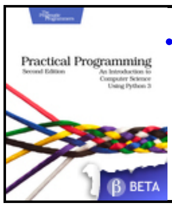
Functions, Variables, and the Call Stack



- 3.5 Tracing Function Calls in the Memory Model

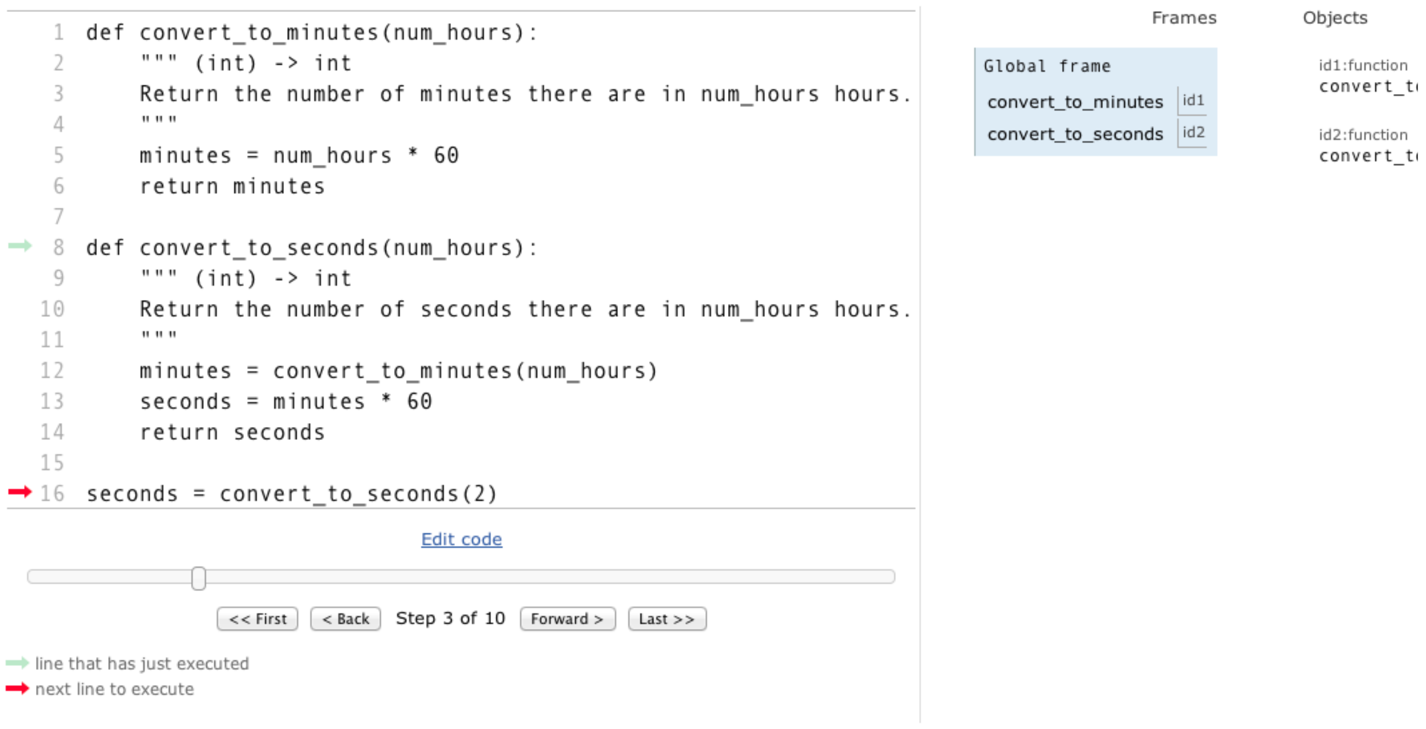
Optional reading

Understanding Scope

Below is an explanation and review of the example used in the video.

