Lecture #3: Recap of Function Evaluation; Control

Functions can only manipulate their local environment.

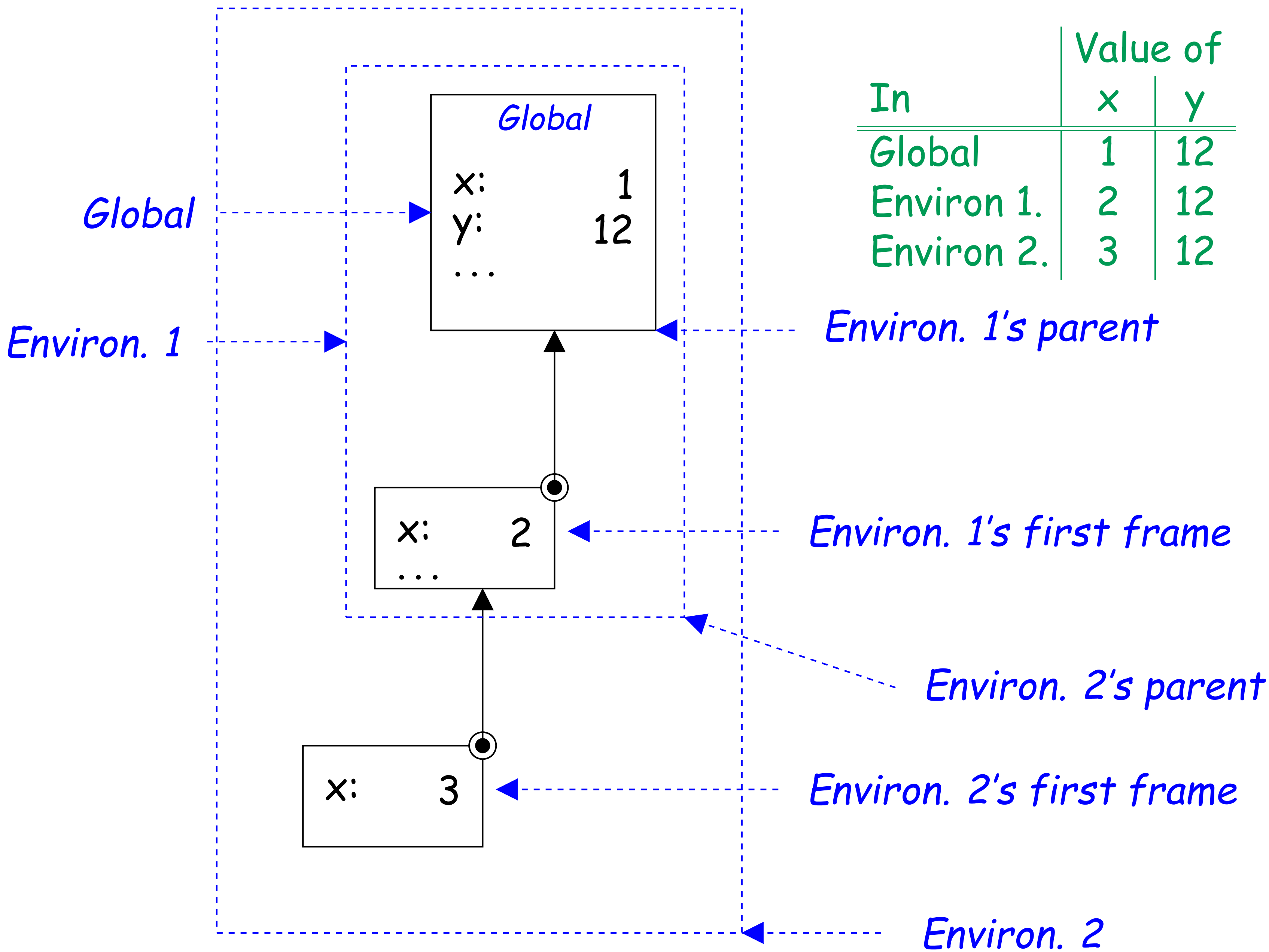
Announcements

- Labs 1 and 2 due Tuesday (at 11:59PM).
- Homework 1 due Thursday.
- Orientations starting: lab orientations are Mondays, discussion orientations Wednesdays. These are recorded.
- Lab party on Monday, homework party on Tuesday. See Piazza @151.
- Conceptual office hours starting this week. See Piazza @174.
- Ask questions on the Piazza thread for today's lecture (@155).

