Environments

Class outline:

- Multiple environments
- Environments for HOFs
- Local names
- Function composition
- Self-referencing functions
- Currying

Multiple Environments

Life cycle of a function

		What happens?
Def statement	`def square( x ):` `  return x * x`	• A new function is created! • Name bound to that function in the current frame.
Call expression	`square( 2 + 2 )`	• Operator & operands evaluated • Function (value of operator) called on arguments (values of operands)
Calling/applying	4 ▶ `def square( x )` ▶ 16	• A new frame is created! • Parameters bound to arguments • Body is executed in that new environment

A nested call expression

1.
2.
3.

```
def square(x):
    return x * x
square(square(3))
```

A nested call expression

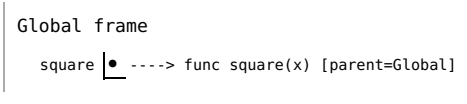
1. next
2.
3.

```
def square(x):
    return x * x
square(square(3))
```

A nested call expression

1. prev
2.
3. next

```
def square(x):
    return x * x
square(square(3))
```



A nested call expression

1. prev
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```
def square(x):
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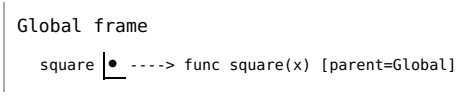
square(square(3))
```



```
square( square(3) )
```

A nested call expression

1. prev
2.
3. next

```
def square(x):
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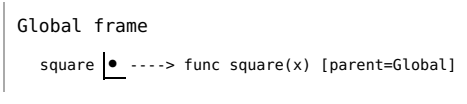
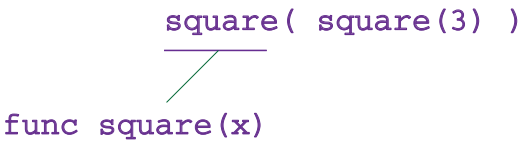
square(square(3))
```




square(square(3))
func square(x)

A nested call expression

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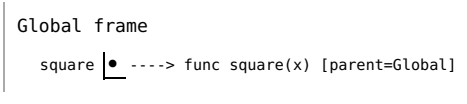
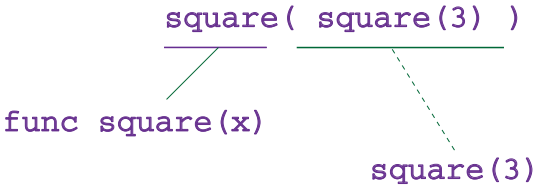
square(square(3))
```




square(square(3))
func square(x)
square(3)

A nested call expression

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def square(x):
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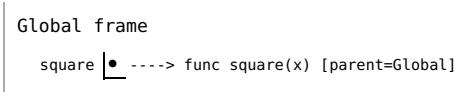
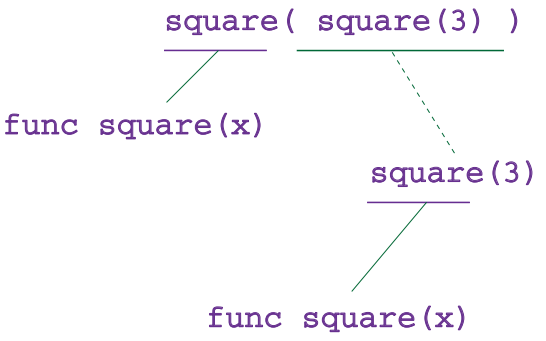
square(square(3))
```




square(square(3))
func square(x)
square(3)
func square(x)

A nested call expression

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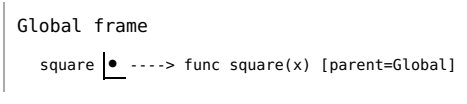

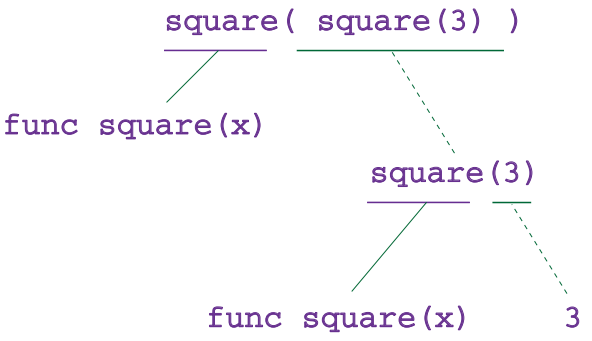
square(square(3))
func square(x)
square(3)
func square(x)
3

A nested call expression

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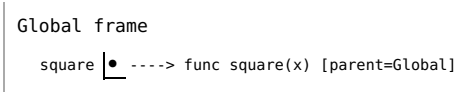

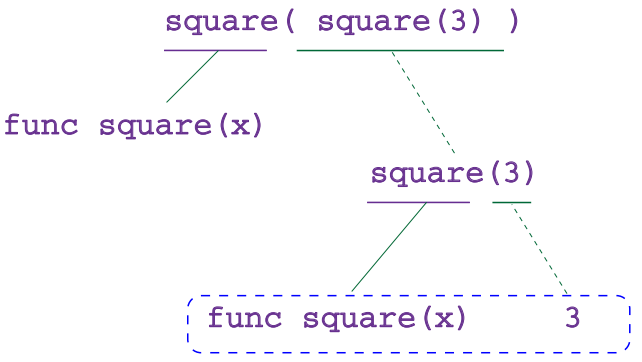
square(square(3))
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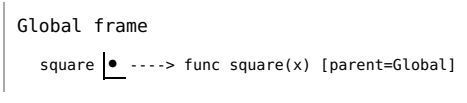

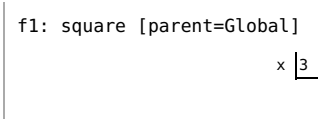

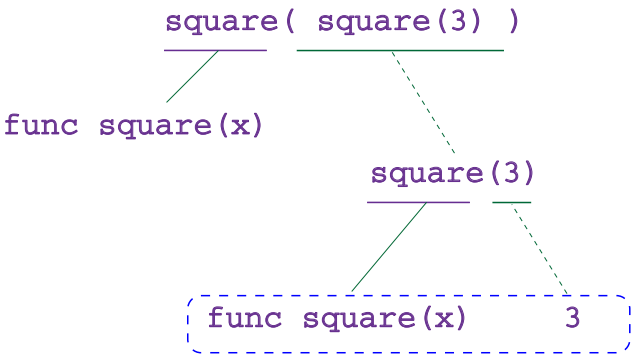
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square(3)
func square(x)
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A nested call expression

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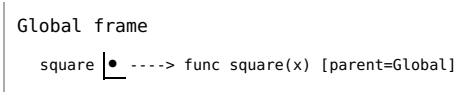

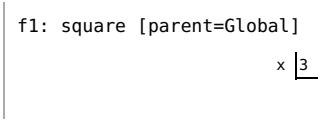

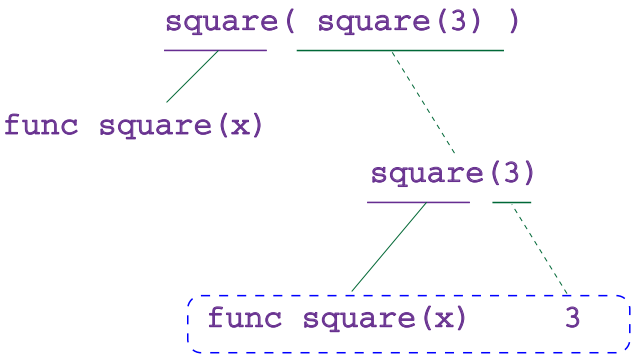
square(square(3))
func square(x)
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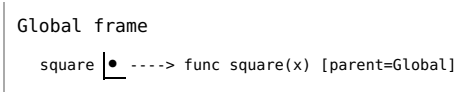
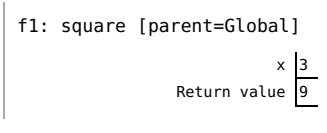
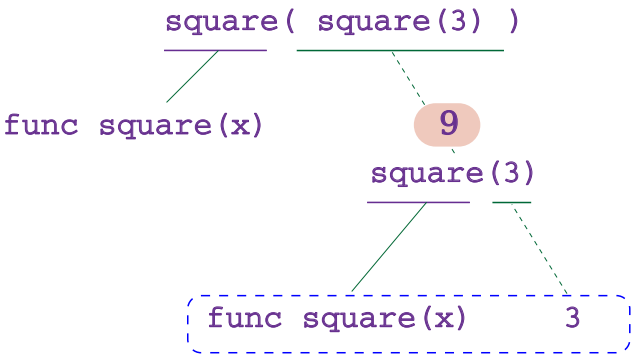
```



