Announcements
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Abstraction
Functional Abstractions
def square(x):
    return mul(x, x)
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def square(x):
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def sum_squares(x, y):
    return square(x) + square(y)
What does \texttt{sum\_squares} need to know about \texttt{square}?

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    return pow(x, 2)
def square(x):
    return mul(x, x-1) + x
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If the name “square” were bound to a built-in function, sum_squares would still work identically.
Choosing Names
Choosing Names

Names typically don’t matter for correctness

but

they matter a lot for composition
Choosing Names

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Names should convey the meaning or purpose of the values to which they are bound.
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Reasons to add a new name
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More Naming Tips

• Names can be long if they help document your code:

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average_age = average(age, students)
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is preferable to

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aa = avg(a, st)
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(Demo)
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def triple(x):
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Function decorator

Decorated function
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(Demo)

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def triple(x):
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triple = trace(triple)
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Function Decorators

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Why not just use this?
Currying
Function Currying
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def make_adder(n):
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Function Currying

```python
def make_adder(n):
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>>> make_adder(2)(3)
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>>> add(2, 3)
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There's a general relationship between these functions.
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There's a general relationship between these functions (Demo)

**Curry:** Transform a multi-argument function into a single-argument, higher-order function
Review
What Would Python Print?
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<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
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</tbody>
</table>

This expression evaluates to 5 and displays 5 in interactive output.
What Would Python Print?

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

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

print(5)
```

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print(5)
What Would Python Print?

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from operator import add, mul

def square(x):
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def square(x):
    return mul(x, x)
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The print function returns None. It also displays its arguments (separated by spaces) when it is called.

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from operator import add, mul

def square(x):
    return mul(x, x)
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<tr>
<td>print(5)</td>
<td>None</td>
<td>5</td>
</tr>
<tr>
<td>print(print(5))</td>
<td></td>
<td>5</td>
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What Would Python Print?

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

```python
from operator import add, mul

def square(x):
    return mul(x, x)

print(print(5))
None
```

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```python
from operator import add, mul

def square(x):
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</tr>
<tr>
<td>print(print(5))</td>
<td>None</td>
<td>5 None</td>
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What Would Python Print?

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

```python
from operator import add, mul

def square(x):
    return mul(x, x)

print(print(5))  # None

print(5)  # None 5

print(print(5))  # None

print(print(5))  # None
```

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<td>5 None</td>
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**What Would Python Print?**

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

```python
from operator import add, mul

def square(x):
    return mul(x, x)

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

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<td>5</td>
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<tr>
<td>print(print(5))</td>
<td>None</td>
<td>5</td>
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</tbody>
</table>

```python
def delay(arg):
    print('delayed')
    def g():
        return arg
    return g
```
## What Would Python Print?

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

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

def g():
    return delay(delay)()(6)()
```

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<td>5</td>
</tr>
<tr>
<td><code>print(print(5))</code></td>
<td>None</td>
<td>5</td>
</tr>
<tr>
<td><code>delay(delay)(6)()</code></td>
<td>None</td>
<td>5</td>
</tr>
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</table>

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

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

def g():
    return delay(delay)()(6)()
```
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)

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

def g():
    return

print(print(5))
print(delay(delay)()(6))
```

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<tr>
<td>print(print(5))</td>
<td>None</td>
<td>5</td>
</tr>
<tr>
<td>delay(delay)()(6)</td>
<td>None</td>
<td>None</td>
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</table>

Names in nested def statements can refer to their enclosing scope.
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 takes any argument and returns a function that returns that arg

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

def square(x):
    return mul(x, x)

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

This expression | Evaluates to | Interactive Output
---|---|---
5 | 5 | 5
print(5) | None | 5
print(print(5)) | None | 5 None
delay(delay)()(6)() | None | None
```
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)

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

def g():
    return
return
```

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

Names in nested def statements can refer to their enclosing scope

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<tr>
<td>print(print(5))</td>
<td>None</td>
<td>5</td>
</tr>
<tr>
<td>delay(delay)()(6)()</td>
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What Would Python Print?

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

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

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

def g():
    return arg

What Would Python Print?

