Crossing paths // Unsplash user @gcalebjones

BBM 101

Introduction to Programming I

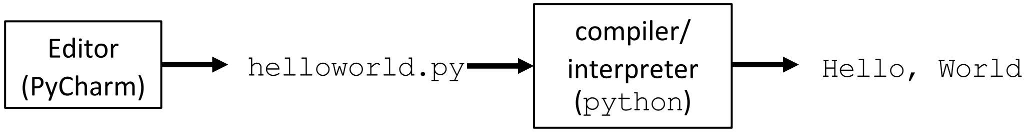
Lecture #05 –Control Flow, Functions

HACETTEPE UNIVERSITY

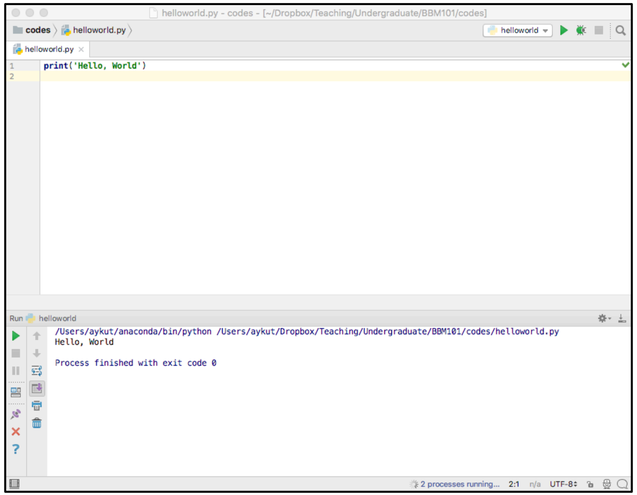
Fuat Akal, Aykut Erdem & Erkut Erdem // Fall 2019

Last time... **Introduction to Python**

Programming in Python



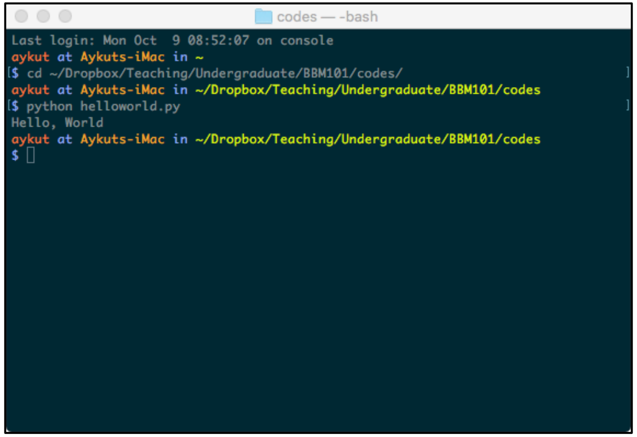
Editor (PyCharm) → `helloworld.py` → compiler/ interpreter (`python`) → `Hello, World`



```python
print('Hello, World')
```

```
/Users/aykut/anaconda/bin/python /Users/aykut/Dropbox/Teaching/Undergraduate/BBM101/codes/helloworld.py
Hello, World

Process finished with exit code 0
```

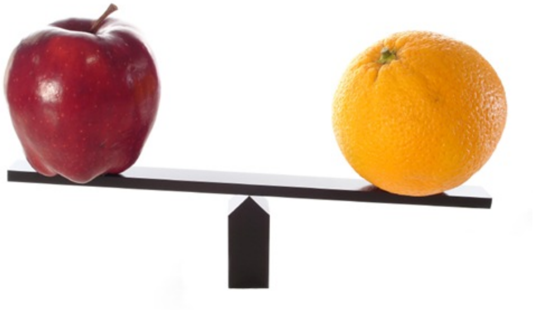


```
Last login: Mon Oct  9 08:52:07 on console
aykut at Aykuts-iMac in ~
$ cd ~/Dropbox/Teaching/Undergraduate/BBM101/codes/
aykut at Aykuts-iMac in ~/Dropbox/Teaching/Undergraduate/BBM101/codes
$ python helloworld.py
Hello, World
aykut at Aykuts-iMac in ~/Dropbox/Teaching/Undergraduate/BBM101/codes
$ 
```

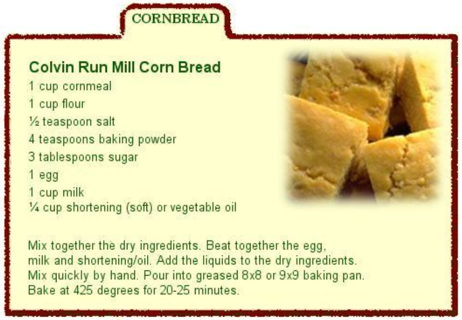
1. Python is like a calculator

2. A variable is a container

3. Different types cannot be compared



4. A program is a recipe



CORNBREAD

Colvin Run Mill Corn Bread

1 cup cornmeal
1 cup flour
½ teaspoon salt
4 teaspoons baking powder
3 tablespoons sugar
1 egg
1 cup milk
¼ cup shortening (soft) or vegetable oil

Mix together the dry ingredients. Beat together the egg, milk and shortening/oil. Add the liquids to the dry ingredients. Mix quickly by hand. Pour into greased 8x8 or 9x9 baking pan. Bake at 425 degrees for 20-25 minutes.

Lecture Overview

- Control Flow

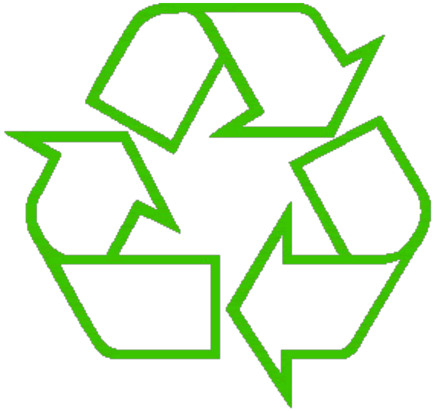
- Functions

Disclaimer: Much of the material and slides for this lecture were borrowed from
—Ruth Anderson, Michael Ernst and Bill Howe's CSE 140 class

Lecture Overview

- Control Flow

- Functions



Repeating yourself

Making decisions

Temperature Conversion Chart

Recall the exercise from the previous lecture

```
fahr = 30
cent = (fahr -32)/9.0*5
print(fahr, cent)
fahr = 40
cent = (fahr -32)/9.0*5
print(fahr, cent)
fahr = 50
cent = (fahr -32)/9.0*5
print(fahr, cent)
fahr = 60
cent = (fahr -32)/9.0*5
print(fahr, cent)
fahr = 70
cent = (fahr -32)/9.0*5
print(fahr, cent)
Print("All done")
```

```
Output:
30 -1.11
40 4.44
50 10.0
60 15.55
70 21.11
All done
```

Temperature Conversion Chart

A better way to repeat yourself:

for loop

loop variable or iteration variable

A list

Colon is required

Loop *body* is indented

```
for f in [30,40,50,60,70]:
    print(f, (f-32)/9.0*5)
print("All done")
```

Execute the body 5 times:

- once with f = 30
- once with f = 40
- once with f = 50
- once with f = 60
- once with f = 70