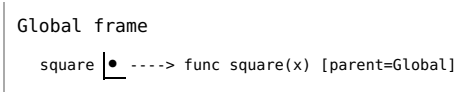


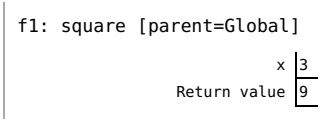

square(square(3))
func square(x)
9
square(3)
func square(x)
3

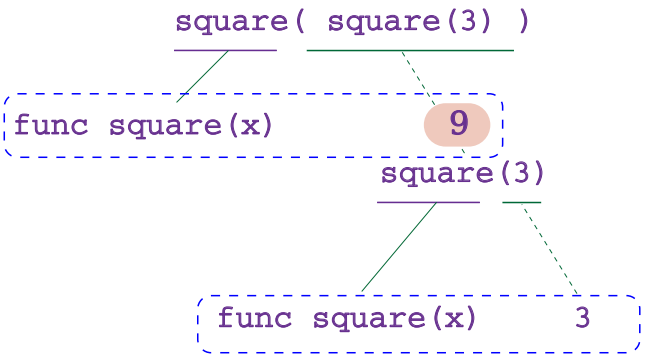
A nested call expression

1. next
2.
3. prev

```
def square(x):
    return x * x
square(square(3))
```






square(square(3))
func square(x)
9
square(3)
func square(x)
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A nested call expression

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prev

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def square(x):
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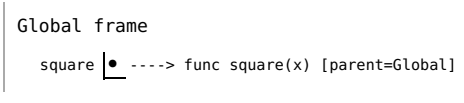
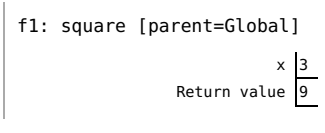
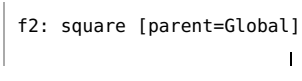
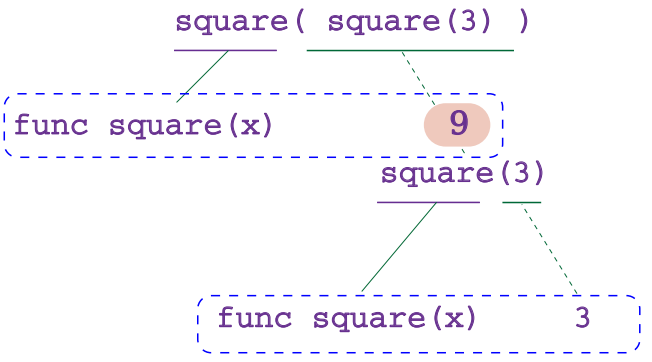






x 9



A nested call expression

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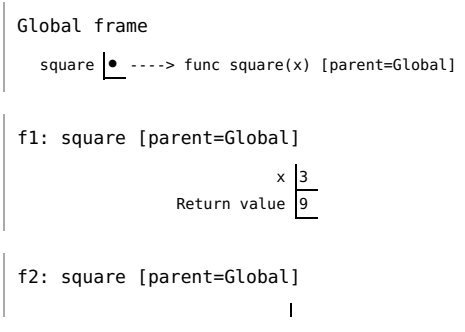