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</tr>
<tr>
<td>print(print(5))</td>
<td>None</td>
<td>5</td>
</tr>
<tr>
<td>delay(delay)()()</td>
<td>None</td>
<td>5</td>
</tr>
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</table>
```

Names in nested def statements can refer to their enclosing scope.
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 takes any argument and returns a function that returns that arg

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

def g():
    return
return g
```

### This expression | Evaluates to | Interactive Output
---|---|---
5 | 5 | 5
```
print(5)  
```
None | 5 | None
```
print(print(5))  
```
None | 5 | None
```
```
delay(delay)()(6)()  
```
None | None | None
What Would Python Print?

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

```python
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():
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Names in nested def statements can refer to their enclosing scope
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<td>5</td>
</tr>
<tr>
<td>print(print(5))</td>
<td>None</td>
<td>5 None</td>
</tr>
<tr>
<td>delay(delay)()(6)()</td>
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This expression Evaluates to Interactive Output
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 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
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<tr>
<td><code>print(print(5))</code></td>
<td>None</td>
<td>5</td>
</tr>
<tr>
<td><code>delay(delay)(6)()</code></td>
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What Would Python Print?

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

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

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

def g():
    return
return g
```

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

Names in nested def statements can refer to their enclosing scope

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<td>5</td>
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<tr>
<td>print(print(5))</td>
<td>None</td>
<td>5, None</td>
</tr>
<tr>
<td>(delay(delay)())(6)()</td>
<td>delayed</td>
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What Would Python Print?

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

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

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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)

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

print(print(5))
```

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<td>print(5)</td>
<td>None</td>
<td>5</td>
</tr>
<tr>
<td>print(print(5))</td>
<td>None</td>
<td>5, None</td>
</tr>
<tr>
<td>(delay(delay))()()</td>
<td>6</td>
<td>delayed 6</td>
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What Would Python Print?

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

```python
from operator import add, mul

def square(x):
    return mul(x, x)

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

print(print(5))  # None
print(print(5))  # None
print(5)  # 5
print(delay(print)(())())  # delayed delayed 6
print(delay(print)(())())  # delayed delayed 6
```

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<td>5 None</td>
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<tr>
<td>delay(delay)()</td>
<td>6</td>
<td>delayed delayed 6</td>
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<td>print(delay(print)()())</td>
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<td>delayed delayed 6</td>
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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 takes any argument and returns a function that returns that arg

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

def g():
    return
return g

Names in nested def statements can refer to their enclosing scope

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<td>None</td>
<td>5 None</td>
</tr>
<tr>
<td>delay(delay)()(6)()</td>
<td>6</td>
<td>delayed 6</td>
</tr>
<tr>
<td>print(delay(print)()(4))</td>
<td>delayed</td>
<td>delayed</td>
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What Would Python Print?

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

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

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

def square(x):
    return mul(x, x)

Names in nested def statements can refer to their enclosing scope

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<td>print(print(5))</td>
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</tr>
<tr>
<td>delay(delay)()(6)()</td>
<td>6</td>
<td>delayed 6</td>
</tr>
<tr>
<td>delay(print)()(4)</td>
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What Would Python Print?

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

```python
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

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

```
def g():
    return arg
return g
```

Names in nested def statements can refer to their enclosing scope

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<td>5</td>
</tr>
<tr>
<td>print(print(5))</td>
<td>None</td>
<td>5</td>
</tr>
<tr>
<td>delay(delay)(6)()</td>
<td>6</td>
<td>delayed</td>
</tr>
<tr>
<td>delay(print)(4)</td>
<td>None</td>
<td>delayed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>delayed</td>
</tr>
<tr>
<td></td>
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<td>4</td>
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<tr>
<td></td>
<td></td>
<td>None</td>
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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)
```

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

```
def g():
    return arg
return g
```

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

Names in nested def statements can refer to their enclosing scope

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</tr>
<tr>
<td>print(print(5))</td>
<td>None</td>
<td>5 None</td>
</tr>
<tr>
<td>delay(delay)(()()6)()</td>
<td>6</td>
<td>delayed delayed 6</td>
</tr>
<tr>
<td>print(delay(print)()()4)</td>
<td>None</td>
<td>delayed 4 None</td>
</tr>
</tbody>
</table>
def horse(mask):
    horse = mask
    def mask(horse):
        return horse
    return horse(mask)

mask = lambda horse: horse(2)
horse(mask)
def horse(mask):
    horse = mask
    def mask(horse):
        return horse
    return horse(mask)

mask = lambda horse: horse(2)
horse(mask)
def horse(mask):
    horse = mask
    def mask(horse):
        return horse
    return horse(mask)

mask = lambda horse: horse(2)
horse(mask)
def horse(mask):
    horse = mask
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