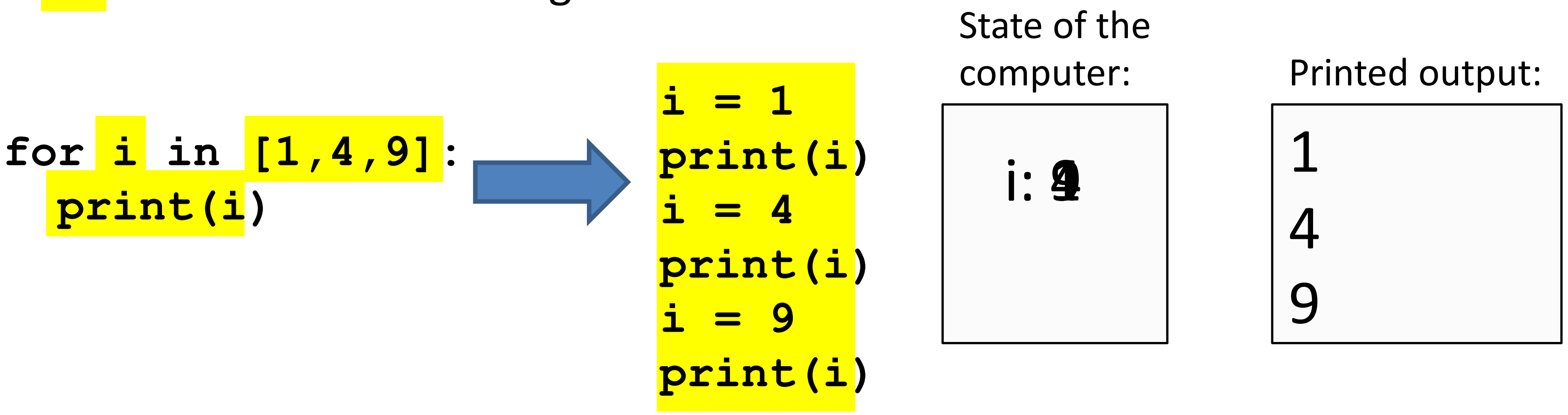
Indentation is significant

```
Output:
30 -1.11
40 4.44
50 10.0
60 15.55
70 21.11
All done
```

How a Loop is Executed: Transformation Approach

Idea: convert a **`for`** loop into something we know how to execute

1. Evaluate the sequence expression
2. Write an assignment to the loop variable, for each sequence element
3. Write a copy of the loop after each assignment
4. Execute the resulting statements



```
for i in [1,4,9]:
  print(i)
```

```
i = 1
print(i)
i = 4
print(i)
i = 9
print(i)
```

State of the computer:

i: 9

Printed output:

```
1
4
9
```

How a Loop is Executed: Direct Approach

1. Evaluate the sequence expression
2. While there are sequence elements left:
    a) Assign the loop variable to the next remaining sequence element
    b) Execute the loop body

Current location in list

```
for i in [1,4,9]:
    print(i)
```

State of the computer:

Printed output:

```
1
4
9
```

The Body can be Multiple Statements

Execute whole body, then execute whole body again, etc.

```
for i in [3,4,5]:
   print("Start body")
   print(i)
   print(i*i)
```

loop body:
3 statements

<u>Output:</u>

```
Start body
3
9
Start body
4
16
Start body
5
25
```

<u>NOT:</u>

~~Start body~~
~~Start body~~
~~Start body~~
~~3~~
~~4~~
~~5~~
~~9~~
~~16~~
~~25~~

Convention: often use *i* or *j* as loop variable if values are integers

This is an exception to the rule that variable names should be descriptive

Indentation in Loop is <u>Significant</u>

- Every statement in the body must have exactly the same indentation
- That’s how Python knows where the body ends

```
for i in [3,4,5]:
    print("Start body")
     print(i)
    print(i*i)
```

Error!

- Compare the results of these loops:

```
for f in [30,40,50,60,70]:
    print(f, (f-32)/9.0*5)
print("All done")

for f in [30,40,50,60,70]:
    print(f, (f-32)/9.0*5)
    print("All done")
```

The Body can be Multiple Statements

How many statements does this loop contain?

```
for i in [0,1]:
    print("Outer", i)
    for j in [2,3]:
        print(" Inner", j)
        print("  Sum", i+j)
    print("Outer", i)
```

"nested" loop body: 2 statements

loop body: 3 statements

What is the output?

```
Output:
Outer 0
  Inner 2
    Sum 2
  Inner 3
    Sum 3
Outer 0
Outer 1
  Inner 2
    Sum 3
  Inner 3
    Sum 4
Outer 1
```

Understand Loops Through the Transformation Approach

Key idea:

1. Assign each sequence element to the loop variable
2. Duplicate the body

```
for i in [0,1]:
  print("Outer", i)
  for j in [2,3]:
    print(" Inner", j)
```

```
i = 0
print("Outer", i)
for j in [2,3]:
  print(" Inner", j)
i = 1
print("Outer", i)
for j in [2,3]:
  print(" Inner", j)
```

```
i = 0
print("Outer", i)
j = 2
print(" Inner", j)
j = 3
print(" Inner", j)
i = 1
print("Outer", i)
for j in [2,3]:
  print(" Inner", j)
```

Fix This Loop

```
# Goal:  print 1, 2, 3, …, 48, 49, 50
for tens_digit in [0, 1, 2, 3, 4]:
  for ones_digit in [1, 2, 3, 4, 5, 6, 7, 8, 9]:
    print(tens_digit * 10 + ones_digit)
```

What does it actually print?

How can we change it to correct its output?

Moral: Watch out for *edge conditions* (beginning or end of loop)

Some Fixes

```
# Goal:  print 1, 2, 3, …, 48, 49, 50

for tens_digit in [0, 1, 2, 3, 4]:
  for ones_digit in [0, 1, 2, 3, 4, 5, 6, 7, 8, 9]:
    print(tens_digit * 10 + ones_digit + 1)

for tens_digit in [0, 1, 2, 3, 4]:
  for ones_digit in [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]:
    print(tens_digit * 10 + ones_digit)
```

- Analyze each of the above

Test Your Understanding of Loops

Output:

Puzzle 1:

```
for i in [0,1]:
  print(i)
print(i)
```

```
0
1
1
```

Puzzle 2:

```
i = 5
for i in []:
  print(i)
```

```
(no output)
```

Puzzle 3:

```
for i in [0,1]:
  print("Outer", i)
  for i in [2,3]:
    print(" Inner", i)
  print("Outer", i)
```

Reusing loop variable (don't do this!)

inner loop body

outer loop body

```
Outer 0
  Inner 2
  Inner 3
Outer 3
Outer 1
  Inner 2
  Inner 3
Outer 3
```

The Range Function

As an implicit list:

```
for i in range(5):
   … body …
```

The list [0,1,2,3,4]

Upper limit (*exclusive*)

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

Lower limit (*inclusive*)

`range(1,5)` = [1,2,3,4]

step (distance between elements)

