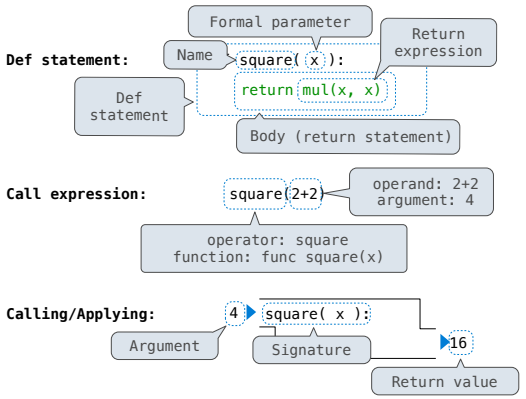
Multiple Environments

Life Cycle of a User-Defined Function



What happens?

Def statement:

A new function is created!

Name bound to that function in the current frame

Call expression:

Operator & operands evaluated

Function (value of operator) called on arguments (values of operands)

Calling/Applying:

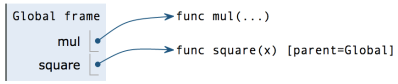
A new frame is created!

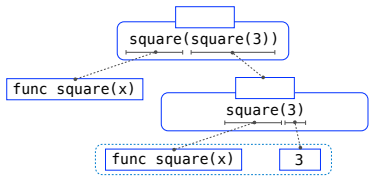
Parameters bound to arguments

Body is executed in that new environment

Multiple Environments in One Diagram!

```
1 from operator import mul
2 def square(x):
3     return mul(x, x)
4 square(square(3))
```





Interactive Diagram

Multiple Environments in One Diagram!

```
1 from operator import mul
2 def square(x):
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```
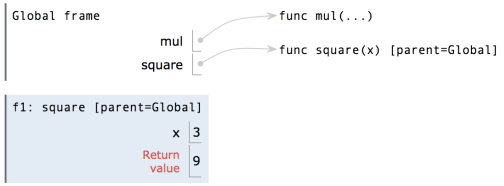
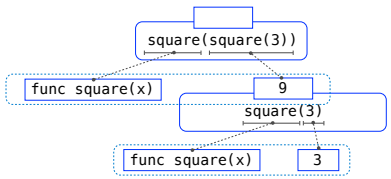
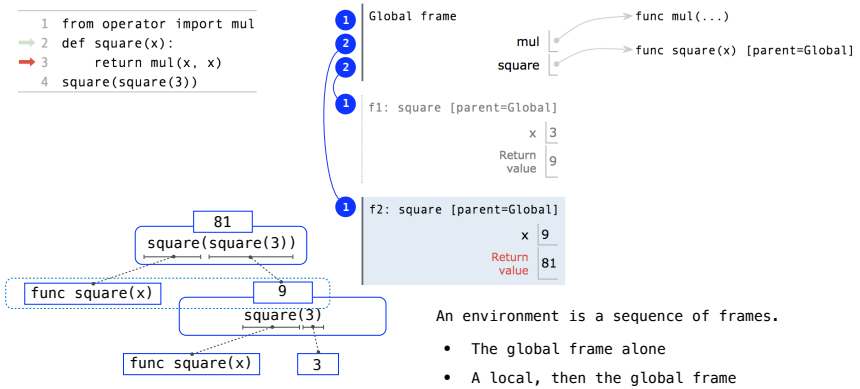





Interactive Diagram

Multiple Environments in One Diagram!

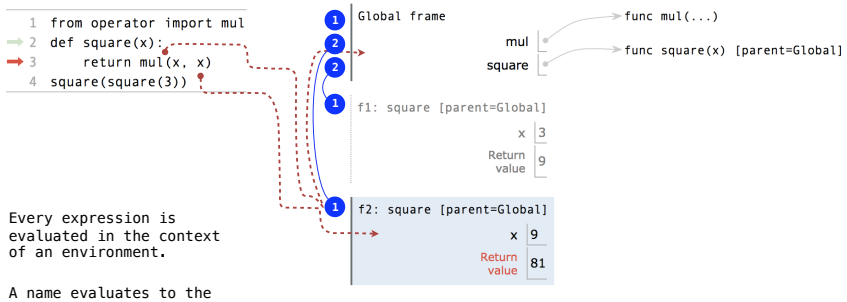


An environment is a sequence of frames.

- The global frame alone
- A local, then the global frame

Interactive Diagram

Names Have No Meaning Without Environments



Every expression is evaluated in the context of an environment.

A name evaluates to the value bound to that name in the earliest frame of the current environment in which that name is found.

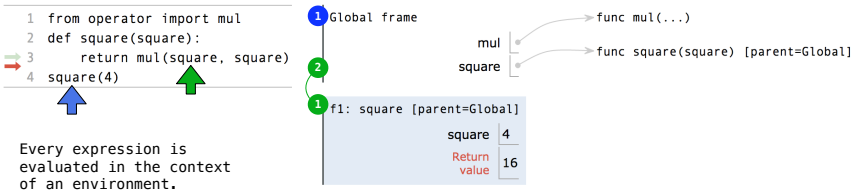
An environment is a sequence of frames.

- The global frame alone
- A local, then the global frame

Interactive Diagram

Names Have Different Meanings in Different Environments

A call expression and the body of the function being called are evaluated in different environments



Every expression is evaluated in the context of an environment.

A name evaluates to the value bound to that name in the earliest frame of the current environment in which that name is found.

Interactive Diagram

Environments for Higher-Order Functions

Environments Enable Higher-Order Functions

Functions are first-class: Functions are values in our programming language

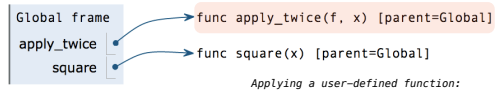
Higher-order function: A function that takes a function as an argument value **or**
A function that returns a function as a return value

Environment diagrams describe how higher-order functions work!

(Demo)

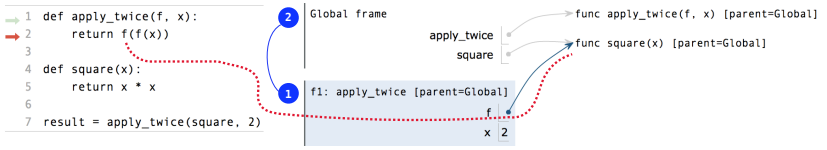
Names can be Bound to Functional Arguments