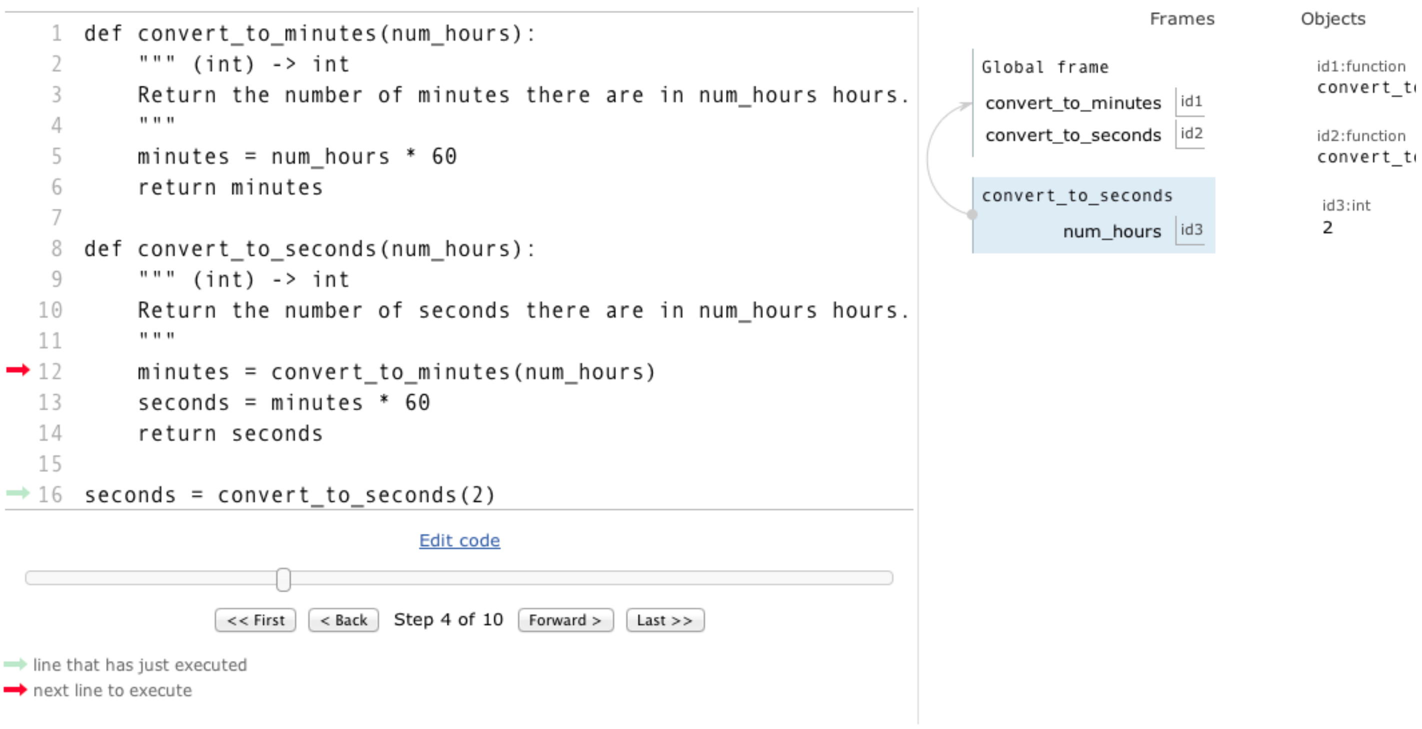
```
def convert_to_minutes(num_hours):
    """ (int) -> int
    Return the number of minutes there are in num_hours hours.
    """
    minutes = num_hours * 60
    return minutes

def convert_to_seconds(num_hours):
    """ (int) -> int
    Return the number of seconds there are in num_hours hours.
    """
    minutes = convert_to_minutes(num_hours)
    seconds = minutes * 60
    return seconds

seconds = convert_to_seconds(2)
```

Python defines the first two functions, creates objects for them in the heap, and, in the stack frame for the main program, creates variables that refer to those function objects.