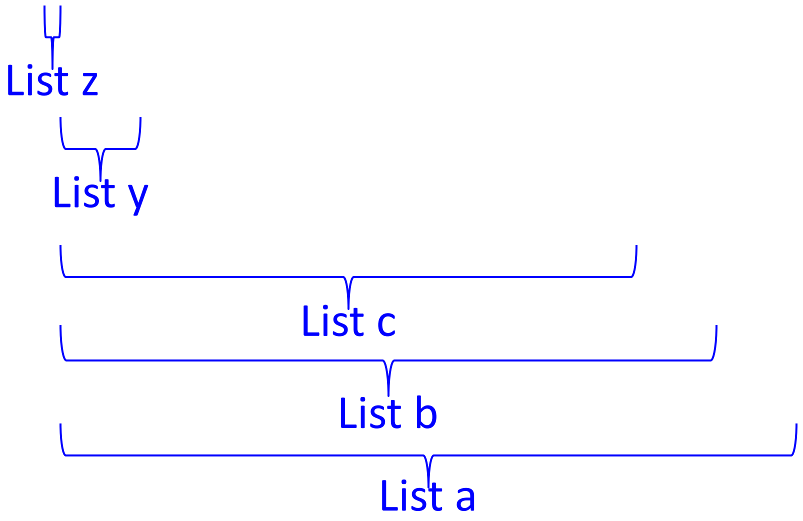
`range(1,10,2)` = [1,3,5,7,9]

Decomposing a List Computation

- To compute a value for a list:
  - Compute a partial result for all but the last element
  - Combine the partial result with the last element

Example: sum of a list:

[3, 1, 4, 1, 5, 9, 2, 6, 5]



List z

List y

List c

List b

List a

sum(List a) = sum(List b) + 5
sum(List b) = sum(List c) + 6
…
sum(List y) = sum(List z) + 3
sum(empty list) = 0

How to Process a List: One Element at a Time

- A common pattern when processing a list:

```
result = initial_value
for element in list:
  result = updated result
use result
```

```
# Sum of a list
result = 0
for element in mylist:
  result = result + element
print result
```

- **`initial_value`** is a correct result for an empty list

- As each element is processed, **`result`** is a correct result for a prefix of the list

- When all elements have been processed, **`result`** is a correct result for the whole list

Some Loops

```
# Sum of a list of values, what values?
result = 0
for element in range(5): # [0,1,2,3,4]
  result = result + element
print("The sum is: " + str(result))
```

```
The sum is: 10
```

```
# Sum of a list of values, what values?
result = 0
for element in range(5,1,-1):
  result = result + element
print("The sum is:", result)
```

```
5, 4, 3, 2
The sum is: 14
```

```
# Sum of a list of values, what values?
result = 0
for element in range(0,8,2):
  result = result + element
print("The sum is:", result)
```

```
0, 2, 4, 6
The sum is: 12
```

```
# Sum of a list of values, what values?
result = 0
size = 5
for element in range(size):
  result = result + element
print("When size = " + str(size) + ", the result is " + str(result))
```

```
0, 1, 2, 3, 4
When size = 5, the result is 10
```

Examples of List Processing

```
result = initial_value
for element in list:
  result = updated result
```

- Product of a list:

```
result = 1
for element in mylist:
  result = result * element
```

- Maximum of a list:

```
result = mylist[0]
for element in mylist:
  result = max(result, element)
```

The first element of the list (counting from zero)

- Approximate the value 3 by 1 + 2/3 + 4/9 + 8/27 + 16/81 + … = $(2/3)^0 + (2/3)^1 + (2/3)^2 + (2/3)^3 + \ldots + (2/3)^{10}$

```
result = 0
for element in range(11):
  result = result + (2.0/3.0)**element
```

Exercise with Loops

- Write a simple program to add values between two given inputs a, b
- e.g., if a=5, b=9, it returns sum of (5+6+7+8+9)
- Hint: we did some 'algorithmic thinking' and 'problem solving' here!

Notice this form of the assignment statement!

```
a, b = 5, 9
total = 0
for x in range(a, b+1):
    total += x
print(total)
```

Another Type of Loops – **while**

- The **while** loop is used for repeated execution as long as an expression is true

```
n = 100
s = 0
counter = 1
while counter <= n:
    s = s + counter
    counter += 1

print("Sum of 1 until ” + str(n) + ": ” + str(s))
```

```
Sum of 1 until 100: 5050
```

Making Decisions

- How do we compute absolute value?

```
abs(5) = 5
abs(0) = 0
abs(-22) = 22
```

Absolute Value Solution

If *the value is negative*, negate it.

Otherwise, use the original value.

```
val = -10

# calculate absolute value of val
if val < 0:
    result = - val
else:
    result = val

print(result)
```

Another approach
that does the same thing
without using **result**:

```
val = -10

if val < 0:
    print(- val)
else:
    print(val)
```

In this example, **result** will always be assigned a value.

Absolute Value Solution

As with loops, a sequence of statements could be used in place of a single statement inside an if statement:

```
val = -10

# calculate absolute value of val
if val < 0:
    result = - val
    print("val is negative!")
    print("I had to do extra work!")
else:
    result = val
    print("val is positive")
print(result)
```

Absolute Value Solution

What happens here?

```
val = 5

# calculate absolute value of val
if val < 0:
    result = - val
    print("val is negative!")
else:
    for i in range(val):
        print("val is positive!")
    result = val
print(result)
```

Another if

It is **not required that anything happens**…

```
val = -10

if val < 0:
     print("negative value!")
```

What happens when val = 5?

The if Body can be Any Statements

```
# height is in km
if height > 100:
    print("space")
else:
    if height > 50:
        print("mesosphere")
    else:
        if height > 20:
            print("stratosphere")
        else:
            print("troposphere")
```

then clause

else clause

t

f

t

f

Execution gets here only if “height > 100” is false

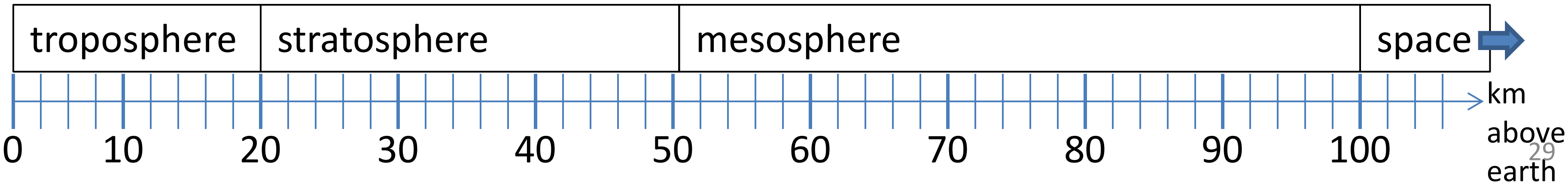
Execution gets here only if “height > 100” is false AND “height > 50” is true

Written differently!

```
# height is in km
if height > 50:
    if height > 100:
        print("space")
    else:
        print("mesosphere")
else:
    if height > 20:
        print("stratosphere")
    else:
        print("troposphere")
```

but more efficient!

```
# height is in km
if height > 100:
    print("space")
elif height > 50:
    print("mesosphere")
elif height > 20:
    print("stratosphere")
else:
    print("troposphere")
```