Summary: Environments

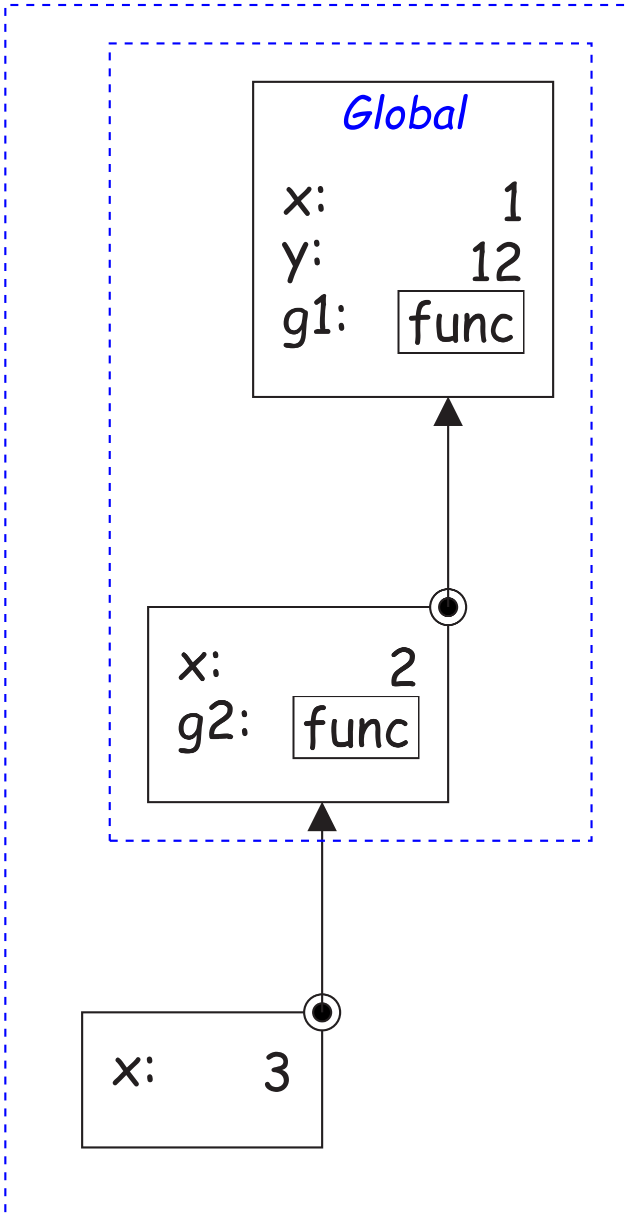
- *Environments* map names to values.
- They consist of chains of *environment frames.*
- An environment is either a *global frame* or a first (local) frame chained to a *parent environment* (which is itself either a global frame or ...).
- We say that a name is *bound to* a value in a frame.
- The *value (or meaning) of a name* in an environment is the value it is bound to in the first frame, if there is one, ...
- ...or if not, the meaning of the name in the parent environment (recursively).
- Every expression and statement is evaluated (executed) in an environment, which determines the meaning of its names.
- Expressions and subexpressions (pieces of an expression) are evaluated in the same environment as the statement or expression containing them.

A Sample Environment Chain



In	Value of x	y
Global	1	12
Environ 1.	2	12
Environ 2.	3	12

Creating the Sample Environment Chain



Executing the following code will result in the environment on the left when execution reaches the comment.

```
x = 1
y = 12
def g1(x):
    def g2(x):
        # Stop here
        print(x)
    g2(x + 1)
g1(2)
```

Global Frames

x 1
y 12
g1

func g1(x)
[parent=Global]

combination of function, code, parent environment → closure
闭包

The call to print is executed in this environment. Continuing from the comment, the program would print 3.

