COMP1730/COMP6730
Programming for Scientists

Functions: advanced topics



## Academic integrity (reminder)

* Academic integrity is taken seriously at ANU! – Academic Integrity Rule 2021 is a legal document at the University
* Discussing programming problems (e.g. from labs) and ways to solve them with other students is a great way to learn – just don't discuss assessment problems
* All assignments are **individual**. You must write your own code, and be able to show that you understand every aspect of what you have written
* Suspected cheating/plagiarism will be investigated seriously accordingly to ANU academic integrity rule



## Lecture outline

* Namespaces & references
* Recursion revisited



## Namespaces and function calls

* Assignment statement (e.g., `variable=value`) associates a variable name with a reference to a value
* This association is stored in a **namespace** (a.k.a. **frame**), i.e., a mapping among variable names and references to values
* Whenever a function is called, a new **local namespace** is dynamically created
* Assignments to variables (including parameters) during execution of the function are registered in the local namespace
* The local namespace **disappears** when the function call ends

## Scope of a variable

- The **scope** of a variable is **the set of program statements over which a variable exists**, i.e., that can refer to the variable
- In other words, the set of program statements over which the namespace the variable is defined in persists
- Because there are several namespaces, **there can be different variables with the same name in different scopes**

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## Different vars with same name in different scopes

```
def f(x):
    y = x ** 2
    return y - 1

x = 1
y = f(x + 1)
```

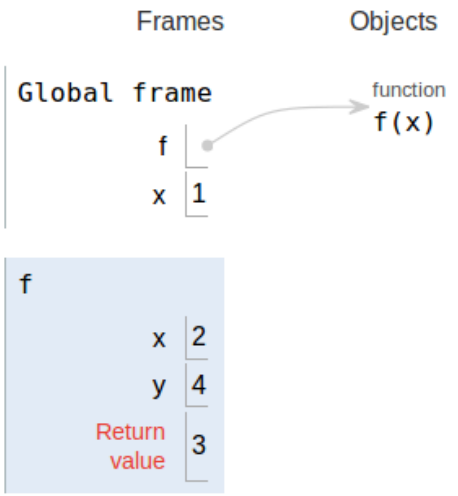


Image from pythontutor.com

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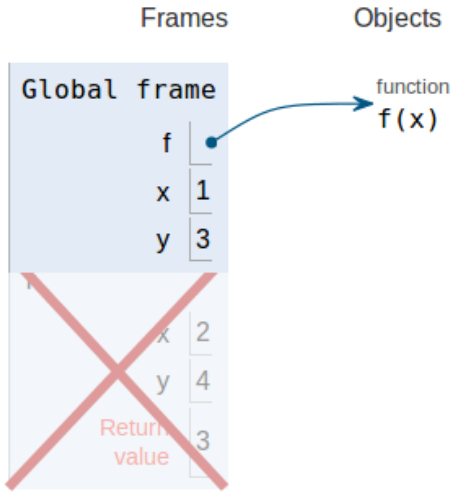


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## The local assignment rule

- Python considers a variable that is assigned **anywhere** in the function suite to be a **local variable** (this includes parameters)
- When a non-local variable is evaluated, its value is taken from the (enclosing) global namespace
- However, if a function assigns to a variable that is also defined in the global namespace, the local assignment **shadows** the non-local variable (i.e. as if the non-local variable did not exist)
- **WARNING**: If we refer to this local variable before assignment, Python will raise an `UnboundLocalError` (see next slide)

## Example: function that reads non-local variable versus function that shadows non-local variable

```
def f(x):
    return x ** y
>>> y = 2
>>> f(2)
4
```

```
def f(x):
    if y < 1:
        y = 1
    return x ** y
>>> y = 2
>>> f(2)
UnboundLocalError:
 local variable 'y'
 referenced before
 assignment
```

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## Modifying is NOT assignment!

- Assignment changes/creates the association between a name and a reference to a value (in the current namespace)
- A modifying operation on a mutable object does NOT change any name–value association

```
def f(x):
  y = x ** 2
  f_list.append([x,y])
  return y

>>> f_list = []
>>> f(2)
4
>>> f(3)
9
>>> f_list
[[2, 4], [3, 9]]
```

Example of function that modifies non-local list

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## Function params hold references to args values

- When a function is called, its parameters are assigned **references** to the argument values
- If a parameter name refers to a **mutable object** (e.g., list, NumPy array, or dictionary), modifications to this object made in the function suite are visible outside the function's scope

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## Example of function that modifies mutable object through parameter

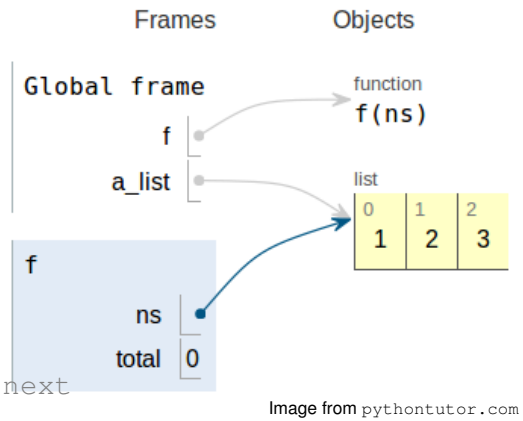
```
def f(ns):
  total = 0
  while len(ns) > 0:
        next = ns.pop(0)
        total = total + next
  return total

>>> a_list = [1,2,3]
>>> f(a_list)
6
>>> a_list
[]
```