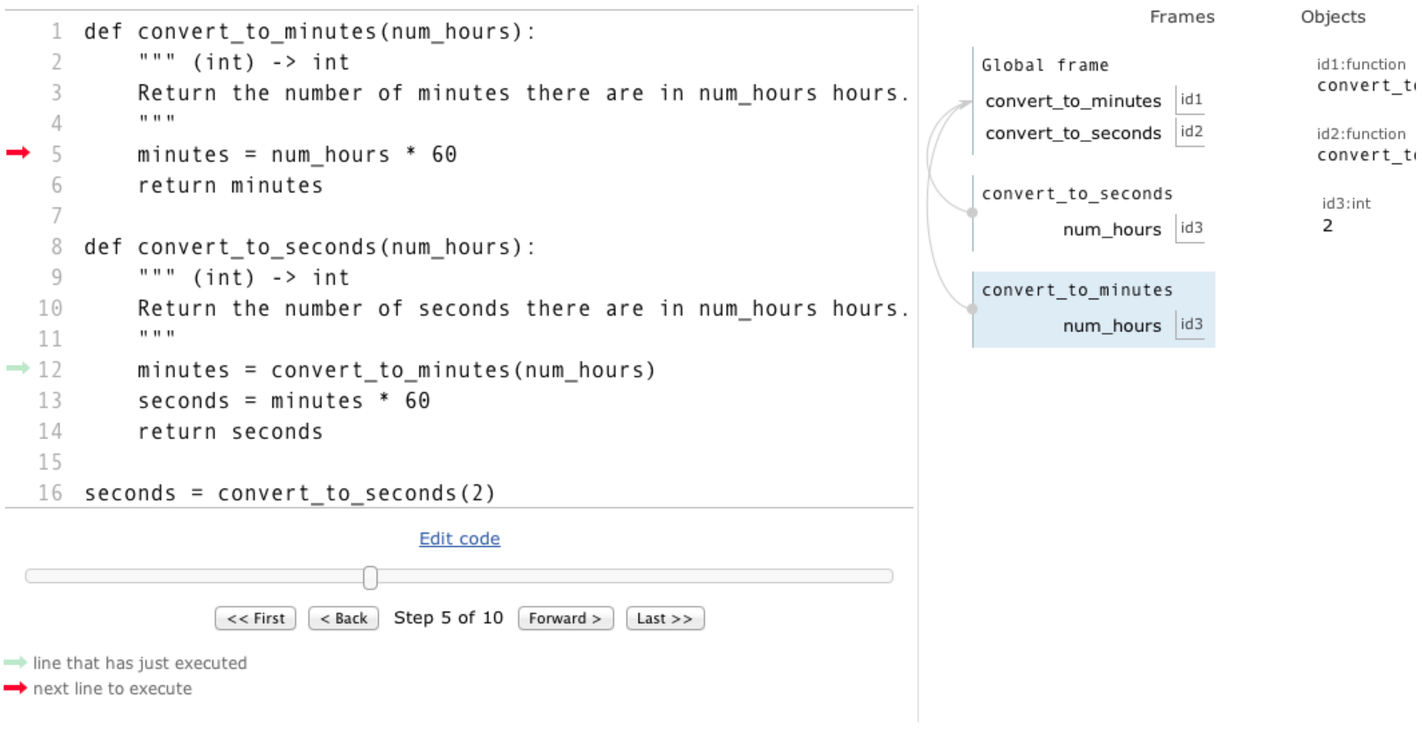
```
 1 def convert_to_minutes(num_hours):
 2     """ (int) -> int
 3     Return the number of minutes there are in num_hours hours.
 4     """
 5     minutes = num_hours * 60
 6     return minutes
 7
 8 def convert_to_seconds(num_hours):
 9     """ (int) -> int
10     Return the number of seconds there are in num_hours hours.
11     """
12     minutes = convert_to_minutes(num_hours)
13     seconds = minutes * 60
14     return seconds
15
16 seconds = convert_to_seconds(2)
```