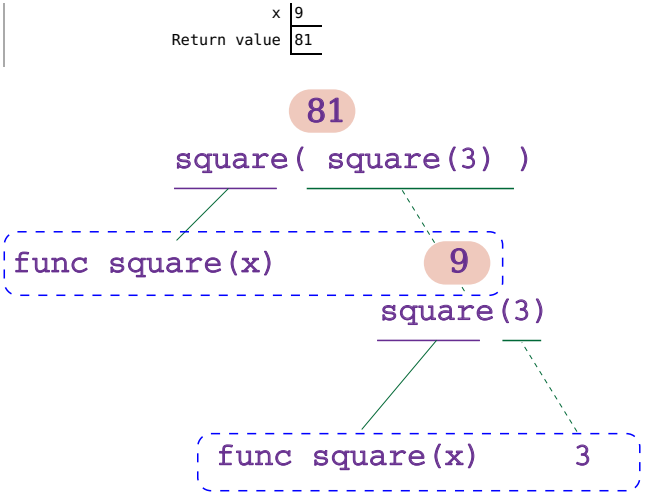
x 9
Return value 81
81
square(square(3))
func square(x)
9
square(3)
func square(x)
3

Multiple environments in one diagram!

```
def square(x):
    return x * x
square(square(3))
```

An environment is a sequence of frames.

Multiple environments in one diagram!

```
def square(x):
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An environment is a sequence of frames.

- Environment: Global frame

Multiple environments in one diagram!

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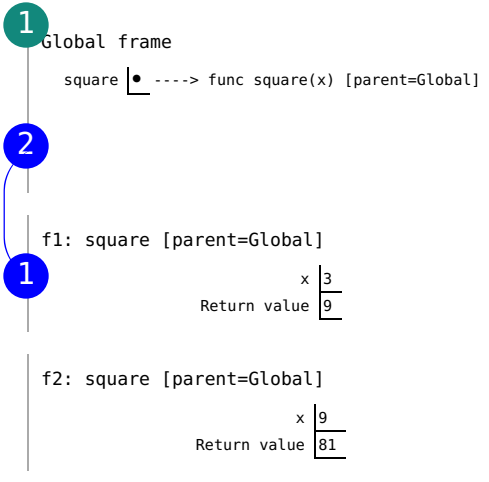

An environment is a sequence of frames.

- Environment: Global frame
- Environment: Local frame (f1), then global frame

Multiple environments in one diagram!

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def square(x):
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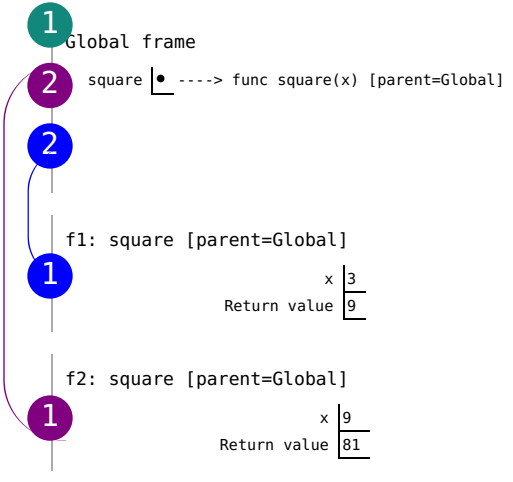
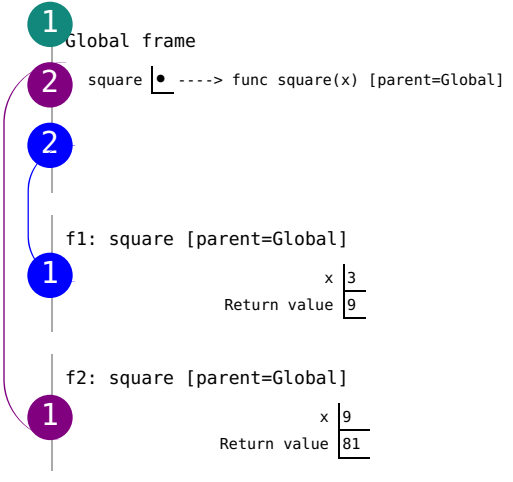


An environment is a sequence of frames.

- Environment: Global frame
- Environment: Local frame (f1), then global frame
- Environment: Local frame (f2), then global frame

Names have no meanings without environments

```
def square(x):
    return x * x
square(square(3))
```



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.

Names have different meanings in different environments

```
def square(square):
    return square * square
square(4)
```

Every expression is evaluated in the context of an environment.

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Names have different meanings in different environments

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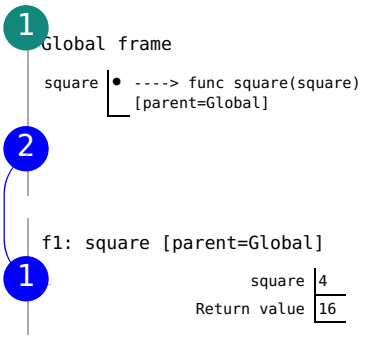
```



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

Environments for higher-order functions

Review: Higher-order functions

A higher-order function is either...