Version 1

```
# height is in km
if height > 100:
  print("space")
else:
  if height > 50:
    print("mesosphere")
  else:
    if height > 20:
      print("stratosphere")
    else:
      print("troposphere")
```

then clause

else clause

t

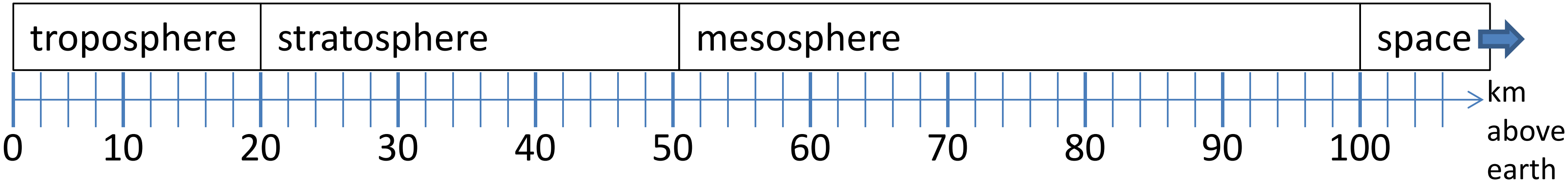
e

t

e

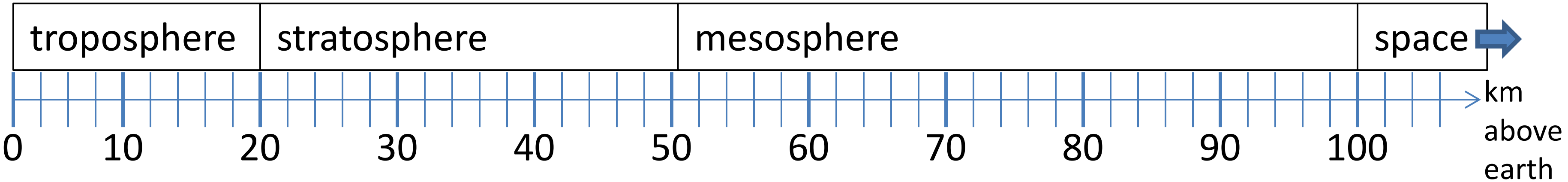
Execution gets here only if “height <= 100” is true

Execution gets here only if “height <= 100” is true AND “height > 50” is true



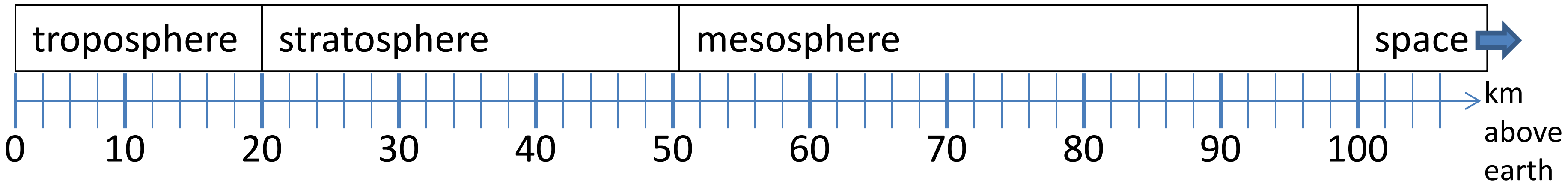
Version 1

```
# height is in km
if height > 100:
  print("space")
else:
  if height > 50:
    print("mesosphere")
  else:
    if height > 20:
      print("stratosphere")
    else:
      print("troposphere")
```



Version 2

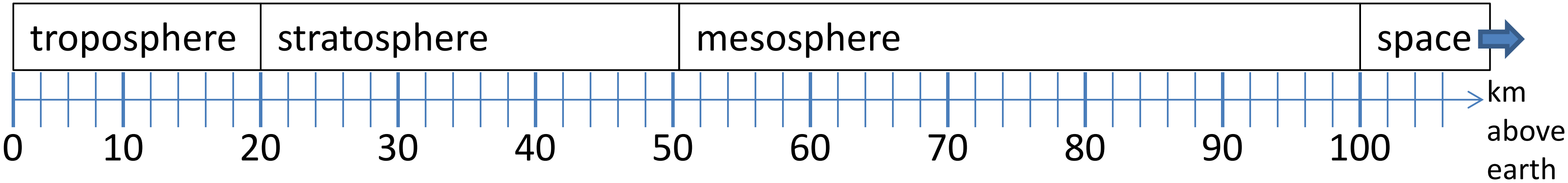
```
if height > 50:
  if height > 100:
    print("space")
  else:
    print("mesosphere")
else:
  if height > 20:
    print("stratosphere")
  else:
    print("troposphere")
```



Version 3

```
if height > 100:
  print("space")
elif height > 50:
  print("mesosphere")
elif height > 20:
  print("stratosphere")
else:
  print("troposphere")
```

ONE of the print statements is guaranteed to execute: whichever condition it encounters **first** that is true

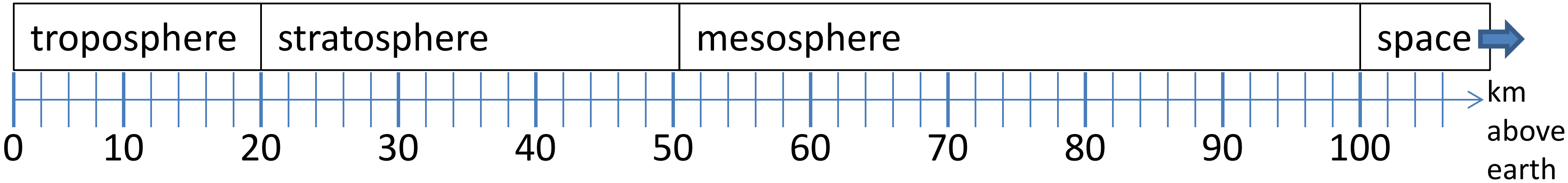


Order Matters

```
# version 3
if height > 100:
  print("space")
elif height > 50:
  print("mesosphere")
elif height > 20:
  print("stratosphere")
else:
  print("troposphere")
```

```
# broken version 3
if height > 20:
  print("stratosphere")
elif height > 50:
  print("mesosphere")
elif height > 100:
  print("space")
else:
  print("troposphere")
```

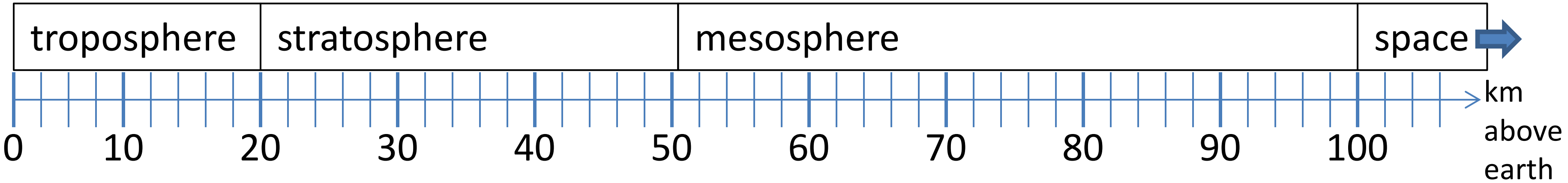
Try height = 72 on both versions, what happens?