After that, it executes the assignment statement on line 16. The right-hand side of the assignment statement is a function call so we evaluate the argument, `2`, first. The frame for `convert_to_seconds` will appear on the call stack. The parameter, `num_hours`, will refer to the value `2`.



```
def convert_to_minutes(num_hours):
    """ (int) -> int
    Return the number of minutes there are in num_hours hours.
    """
    minutes = num_hours * 60
    return minutes

def convert_to_seconds(num_hours):
    """ (int) -> int
    Return the number of seconds there are in num_hours hours.
    """
    minutes = convert_to_minutes(num_hours)
    seconds = minutes * 60
    return seconds

seconds = convert_to_seconds(2)
```

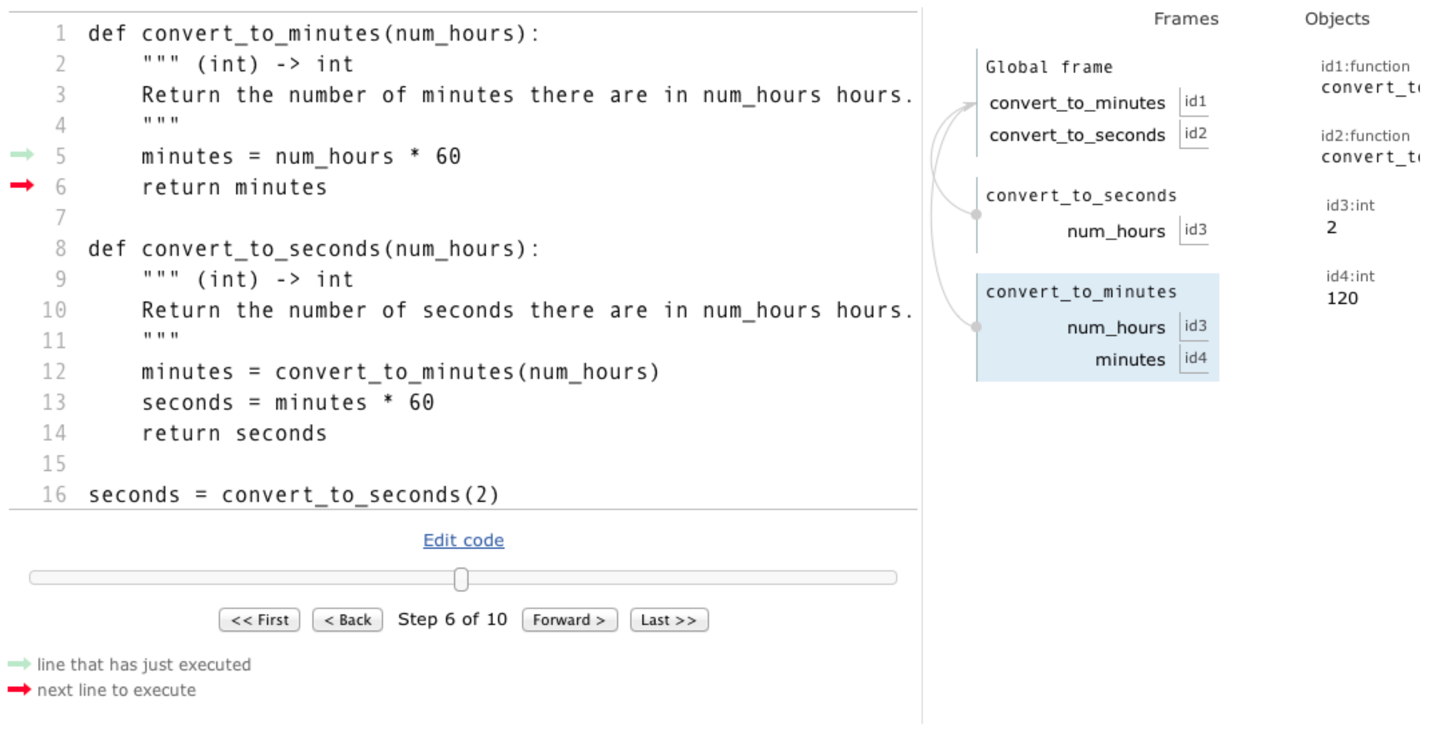
The first statement in function `convert_to_seconds` is an assignment statement. Again, we evaluate the expression on the right-hand side. This is a function call so we evaluate the argument, `num_hours`. This produces the value `2`. A stack frame for function `convert_to_minutes` is created on the call stack. Python stores the memory address of `2` in the parameter for `convert_to_minutes`, which also happens to be called `num_hours`.



```
def convert_to_minutes(num_hours):
    """ (int) -> int
    Return the number of minutes there are in num_hours hours.
    """
    minutes = num_hours * 60
    return minutes

def convert_to_seconds(num_hours):
    """ (int) -> int
    Return the number of seconds there are in num_hours hours.
    """
    minutes = convert_to_minutes(num_hours)
    seconds = minutes * 60
    return seconds

seconds = convert_to_seconds(2)
```