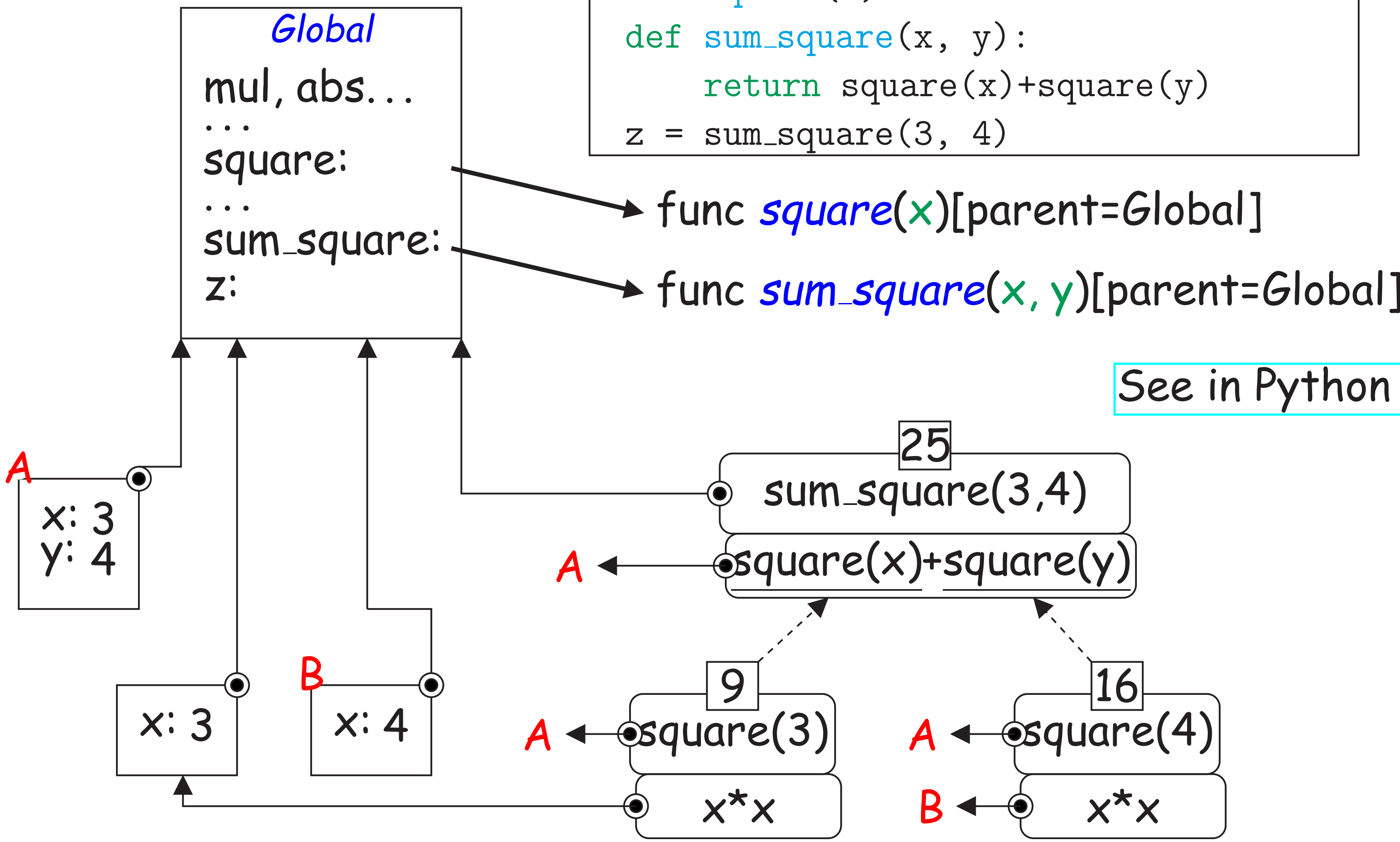
Execute in Python tutor

Environments: Binding and Evaluation

- *Assigning* to a variable binds a value to it in (for now) the first frame of the environment in which the assignment is executed.
- *Def statements* bind a name to a function value in the first frame of the environment in which the def statement is executed.
- This new function value contains a link to this same environment.
- *Calling* a user-defined function creates a new local environment frame that binds the function's *formal parameters* to the operand values (*actual parameters*) in the call.
- This new local frame is attached to an existing (parent) frame that is taken from the function value that is called, forming a new local environment in which the function's body is evaluated.

