

Import statement

→ 1 from math import pi

→ 2 tau = 2 * pi

Assignment statement

Global frame

Name

pi

Value

3.1416

Binding

Code (left):

Statements and expressions
Red arrow points to next line.
Gray arrow points to the line just executed

Frames (right):

A name is bound to a value
In a frame, there is at most one binding per name

1 from operator import mul

2 def square(x):

→ 3 return mul(x, x)

4 square(-2)

Global frame

mul

square

Intrinsic name of function called

mul

square

Local frame

f1: square [parent=Global]

Formal parameter bound to argument

x

-2

Return value

4

Return value is not a binding!

Built-in function

func mul(...) [parent=Global]

func square(x) [parent=Global]

User-defined function

1 from operator import mul

→ 2 def square(x):

→ 3 return mul(x, x)

4 square(square(3))

Global frame

mul

square

f1: square [parent=Global]

x

3

Return value

9

f2: square [parent=Global]

x

9

Return value

81

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

- Evaluation rule for call expressions:

1.Evaluate the operator and operand subexpressions.

2.Apply the function that is the value of the operator subexpression to the arguments that are the values of the operand subexpressions.
- Applying user-defined functions:

1.Create a new local frame with the same parent as the function that was applied.

2.Bind the arguments to the function's formal parameter names in that frame.

3.Execute the body of the function in the environment beginning at that frame.
- Execution rule for def statements:

1.Create a new function value with the specified name, formal parameters, and function body.

2.Its parent is the first frame of the current environment.

3.Bind the name of the function to the function value in the first frame of the current environment.
- Execution rule for assignment statements:

1.Evaluate the expression(s) on the right of the equal sign.

2.Simultaneously bind the names on the left to those values, in the first frame of the current environment.
- Execution rule for conditional statements:

Each clause is considered in order.

1.Evaluate the header's expression.

2.If it is a true value, execute the suite, then skip the remaining clauses in the statement.
- Evaluation rule for or expressions:

1.Evaluate the subexpression <left>.

2.If the result is a true value v, then the expression evaluates to v.

3.Otherwise, the expression evaluates to the value of the subexpression <right>.
- Evaluation rule for and expressions:

1.Evaluate the subexpression <left>.

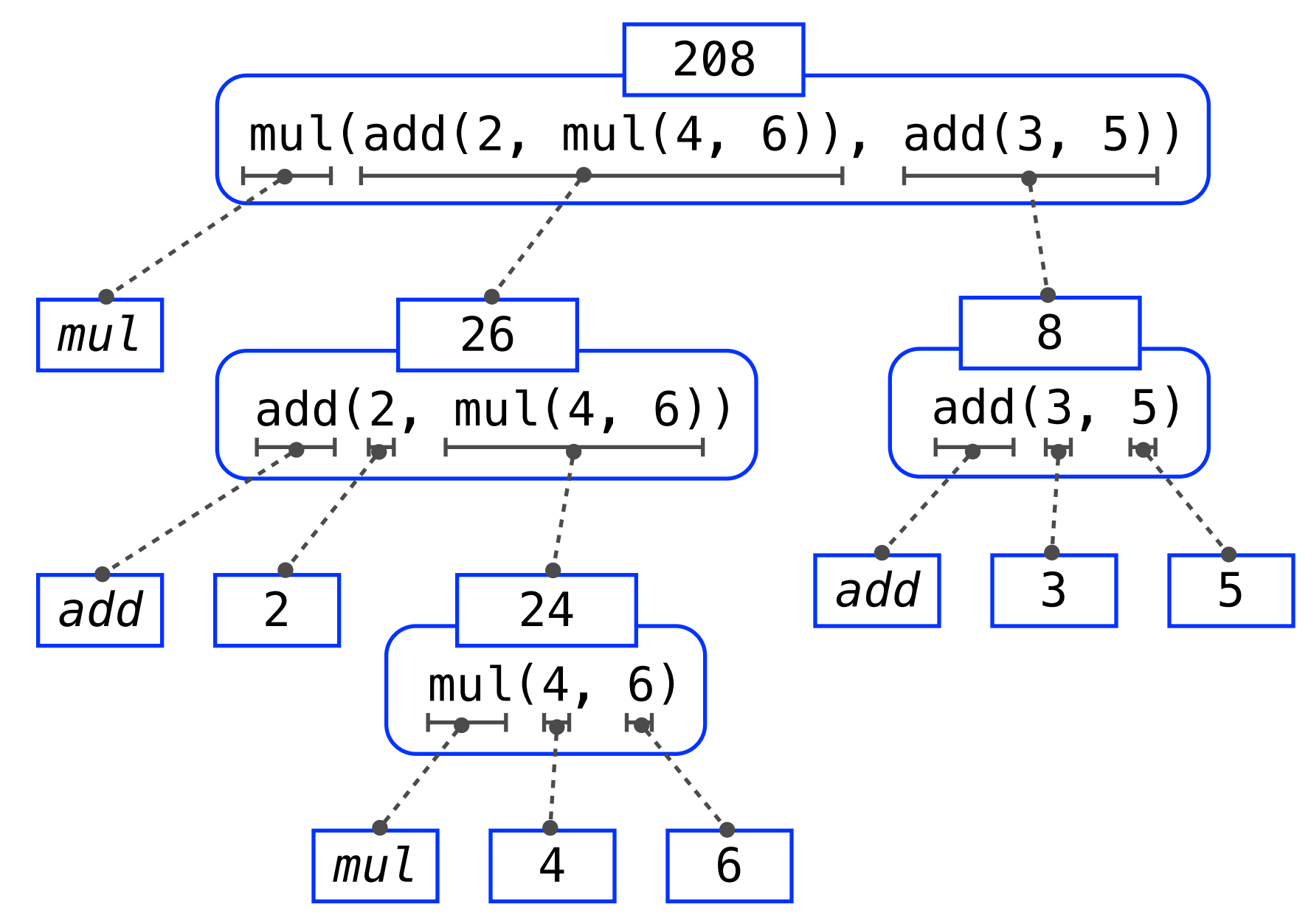
2.If the result is a false value v, then the expression evaluates to v.