- A function that takes a function as an argument value
  `summation(5, lambda x: x**2)`
- A function that returns a function as a return value
  `make_adder(3)(1)`

Functions are first class: Functions are values in Python.

Example: Apply twice

```
def apply_twice(f, x):
    return f(f(x))

def square(x):
    return x ** 2

apply_twice(square, 3)
```

View in PythonTutor

Arguments bound to functions

Arguments bound to functions

Arguments bound to functions

Environments for nested definitions

Example: Make texter

```
def make_texter(emoji):
    def texter(text):
        return emoji + text + emoji
    return texter

happy_text = make_texter("😄")
result = happy_text("lets go to the beach!")
```

View in PythonTutor

Environments for nested def statements

Environments for nested def statements

- Every user-defined **function** has a parent frame
- The parent of a **function** is the **frame in which it was defined**

Environments for nested def statements

- Every user-defined **function** has a parent frame
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Environments for nested def statements

- Every user-defined **function** has a parent frame
- The parent of a **function** is the **frame in which it was defined**
- Every local **frame** has a parent frame
- The parent of a **frame** is the **parent of the called function**
- An environment is a **sequence of frames**.

How to draw an environment diagram

When a function is defined:

1. Create a function value:
   `func <name>(<formal parameters>) [parent=<label>]`
2. Its parent is the current frame.
3. 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

Example: Thingy Bobber

```
def thingy(x, y):
    return bobber(y)

def bobber(a):
    return a + y

result = thingy("ma", "jig")
```

What do you think will happen?

Example: Thingy Bobber

```
def thingy(x, y):
    return bobber(y)

def bobber(a):
    return a + y

result = thingy("ma", "jig")
```

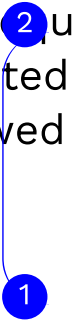
What do you think will happen?

View in PythonTutor

Local name visibility

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 consists of one local frame followed by the global frame.



Function Composition

Example: Composer

```
def happy(text):
    return "☻" + text + "☻"

def sad(text):
    return "☹" + text + "☹"

def composer(f, g):
    def composed(x):
        return f(g(x))
    return composed

msg1 = composer(sad, happy)("cs61a!")
msg2 = composer(happy, sad)("eecs16a!")
```

What do you think will happen?

Example: Composer (Part 2)

One of the composed functions could itself be an HOF...

```
def happy(text):
    return "☻" + text + "☻"

def sad(text):
    return "☹" + text + "☹"

def make_texter(emoji):
    def texter(text):
        return emoji + text + emoji
    return texter

def composer(f, g):
    def composed(x):
        return f(g(x))
    return composed

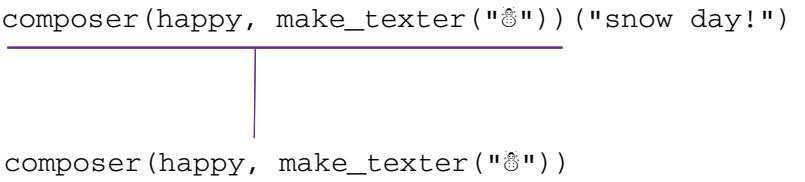
composer(happy, make_texter("☃"))('snow day!')
```

View in PythonTutor

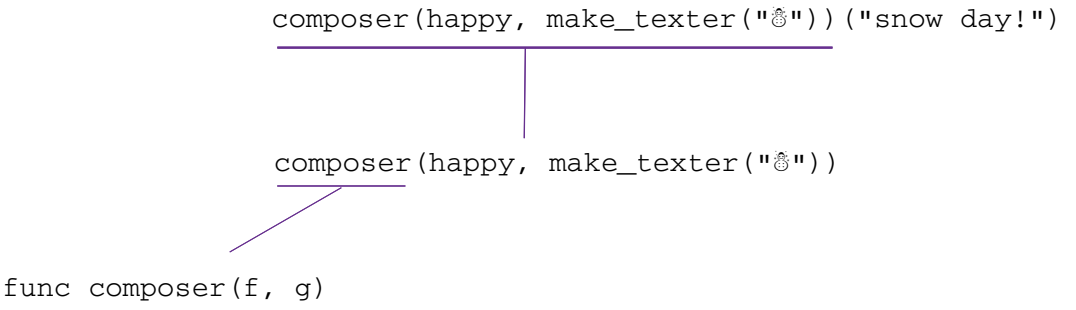
Composer 2 expression tree

```
composer(happy, make_texter("☃"))("snow day!")
```