Version 3

```
# incomplete version 3
if height > 100:
  print("space")
elif height > 50:
  print("mesosphere")
elif height > 20:
  print("stratosphere")
```

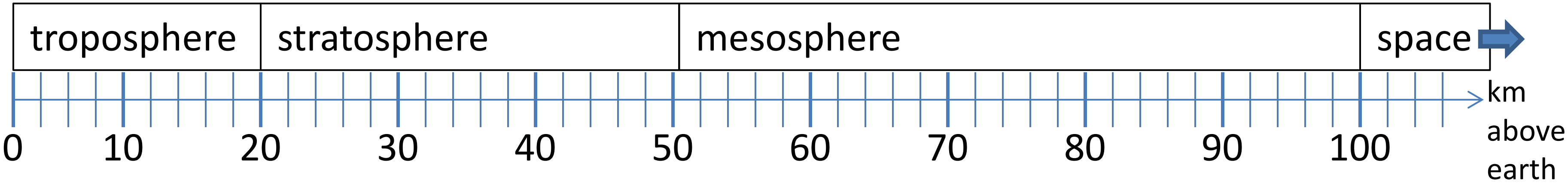
In this case it is possible that nothing is printed at all, when?



What Happens Here?

```
# height is in km
if height > 100:
  print("space")
if height > 50:
  print("mesosphere")
if height > 20:
  print("stratosphere")
else:
  print("troposphere")
```

Try height = 72



`divisorpattern.py`: Accept integer command-line argument *n*. Write to standard output an *n*-by-*n* table with an asterisk in row i and column j if either i divides j or j divides i.

```
import sys

n = int(sys.argv[1])
for i in range(1, n + 1):
    for j in range(1, n + 1):
        if (i % j == 0) or (j % i == 0):
            print(‘* ‘, end=‘‘)
        else:
            print(‘  ‘, end=‘‘)
    print(i)
```

```
$ python divisorpattern.py 3
* * * 1
* *   2
*   * 3
```

```
$ python divisorpattern.py 10
* * * * * * * * * * 1
* *   *   *   *   * 2
*   *     *     *     3
* *   *       *     4
*       *         * 5
* * *     *         6
*           *       7
* *   *       *     8
*   *           *   9
* *     *         * 10
```

Variable trace (`n = 3`)

i	j	output
1	1	’* ’
1	2	’* ’
1	3	’* 1\n’
2	1	’* ’
2	2	’* ’
2	3	’ 2\n’
3	1	’* ’
3	2	’ ’
3	3	’* 3\n’

The **break** Statement

- The **break** statement terminates the current loop and resumes execution at the next statement

```
for letter in 'hollywood':
   if letter == 'l':
      break
   print ('Current Letter :', letter)
```

```
Current Letter : h
Current Letter : o
```

The **continue** Statement

- The **continue** statement in Python returns the control to the beginning of the while loop.

```
for letter in 'hollywood':
   if letter == 'l':
      continue
   print ('Current Letter :', letter)
```

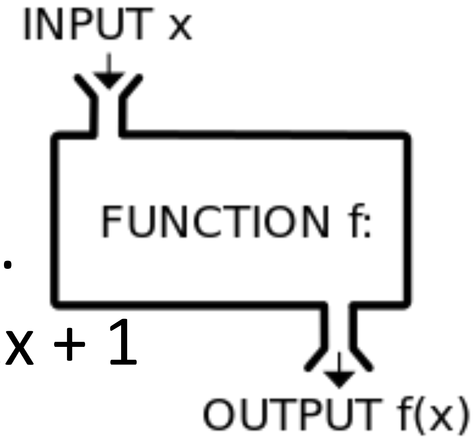
```
Current Letter : h
Current Letter : o
Current Letter : y
Current Letter : w
Current Letter : o
Current Letter : o
Current Letter : d
```

Lecture Overview

- Control Flow

- Functions

Functions



- In math, you use functions: sine, cosine, …
- In math, you define functions: f(x) = $x^2 + 2x + 1$

- A function packages up and names a computation
- Enables re-use of the computation (generalization)
- **D**on't **R**epeat **Y**ourself (DRY principle)
- Shorter, easier to understand, less error-prone

- Python lets you use and define functions
- We have already seen some Python functions:
  – **`len`**, **`float`**, **`int`**, **`str`**, **`range`**

Using ("calling") a Function

```
len("hello")          len("")
round(2.718)          round(3.14)
pow(2, 3)             range(1, 5)
math.sin(0)           math.sin(math.pi / 2)
```

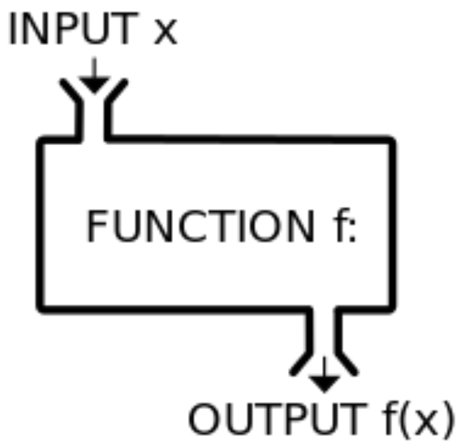
- Some need no input:

