

# Tree Recursion

# Class outline:

- Order of recursive calls
- Tree recursion
- Counting partitions

# Order of recursive calls

# The cascade function

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

What would this display?

```
cascade(123)
```

# The cascade function

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

What would this display?

```
cascade(123)
```

```
1  
12  
123  
12  
1
```

```
123  
12  
1  
12  
123
```

# Cascade environment diagram

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



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- 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]

n	123
Return value	None

```
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

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

```
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
```

# Inverse cascade solution

```
def inverse_cascade(n):  
    grow(n)  
    print(n)  
    shrink(n)
```

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



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# Inverse cascade solution

```
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(
```



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# Inverse cascade solution

```
def inverse_cascade(n):  
    grow(n)  
    print(n)  
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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(
```



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# Inverse cascade solution

```
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)
```

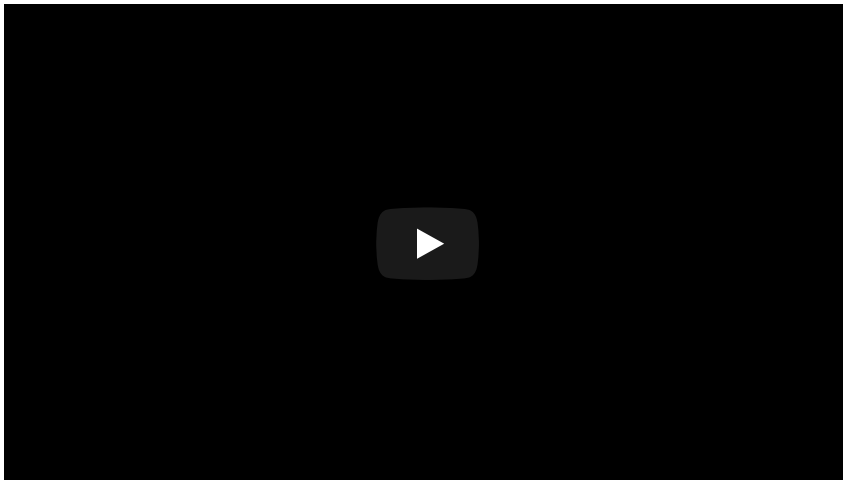


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# Tree recursion (Multiple recursion)

# Tree Recursion

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



Sierpinski curve

# Recursive Virahanka-Fibonacci

The  $n$ th 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  
    """
```



# Recursive Virahanka-Fibonacci

The  $n$ th number is defined as:

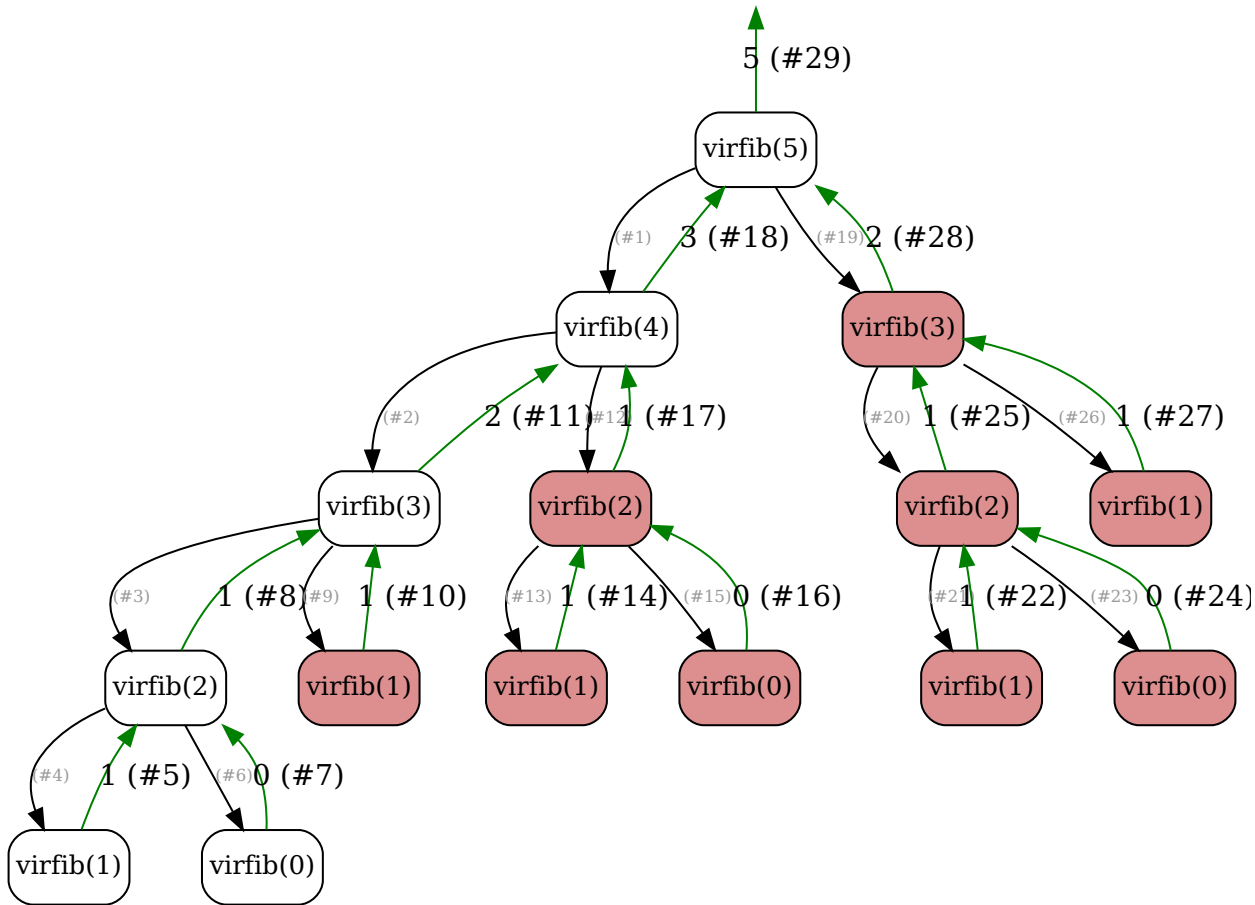
$$\text{virfib}(n) = \begin{cases} 0 & \text{if } n = 0 \\ 1 & \text{if } n = 1 \\ \text{virfib}(n-1) + \text{virfib}(n-2) & \text{otherwise} \end{cases}$$

```
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-1) + virfib(n-2)
```

# A tree-recursive call graph

# Redundant computations

The function is called on the same number multiple times. 🐱



(We will speed up this computation dramatically in a few weeks by remembering results)

# 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.

```
count_partitions(6, 4) # n, m
```

$$2 + 4 = 6$$

$$1 + 1 + 4 = 6$$

$$3 + 3 = 6$$

$$1 + 2 + 3 = 6$$

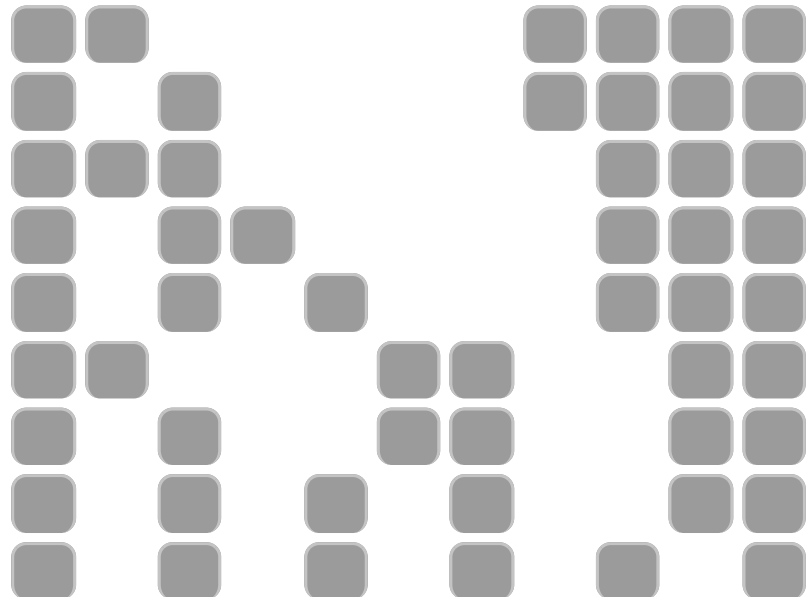
$$1 + 1 + 1 + 3 = 6$$

$$2 + 2 + 2 = 6$$

$$1 + 1 + 2 + 2 = 6$$

$$1 + 1 + 1 + 1 + 2 = 6$$

$$1 + 1 + 1 + 1 + 1 + 1 = 6$$



# 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.

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Recursive decomposition: finding simpler instances of the problem.