We now see that there are two variables called `num_hours` in the call stack; one is in `convert_to_minutes` and the other is in `convert_to_seconds`.

The next line of code Python executes is `minutes = num_hours * 60`. However, which instance of `num_hours` will be used? Python always uses the variable in the current stack frame. With an assignment statement, if the variable does not exist in the current stack frame, Python creates it. So, once `num_hours * 60` is evaluated, variable `minutes` is created in the current stack frame.



```
def convert_to_minutes(num_hours):
    """ (int) -> int
    Return the number of minutes there are in num_hours hours.
    """
    minutes = num_hours * 60
    return minutes

def convert_to_seconds(num_hours):
    """ (int) -> int
    Return the number of seconds there are in num_hours hours.
    """
    minutes = convert_to_minutes(num_hours)
    seconds = minutes * 60
    return seconds

seconds = convert_to_seconds(2)
```

Frames

Global frame
convert_to_minutes id1
convert_to_seconds id2

convert_to_seconds
num_hours id3

convert_to_minutes
num_hours id3
minutes id4

Objects

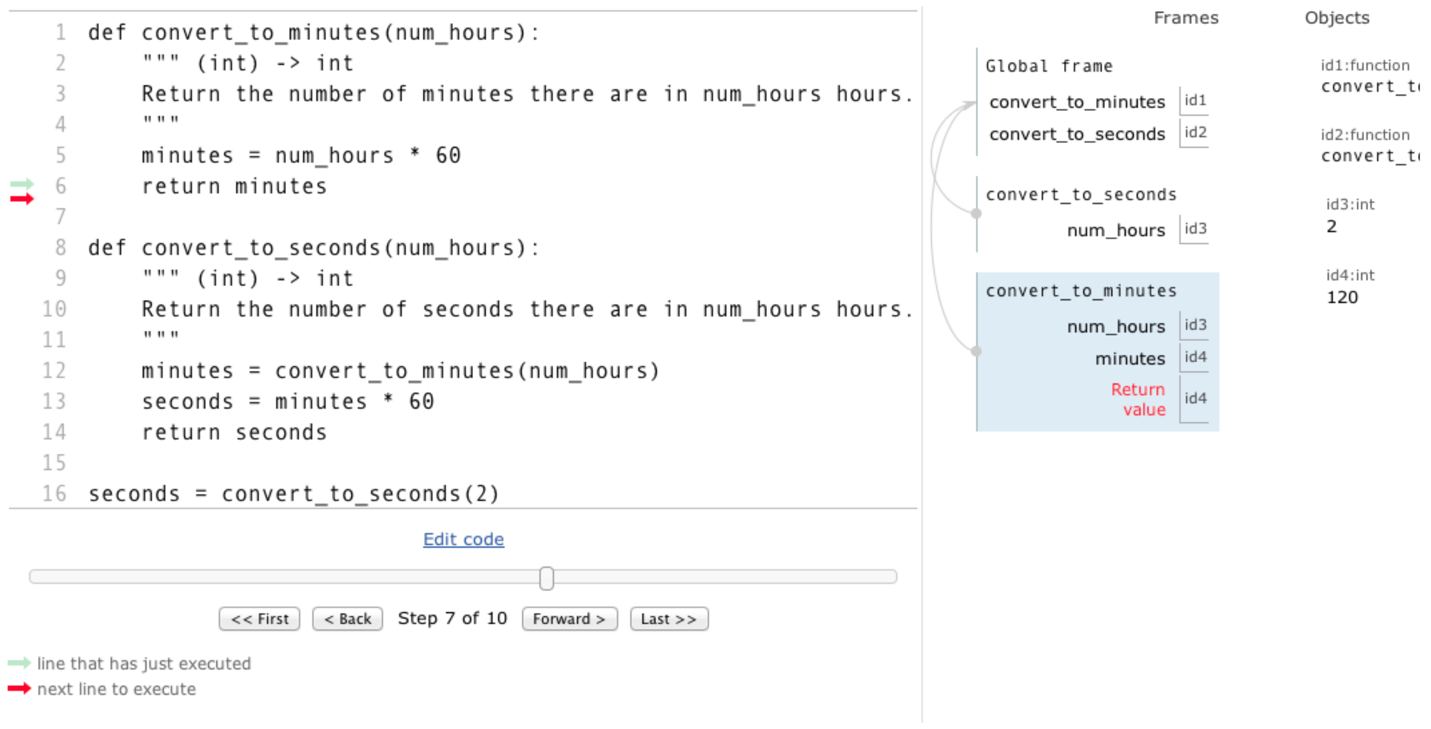
id1:function
convert_t

id2:function
convert_t

id3:int
2

id4:int
120

The last line of the function is `return minutes`. Once this statement is complete, Python will return to the frame just underneath the top of the call stack.



```
def convert_to_minutes(num_hours):
    """ (int) -> int
    Return the number of minutes there are in num_hours hours.
    """
    minutes = num_hours * 60
    return minutes

def convert_to_seconds(num_hours):
    """ (int) -> int
    Return the number of seconds there are in num_hours hours.
    """
    minutes = convert_to_minutes(num_hours)
    seconds = minutes * 60
    return seconds

seconds = convert_to_seconds(2)
```

