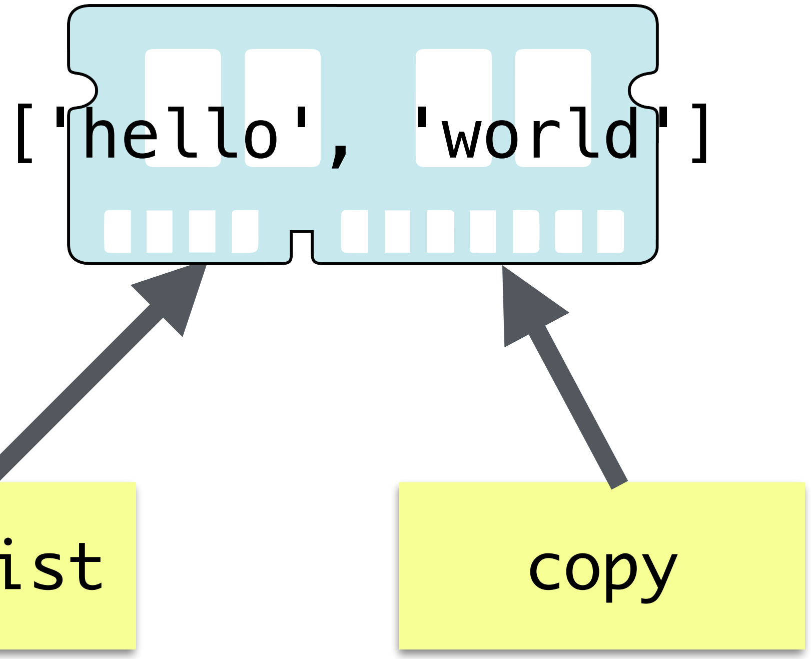


Since a list is **mutable**, we are not creating a clone, but rather an **alias**

List Aliasing

- Any assignment or operation that creates a new name for an existing **mutable object** implicitly creates an ***alias***

```
>>> word_list = ["hello"]
>>> copy = word_list
>>> word_list.append("world")
>>> copy
['hello', 'world']
```



Changing `word_list` changes `copy`

Summary: Mutability in Python

Strings, Ints, Floats are Immutable

- Once you create them, their value **cannot** be changed
- Referring to these objects by a new variable name creates a **clone**
- All expressions that manipulate these objects yield a **new object**. ***They do not modify*** the original object

Lists are Mutable

- List values **can** be changed
  - Can mutate a list (using direct assignment or `.append()`)
- Attempts to refer to a list by a new variable name creates an **alias**