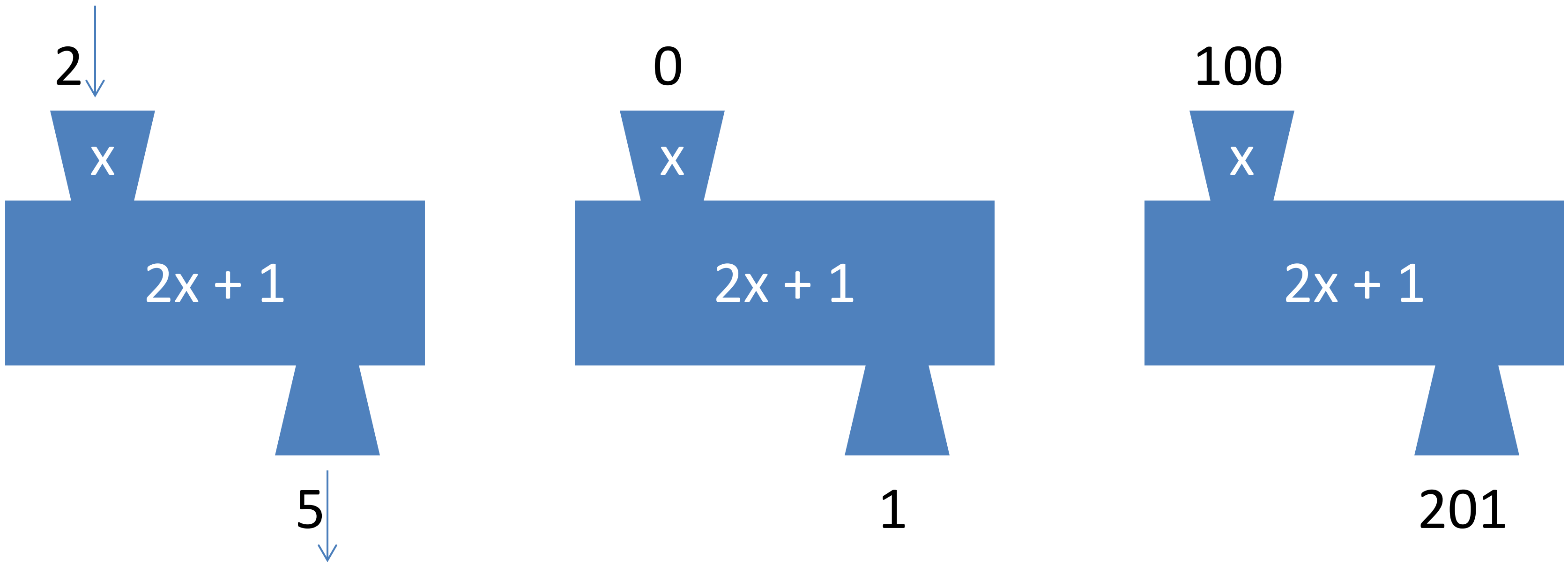
  ```
  random.random()
  ```

- All produce output

A Function is a Machine

- You give it input
- It produces a result (output)

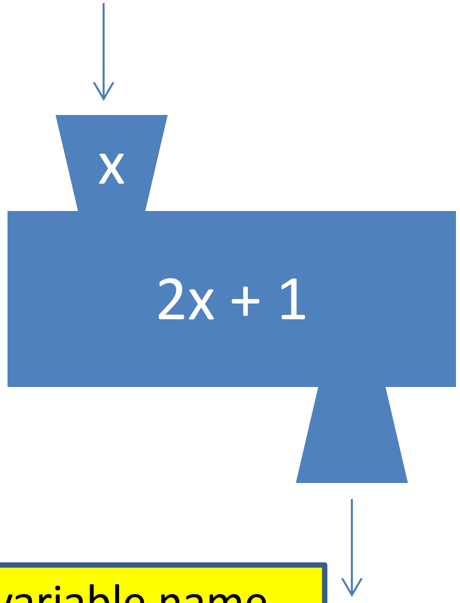




In math: func(x) = 2x + 1

Creating a Function

Define the machine,
including the input and the result



Name of the function.
Like "y = 5" for a variable

Keyword that means:
I am **def**ining a function

Input variable name,
or "formal parameter"

```
def dbl_plus(x):
    return 2*x + 1
```

Keyword that means:
This is the result

Return expression
(part of the **return** statement)

More Function Examples

Define the machine, including the input and the result

```
def square(x):
  return x * x

def fahr_to_cent(fahr):
  return (fahr – 32) / 9.0 * 5

def cent_to_fahr(cent):
  result = cent / 5.0 * 9 + 32
  return result

def abs(x):
  if x < 0:
    return – x
  else:
    return x
```

```
def print_hello():
  print("Hello, world")
```

No return statement
Returns the value None
Are also called ‘procedures’

```
def print_fahr_to_cent(fahr):
  result = fahr_to_cent(fahr)
  print(result)
```

What is the result of:

```
x = 42
square(3) + square(4)
print(x)
boiling = fahr_to_cent(212)
cold = cent_to_fahr(-40)
print(result)
print(abs(-22))
print(print_fahr_to_cent(32))
```

Python Interpreter

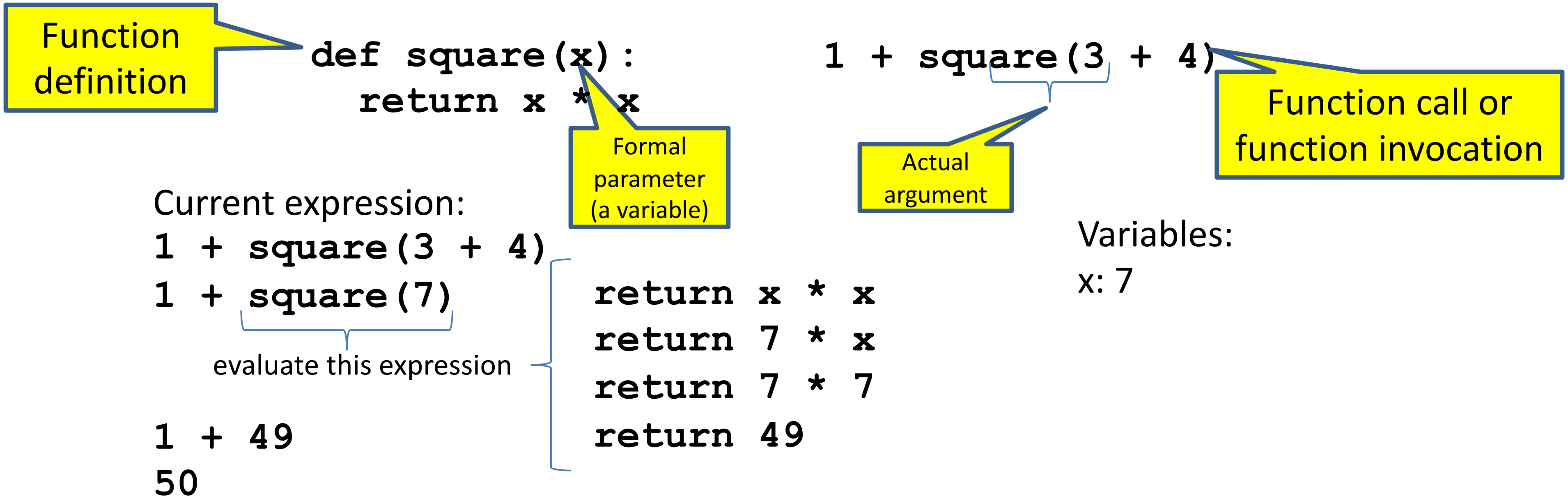
- An expression evaluates to a value
  - Which can be used by the containing expression or statement
- **`print("test")`** statement writes text to the screen
- The Python interpreter (command shell) reads statements and expressions, then executes them
- If the interpreter executes an expression, it prints its value
- In a program, evaluating an expression does not print it
- In a program, printing an expression does not permit it to be used elsewhere

An example

```
def lyrics():
    print("The very first line")
print(lyrics())
```

```
The very first line
None
```

How Python Executes a Function Call



Function definition

```
def square(x):
    return x * x
```

Formal parameter (a variable)

```
1 + square(3 + 4)
```

Actual argument

Function call or function invocation

Current expression:

```
1 + square(3 + 4)
1 + square(7)
```

evaluate this expression

```
return x * x
return 7 * x
return 7 * 7
return 49
```

```
1 + 49
50
```

Variables:
x: 7

1. Evaluate the **argument** (at the call site)
2. Assign the **formal parameter name** to the argument’s value
   - A *new* variable, not reuse of any existing variable of the same name
3. Evaluate the **statements** in the body one by one
4. At a **return** statement:
   - Remember the value of the expression
   - Formal parameter variable disappears – exists only during the call!
   - The call expression evaluates to the return value