Frames

Global frame
convert_to_minutes id1
convert_to_seconds id2

convert_to_seconds
num_hours id3

convert_to_minutes
num_hours id3
minutes id4
Return value id4

Objects

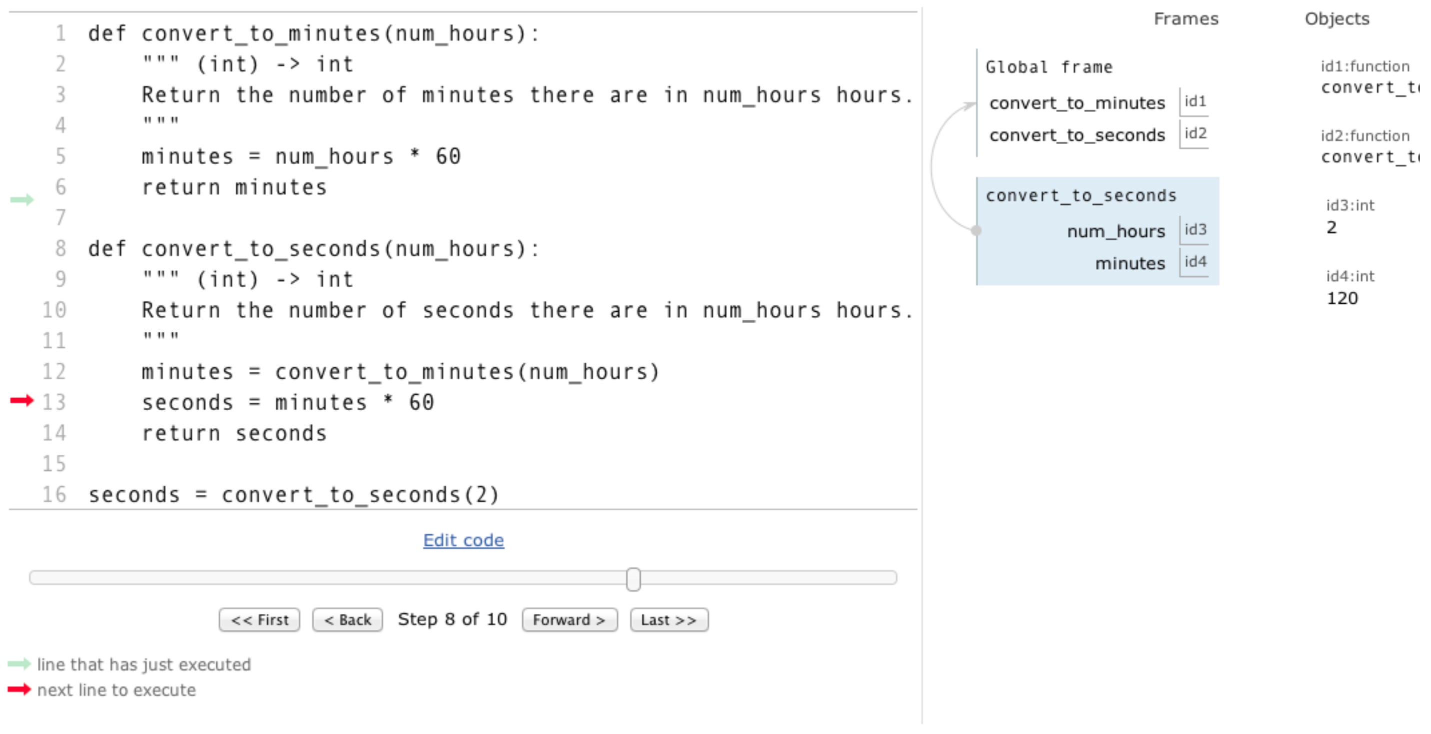
id1:function
convert_t

id2:function
convert_t

id3:int
2

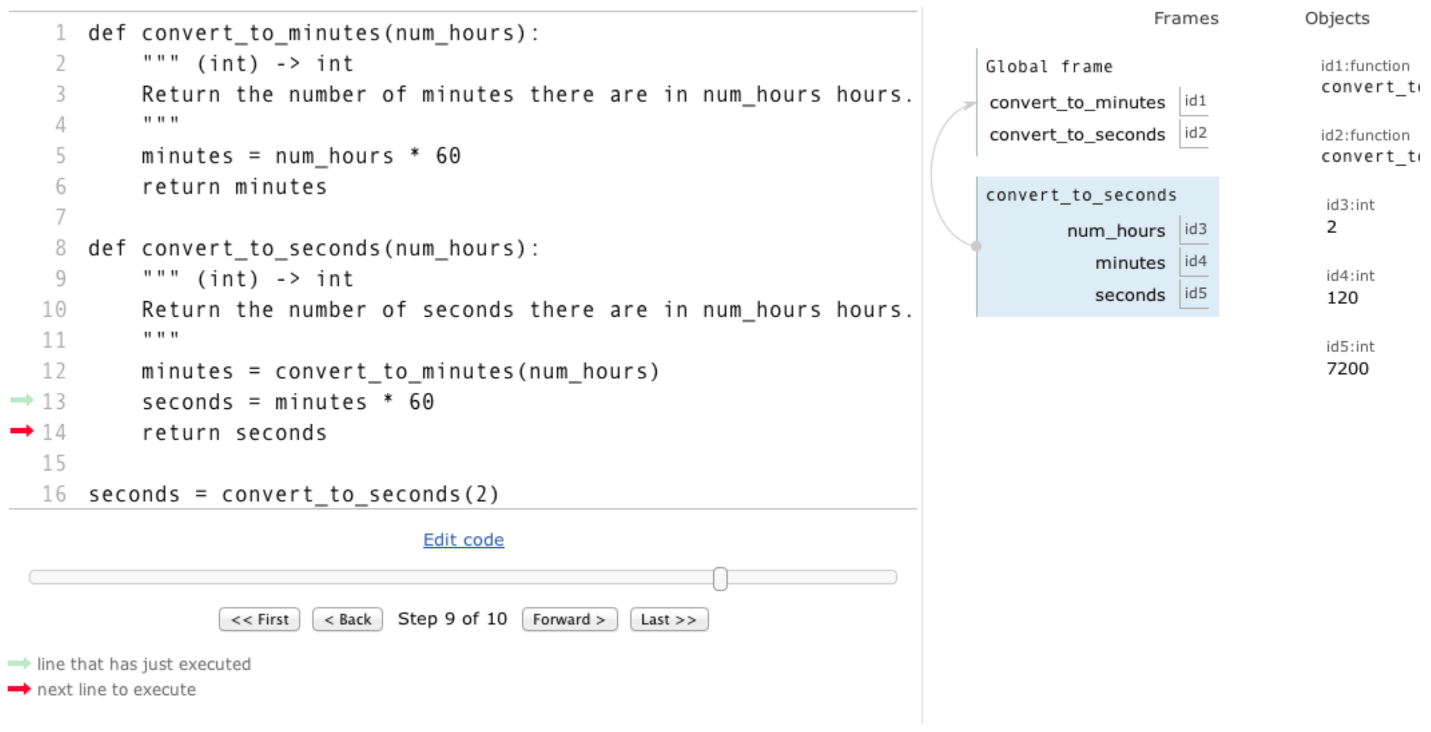
id4:int
120

So, Python is going to produce the value `120`, remove the current stack frame, create a new variable called `minutes` in the stack frame for `convert_to_seconds`, and store the memory adress of `120` in that variable.