Explore two possibilities:





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Recursive decomposition: finding simpler instances of the problem.

Explore two possibilities:

Use at least one 4





# Counting partitions approach

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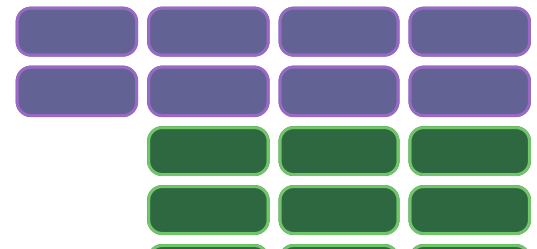
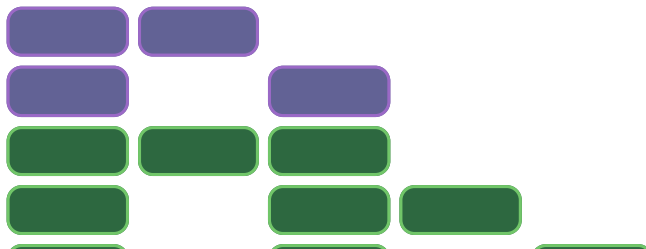
```
count_partitions(6, 4) # n, m
```

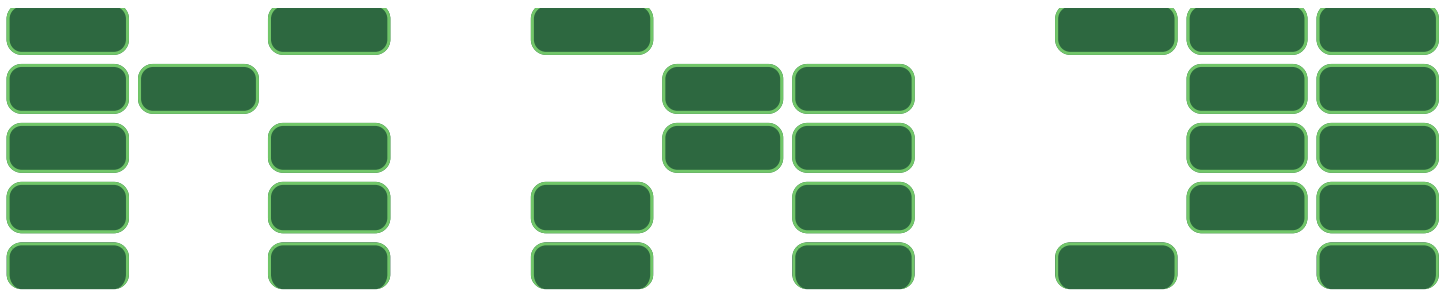
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Explore two possibilities:

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Don't use any 4





# Counting partitions approach

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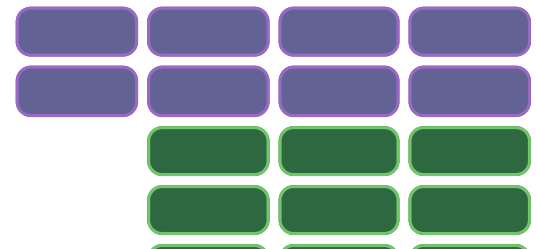
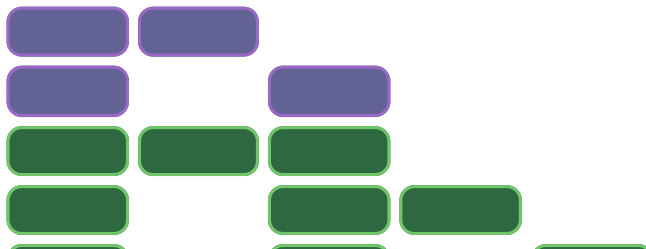
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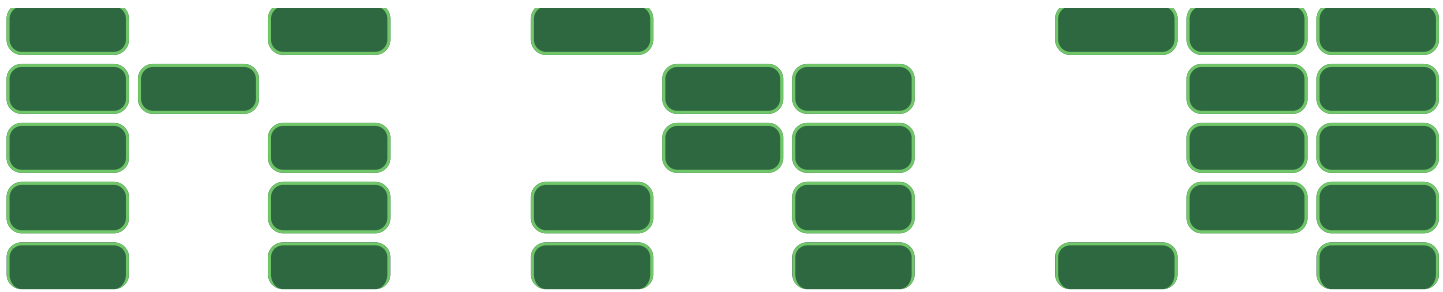
Explore two possibilities:

Use at least one 4

Don't use any 4

Tree recursion often involves exploring different choices.





# Counting partitions approach

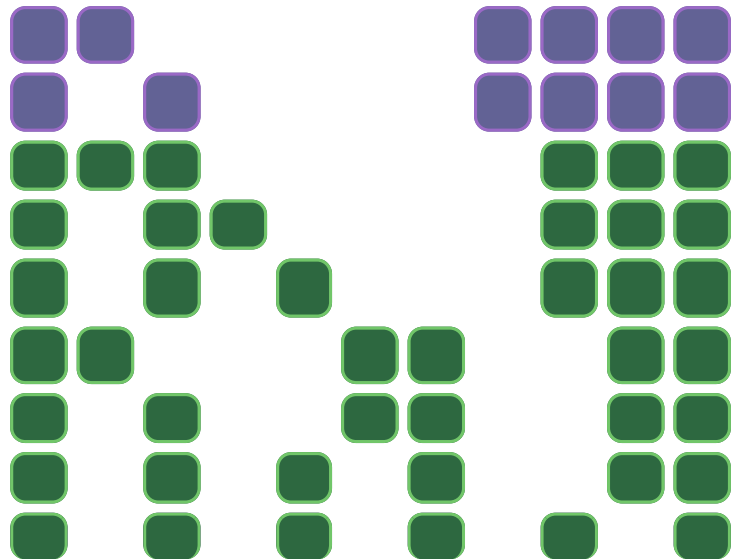
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```
count_partitions(6, 4) # n, m
```

Solve two simpler problems:

```
count_partitions(2, 4)
```

```
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.

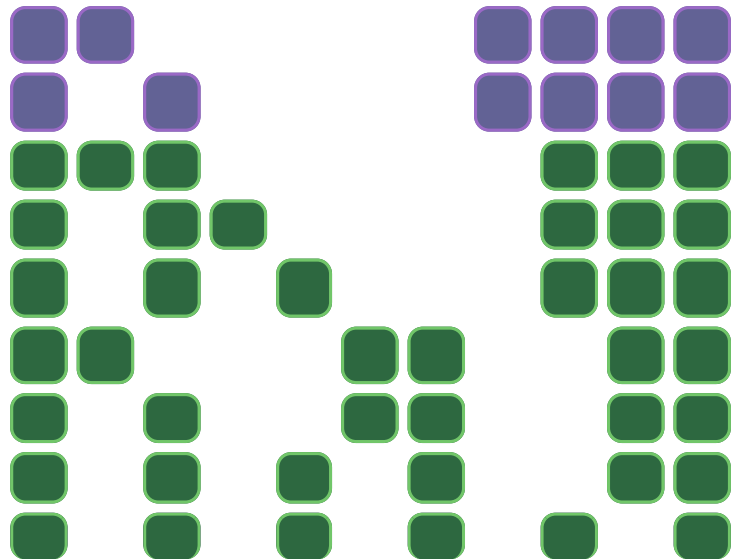
```
count_partitions(6, 4) # n, m
```

Solve two simpler problems:

```
count_partitions(2, 4)
```

```
count_partitions(n-m, m)
```

```
count_partitions(6, 3)
```





