# Environment Diagrams

# What are Environment Diagrams?

- A visual tool to keep track of bindings & state of a computer program

- In this class, we use Python as our primary language
  - The diagrams we teach can be applied to similar languages

# Why do we use Environment Diagrams?

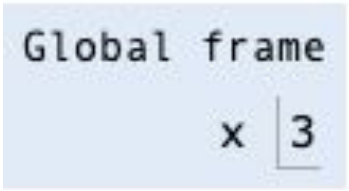
- Environment Diagrams are conceptual
  - understand *why* programs work the way they do
  - confidently predict how a program will behave
- Environment Diagrams are helpful for debugging
  - When you're really stuck,

    diagramming code > staring at lines of code
- Environment Diagrams will be used in future courses
  - CS 61C (Machine Structures)
  - CS 164 (Programming Languages and Compilers)

# What do we've seen so far

**Assignment Statements**

```
x = 1
x = x + x + x
```

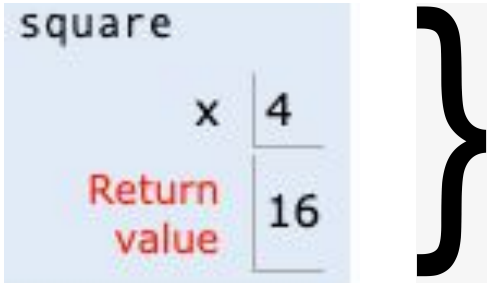



**Def Statements**

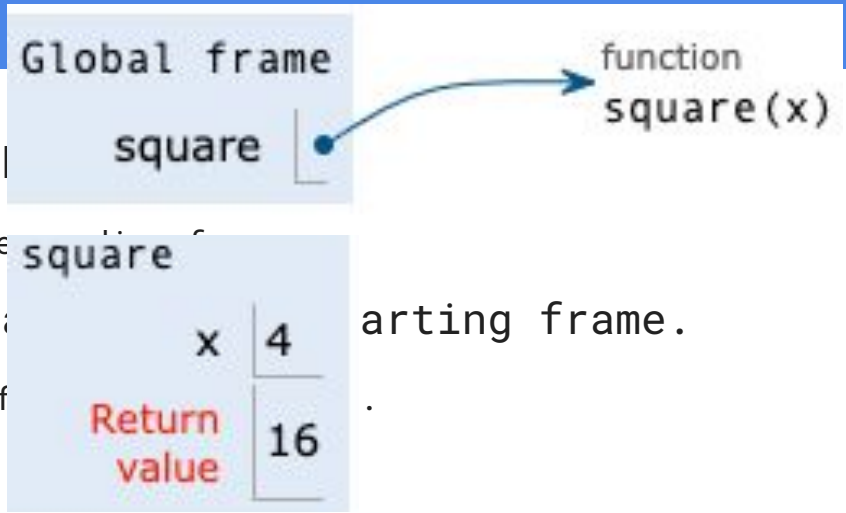
```
def square(x):
    return x * x
```


**Call Expressions**

```
square(4)
```



# Terminology: Frames




A **frame** keeps track of varia

- Every call expression has a corre

**Global**, a.k.a. the global fr arting frame.

- It doesn't correspond to a specif .

**Parent frames**

- The parent of a function is the frame in which it was defined.
- If you can't find a variable in the current frame, you check it's parent, and so on. If you can't find the variable, NameError

Demo

# How to draw an Environment Diagram

**When a function is defined:**

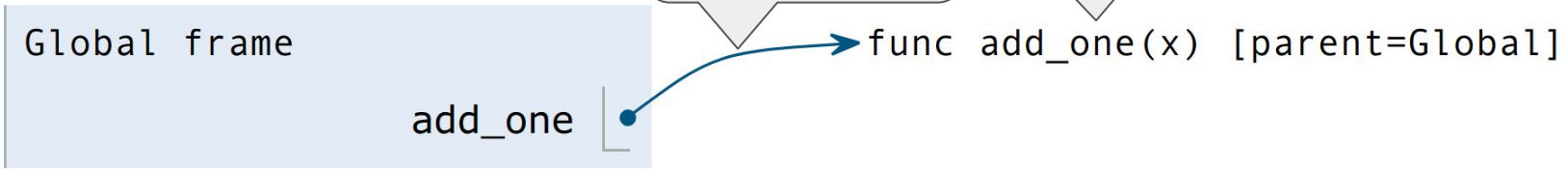
Create a function value:

```
    func <name>(<formal parameters>) [parent=<label>]
```

Its parent is the current frame.