3.Otherwise, the expression evaluates to the value of the subexpression <right>.
- Evaluation rule for not expressions:

1.Evaluate <exp>; The value is True if the result is a false value, and False otherwise.
- Execution rule for while statements:

1. Evaluate the header's expression.

2. If it is a true value, execute the (whole) suite, then return to step 1.



Pure Functions

-2

abs(number):

2

2, 10

pow(x, y):

1024

Non-Pure Functions

-2

print(...):

None

display "-2"

Defining:

Formal parameter

Return expression

Def statement

>>> def square(x):

return mul(x, x)

Body (return statement)

Call expression:

square(2+2)

operand: 2+2

argument: 4

operator: square

function: func square(x)

Calling/Applying:

Argument

Intrinsic name

Return value

4

square(x):

return mul(x, x)

16

Compound statement

Clause

<header>:

<statement>

<statement>

Suite

<separating header>:

<statement>

<statement>

...

def abs_value(x):

1 statement,

3 clauses,

3 headers,

3 suites,

2 boolean contexts

if x > 0:

return x

elif x == 0:

return 0

else:

return -x

1 def f(x, y):

2 return g(x)

3

4 def g(a):

5 return a + y

6

7 result = f(1, 2)

"y" is not found

Error

"y" is not found

Global frame

f

g

f1: f [parent=Global]

x

1

y

2

f2: g [parent=Global]

a

1

•An environment is a sequence of frames

•An environment for a non-nested function (no def within def) consists of one local frame, followed by the global frame

1 from operator import mul

2 def square(square):

→ 3 return mul(square, square)

4 square(4)

Global frame

mul

square

f1: square [parent=Global]

square

4

Return value

16

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

def fib(n):

"""Compute the nth Fibonacci number, for N >= 1."""

pred, curr = 0, 1 # Zeroth and first Fibonacci numbers

k = 1 # curr is the kth Fibonacci number

while k < n:

pred, curr = curr, pred + curr

k = k + 1

return curr

def cube(k):

return pow(k, 3)

Function of a single argument (not called term)

def summation(n, term):

"""Sum the first n terms of a sequence.

>>> summation(5, cube)

225

total, k = 0, 1

while k <= n:

total, k = total + term(k), k + 1

return total

0 + 1^3 + 2^3 + 3^3 + 4^3 + 5^3

The cube function is passed as an argument value

The function bound to term gets called here

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

Nested def statements: Functions defined within other function bodies are bound to names in the local frame


```
def make_adder(n):  
    """Return a function that takes one argument k and returns k + n.  
    """  
    >>> add_three = make_adder(3)  
    >>> add_three(4)  
    7  
    """  
    def adder(k):  
        return k + n  
    return adder
```

A function that returns a function

Return a function that takes one argument k and returns k + n.