How to Avoid Aliasing Side-effects

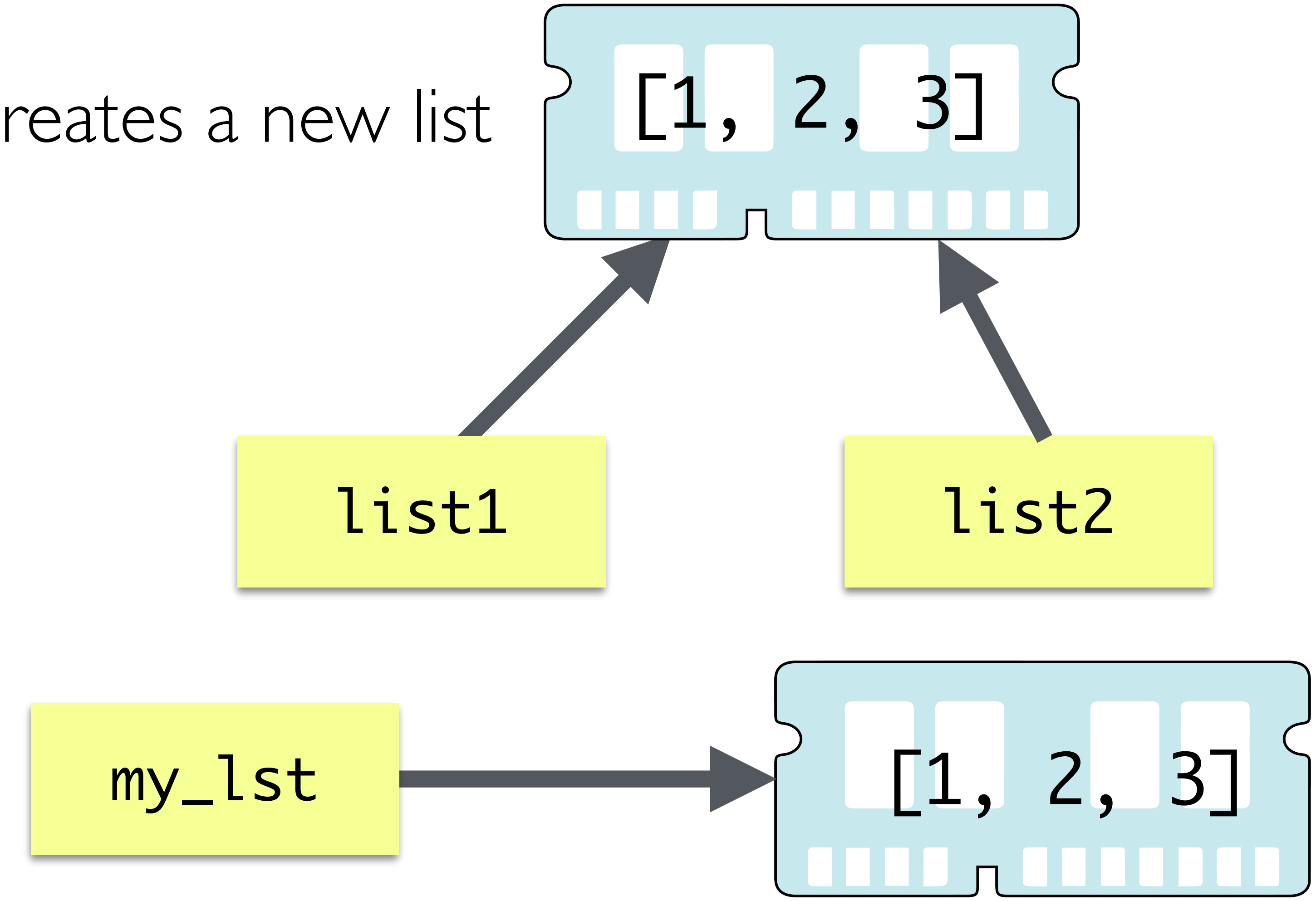
Using Immutable Types

- Aliases are **never created** for immutable data types
- We can safely make **clones** and not worry about accidentally modifying the original
- Thus any operation on strings, ints, or floats is safe from aliasing
    - Sequence operations such as slicing (`[start:end]`) and concatenation (**+**) always create **new strings** as it is impossible to mutate strings
- We will see an immutable alternative to lists next week
    - tuples (an immutable sequence)

Avoiding Aliasing with Lists

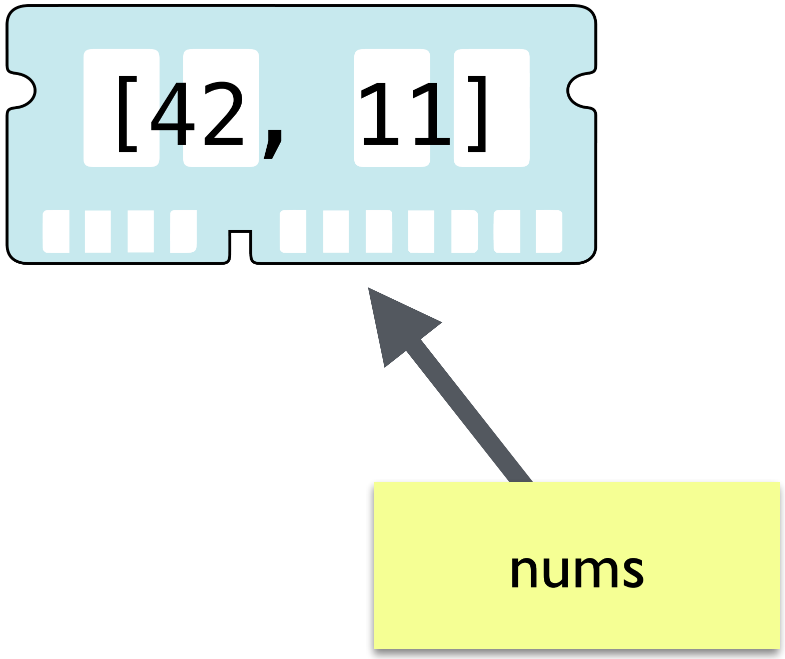
- When using lists, we can avoid aliasing by being careful
- An assignment of a *literal value* (i.e., an expression with no variables) to a variable **creates a new object**
- An assignment of a *new list* (i.e., an expression enclosed with `[]`) to a variable **creates a new object**
  - `var = [item]` always creates a new list

```
>>> list1 = [1, 2, 3]
>>> list2 = list1
>>> my_lst = [1, 2, 3]
```