Example of Function Invocation

```
def square(x):
  return x * x
```

```
                                        Variables:
square(3) + square(4)                   (none)
return x * x                            x: 3
return 3 * x                            x: 3
return 3 * 3                            x: 3
return 9                                x: 3
9 + square(4)                           (none)
     return x * x                       x: 4
     return 4 * x                       x: 4
     return 4 * 4                       x: 4
     return 16                          x: 4
9 + 16                                  (none)
25                                      (none)
```

Expression with Nested Function Invocations: Only One Executes at a Time

```
def fahr_to_cent(fahr):
  return (fahr – 32) / 9.0 * 5

def cent_to_fahr(cent):
  return cent / 5.0 * 9 + 32
```

```
                                                  Variables:
fahr_to_cent(cent_to_fahr(20))                    (none)
                 return cent / 5.0 * 9 + 32       cent: 20
                 return 20 / 5.0 * 9 + 32         cent: 20
                 return 68                        cent: 20
fahr_to_cent(68)                                  (none)
return (fahr – 32) / 9.0 * 5                      fahr: 68
return (68 – 32) / 9.0 * 5                        fahr: 68
return 20                                         fahr: 68
20                                                (none)
```

Expression with Nested Function Invocations: Only One Executes at a Time

```
def square(x):
  return x * x

                                         Variables:
square(square(3))                        (none)
         return x * x                    x=3
         return 3 * x                    x=3
         return 3 * 3                    x=3
         return 9                        x=3
square(9)                                (none)
     return x * x                        x=9
     return 9 * x                        x=9
     return 9 * 9                        x=9
     return 81                           x=9
81                                       (none)
```

Function that Invokes Another Function: Both Function Invocations are Active

```
import math

def square(z):
  return z*z
def hypoten_use(x, y):
  return math.sqrt(square(x) + square(y))
                                                  Variables:
hypoten_use(3, 4)                                 (none)
  return math.sqrt(square(x) + square(y))         x:3    y:4
  return math.sqrt(square(3) + square(y))         x:3    y:4
    return z*z                                    z: 3
    return 3*3                                    z: 3
    return 9                                      z: 3
  return math.sqrt(9 + square(y))                 x: 3   y:4
  return math.sqrt(9 + square(4))                 x: 3   y:4
    return z*z                                    z: 4
    return 4*4                                    z: 4
    return 16                                     z: 4
  return math.sqrt(9 + 16)                        x: 3   y:4
  return math.sqrt(25)                            x: 3   y:4
  return 5                                        x:3    y:4
5                                                 (none)
```

Shadowing of Formal Variable Names

```
import math
def square(x):
  return x*x
def hypotenuse(x, y):
  return math.sqrt(square(x) + square(y))
```

Same formal parameter name

```
                                                  Variables:
hypotenuse(3, 4)                                  (none)
  return math.sqrt(square(x) + square(y))         x: 3   y:4
  return math.sqrt(square(3) + square(y))         x: 3   y:4
    return x*x                                       x: 3
    return 3*3                                       x: 3
    return 9                                         x: 3
  return math.sqrt(9 + square(y))                 x: 3   y:4
  return math.sqrt(9 + square(4))                 x: 3   y:4
    return x*x                                       x: 4
    return 4*4                                       x: 4
    return 16                                        x: 4
  return math.sqrt(9 + 16)                        x: 3   y:4
  return math.sqrt(25)                            x: 3   y:4
  return 5                                        x:3    y:4
5                                                 (none)
```

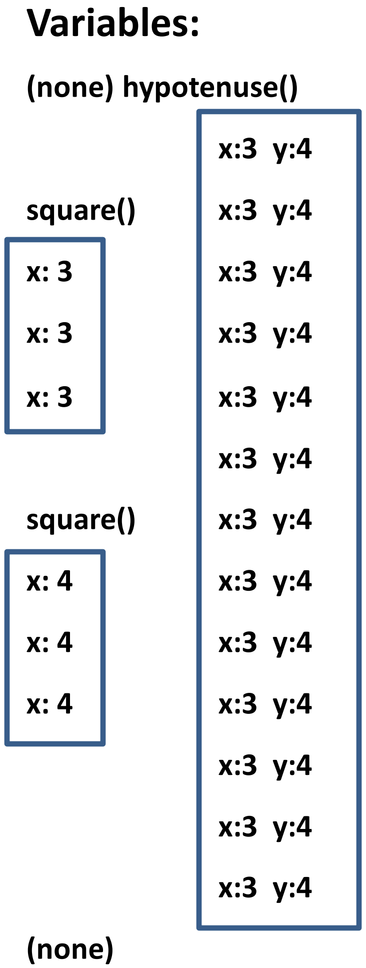
Formal parameter is a *new* variable

Shadowing of Formal Variable Names

```
import math
def square(x):
  return x*x
def hypotenuse(x, y):
  return math.sqrt(square(x) + square(y))

hypotenuse(3, 4)
  return math.sqrt(square(x) + square(y))
  return math.sqrt(square(3) + square(y))
    return x*x
    return 3*3
    return 9
  return math.sqrt(9 + square(y))
  return math.sqrt(9 + square(4))
    return x*x
    return 4*4
    return 16
  return math.sqrt(9 + 16)
  return math.sqrt(25)
  return 5
5
```

Same diagram, with *variable scopes* or *environment frames* shown explicitly



In a Function Body, Assignment Creates a Temporary Variable (like the formal parameter)

```
  stored = 0
  def store_it(arg):
     stored = arg
     return stored
★ y = store_it(22)
  print(y)
★ print(stored)
```

Show evaluation of the starred expressions:

```
y = store_it(22)
        stored = arg; return stored
        stored = 22; return stored
        return stored
        return 22
y = 22
print(stored)
print(0)
```

Variables:

store_it()	Global or top level
	stored: 0
arg: 22	stored: 0
arg: 22	stored: 0
arg: 22 stored: 22	stored: 0
arg: 22 stored: 22	stored: 0 y: 22
	stored: 0 y: 22
	stored: 0 y: 22

How to Look Up a Variable

Idea: find the nearest variable of the given name

1. Check whether the variable is defined in the local scope
2. … check any intermediate scopes …
3. Check whether the variable is defined in the global scope

If a local and a global variable have the same name, the global variable is inaccessible (“shadowed”)

This is confusing; try to avoid such shadowing

```
x = 22
stored = 100
def lookup():
    x = 42
    return stored + x
lookup()
x = 5
stored = 200
lookup()
```

```
def lookup():
    x = 42
    return stored + x
x = 22
stored = 100
lookup()
x = 5
stored = 200
lookup()
```

What happens if we define **stored** *after* **lookup()**?