Similar to previous example, HOWEVER, we can now tell from the function's signature that the function is going to access to such mutable object

## Example of function that modifies mutable object through parameter

```
def f(ns):
    total = 0
    while len(ns) > 0:
        next = ns.pop(0)
        total = total + next
    return total
```

```
>>> a_list = [1,2,3]
>>> l_sum = f(a_list)
```

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## Other namespaces

- Python's built-in functions (e.g., `type`, `max`, etc.) are defined in a separate namespace accessible from any part in the program
  - Programmer-defined names **override** built-in names
- Imported modules are executed in their own namespace
  - Names in a module namespace are accessed from outside by prefixing the name of the module to the name

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## Guidelines for good functions

- Accessing global variables within functions (specially if we modify them) is in general a bad practice that should be avoided
- Try to stick to functions that **access ONLY local variables**
  - Use parameters for all inputs to the function
  - Return all function outputs
    (for multiple outputs, return a tuple or list)
- In general, don't modify mutable argument values through the function parameters, unless there is a good reason for doing so (e.g., if it is the **specific purpose** of the function)

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## Recursion revisited

- A recursive function is often described as **a function that calls itself**
- Function calls form a **stack**: when the $i$-th function call ends, execution returns to where the call was made in the $(i-1)$-th function suite
- The function suite **MUST HAVE** a branching statement, such that a recursive call does not always take place (**base case**); otherwise, recursion never ends
- Recursion is a way to think about how to solve problems: reducing it to a smaller instance of itself

# Example (contrived)

```
def f(x):
  """
    Returns 2 to the power of x
    x is an integer >= 0
  """
  if x == 0:
      return 1     # base case
  else:
      y = f(x - 1) # recursive call
  return 2 * y
```

Note that $2^x = 2 * 2^{x-1}$ for $x > 0$

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```
1 def f(x):
      ...
2 y = f(2)
                  x = 2
                3 if x == 0:
                4 else:
                5 y = f(x - 1)
                                  x = 1
                                6 if x == 0:
                                7 else:
                                8 y = f(x - 1)
                                                  x = 0
                                               9 if x == 0:
                                              10 return 1
                                  x = 1, y = 1
                                11 return 2 * y
                  x = 2, y = 2
                12 return 2 * y
y = 4
```

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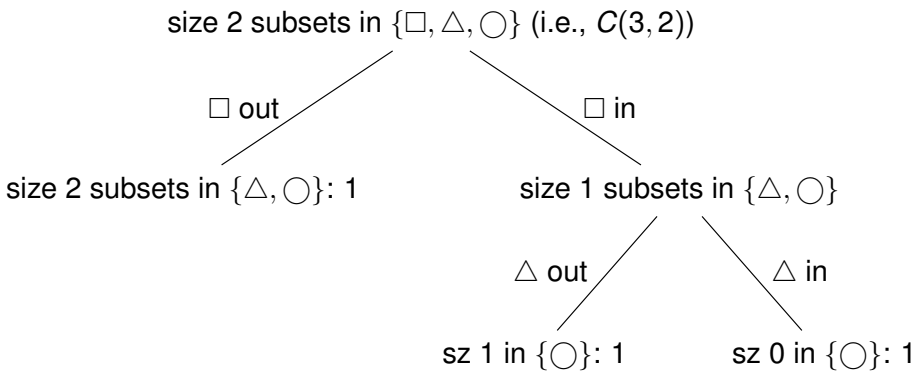
# Another example

- Compute number of different subsets with $k$ elements (i.e., of size $k$) in a set with $n$ elements ($n \geq k \geq 0$)
- Denoted as $C(n, k)$ (example with $n = 3$, $k = 2$)

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- Recursive formulation:

$$C(n, k) = C(n-1, k) + C(n-1, k-1)$$
$$C(n, 0) = 1$$
$$C(n, n) = 1$$

```
def C(n, k):
  if k==n or k == 0:
      return 1  # base cases
  else:
      return C(n-1, k) + C(n-1, k-1) # recursive calls
```

```
1 ans = choices(3,2)
        n = 3, k = 2
2 if k == 0 or k == n:
3 else:
4 choices(n - 1, k)
          n = 2, k = 2
5 if k == 0 or k == n:
6 return 1
7 choices(n - 1, k - 1)
          n = 2, k = 1
8 if k == 0 or k == n:
9 else:
10 choices(n - 1, k)
           n = 1, k = 1
11 if k == 0 or k == n:
12 return 1
13 choices(n - 1, k - 1)
           n = 1, k = 0
14 if k == 0 or k == n:
```

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```
4 choices(n - 1, k)
          n = 2, k = 2
5 if k == 0 or k == n:
6 return 1
7 choices(n - 1, k - 1)
          n = 2, k = 1
8 if k == 0 or k == n:
9 else:
10 choices(n - 1, k)
           n = 1, k = 1
11 if k == 0 or k == n:
12 return 1
13 choices(n - 1, k - 1)
           n = 1, k = 0
14 if k == 0 or k == n:
15 return 1
16 return 1 + 1
17 return 1 + 2
```

ans = 3

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## Example: Sudoku solver