Sequence Operations on Lists

- We can force Python to create a clone of a list instead of an alias by using sequence operations
- Sequence operations such as slicing `[:]` and concatenation `(+)` on lists create **new lists**
    - They do not create an alias or mutate the original list



```
>>> nums = [42, 11]
```

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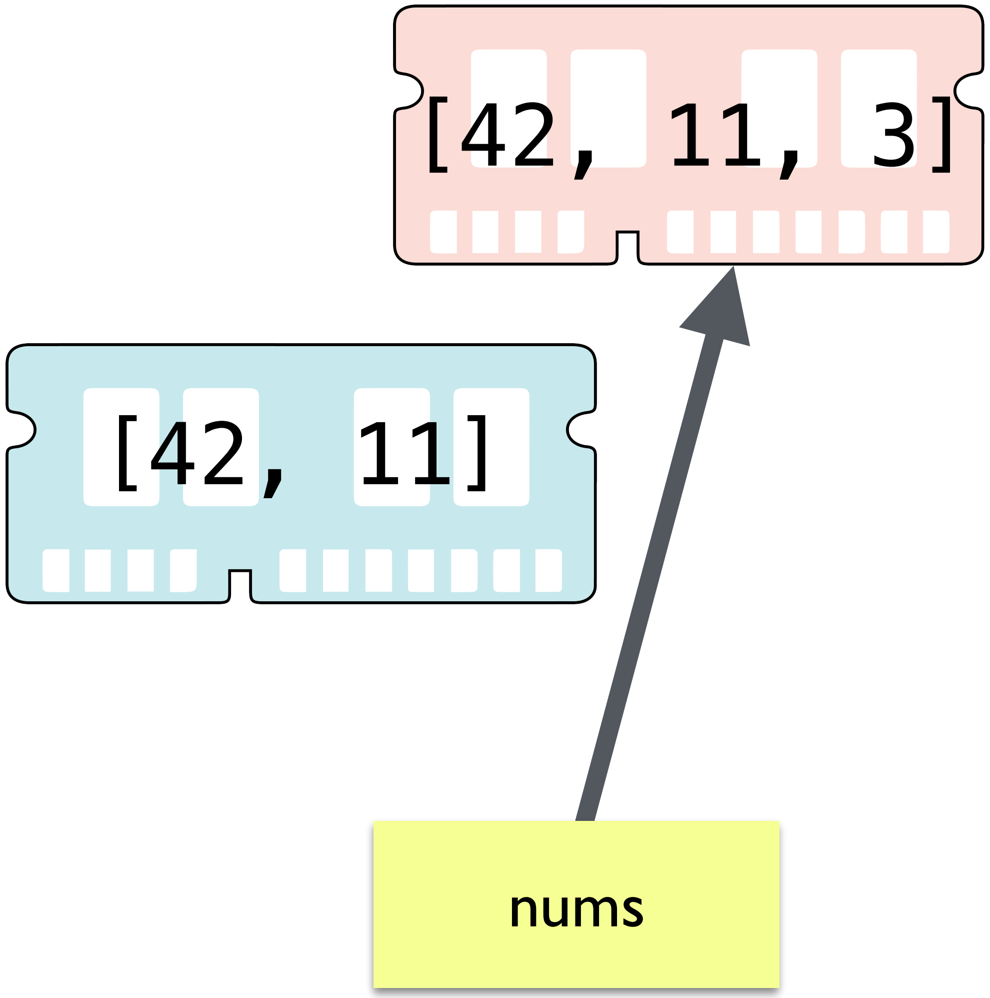

```
>>> nums = [42, 11]
>>> nums = nums + [3]
```