# Counting partitions approach

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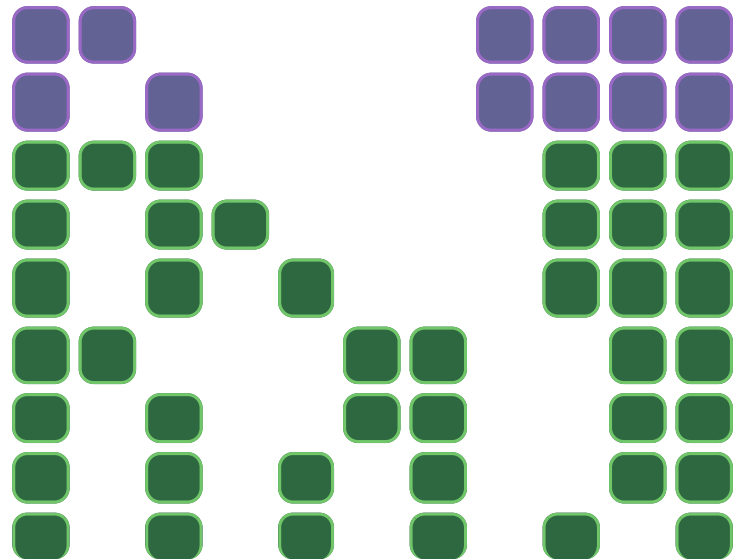
Solve two simpler problems:

```
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.

```
count_partitions(6, 4) # n, m
```

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)
```

```
def count_partitions(n, m):
    """
    >>> count_partitions(6, 4)
```

9

"" ""

# 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.

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count_partitions(6, 4) # n, m
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```
count_partitions(6, 3)
count_partitions(n, m-1)
```

```
def count_partitions(n, m):
    """
    >>> count_partitions(6, 4)
```

9

"""

**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.

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Solve two simpler problems:

**with** parts of size  $m$ :

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count_partitions(n-m, m)
```

**without** parts of size  $m$ :

```
count_partitions(6, 3)
count_partitions(n, m-1)
```

```
def count_partitions(n, m):
    """
    >>> count_partitions(6, 4)
```

```
9
"""
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
```