Example: Evaluation of a Call: sum_square(3,4)

```
def square(x): return x*x
def sum_square(x, y):
    return square(x)+square(y)
z = sum_square(3, 4)
```



See in Python Tutor

What Does This Do (And Why)?

```
def id(x):
    return x
print(id(id)(id(13)))
```

Execute this

Answer

```
def id(x):
    return x
print(id(id)(id(13)))
```

- We'll denote the user-defined function value created by def id():... by the shorthand $\boxed{\text{id}}$.
- Evaluation proceeds like this:

  id(id)(id(13))

  $\Longrightarrow$ $\boxed{\text{id}}$ ($\boxed{\text{id}}$)($\boxed{\text{id}}$ ($\boxed{13}$))

  $\Longrightarrow$ $\boxed{\text{id}}$ ($\boxed{\text{id}}$ ($\boxed{13}$))

  (because first $\boxed{\textit{id}}$ call returns its argument).

  $\Longrightarrow$ $\boxed{\text{id}}$ ($\boxed{13}$))

  (because inner $\boxed{\textit{id}}$ call returns its argument).

  $\Longrightarrow$ $\boxed{13}$

  (because call to returned $\boxed{\textit{id}}$ value returns its argument).

- *Important:* There is nothing new on this slide! Everything follows from what you've seen so far.

Nested Functions

- In lecture #2, I had this example:

```
def incr(n):
    def f(x):
        return n + x
    return f

incr(5)(6)
```

- We evaluated the argument to print by substitution:

```
incr(5)   ===> | def f(x): return 5 + x |  ===> | func f(x): 5 + x |
               | return f               |

incr(5)(6) ===> | func f(x): 5 + x |(6) ===> 5 + 6 ===> 11
```

- So how does this work with environments?

Global Frame

incr → func incr(n) [parent: Global]

f1: incr [parent: Global]

n 5

f → func f(x) [parent: f1]

Return value

f2: f [parent: f1]