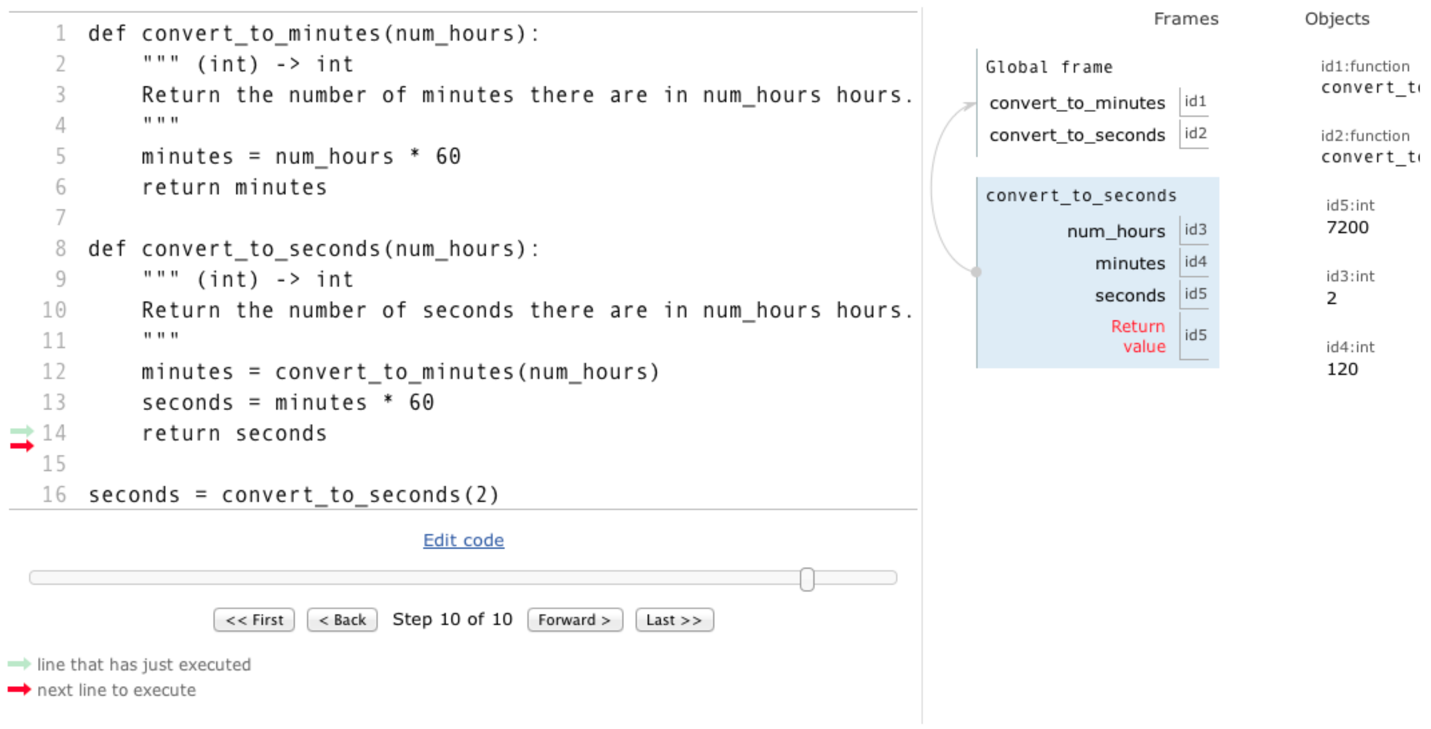
```
def convert_to_minutes(num_hours):
    """ (int) -> int
    Return the number of minutes there are in num_hours hours.
    """
    minutes = num_hours * 60
    return minutes

def convert_to_seconds(num_hours):
    """ (int) -> int
    Return the number of seconds there are in num_hours hours.
    """
    minutes = convert_to_minutes(num_hours)
    seconds = minutes * 60
    return seconds

seconds = convert_to_seconds(2)
```

Python then executes `seconds = minutes * 60`. Python evaluates the right-hand side, which produces `7200`, and stores the memory address of that value in variable `seconds`. Since this variable does not exist yet, Python creates it in the current stack frame.



```
def convert_to_minutes(num_hours):
    """ (int) -> int
    Return the number of minutes there are in num_hours hours.
    """
    minutes = num_hours * 60
    return minutes

def convert_to_seconds(num_hours):
    """ (int) -> int
    Return the number of seconds there are in num_hours hours.
    """
    minutes = convert_to_minutes(num_hours)
    seconds = minutes * 60
    return seconds

seconds = convert_to_seconds(2)
```

Next is a return statement. Like we saw above, that is going to return control back to the the main module.