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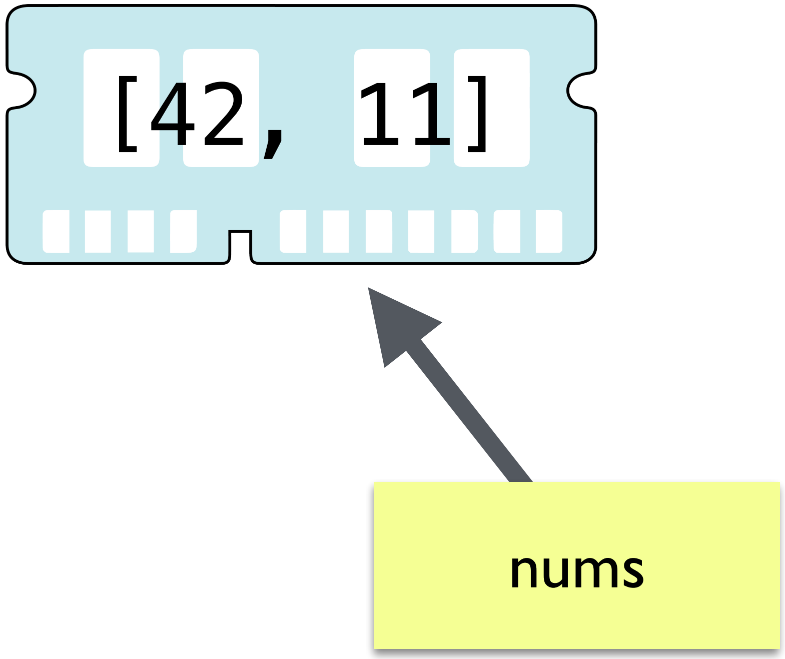
```



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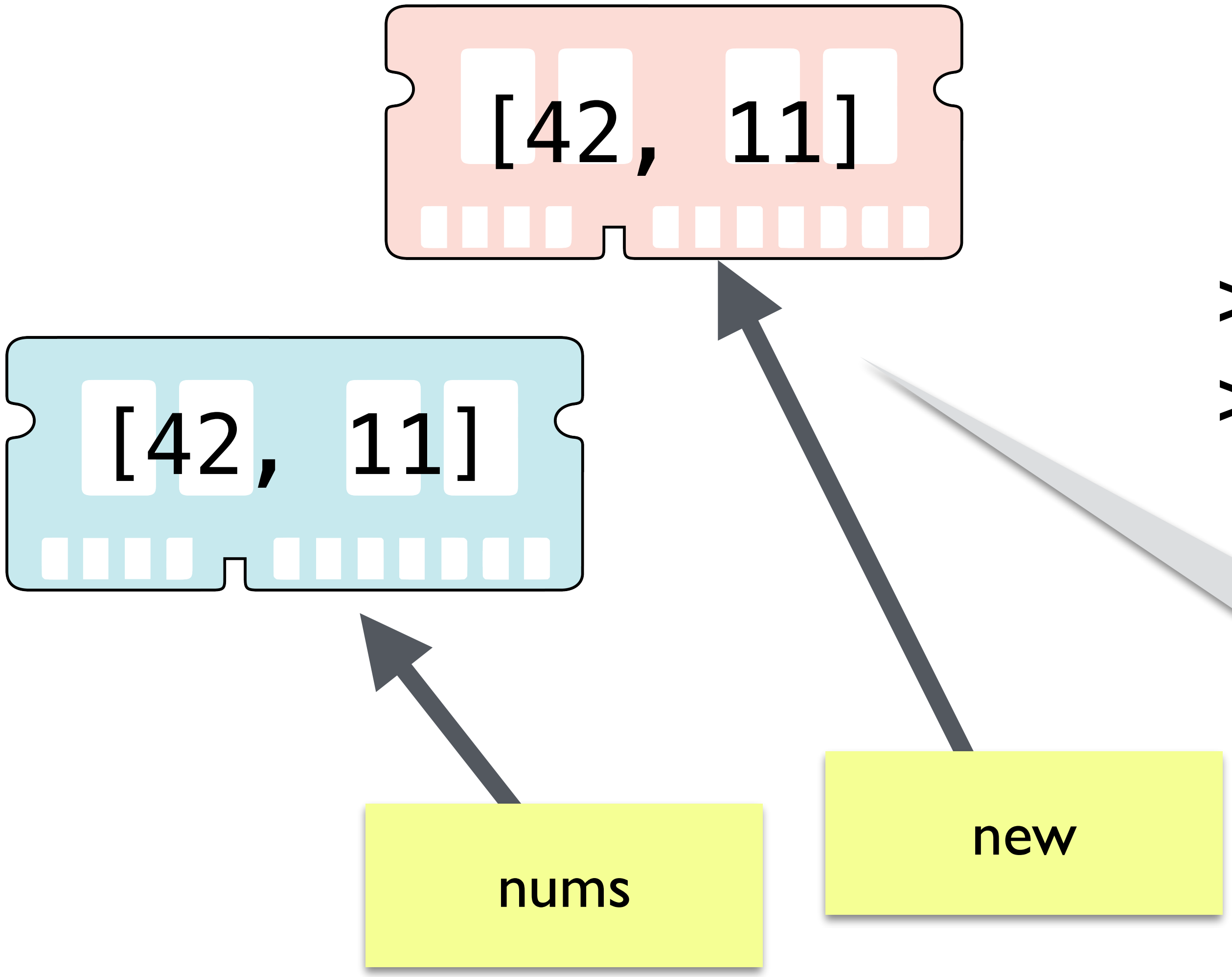