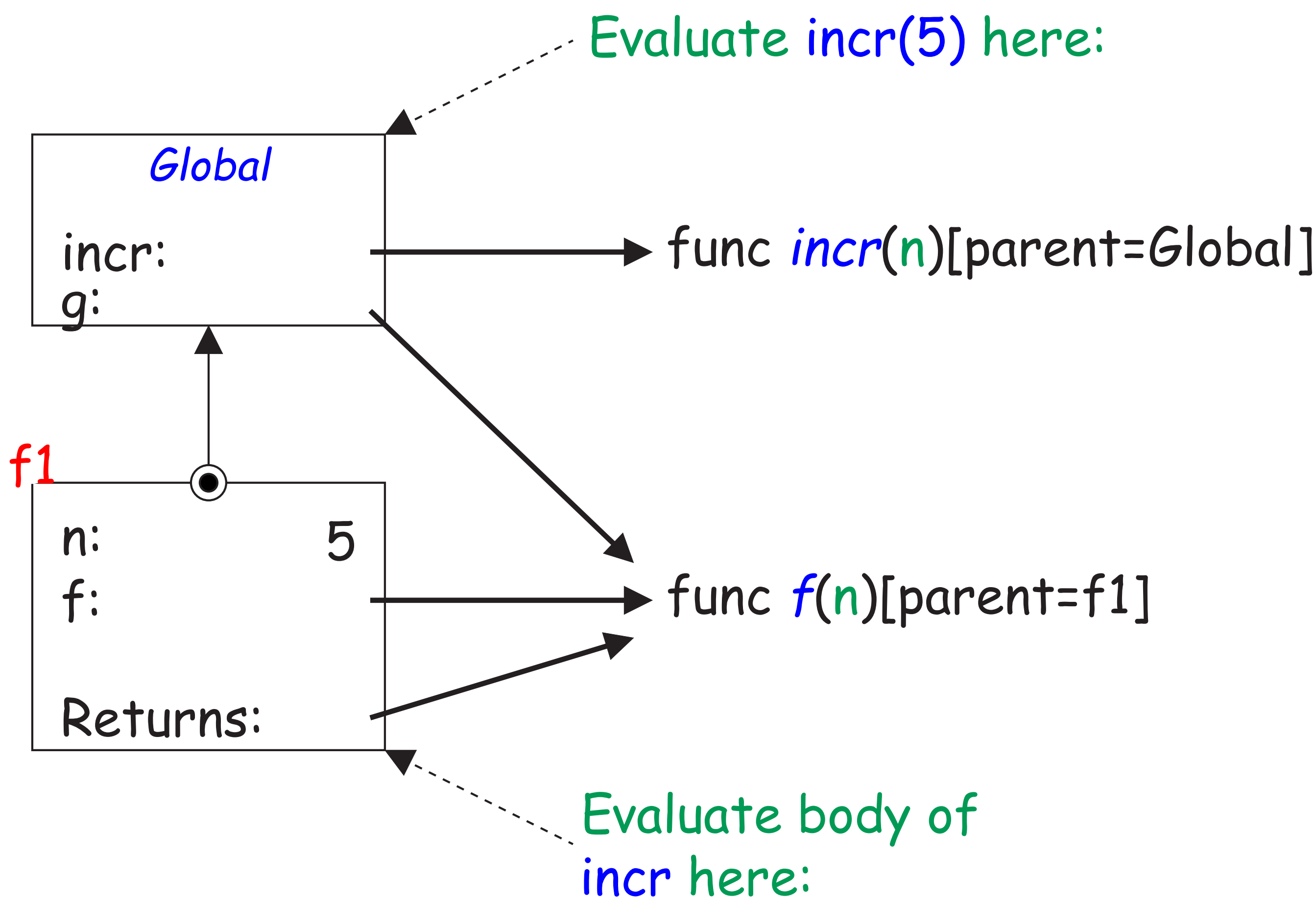
x 6

Return value 11

Environments for incr (I)

```
def incr(n):
    def f(x):
        return n + x
    return f

# Break incr(5)(6)
# into two steps:
g = incr(5)
print(g(6))
```