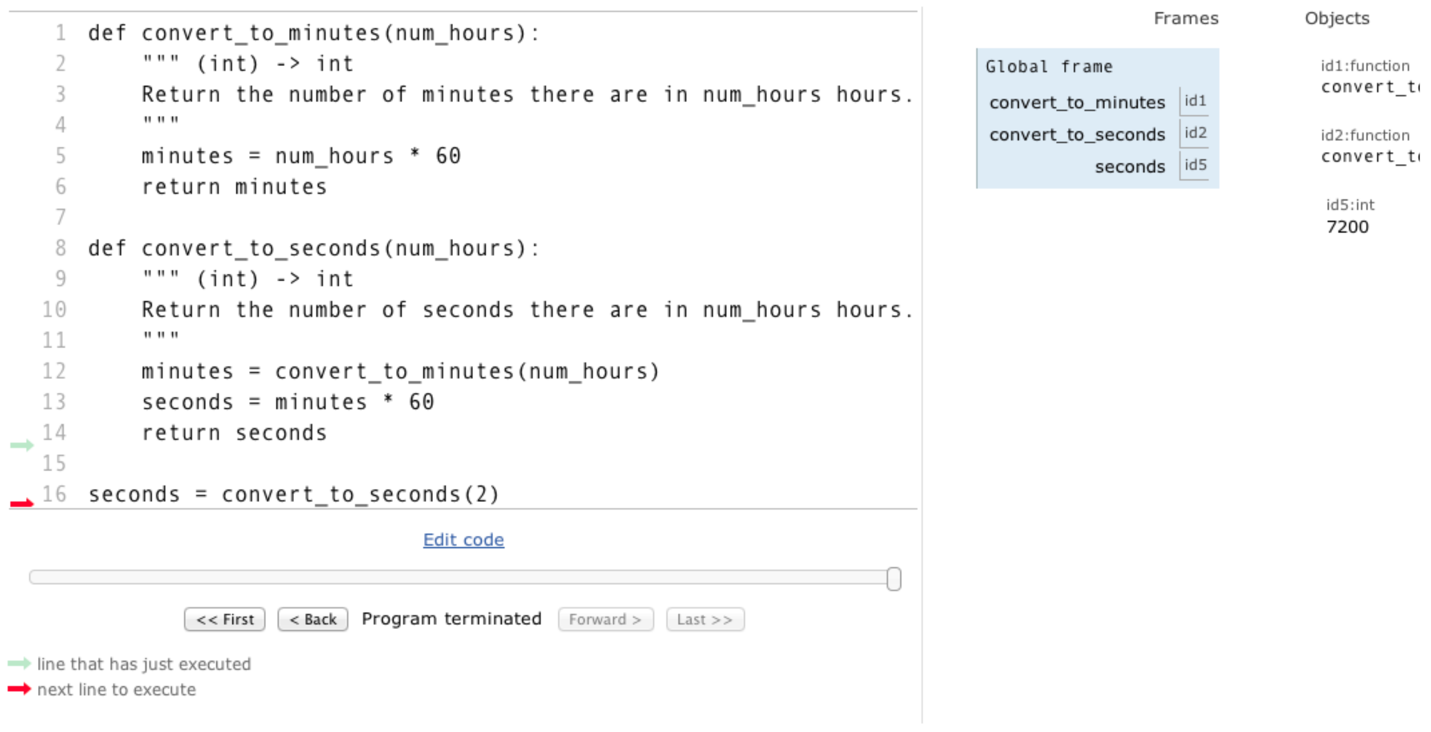


```
 1  def convert_to_minutes(num_hours):
 2      """ (int) -> int
 3      Return the number of minutes there are in num_hours hours.
 4      """
 5      minutes = num_hours * 60
 6      return minutes
 7
 8  def convert_to_seconds(num_hours):
 9      """ (int) -> int
10      Return the number of seconds there are in num_hours hours.
11      """
12      minutes = convert_to_minutes(num_hours)
13      seconds = minutes * 60
14      return seconds
15
16  seconds = convert_to_seconds(2)
```

Step 10 of 10

```
Frames                                  Objects

Global frame                            id1:function
  convert_to_minutes   id1              convert_t
  convert_to_seconds   id2
                                        id2:function
convert_to_seconds                      convert_t
           num_hours   id3
             minutes   id4              id5:int
             seconds   id5              7200
        Return value   id5
                                        id3:int
                                        2

                                        id4:int
                                        120
```

Once the frame for `convert_to_seconds` is removed, the assignment statement on line 16 (which has been paused a long time!) is completed, and a new variable `seconds` is created in the stack frame for the main program.



```
 1  def convert_to_minutes(num_hours):
 2      """ (int) -> int
 3      Return the number of minutes there are in num_hours hours.
 4      """
 5      minutes = num_hours * 60
 6      return minutes
 7
 8  def convert_to_seconds(num_hours):
 9      """ (int) -> int
10      Return the number of seconds there are in num_hours hours.
11      """
12      minutes = convert_to_minutes(num_hours)
13      seconds = minutes * 60
14      return seconds
15
16  seconds = convert_to_seconds(2)
```

Program terminated

```
Frames                                  Objects

Global frame                            id1:function
  convert_to_minutes   id1              convert_t
  convert_to_seconds   id2
             seconds   id5              id2:function
                                        convert_t

                                        id5:int
                                        7200
```

Notes and assignment and return statements

Assignment statement and computer memory

```
variable = expression
```

If a variable does not exist in the current stack frame, Python creates it.

Return statement and computer memory

```
return expression
```

In addition to evaluating the expression and yielding its value, `return` also erases the stack frame on top of the call stack.

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