```
>>> nums = [42, 11]
>>> new = nums[:]
```

new is a **clone** but not an alias!

Sequence Operations on Lists

- We can force Python to create a clone of a list instead of an alias by using sequence operations
- Sequence operations such as slicing `[:]` and concatenation `(+)` on lists create **new lists**
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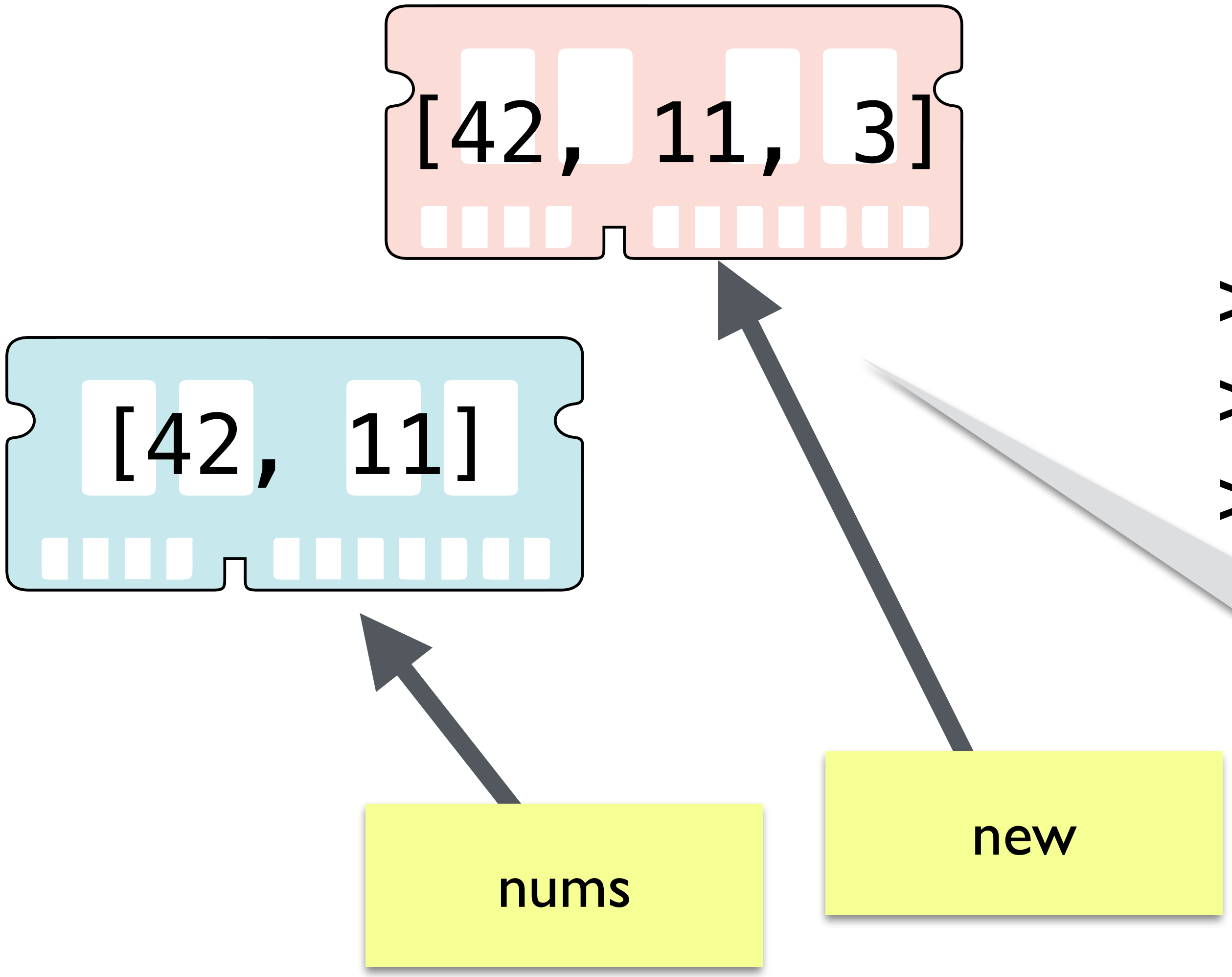