```
1 def apply_twice(f, x):
2     return f(f(x))
3
4 def square(x):
5     return x * x
6
7 result = apply_twice(square, 2)
```



Applying a user-defined function:

- Create a new frame
- Bind formal parameters (f & x) to arguments
- Execute the body: return f(f(x))



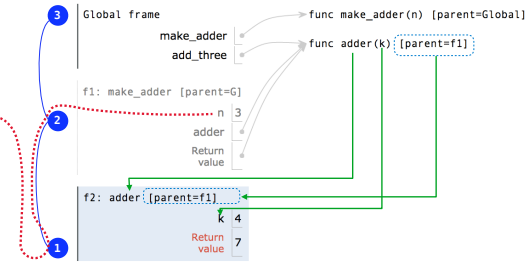
Environments for Nested Definitions

(Demo)

Environment Diagrams for Nested Def Statements

```
1 def make_adder(n):
2     def adder(k):
3         return k + n
4     return adder
5
6 add_three = make_adder(3)
7 add_three(4)
```

Nested def



- Every user-defined function has a parent frame (often global)
- The parent of a function is the frame in which it was defined
- Every local frame has a parent frame (often global)
- The parent of a frame is the parent of the function called

How to Draw an Environment Diagram

When a function is defined:

Create a function value: `func <name>(<formal parameters>) [parent=<label>]`

Its parent is the current frame.

`f1: make_adder` `func adder(k) [parent=f1]`

Bind `<name>` to the function value in the current frame

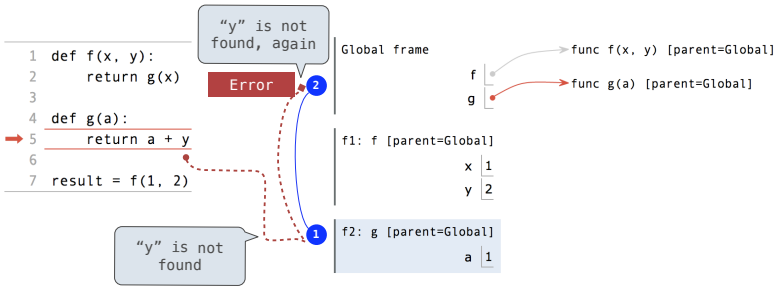
When a function is called:

1. Add a local frame, titled with the `<name>` of the function being called.
2. Copy the parent of the function to the local frame: `[parent=<label>]`
3. Bind the `<formal parameters>` to the arguments in the local frame.
4. Execute the body of the function in the environment that starts with the local frame.

Local Names

(Demo)

Local Names are not Visible to Other (Non-Nested) Functions



- An environment is a sequence of frames.
- The environment created by calling a top-level function (no def within def) consists of one local frame, followed by the global frame.

Lambda Expressions

(Demo)

Lambda Expressions