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

```
def add_one(x):
    y = x + 1
```



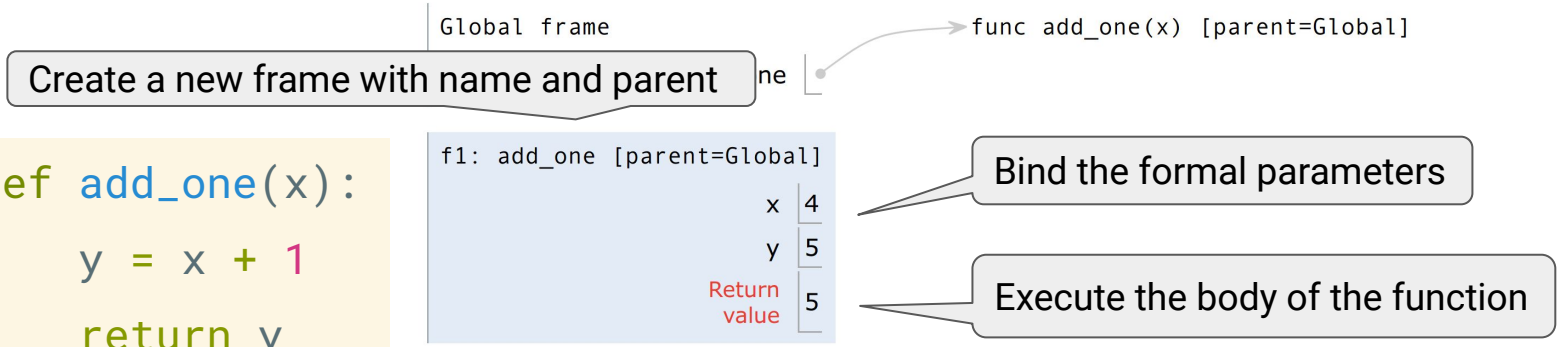
# How to draw an Environment Diagram

Demo

**When a function is applied:**

1. Add a local frame, titled with the <name> of the function being applied.
2. Copy the parent of the **function** (not always the current frame) 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

```
def add_one(x):
    y = x + 1
    return y
add_one(4)
```



# Check Your Understanding

**Draw the environment diagram**

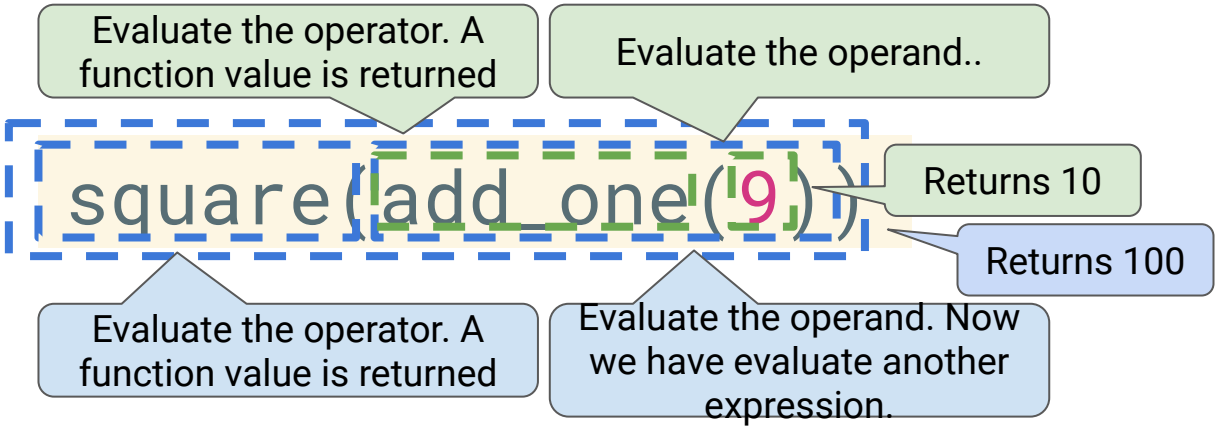
```
def square(x):
    return x * x

def sum_of_squares(x, y):
    return square(x) + square(y)

sum_of_squares(3, 4)
```