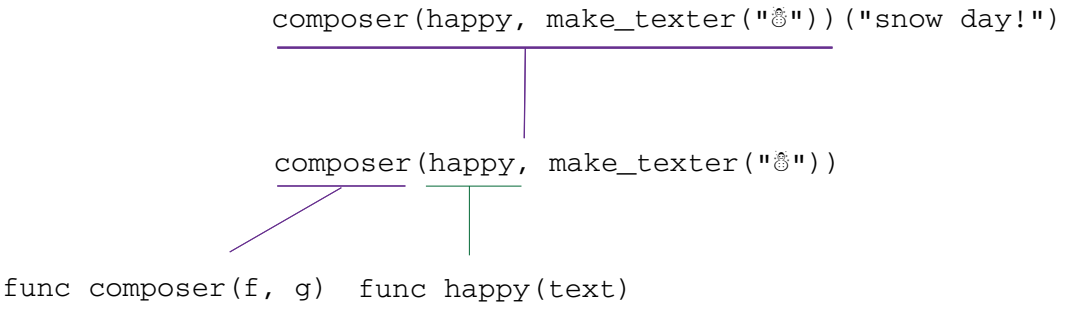
Composer 2 expression tree



Composer 2 expression tree



Composer 2 expression tree



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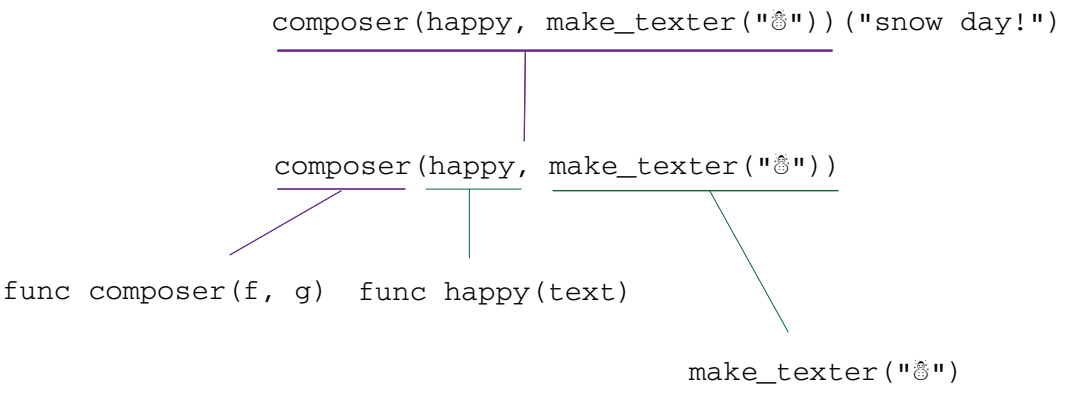
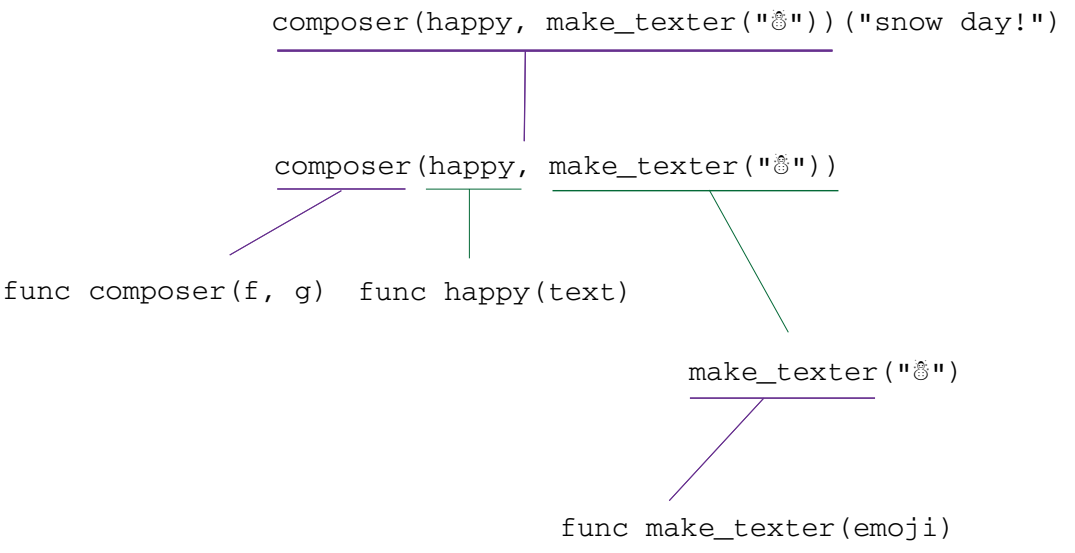
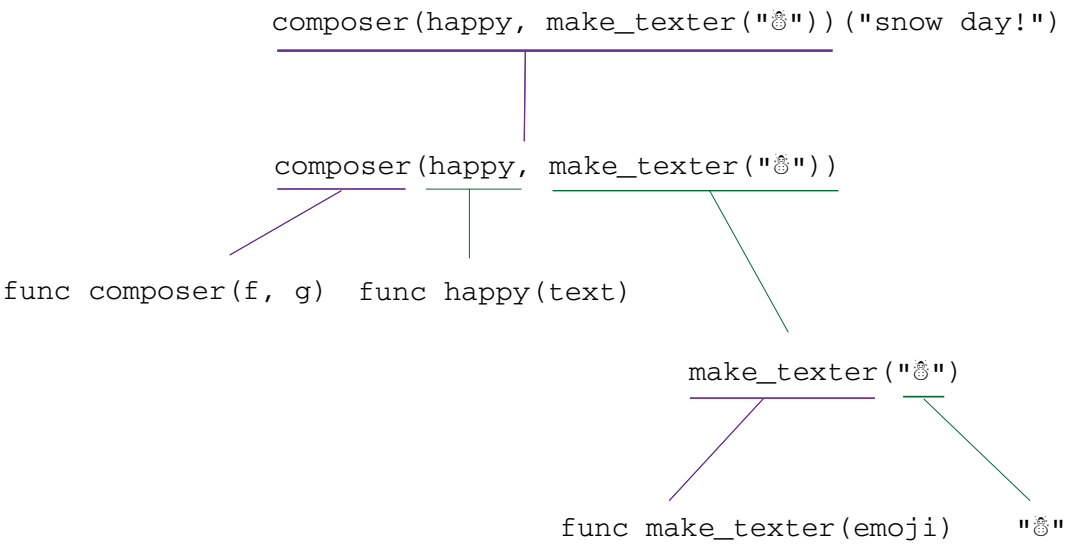