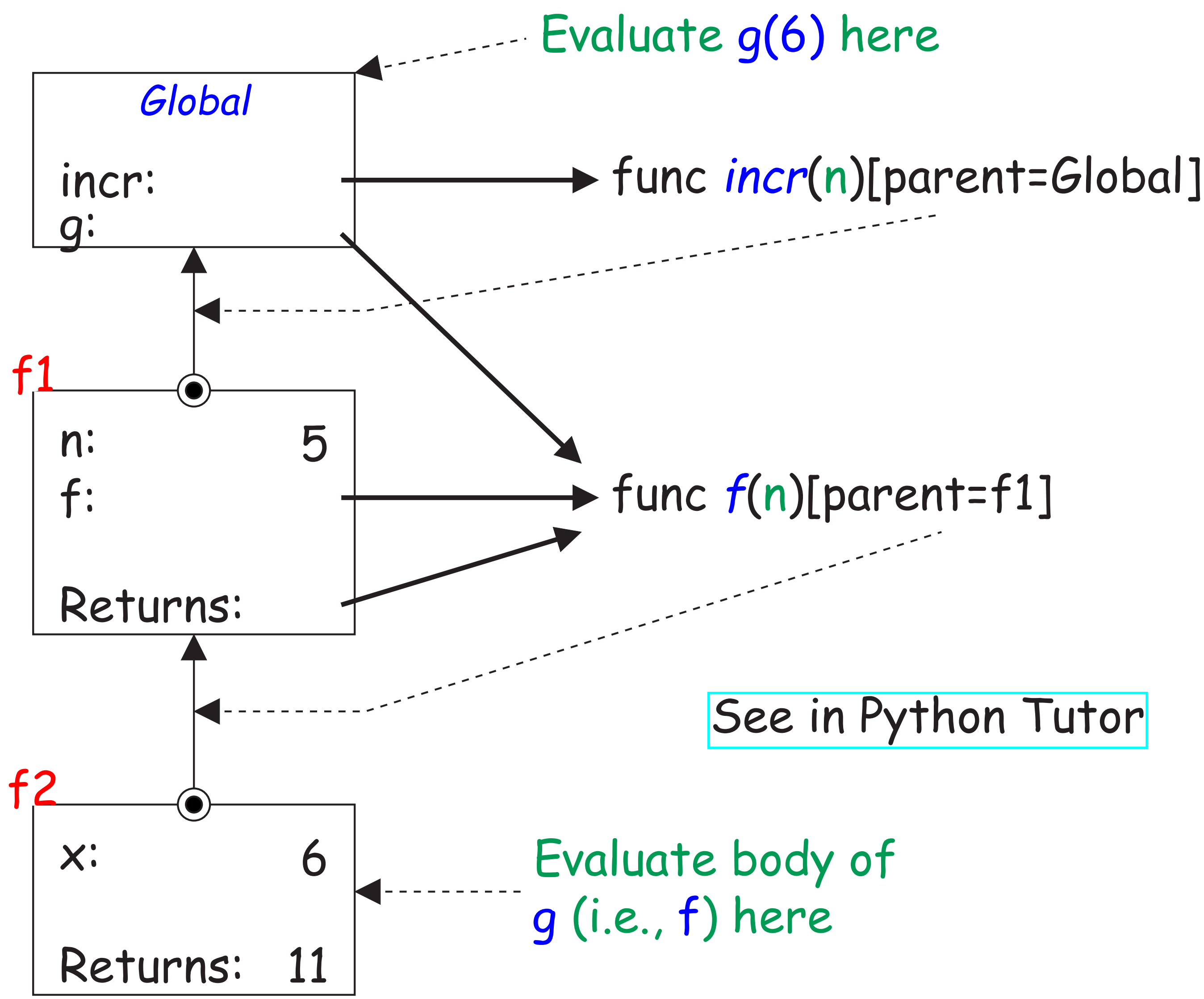


- The parent points of incr is Global because the definition of incr was evaluated in the global environment.
- The parent pointer for the value of g (returned by incr(5)) is f1, not Global, because the definition of f was evaluated in f1.

Environments for incr (II)

```
def incr(n):
    def f(x):
        return n + x
    return f

g = incr(5)
print(g(6))
```



- f2 gets its parent pointer from g's value, since it is the local frame for evaluating a call to g. (Same rule for f1.)

Recap

- Every expression or statement is evaluated in an environment—a sequence of frames.
- Every assignment to a variable and every **def** binds (or changes the binding) of its variable or defined name in the first frame of this environment.
- Every frame (except the global frame) is linked to a parent frame.
- Every function *value* is linked to the environment in which its **def** is evaluated.
- Every function *call* creates a new local frame that is linked to the same frame as the function value being called.
- The total effect is the same as for the substitution model, but we can also handle changes in the values of variables.
- Looking ahead, there are still two constructs—**global** and **nonlocal**—that will require additions.
- But what we have here basically covers how names work in most of Python.

New Topic: Control

- The expressions we've seen evaluate all of their operands in the order written.
- While there are very clever ways to do everything with just this [challenge!], it's generally clearer to introduce constructs that *control* the order in which their components execute.
- A *control expression* evaluates some or all of its operands in an order depending on the kind of expression, and typically on the values of those operands.
- A *statement* is a construct that produces no value, but is used solely for its side effects.
- A *control statement* is a statement that, like a control expression, evaluates some or all of its operands, etc.
- We typically speak of statements being *executed* rather than evaluated, but the two concepts are essentially the same, apart from the question of a value.

Conditional Expressions (I)

- The most common kind of control is *conditional evaluation* (or *execution*).
- In Python, to evaluate

  TruePart `if` *Condition* `else` *FalsePart*

  - First evaluate *Condition*.
  - If the result is a "*true value,*" evaluate *TruePart*; its value is then the value of the whole expression.
  - Otherwise, evaluate *FalsePart*; its value is then the value of the whole expression.
- **Example:**

If x is 2:	If x is 0:
1 / x if x != 0 else 1	1 / x if x != 0 else 1
1 / x if $\boxed{2}$!= 0 else 1	1 / x if 0 != 0 else 1
$\Longrightarrow$ 1 / x if $\boxed{\text{True}}$ else 1	$\Longrightarrow$ 1 / x if $\boxed{\text{False}}$ else 1
$\Longrightarrow$ 1 / x	$\Longrightarrow$ 1
$\Longrightarrow$ $\boxed{1}$ / $\boxed{2}$	$\Longrightarrow$ $\boxed{1}$
$\Longrightarrow$ $\boxed{0.5}$	

“True Values”

- Conditions in conditional constructs can have any value, not just True or False.
- For convenience, Python treats a number of values as indicating “false”:
  - False
  - None
  - 0
  - Empty strings, sets, lists, tuples, and dictionaries.
- All else is a “true value” by default.
- For example:

```
13 if 0 else 5 == 13 if [] else 5 == 5
```

.

Conditional Expressions (II)

- To evaluate

  Left and *Right*

  - Evaluate *Left*.
  - If it is a false value, that becomes the value of the whole expression.
  - Otherwise the value of the expression is that of *Right*.
- This is an example of something called "*short-circuit evaluation*." 短路原则.
- For example,

  5 and "Hello" $\Longrightarrow$ $\boxed{\text{"Hello"}}$.

  [] and 1 / 0 $\Longrightarrow$ $\boxed{\text{[]}}$. (1/0 is not evaluated.)