# Review: Evaluation Order

Demo

Remember to evaluate the **operator**, then the **operand(s)**, then apply the **operator** onto the **operand(s)**.

```
def add_one(x):
    y = x + 1
    return y


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




What will the environment diagram look like? (**When are frames created?**)

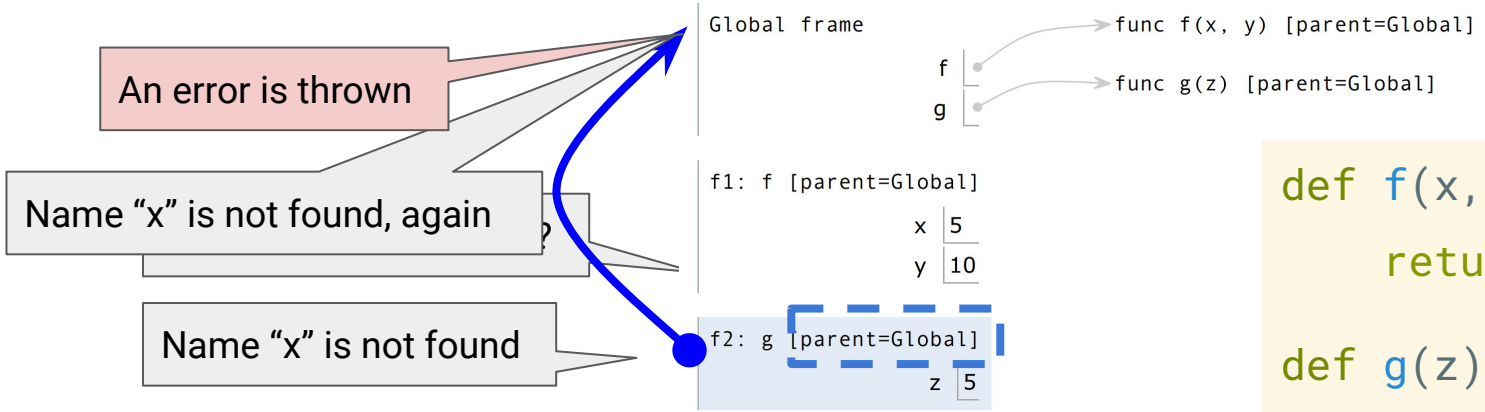
The environment diagram should reflect Python's evaluation.

# Variable Lookup

# Local Names

**Variable Lookup:**

- Lookup name in the current frame
- Lookup name in parent frame, its parent frame, etc..
- Stop at the global frame
- If not found, an error is thrown




```
def f(x, y):
    return g(x)

def g(z):
    return z + x
```

Important: There was no lookup done in f1 since the parent of f2 was Global

What happens here?

```
result = f(5, 10)
```

# Evaluation vs Apply

Demo

```
def a_plus_bc(a, b, c):
    """
    >>> a_plus_bc(2, 3, 4) # 2 + 3 * 4
    14
    """
    bc = b * c
```

```
a_plus_bc(square(2), 3, square(square(3)))
```

**Apply** operator `a_plus_bc` function to operand `4, 3, 81`.

How many frames are created?
In what order?

**Apply** operator `square` function to operand 2.

**Apply** operator `square` function to operand 9.

**Apply** operator `square` function to operand 3.

# Break/Q&A

# Lambda Expressions

# Lambda Expressions

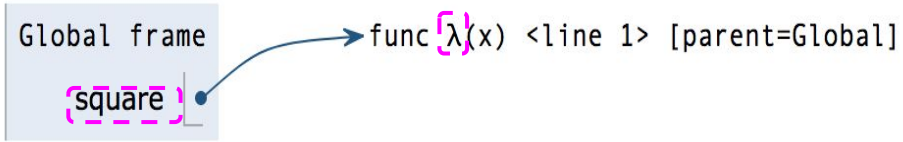
Expressions that evaluate to functions!

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