Composer 2 expression tree



Composer 2 expression tree



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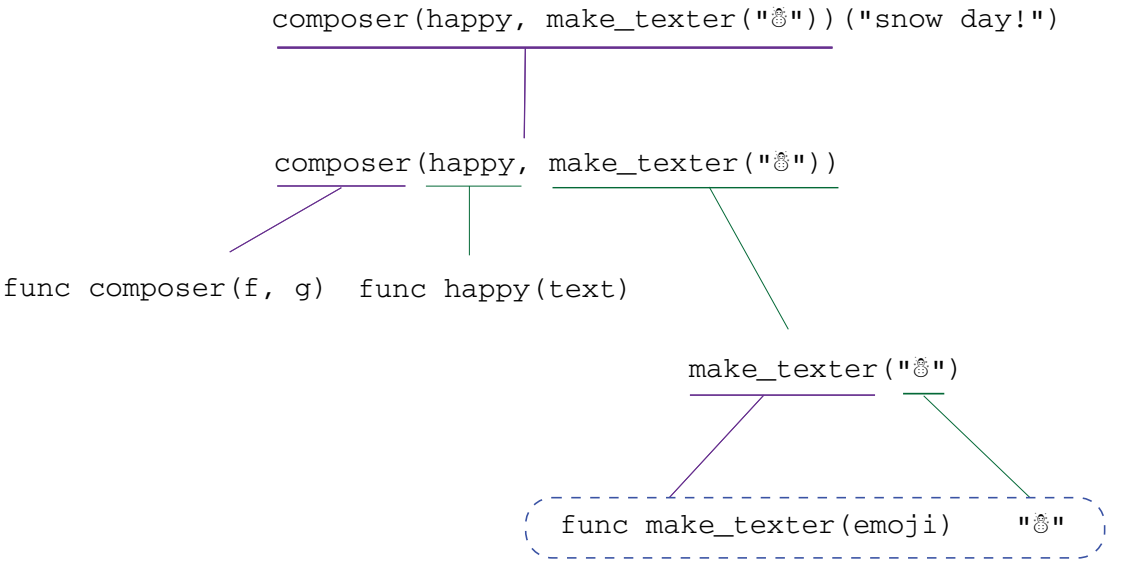

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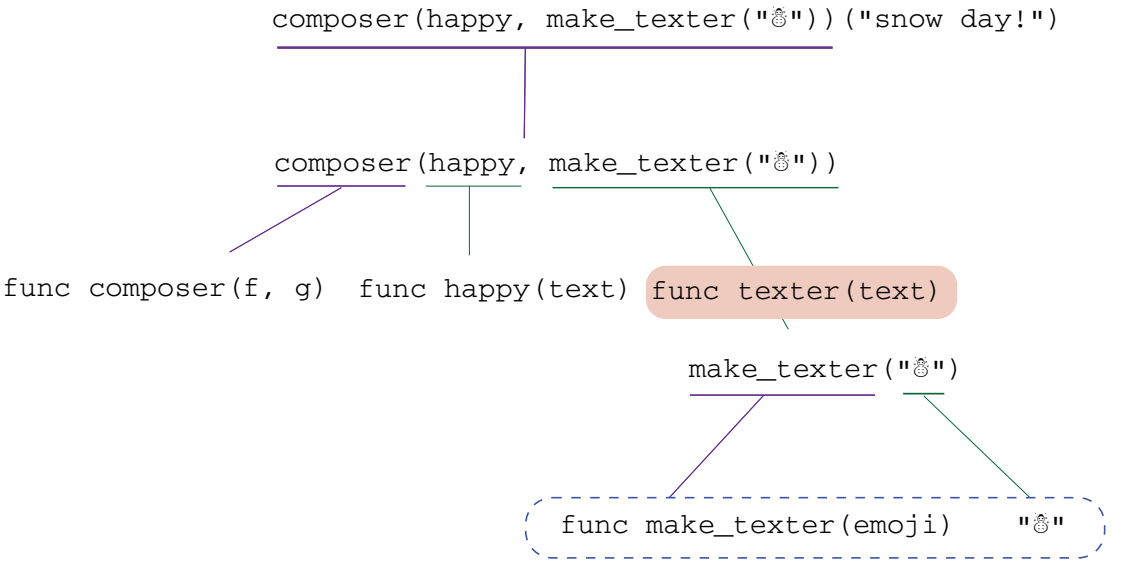

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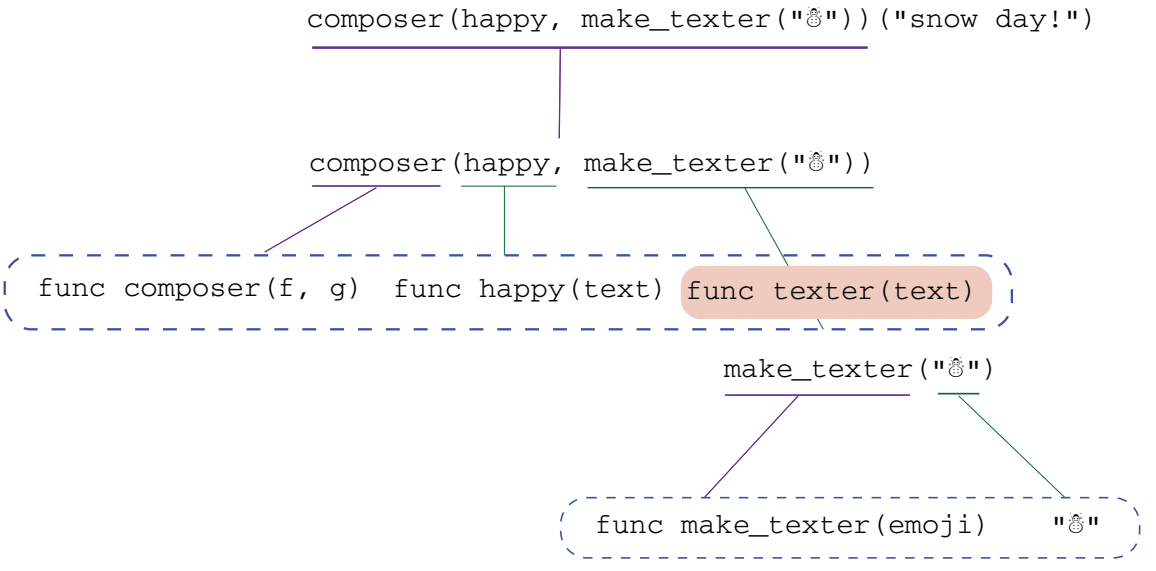