# Count partitions call graph



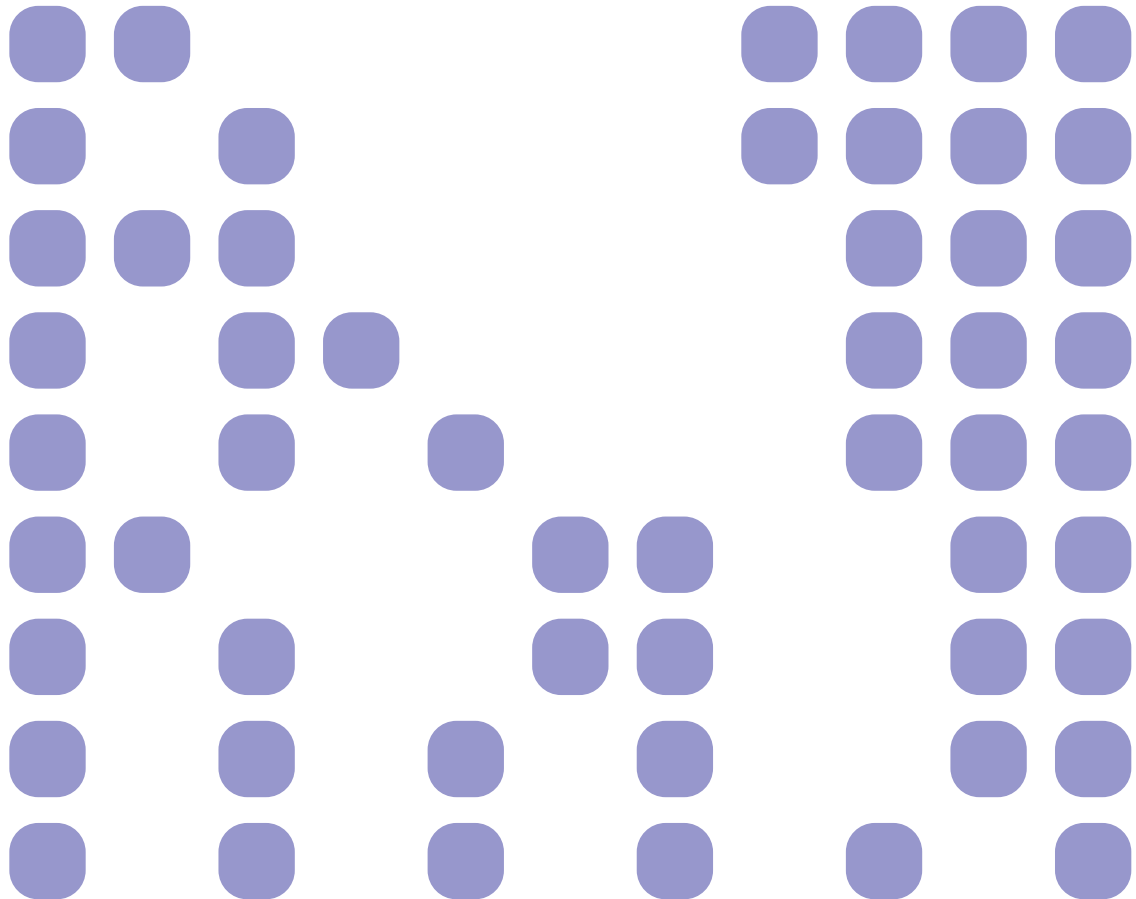
# Count partitions variant

To save on unneeded calls, we can cap `m`, the maximum partition size, based on `n`. We can also add a base case for `m` of size 1.

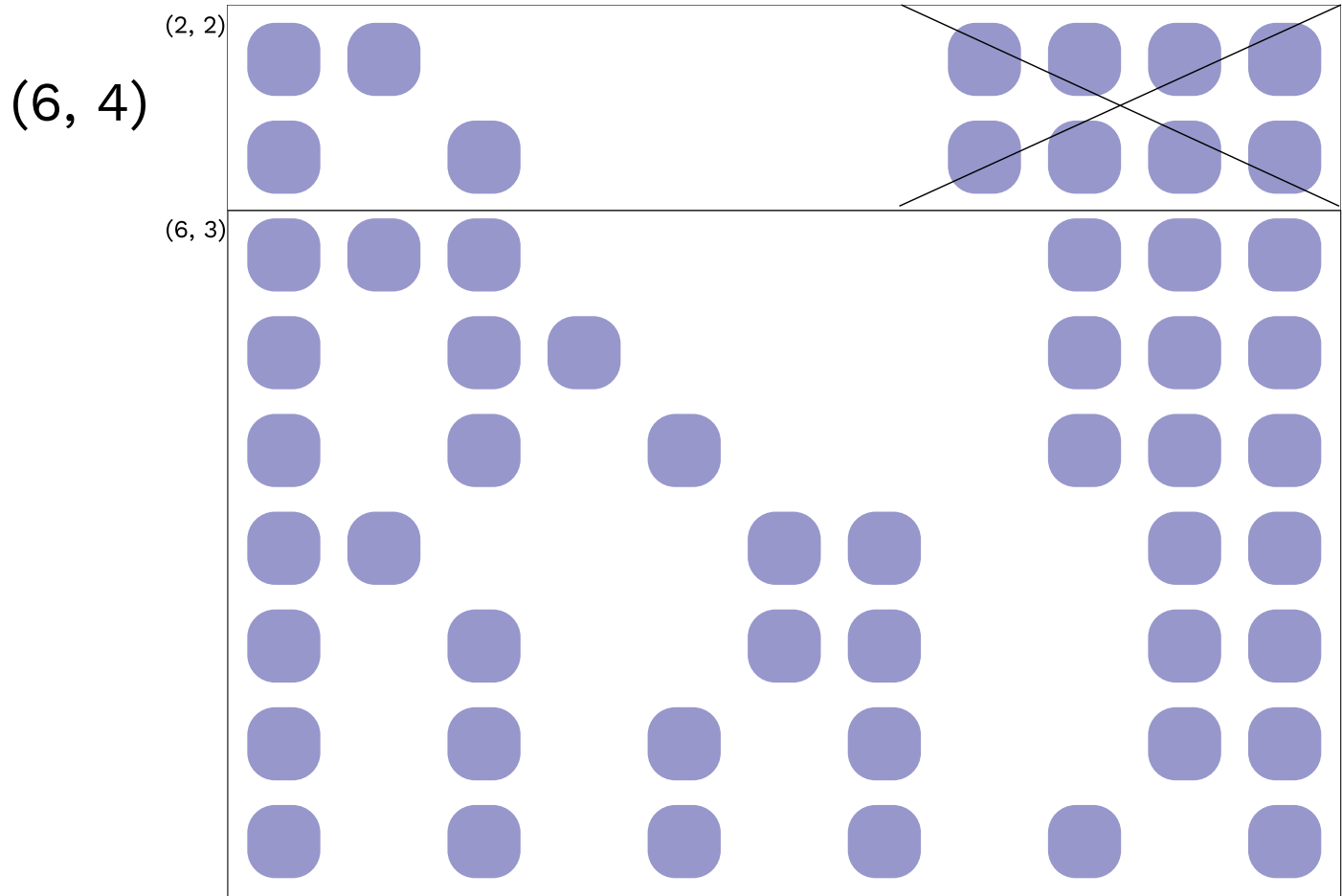
```
def count_partitions(n, m):
    if m == 1 or n == 0:
        return 1
    elif n < 0:
        return 0
    else:
        # Number of partitions using a partition of size M
        leftover = n - m
        with_m = count_partitions(leftover, min(leftover, m))
        # Number of partitions using size up to M-1
        without_m = count_partitions(n, m-1)
        return with_m + without_m
```