```
>>> nums = [42, 11]
>>> new = nums[:]
>>> new.append(3)
```

`new` is a **clone** but not an alias!

Takeaways

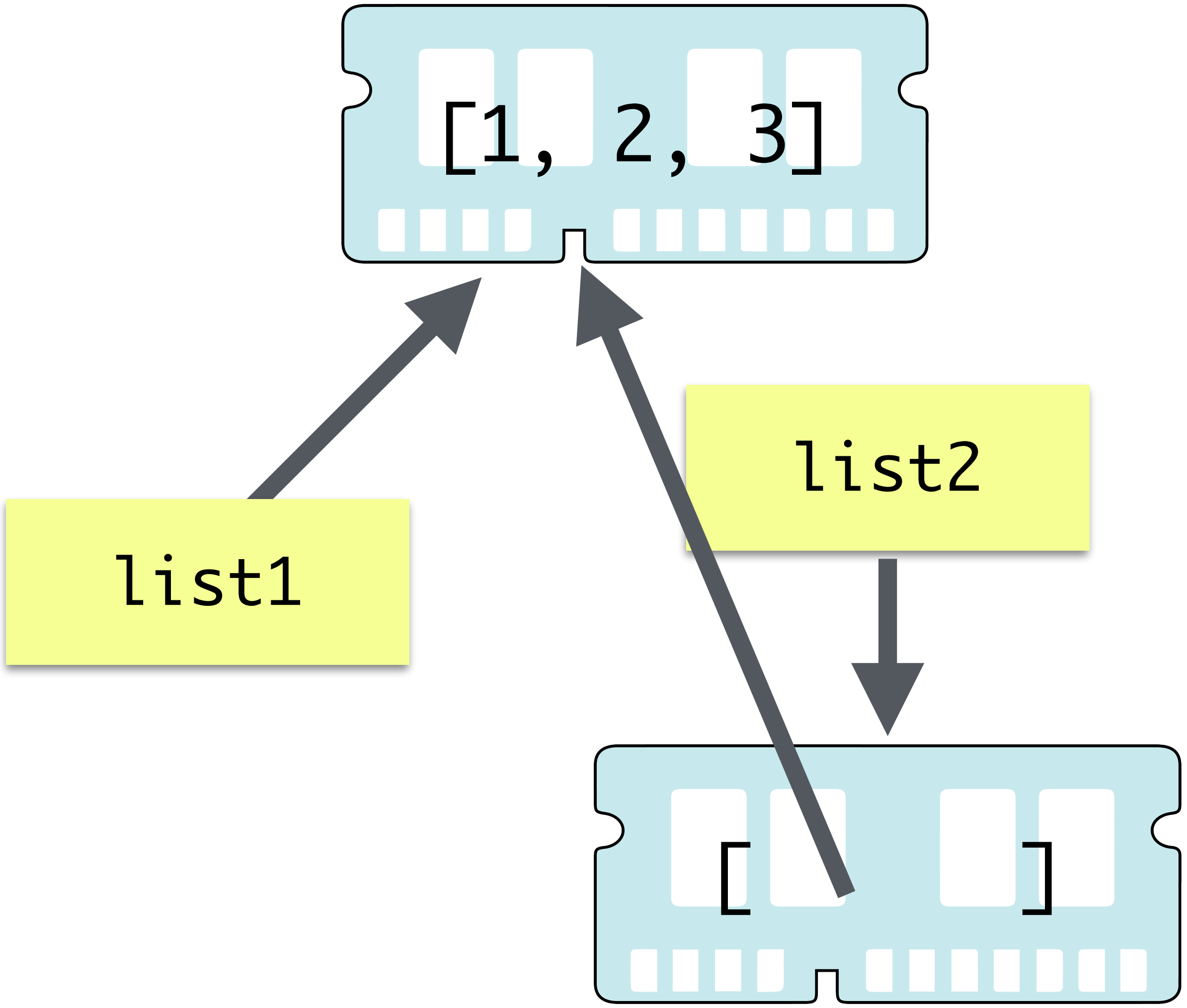
- We **cannot change** the value of **immutable** objects such as strings
  - Attempts to copy or to modify them creates a new object
  - No need to worry about aliasing side effects
- We **can change** the value of **mutable** objects such as lists
  - When using the **+=** operator with lists mutates the list!
    - Python secretly calls `.append()`
  - Need to be mindful of **aliasing**; be careful to avoid unintended aliases
  - You can create a "true clone" of a list using slicing or by creating a new list containing the same items (e.g., using a loop or list comprehension)

Advanced:
Aliasing in Nested Lists

Nested Lists: Aliasing Nightmare

- Nested lists create more complicated aliasing side effects
- An assignment to a new variable **creates a new list**