```
>>> square = lambda x: x * x
>>> square
<function <lambda> ... >
>>> square(4)
16
>>> x = square(5)
>>> x
25
```

# Lambda Expressions vs `def` Statements

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




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

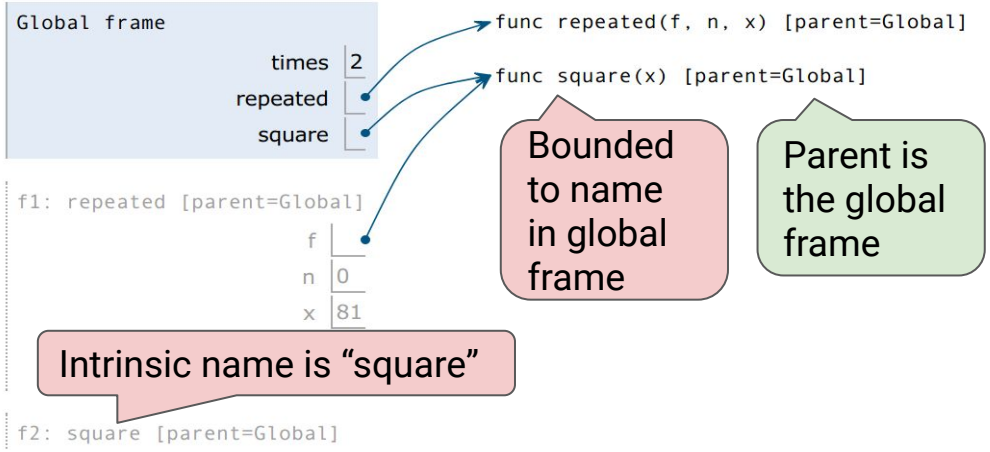

- Both create a function with the same behavior
- The parent frame of each function is the frame in which they were defined
- Both bind the function to the same name
- Only the `def` statement gives the function an intrinsic name

# Environment Diagram

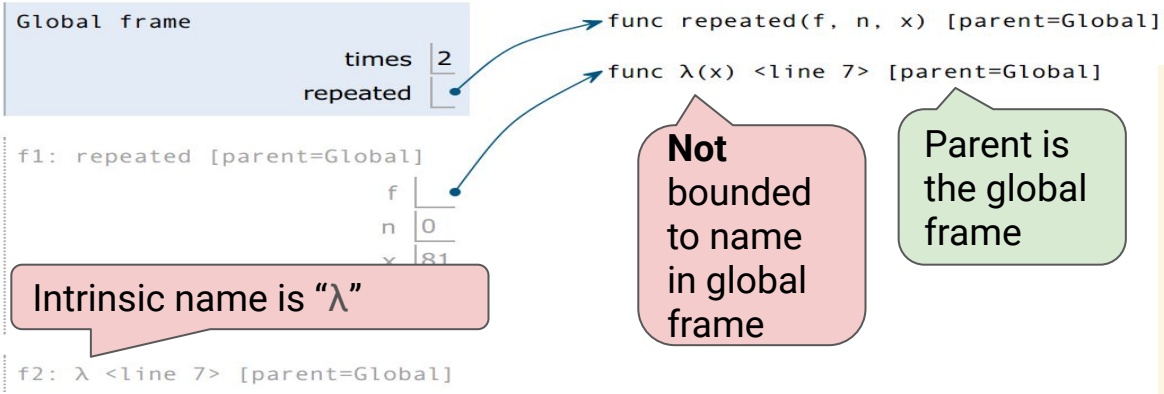
```
times = 2

def repeated(f, n, x):
    while n > 0:
        x = f(x)
        n -= 1
    return x

repeated(lambda x: x*x, times, 3)
```

```
repeated(square, times, 3)
```

# Comparisons




```
times = 2
def repeated(f, n, x):
    while n > 0:
        x = f(x)
        n -= 1
    return x
def square(x):
    return x * x
repeated(square, times, 3)
```




```
times = 2
def repeated(f, n, x):
    while n > 0:
        x = f(x)
        n -= 1
    return x
```

# Higher Order Functions

# Higher Order Functions

A function that ...

- takes a function as an argument value, and/or
- returns a function as a return value

You just saw this in

the previous example!

```
times = 2

def repeated(f, n, x):
    while n > 0:
        x = f(x)
        n -= 1
    return x

repeated(lambda x: x*x, times, 3)
```

# Locally Defined Functions

```
>>> def make_greeter(name):
...         return lambda greeting: print(greeting, name)
>>> greeter_function = make_greeter("Tiffany")
>>> greeter_function("Hey what's up, ")
```

**Currying**

```
>>> make_greeter("Tiffany")("Where's the party at, ")
```

# Summary

- **Environment Diagrams** formalize the evaluation procedure for Python
  - Understanding them will help you think deeply about how the code that you are writing actually works
- **Lambda** functions are similar to functions defined with `def`, but are nameless
- A **Higher Order Function** is a function that either takes in functions as an argument (shown earlier) and/or returns a function as a return value (will see soon)