# Variant call graph

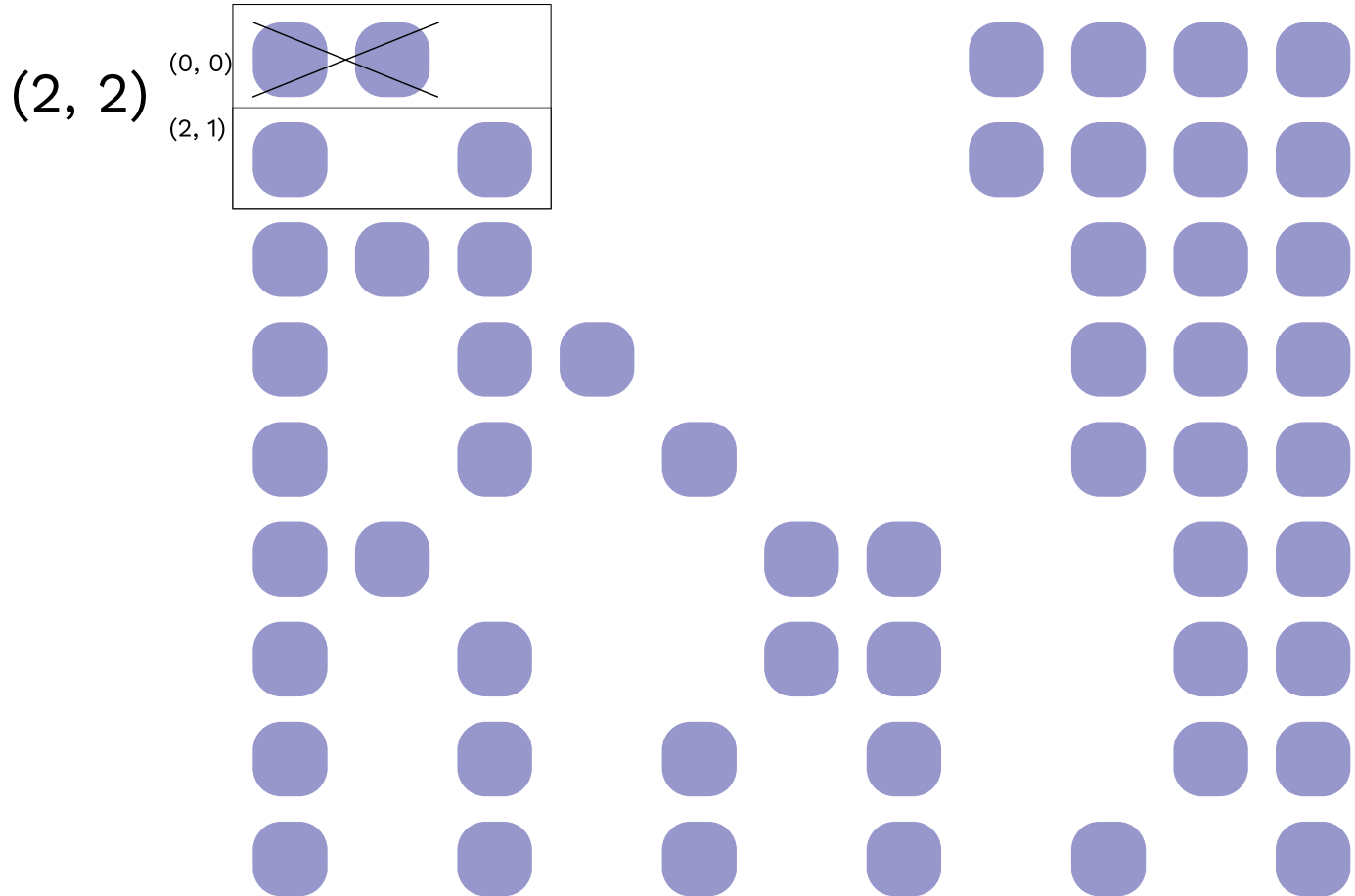
# Variant