```
>>> list1 = [1, 2, 3]
>>> list2 = [list1]
```



(Crazy) Aliasing Examples

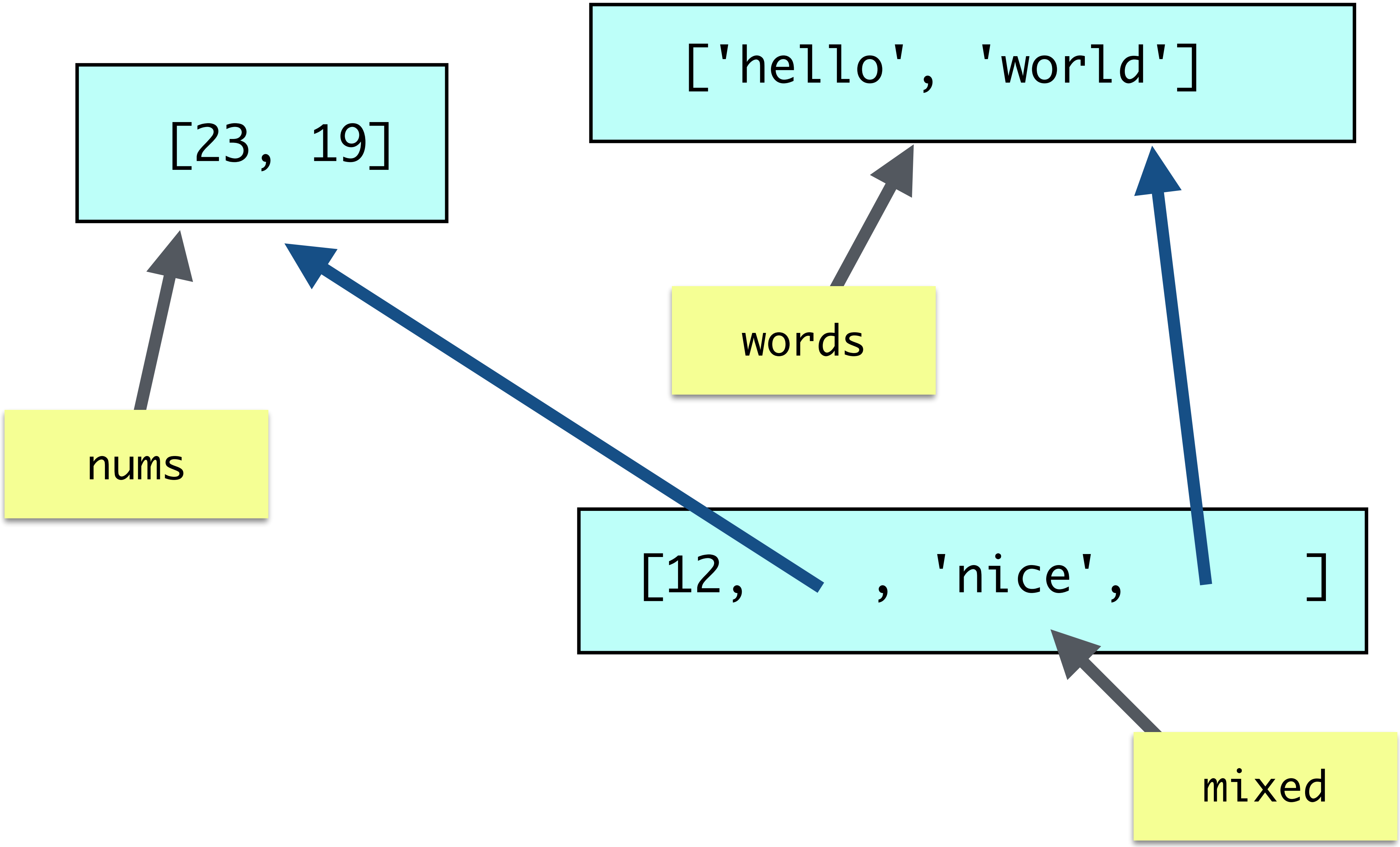
```
>>> nums = [23, 19]
>>> words = ["hello", "world"]
>>> mixed = [12, nums, "nice", words]