```
>>> x = 10
>>> square = x * x
>>> square = lambda x: x * x
>>> square(4)
16
```

An expression: this one evaluates to a number

Also an expression: evaluates to a function

Important: No "return" keyword!

A function with formal parameter x that returns the value of "x * x"

Must be a single expression

Lambda expressions are not common in Python, but important in general

Lambda expressions in Python cannot contain statements at all!

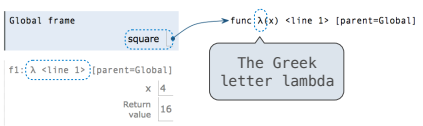
Lambda Expressions Versus Def Statements

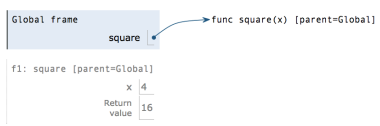
```
square = lambda x: x * x
```

VS

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

- Both create a function with the same domain, range, and behavior.
- Both bind that function to the name square.
- Only the def statement gives the function an intrinsic name, which shows up in environment diagrams but doesn't affect execution (unless the function is printed).



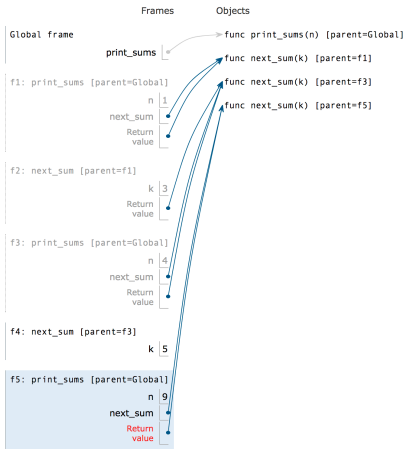


Self-Reference

(Demo)

Returning a Function Using Its Own Name

```
1  def print_sums(n):
2      print(n)
3      def next_sum(k):
4          return print_sums(n+k)
5      return next_sum
6
7  print_sums(1)(3)(5)
```



Review

What Would Python Print?

The print function returns None. It also displays its arguments (separated by spaces) when it is called.

```
from operator import add, mul
def square(x):
    return mul(x, x)
```

A function that always returns the identity function

```
def pirate(arggg):
    print('matey')
    def plunder(arggg):
        return arggg
    return plunder
```

This expression	Evaluates to	Interactive Output
`add(pirate(3)(square)(4), 1)` *func square(x)* *16*	17	Matey 17
`pirate(pirate(pirate))(5)(7)` *Identity function* *5*	Error	Matey Matey Error

A name evaluates to the value bound to that name in the earliest frame of the current environment in which that name is found.

What Would Python Display?

The print function returns None. It also displays its arguments (separated by spaces) when it is called.

```
from operator import add, mul
def square(x):
    return mul(x, x)
```

A function that takes any argument and returns a function that returns that arg

```
def delay(arg):
    print('delayed')
    def g():
        return arg
    return g
```

Names in nested def statements can refer to their enclosing scope

This expression	Evaluates to	Interactive Output
`5`	5	5
`print(5)`	None	5
`print(print(5))` None	None	5 None
`delay(delay)()(6)()`	6	delayed delayed 6
`print(delay(print)()(4))`	None	delayed 4 None


```
def horse(mask):
    horse = mask
    def mask(horse):
        return horse
    return horse(mask)

mask = lambda horse: horse(2)

horse(mask)
```