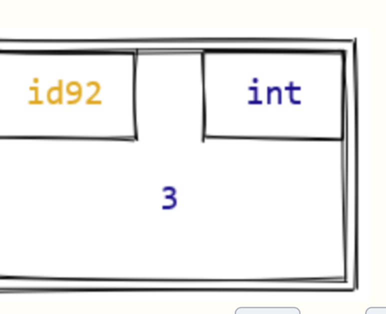
# 6.2 Objects and Object Mutation

In the previous section, we discussed one way that variables can "change value" during the execution of a Python program. In this section, we'll introduce the other way values can change, a phenomenon called *object mutation*. But to understand how object mutation happens, we're first going to need to go a bit deeper into precisely how the Python interpreter stores data.

## *Objects and the Python data model*

Up to this point in our study of the Python programming language, we've talked about representing data in terms of *values* that actually contain the data and *variables* that are names that refer to values. This has been a useful simplification when learning the fundamentals of programming in Python, but we're ready now to go further.

In Python, every piece of data is stored in an entity called an **object**. Every object has three fundamental components: its *id*, its *data type*, and its *value*. A useful metaphor here is to view an object as a box: the object's *id* and *type* are like labels printed on the box, and the *value* is some piece of data that's stored inside the box. In the past when we've talked about "values" in a Python program, we've really been talking about "objects that contain values". And when we've talked about the *data type* of a particular value, we're really been talking about the data type of the object that contains the value.




A visual representation of an object with id `id92`, type `int`, and value `3`.

But what is the id of an object, really? To understand this component, let's think about how data is stored in your computer. Every computer program (whether written in Python or some other language) stores data in computer memory, which you can think of as a very long list of storage locations, each with a unique *memory address*.[1] In Python, every object we use is stored in computer memory at a particular location, and it is the responsibility of the Python interpreter to keep track of which objects are stored at which memory locations. Formally, the **id** of an object is a unique `int` representation of the memory address of the object. As Python programmers, we cannot control or modify which memory address is used to store a given object, but we can access the id of an object using the built-in `id` function:

[1] This is analogous to a very long street, with each building having a unique number as its street address.

```
>>> id(3)
1635361280
>>> id('words')
4297547872
```

Okay, so that's objects, ids, types, and values. But you might be wondering, why are talking about this? Here is the fundamental property that's relevant to our discussion this chapter: **once an object its created, its id and type can never change, but (depending on the data type), its value may change**. To use our earlier analogy, once the Python interpreter has created a "box" to store some data, the labels on the box can't change, but the contents of the box can (sometimes) change. This is the other form of "value change" in a Python program, called *object mutation*.

## *Object mutation*

In 5.7 Nested Loops, we saw how `cartesian_product` could help us calculate the Cartesian product by accumulating all possible pairs of elements in a list. Now, let's consider a similar function that accumulates values in a list:

```
def squares(nums: list[int]) -> list[int]:
    """Return a list of the squares of the given numbers.

    >>> squares([1, 2, 3])
    [1, 4, 9]
    """
    squares_so_far = []

    for num in nums:
        squares_so_far = squares_so_far + [num * num]
    return squares_so_far
```

Both `squares` and `cartesian_product` functions are implemented correctly, but are rather inefficient.[2] In `squares`, each loop iteration creates a new `list` object (a copy of the current list plus one more element at the end) and reassigns `squares_so_far` to it. It would be easier (and faster) if we could somehow reuse the same object but modify it by adding elements to it; the same applies to other collection data types like `set` and `dict` as well.

[2] We'll study what we mean by "inefficient" more precisely later in this course.

In Python, **object mutation** (often shortened to just **mutation**) is an operation that changes the value of an existing object. For example, Python's `list` data type contains several methods that **mutate** the given `list` object rather than create a new one. Here's how we could improve our `squares` implementation by using `list.append`,[3] a method that adds a single value to the end of a list:

[3] Check out Appendix A.2 Python Built-In Data Types Reference for a list of methods, including mutating ones, for lists, sets, dictionaries, and more.

```
def squares(nums: list[int]) -> list[int]:
    """Return a list of the squares of the given numbers.

    >>> squares([1, 2, 3])
    [1, 4, 9]
    """
    squares_so_far = []

    for num in nums:
        list.append(squares_so_far, num * num)
    return squares_so_far
```

Now, `squares` runs by assigning `squares_so_far` to a single list object before the loop, and then mutating that list object at each loop iteration. The outward behaviour is the same, but this code is more efficient because a bunch of new list objects are not created. To use the terminology from before, `squares_so_far` is *not* reassigned; instead, the object that it refers to gets mutated.

One final note: you might notice that the loop body calls `list.append` without an assignment statement. This is because `list.append` returns `None`, a special Python value that indicates "no value". Just as we explored previously with the `print` function, `list.append` has a *side effect* that it mutates its `list` argument, but does not return anything.