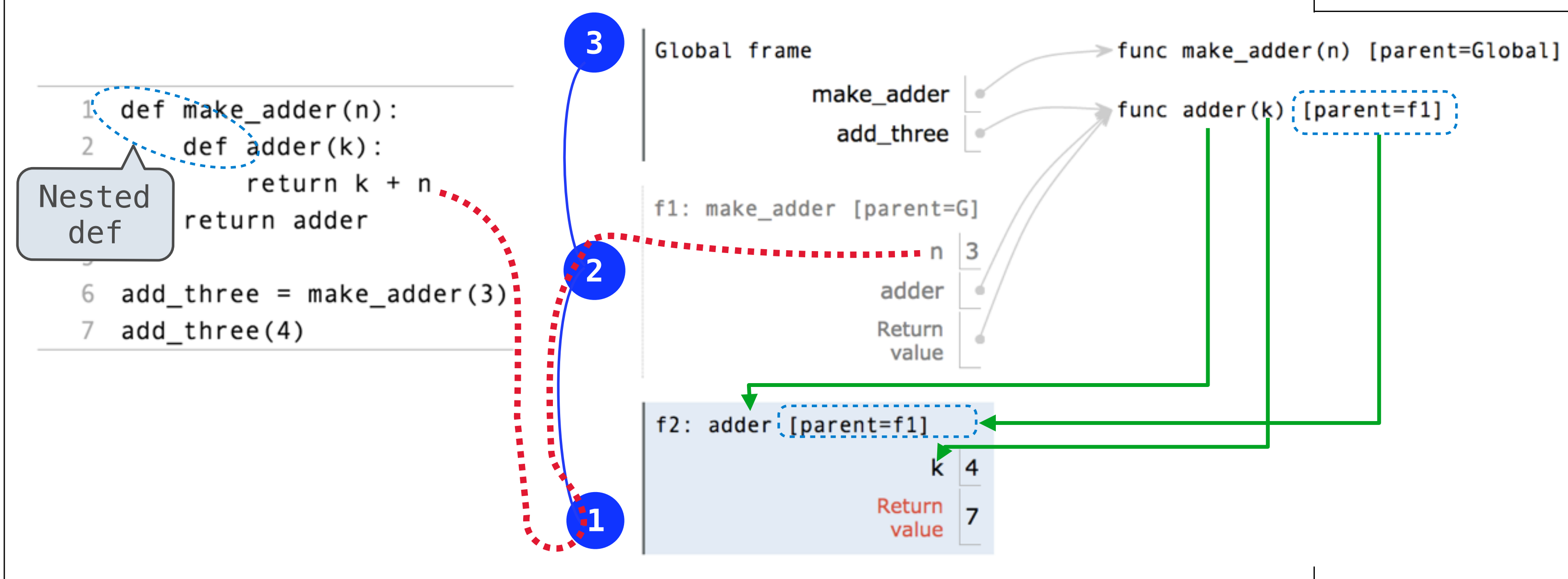
The name add_three is bound to a function

A local def statement

Can refer to names in the enclosing function

- 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**

A function's signature has all the information to create a local frame



```
def compose1(f, g):  
    """Return a function h that composes f and g.  
    """  
    >>> compose1(square, make_adder(2))(3)  
    25  
    """  
    def h(x):  
        return f(g(x))  
    return h
```

Return value of make_adder is an argument to compose1

Anatomy of a recursive function:

- The **def statement header** is similar to other functions
- Conditional statements check for **base cases**
- Base cases are evaluated **without recursive calls**
- Recursive cases are evaluated **with recursive calls**

```
def sum_digits(n):  
    """Return the sum of the digits of positive integer n."""  
    if n < 10:  
        return n  
    else:  
        all_but_last, last = n // 10, n % 10  
        return sum_digits(all_but_last) + last
```

```
1 def cascade(n):  
2   if n < 10:  
3     print(n)  
4   else:  
5     print(n)  
6     cascade(n//10)  
7     print(n)  
8  
9 cascade(123)
```

Global frame

func cascade(n) [parent=Global]

cascade

f1: cascade [parent=Global]

n 123

f2: cascade [parent=Global]

n 12

Return value None

f3: cascade [parent=Global]

n 1


Return value None

Program output:

```
123  
12  
1  
12
```

- Each **cascade** frame is from a different call to **cascade**.
- Until the **Return value** appears, that call has not completed.
- Any statement can appear before or after the recursive call.

```
n: 0, 1, 2, 3, 4, 5, 6, 7, 8,  
fib(n): 0, 1, 1, 2, 3, 5, 8, 13, 21,  
  
def fib(n):  
    if n == 0:  
        return 0  
    elif n == 1:  
        return 1  
    else:  
        return fib(n-2) + fib(n-1)
```



List Comprehension Examples

```
>>> [i for i in range(5)]  
[0, 1, 2, 3, 4]  
>>> [i for i in range(5) if i > 2]  
[3, 4]  
>>> ['odd' if i % 2 == 1 else 'even' for i in range(5)]  
['even', 'odd', 'even', 'odd', 'even']
```

Structure with if

Modified structure with if and else

When a function is defined:

1. Create a **function value**: func **<name>** (**<formal parameters>**)
2. Its parent is the current frame.

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

3. Bind **<name>** to the **function value** in the current frame (which is the first frame of the current environment).

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**.

```
1 def fact(n):  
2   if n == 0:  
3     return 1  
4   else:  
5     return n * fact(n-1)  
6  
7 fact(3)
```

Global frame

func fact(n) [parent=Global]

fact

f1: fact [parent=Global]

n 3

f2: fact [parent=Global]

n 2

f3: fact [parent=Global]

n 1


f4: fact [parent=Global]

n 0

Return value 1

Is **fact** implemented correctly?

1. Verify the base case.
2. Treat **fact** as a functional abstraction!
3. Assume that **fact(n-1)** is correct.
4. Verify that **fact(n)** is correct, assuming that **fact(n-1)** correct.



```
from operator import floordiv, mod  
def divide_exact(n, d):  
    """Return the quotient and remainder of dividing N by D.  
    """  
    >>> q, r = divide_exact(2012, 10)  
    >>> q  
    201  
    >>> r  
    2  
    """  
    return floordiv(n, d), mod(n, d)
```

Multiple assignment to two names

Multiple return values, separated by commas