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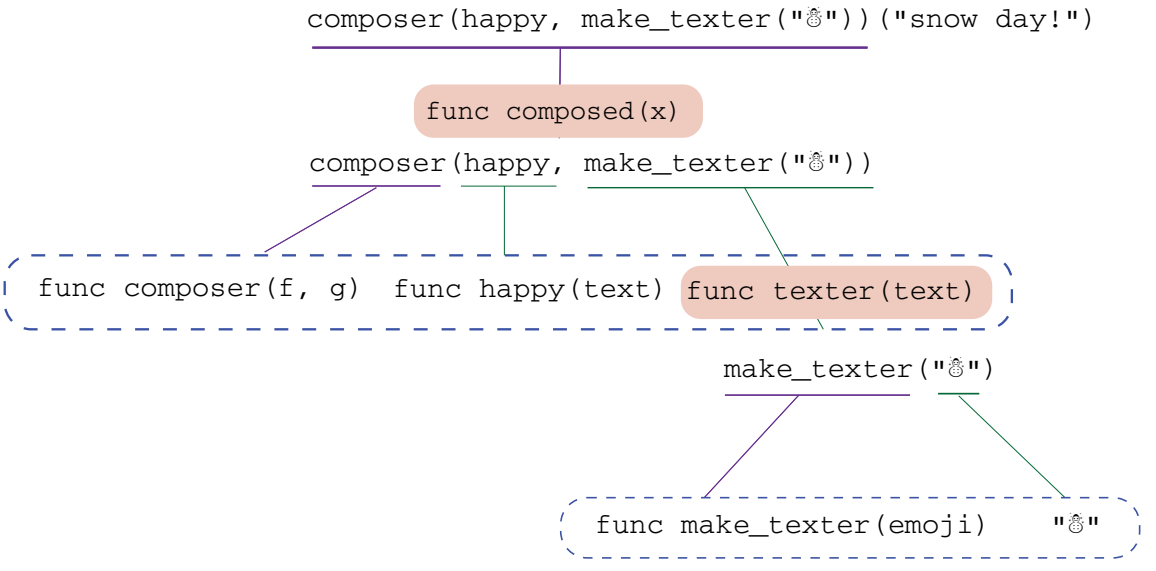

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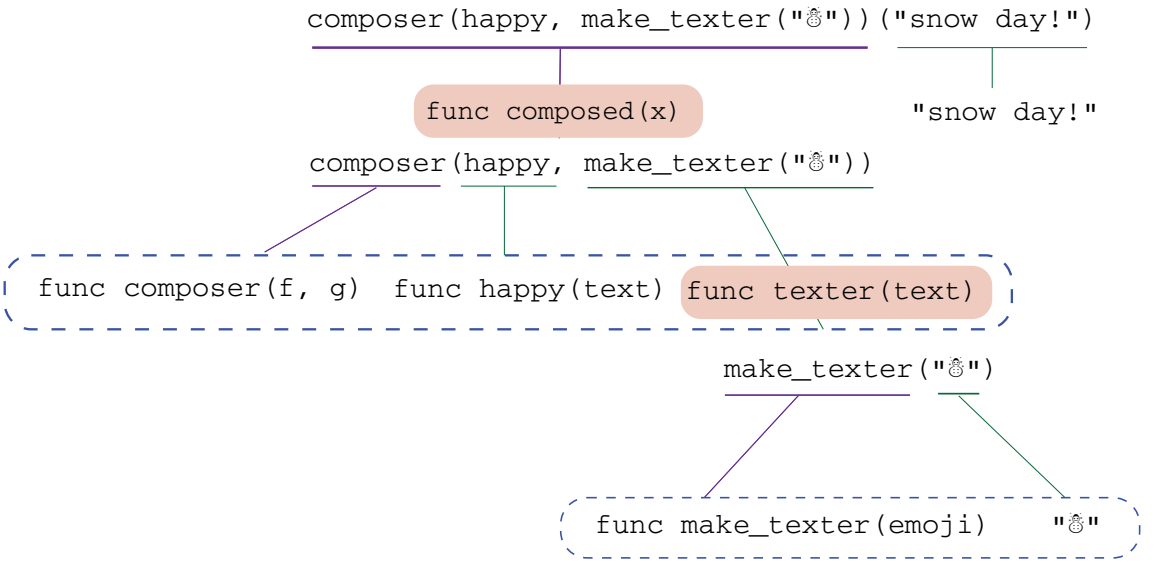

