Tree Recursion
Class outline:

- Order of recursive calls
- Tree recursion
- Counting partitions
Order of recursive calls
def cascade(n):
    if n < 10:
        print(n)
    else:
        print(n)
        cascade(n//10)
        print(n)

cascade(123)
def cascade(n):
    if n < 10:
        print(n)
    else:
        print(n)
        cascade(n//10)
        print(n)

cascade(123)

What would this display?

Answer the poll: lecturepoll.pamelafox2.repl.co
def cascade(n):
    if n < 10:
        print(n)
    else:
        print(n)
        cascade(n//10)
        print(n)

cascade(123)

View in PythonTutor

- 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.

Global frame
  cascade → func cascade(n)[parent=Global]

f1: cascade[parent=Global]

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>123</td>
</tr>
<tr>
<td>Return value</td>
<td>None</td>
</tr>
</tbody>
</table>
f2: cascade[parent=Global]
   n 12
   Return value None

f3: cascade[parent=Global]
   n 1
   Return value None

Print output:

```
123
12
1
12
123
```
Two definitions of cascade

```python
def cascade(n):
    if n < 10:
        print(n)
    else:
        print(n)
        cascade(n//10)
        print(n)
```

```python
def cascade(n):
    print(n)
    if n >= 10:
        cascade(n//10)
        print(n)
```

- If two implementations are equally clear, then the shorter one is usually better
- When learning to write recursive functions, put the base cases first
- Both are recursive functions, even though only the first has typical structure
Inverse cascade

How can we output this cascade instead?

1
12
123
12
1
def inverse_cascade(n):
    grow(n)
    print(n)
    shrink(n)

grow = lambda n: f_then_g(
shrink = lambda n: f_then_g(

View in PythonTutor
def inverse_cascade(n):
    grow(n)
    print(n)
    shrink(n)

def f_then_g(f, g, n):
    if n:
        f(n)
        g(n)

grow = lambda n: f_then_g(
shrink = lambda n: f_then_g(

View in PythonTutor
def inverse_cascade(n):
grow(n)
print(n)
shrink(n)

def f_then_g(f, g, n):
    if n:
        f(n)
        g(n)

grow = lambda n: f_then_g(grow, print, n//10)
shrink = lambda n: f_then_g(

View in PythonTutor
def inverse_cascade(n):
    grow(n)
    print(n)
    shrink(n)

def f_then_g(f, g, n):
    if n:
        f(n)
        g(n)

grow = lambda n: f_then_g(grow, print, n//10)
shrink = lambda n: f_then_g(print, shrink, n//10)

View in PythonTutor
Tree recursion
Tree Recursion

Tree-shaped processes arise whenever a recursive function makes more than one recursive call.

Sierpinski curve
Recursive Virahanka-Fibonacci

The nth number is defined as:

\[
\text{virfib}(n) = \begin{cases} 
0 & \text{if } n = 0 \\
1 & \text{if } n = 1 \\
\text{virfib}(n - 1) + \text{virfib}(n - 2) & \text{otherwise}
\end{cases}
\]

```python
def virfib(n):
    """Compute the nth Virahanka-Fibonacci number, for N >= 1."
    >>> virfib(2)
    1
    >>> virfib(6)
    8
    """
```
Recursive Virahanka-Fibonacci

The nth number is defined as:

\[
\text{virfib}(n) = \begin{cases} 
0 & \text{if } n = 0 \\
1 & \text{if } n = 1 \\
\text{virfib}(n - 1) + \text{virfib}(n - 2) & \text{otherwise}
\end{cases}
\]

def virfib(n):
    """Compute the nth Virahanka-Fibonacci number, for N >= 1."
    >>> virfib(2)
    1
    >>> virfib(6)
    8
    """
    if n == 0:
        return 0
    elif n == 1:
        return 1
    else:
        return virfib(n-2) + virfib(n-1)
A tree-recursive process
Redundant computations

The function is called on the same number multiple times. 😞
(We will speed up this computation dramatically in a few weeks by
Counting partitions
Counting partitions problem

The number of partitions of a positive integer \( n \), using parts up to size \( m \), is the number of ways in which \( n \) can be expressed as the sum of positive integer parts up to \( m \) in increasing order.

\[
\text{count_partitions}(6, 4)
\]

\[
\begin{align*}
2 + 4 &= 6 \\
1 + 1 + 4 &= 6 \\
3 + 3 &= 6 \\
1 + 2 + 3 &= 6 \\
1 + 1 + 1 + 3 &= 6 \\
2 + 2 + 2 &= 6 \\
1 + 1 + 2 + 2 &= 6 \\
1 + 1 + 1 + 1 + 2 &= 6 \\
1 + 1 + 1 + 1 + 1 + 1 &= 6
\end{align*}
\]
Counting partitions approach

The number of partitions of a positive integer $n$, using parts up to size $m$, is the number of ways in which $n$ can be expressed as the sum of positive integer parts up to $m$ in increasing order.

`count_partitions(6, 4)`

Recursive decomposition: finding simpler instances of the problem.

Explore two possibilities:
Counting partitions approach

The number of partitions of a positive integer $n$, using parts up to size $m$, is the number of ways in which $n$ can be expressed as the sum of positive integer parts up to $m$ in increasing order.