Conditional Expressions (III)

- To evaluate

    Left `or` *Right*

    - Evaluate *Left*.
    - If it is a true value, that becomes the value of the whole expression.
    - Otherwise the value of the expression is that of *Right*.

- Another example of "*short-circuit evaluation*."

- For example,

    5 or "Hello" $\Longrightarrow$ $\boxed{5}$.

    [] or "Hello" $\Longrightarrow$ $\boxed{\text{"Hello"}}$.

    [1, 2] or 1 / 0 $\Longrightarrow$ $\boxed{[1, 2]}$.

    [] or 1 / 0 $\Longrightarrow$ $\boxed{\text{ERROR}}$.

Conditional Statement

- Finally, this all comes in statement form:

```
if Condition1:
    Statements1
elif Condition2:
    Statements2
...
else:
    Statementsn
```

- Execute (only) *$Statements_1$* if *$Condition_1$* evaluates to a true value.
- Otherwise execute *$Statements_2$* if *$Condition_2$* evaluates to a true value (**elif**s are optional parts).
- ...
- Otherwise execute *$Statements_n$* (**else** is an optional part).

Examples

```python
# Alternative Definitions

def signum(x):                  def signum(x):
    if x > 0:                       return 1 if x > 0 else 0 if x == 0 else -1
        return 1
    elif x == 0:
        return 0
    else:
        return -1

def max(x, y):                  def max(x, y):
    if x > y:                       return x if x > y else y
        return x
    else:
        return y

def min(x, y):                  def min(x, y):
    if x < y:                       return x if x < y else y
        return x
    return y
```

Side Trip: Suites and Sequences

- The sequence of indented statements after the colon in

```
if x >= 0:
    print(x)
    y = x
```

  is called a *suite*. In effect it is a single statement formed from two.

- Executing the suite itself means executing each of its statements in sequence (unless one of them says otherwise).

- Every statement in the suite has the same indentation, and it ends at the next statement that is indented to a previous level:

```
x = 0
if x > 1:
    print(">1")
    if x < 6:
        print("<6")
    print("x =", x)
# Prints nothing
```

```
x = 0
if x > 1:
    print(">1")
    if x < 6:
        print("<6")
print("x =", x)
# Prints "x = 0"
```

- Every language has some way of *grouping* statements like this.

- Few do it like Python. (Interesting story behind this.)

Iteration

- Suppose you would like to compute $1^2 + 2^2 + \ldots + 100^2$.
- (Yes, I know there is a formula for this. Humor me.)
- You'd probably prefer not to write

```
print(1 ** 2 + 2 ** 2 + ... + 100 ** 2)
```

- Actually, we already know enough to do this:

```
def add_sq(accum, k, n):
    """Return ACCUM + K ** 2 + (K+1)**2 + ... + N**2."""
    if k > n:
        return accum
    else:
        return add_sq(accum + k ** 2, k + 1, n)
print(add_sq(0, 1, 100))
```

- Go ahead: try it in on a small case in the Python Tutor.
- This is an example of a *recursive function*. We'll come back to such functions later in the course.

While Statements

- Usually, though, programmers deal with problems like this summation using some kind of *looping construct*, which explicitly executes statements repeatedly.
- The **while** statement gives us *indefinite repetition*, meaning repetition until some condition is met (or as long as some condition is met).

can't tell how many times it's going to execute

- For our example, (also see a small case in the Python Tutor):

```
accum = 0
k = 1
n = 100
while k <= n:
    accum = accum + k ** 2
    k += 1    # Another way to write k = k + 1
print(accum)
```

- Meaning of the **while** loop:

A. Test the *loop condition* (here, `k <= n`).

B. If it's true, execute the suite that follows (the *loop body*), and then repeat from step A.

C. Otherwise, end the loop (and continue to the print call).

Example: Finding Prime Factors

- A *prime number* is an integer greater than 1 whose only factors are 1 and the number itself (e.g., 3, 5, 7, 11).
- So how do make this function fulfill its comment?

```
def is_prime(n):
    """Return True iff N is prime."""
    return n > 1 and smallest_factor(n) == n

def smallest_factor(n):
    """Returns the smallest value k>1 that evenly divides N."""
    ???

def print_factors(n):
    """Print the prime factors of N."""
    ???
```

- Try filling these in. (See Demo and also 03.py).