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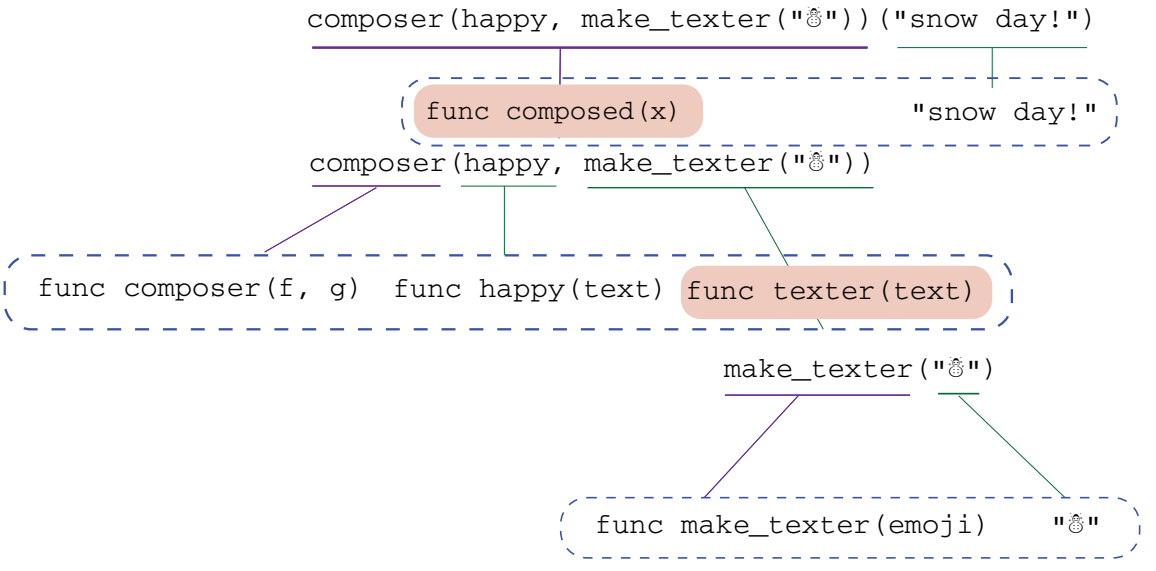

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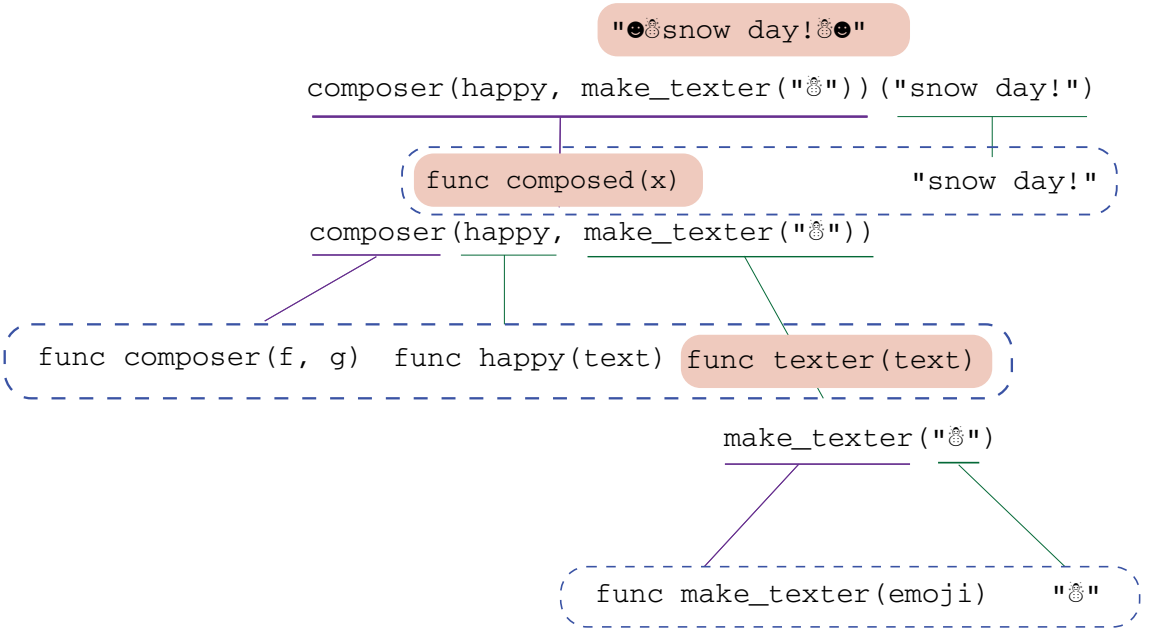

Self-reference

A self-referencing function

A higher-order function could return a function that references its own name.

```
def print_sums(n):
    print(n)
    def next_sum(k):
        return print_sums(n + k)
    return next_sum

print_sums(1)(3)(5)
```

View in PythonTutor

Environment for print_sums

Understanding print_sums

The call:

```
print sums(1)(3)(5)
```

produces the same result as:

```
g1 = print sums(1)
g2 = g1(3)
g2(5)
```

A call to `print sums(x)` returns a function that:

- Prints `x` as a side-effect, and
- Returns a function that, when called with argument `y`, will do the same thing, but with `x+y` instead of `x`.

So these calls will...

- First print 1 and return `g1`,
- which when called with 3, will print 4 (= 1+3) and return `g2`,
- which when called with 5, will print 9 (= 4+5), and return. . . .

Currying

add vs. make_adder

Compare...

```
from operator import add

add(2, 3)
```

```
def make_adder(n):
    return lambda x: n + x

make_adder(2)(3)
```

What's the relationship between `add(2, 3)` and `make_adder(2)(3)`?

Function currying

Currying: Converting a function that takes multiple arguments into a single-argument higher-order function.

A function that currys any two-argument function:

```
def curry2(f):
    def g(x):
        def h(y):
            return f(x, y)
        return h
    return g
```

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    return g
```

```
make_adder = curry2(add)
make_adder(2)(3)
```

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

```
make_adder = curry2(add)
make_adder(2)(3)
```

```
curry2 = lambda f: lambda x: lambda y: f(x, y)
```

Why "currying"?

It's not food! ✖ ✖

Named after American logician Haskell Curry, but actually published first by Russian Moses Schönfinkel, based on principles by German Gottlob Frege.

See also: Stigler's law of eponymy