>>> words += ["sky"]
>>> mixed
```

???

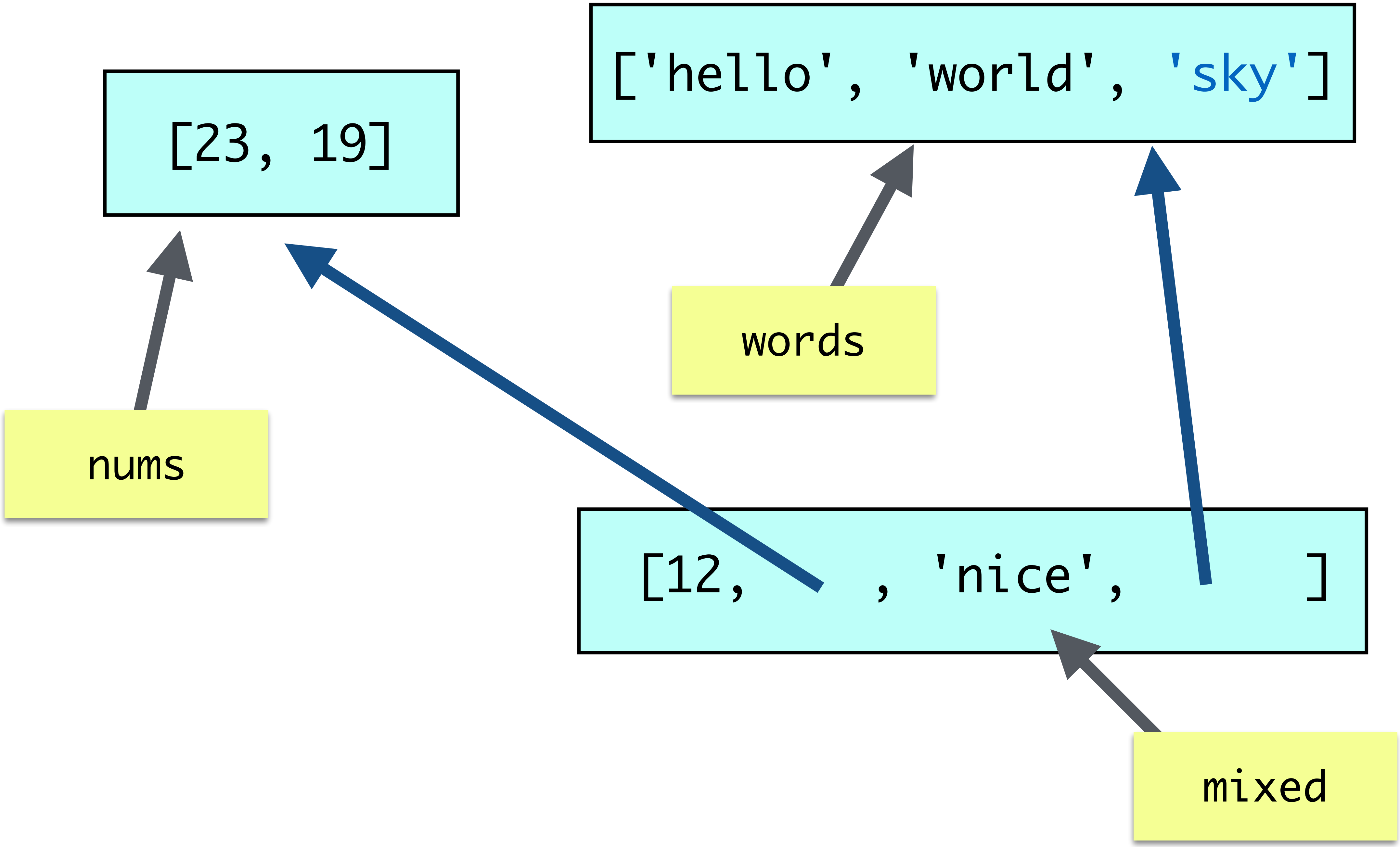
(Crazy) Aliasing Examples

```
>>> nums = [23, 19]
>>> words = ["hello", "world"]
>>> mixed = [12, nums, "nice", words]
```



(Crazy) Aliasing Examples

```
>>> words += ["sky"]
```



[23, 19]

['hello', 'world', 'sky']

words

nums

[12, , 'nice',]

mixed