Local Variables Exist Only while the Function is Executing

```
def cent_to_fahr(cent):
    result = cent / 5.0 * 9 + 32
    return result

tempf = cent_to_fahr(15)
print(result)
```

Use Only the Local and the Global Scope

```
myvar = 1

def outer():
    myvar = 1000
    return inner()

def inner():
    return myvar

print(outer())
```

```
1
```

Abstraction

- Abstraction = ignore some details

- Generalization = become usable in more contexts

- Abstraction over computations:
  - functional abstraction, a.k.a. procedural abstraction

- As long as you know what the function means, you don't care how it computes that value
  - You don't care about the *implementation* (the function body)

Defining Absolute Value

```
def abs(x):
  if val < 0:
    return -1 * val
  else:
    return 1 * val
```

```
def abs(x):
  if val < 0:
    result = - val
  else:
    result = val
  return result
```

```
def abs(x):
  if val < 0:
    return - val
  else:
    return val
```

```
def abs(x):
  return math.sqrt(x*x)
```

They all perform the same task.
Their implementations are different though.

Defining Round (for positive numbers)

```
def round(x):
  return int(x+0.5)
```

```
def round(x):
  fraction = x - int(x)
  if fraction >= .5:
    return int(x) + 1
  else:
    return int(x)
```

Each Variable Should Represent One Thing

```
def atm_to_mbar(pressure):
    return pressure * 1013.25

def mbar_to_mmHg(pressure):
    return pressure * 0.75006

# Confusing
pressure = 1.2 # in atmospheres
pressure = atm_to_mbar(pressure)
pressure = mbar_to_mmHg(pressure)
print(pressure)

# Better
in_atm = 1.2
in_mbar = atm_to_mbar(in_atm)
in_mmHg = mbar_to_mmHg(in_mbar)
print(in_mmHg)
```

```
# Best
def atm_to_mmHg(pressure):
    in_mbar = atm_to_mbar(pressure)
    in_mmHg = mbar_to_mmHg(in_mbar)
    return in_mmHg
print(atm_to_mmHg(1.2))
```

Corollary: Each variable should contain values of only one type

```
# Legal, but confusing: don’t do this!
x = 3
…
x = "hello"
…
x = [3, 1, 4, 1, 5]
…
```

If you use a descriptive variable name, you are unlikely to make these mistakes

Exercises

```
def cent_to_fahr(c):
  print(cent / 5.0 * 9 + 32)

print(cent_to_fahr(20))
```

```
def c_to_f(c):
    print("c_to_f")
    return c / 5.0 * 9 + 32

def make_message(temp):
    print("make_message")
    return ("The temperature is "
+ str(temp))

for tempc in [-40,0,37]:
    tempf = c_to_f(tempc)
    message = make_message(tempf)
    print(message)
```

```
def myfunc(n):
  total = 0
  for i in range(n):
    total = total + i
  return total

print(myfunc(4))
```

```
float(7)
```

```
abs(-20 - 2) + 20
```

What Does This Print?

```
def myfunc(n):
    total = 0
    for i in range(n):
        total = total + i
    return total

print(myfunc(4))
```

6

What Does This Print?

```
def c_to_f(c):
    print("c_to_f")
    return c / 5.0 * 9 + 32

def make_message(temp):
    print("make_message")
    return "The temperature is " + str(temp)

for tempc in [-40,0,37]:
    tempf = c_to_f(tempc)
    message = make_message(tempf)
    print(message)
```

```
c_to_f
make_message
The temperature is -40.0
c_to_f
make_message
The temperature is 32.0
c_to_f
make_message
The temperature is 98.6
```

Decomposing a Problem

- Breaking down a program into functions is *the fundamental activity* of programming!

- How do you decide when to use a function?
  - One rule: DRY (Don’t Repeat Yourself)
  - Whenever you are tempted to copy and paste code, don’t!

- Now, how do you design a function?

Review: How to Evaluate a Function Call

1. Evaluate the function and its arguments to values
   - If the function value is not a function, execution terminates with an error
2. Create a new stack frame
   - The parent frame is the one where the function is defined
   - A frame has bindings from variables to values
   - Looking up a variable starts here
     - Proceeds to the next older frame if no match here
     - The oldest frame is the “global” frame
     - All the frames together are called the “environment”
   - Assignments happen here
3. Assign the actual argument values to the formal parameter variable
   - In the new stack frame
4. Evaluate the body
   - At a return statement, remember the value and exit
   - If at end of the body, return **`None`**
5. Remove the stack frame
6. The call evaluates to the returned value

Functions are Values: The Function can be an Expression

```
import math

def double(x):
    return 2*x
print(double)
myfns = [math.sqrt, int, double, math.cos]
myfns[1](3.14)
myfns[2](3.14)
myfns[3](3.14)

def doubler():
    return double
doubler()(2.718)
```

Nested Scopes

- In Python, one can always determine the scope of a name by looking at the program text.
  - **static** or **lexical scoping**

```
def f(x):
   def g():
      x = "abc"
      print("x =", x)
   def h():
      z = x
      print("z =", z)
   x = x+1
   print("x =", x)
   h()
   g()
   print("x =", x)
   return g

x = 3
z = f(x)
print("x =", x)
print("z =", z)
z()
```

```
x = 4
z = 4
x = abc
x = 4
x = 3
z = <function f.<locals>.g at
0x7f06d7fa2ea0>
x = abc
```

Anonymous (lambda) Functions

- Anonymous functions are also called lambda functions in Python because instead of declaring them with the standard **def** keyword, you use the **lambda** keyword.

```
double = lambda x: x*2
double(5)
```

lambda x: x*2 is the lambda function.
x is the argument
x*2 is the expression or instruction that gets evaluated and returned.

```
lambda x, y: x + y;

is equal to

def sum(x, y):
    return x+y
```

You use lambda functions when you require a nameless function for a short period of time, and that is created at runtime.

Two Types of Documentation

1. Documentation for users/clients/callers
   - Document the *purpose* or *meaning* or *abstraction* that the function represents
   - Tells what the function does
   - Should be written for *every* function
2. Documentation for programmers who are reading the code
   - Document the *implementation* – specific code choices
   - Tells how the function does it
   - Only necessary for tricky or interesting bits of the code

For users: a string as the first element of the function body

For programmers: arbitrary text after **#**

called docstring

```
def square(x):
    """Returns the square of its argument."""
    # "x*x" can be more precise than "x**2"
    return x*x
```

Multi-line Strings

- New way to write a string – surrounded by three quotes instead of just one
  - `"hello"`
  - `'hello'`
  - `"""hello"""`
  - `'''hello'''`

- Any of these works for a documentation string

- Triple-quote version:
  - can include newlines (carriage returns), so the string can span multiple lines
  - can include quotation marks

Don’t Write Useless Comments

- Comments should give information that is not apparent from the code
- Here is a counter-productive comment that merely clutters the code, which makes the code *harder* to read:

```
# increment the value of x
x = x + 1
```

Where to Write Comments

- By convention, write a comment *above* the code that it describes (or, more rarely, on the same line)
  - First, a reader sees the English intuition or explanation, then the possibly-confusing code

```
# The following code is adapted from
# "Introduction to Algorithms", by Cormen et al.,
# section 14.22.
while (n > i):
    ...
```

- A comment may appear anywhere in your program, including at the end of a line:

```
x = y + x    # a comment about this line
```

- For a line that starts with **#**, indentation must be consistent with surrounding code