$count\_partitions(6, 4)$

Recursive decomposition: finding simpler instances of the problem.

Explore two possibilities:

Use at least one 4
Counting partitions approach

The number of partitions of a positive integer \( n \), using parts up to size \( m \), is the number of ways in which \( n \) can be expressed as the sum of positive integer parts up to \( m \) in increasing order.

\[
\text{count\_partitions}(6, 4)
\]

Recursive decomposition: finding simpler instances of the problem.

Explore two possibilities:

- Use at least one 4
- Don't use any 4

\[
\begin{array}{c}
\text{Use at least one 4} \\
\text{Don't use any 4}
\end{array}
\]
Counting partitions approach

The number of partitions of a positive integer \( n \), using parts up to size \( m \), is the number of ways in which \( n \) can be expressed as the sum of positive integer parts up to \( m \) in increasing order.

`count_partitions(6, 4)`

Recursive decomposition: finding simpler instances of the problem.

Explore two possibilities:

- **Use at least one 4**
- **Don't use any 4**

Tree recursion often involves exploring different choices.
Counting partitions approach

The number of partitions of a positive integer \( n \), using parts up to size \( m \), is the number of ways in which \( n \) can be expressed as the sum of positive integer parts up to \( m \) in increasing order.

\[
\text{count_partitions}(6, 4)
\]

Solve two simpler problems:

\[
\text{count_partitions}(2, 4)
\]

\[
\text{count_partitions}(6, 3)
\]
Counting partitions approach

The number of partitions of a positive integer $n$, using parts up to size $m$, is the number of ways in which $n$ can be expressed as the sum of positive integer parts up to $m$ in increasing order.

$\text{count_partitions}(6, 4)$

Solve two simpler problems:

$\text{count_partitions}(2, 4)$

$\text{count_partitions}(n-m, m)$

$\text{count_partitions}(6, 3)$
Counting partitions approach

The number of partitions of a positive integer $n$, using parts up to size $m$, is the number of ways in which $n$ can be expressed as the sum of positive integer parts up to $m$ in increasing order.

count_partitions(6, 4)

Solve two simpler problems:

count_partitions(2, 4)
count_partitions(n-m, m)
count_partitions(6, 3)
count_partitions(n, m-1)
Counting partitions code

The number of partitions of a positive integer \( n \), using parts up to size \( m \), is the number of ways in which \( n \) can be expressed as the sum of positive integer parts up to \( m \) in increasing order.

\[
\text{count_partitions}(6, 4)
\]

Solve two simpler problems:

**with** parts of size \( m \):

\[
\text{count_partitions}(2, 4) \\
\text{count_partitions}(n-m, m)
\]

**without** parts of size \( m \):

\[
\text{count_partitions}(6, 3) \\
\text{count_partitions}(n, m-1)
\]

```python
def count_partitions(n, m):
    """
    >>> count_partitions(6, 4)
```
Counting partitions code

The number of partitions of a positive integer \( n \), using parts up to size \( m \), is the number of ways in which \( n \) can be expressed as the sum of positive integer parts up to \( m \) in increasing order.

\[
\text{count_partitions}(6, 4)
\]

Solve two simpler problems:

**with** parts of size \( m \):

\[
\text{count_partitions}(2, 4) \\
\text{count_partitions}(n-m, m)
\]

**without** parts of size \( m \):

\[
\text{count_partitions}(6, 3) \\
\text{count_partitions}(n, m-1)
\]

def count_partitions(n, m):
    
    >>> count_partitions(6, 4)
else:
    with_m = count_partitions(n-m, m)
    without_m = count_partitions(n, m-1)
    return with_m + without_m
Counting partitions code

The number of partitions of a positive integer \( n \), using parts up to size \( m \), is the number of ways in which \( n \) can be expressed as the sum of positive integer parts up to \( m \) in increasing order.

```python
def count_partitions(n, m):
    """
    >>> count_partitions(6, 4)
    Solve two simpler problems:
    with parts of size \( m \):
    count_partitions(2, 4)
count_partitions(n-m, m)
    without parts of size \( m \):
    count_partitions(6, 3)
count_partitions(n, m-1)
```
if n == 0:
    return 1
elif n < 0:
    return 0
elif m == 0:
    return 0
else:
    with_m = count_partitions(n-m, m)
    without_m = count_partitions(n, m-1)
    return with_m + without_m
Counting partitions process
count_partitions(4,2)
  ret: 3

  count_partitions(2,2)
    ret: 2
      count_partitions(0,2)
        ret: 1
        count_partitions(1,1)
          ret: 1
          count_partitions(0,1)
            ret: 1
            count_partitions(0,1)
              ret: 1

  count_partitions(4,1)
    ret: 1
      count_partitions(3,1)
        ret: 1
        count_partitions(3,0)
          ret: 0
          count_partitions(2,0)
            ret: 1
            count_partitions(0,1)
              ret: 1

  count_partitions(4,0)
    ret: 0
      count_partitions(2,1)
        ret: 1
        count_partitions(2,0)
          ret: 0
          count_partitions(1,0)
            ret: 0