## *Variable reassignment vs. object mutation*

We have now seen both variable reassignment and object mutation, let us take a moment to examine the similarities and differences between the two. We can use as inspiration our two different versions of `squares`, which illustrated these two forms of "value change". Let's extract out the relevant part and look at it in more detail in the Python console. Suppose we have a variable `squares_so_far = [1, 4, 9]` and want to add `16` to the end of it. We can do this through either variable reassignment or object mutation, as shown in the table below.

| Variable reassignment version | Object mutation version |
|---|---|
| First, create the new variable. | First, create the new variable. |
| `>>> squares_so_far = [1, 4, 9]`<br>`>>> squares_so_far`<br>`[1, 4, 9]` | `>>> squares_so_far = [1, 4, 9]`<br>`>>> squares_so_far`<br>`[1, 4, 9]` |
| Then reassign the variable. | Then mutate the object that the variable refers to. |
| `>>> squares_so_far = squares_so_far + [16]`<br>`>>> squares_so_far`<br>`[1, 4, 9, 16]` | `>>> list.append(squares_so_far, 16)`<br>`>>> squares_so_far`<br>`[1, 4, 9, 16]` |

By just looking at the final value of `squares_so_far`, it seems like the variable reassignment version and object mutation version had the same effect. Yet we claimed above that the object mutation version was "faster" because it didn't need to create a copy of the new list. How can we tell this actually happens?

One way is to use the `id` function to inspect the ids of the objects that `squares_so_far` refers to at each step in the process. Let's modify our example to call `id(squares_so_far)` at each step.

| Variable reassignment version | Object mutation version |
|---|---|
| First, create the new variable. | First, create the new variable. |
| `>>> squares_so_far = [1, 4, 9]`<br>`>>> squares_so_far`<br>`[1, 4, 9]`<br>`>>> id(squares_so_far)`<br>`1920480441344` | `>>> squares_so_far = [1, 4, 9]`<br>`>>> squares_so_far`<br>`[1, 4, 9]`<br>`>>> id(squares_so_far)`<br>`1920480441344` |
| Then reassign the variable. | Then mutate the object that the variable refers to. |
| `>>> squares_so_far = squares_so_far + [16]`<br>`>>> squares_so_far`<br>`[1, 4, 9, 16]`<br>`>>> id(squares_so_far)`<br>`1920484788736` | `>>> list.append(squares_so_far, 16)`<br>`>>> squares_so_far`<br>`[1, 4, 9, 16]`<br>`>>> id(squares_so_far)`<br>`1920480441344` |

Of course, the specific `id` values shown are just examples, and will differ on your computer. The important part is that in the variable reassignment version, the id values are different before and after the reassignment. This is consistent with what we said above: the statement `squares_so_far = squares_so_far + [16]` creates a *new list object* and assigns that to `squares_so_far`, and every object has a unique id. On the other hand, in the object mutation version the ids are the same before and after the mutation operation. `squares_so_far` continues to refer to the same list object, but the *value of that object* has changed as a result of the mutation.

## *Reasoning about code with changing values*

Even though variable reassignment and object mutation are distinct concepts, they share a fundamental similarity: they both result in variables changing values over the course of a program. So far we've focused on individual lines of code, but let's now take a step back and consider the implications of "changing values over the course of a program". Consider the following hypothetical function definition:

```
def my_function(...) -> ...:
    x = 10
    y = [1, 2, 3]

    ...  # Many lines of code
    ...  # Many lines of code
    ...  # Many lines of code
    ...  # Many lines of code
    ...  # Many lines of code
    ...  # Many lines of code

    return x * len(y) + ...
```

We've included for effect a large omitted "middle" section of the function body, showing only the initialization of two local variables at the start of the function and a final return statement at the end of the function.

If the omitted code does *not* contain any variable reassignment or object mutation, then we can be sure that in the return statement, `x` still refers to `10` and `y` still refers to `[1, 2, 3]`, regardless of what other computations occurred in the omitted lines! In other words, without reassignment and mutation, these assignment statements are universal across the function body: "for all points in the body of `my_function`, `x == 10` and `y == [1, 2, 3]`." Such universal statements make our code easier to reason about, as we can determine the values of these variables from just the assignment statement that creates them.

Variable reassignment and object mutation weaken this property. For example, if we reassign `x` or `y` (e.g., `x = 100`) in the middle of the function body, the return statement obtains a different value for `x` than `10`. Similarly, if we mutate `y` (e.g., `list.append(y, 100)`), the return statement uses a different value for `y` than `[1, 2, 3]`. *Introducing reassignment and mutation makes our code harder to reason about, as we need to track all changes to variable values line by line.*

Because of this, you should avoid using variable reassignment and object mutation when possible, and use them in structured code patterns like we saw with the loop accumulator pattern. Over the course of this chapter, we'll study other situations where reassignment and mutation are useful, and introduce a new memory model to help us keep track of changing variable values in our code.

## *Summary*

Here is a summary of the three components of a Python object.

| | Object id | Object type | Object value |
|---|---|---|---|
| Description | A unique identifier for the object. | The data type of the object. | The value of the object. |
| How to see it | Built-in `id` function | Built-in `type` function | Evaluate it |
| Example | `>>> id([1, 4, 9])`<br>`1920480441344` | `>>> type([1, 4, 9])`<br>`<class 'list'>` | `>>> [1, 4, 9]`<br>`[1, 4, 9]` |
| Can change? | No | No | Yes, for some data types |
| Unique among all objects | Yes | No | No |

You'll note that we've said that an object's value can change for *some* data types. You're probably wondering which of those data types can change, but perhaps at this point you can anticipate what we'll say next—read on to find out! 😺