visualization



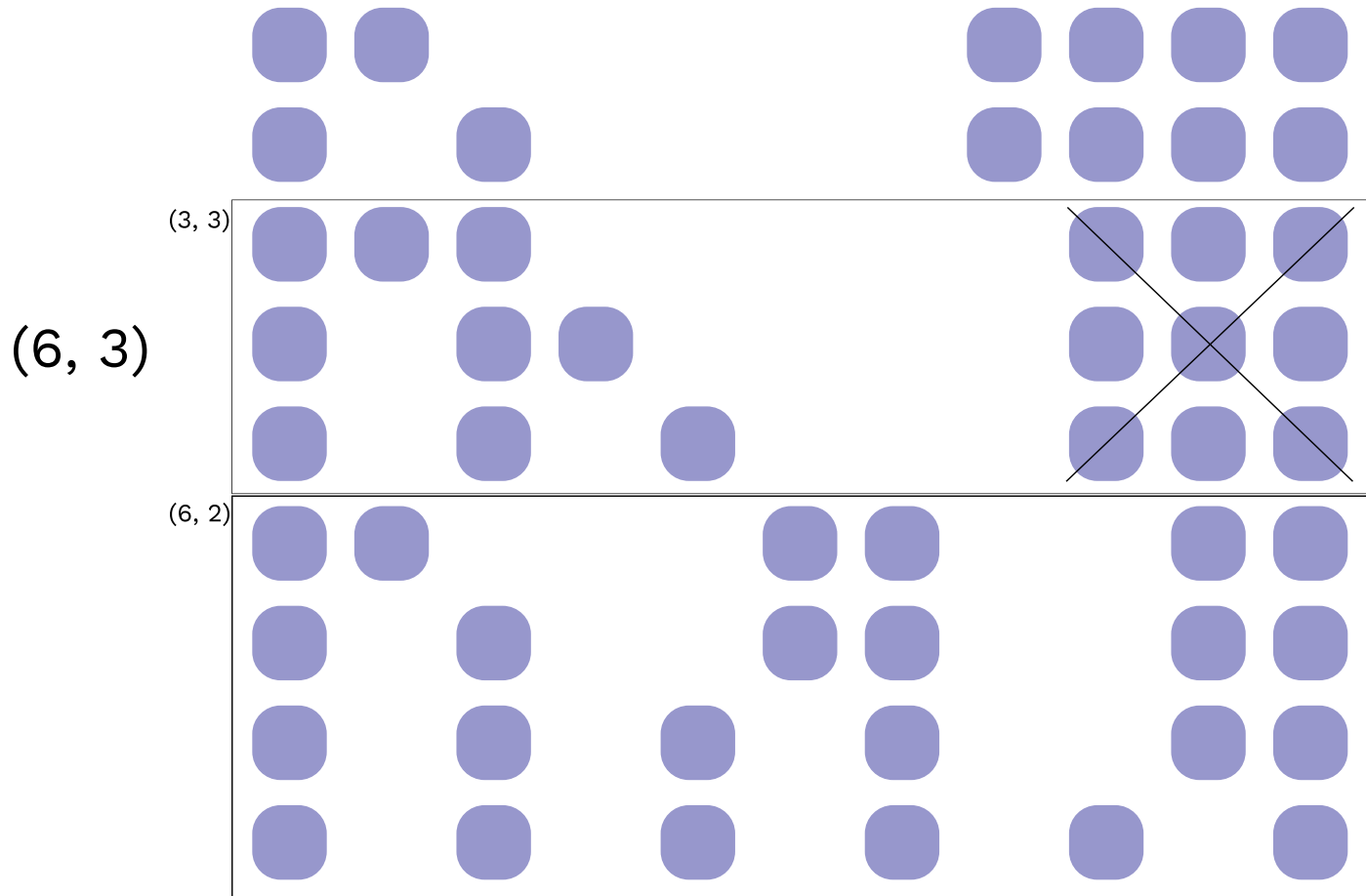
# Variant visualization



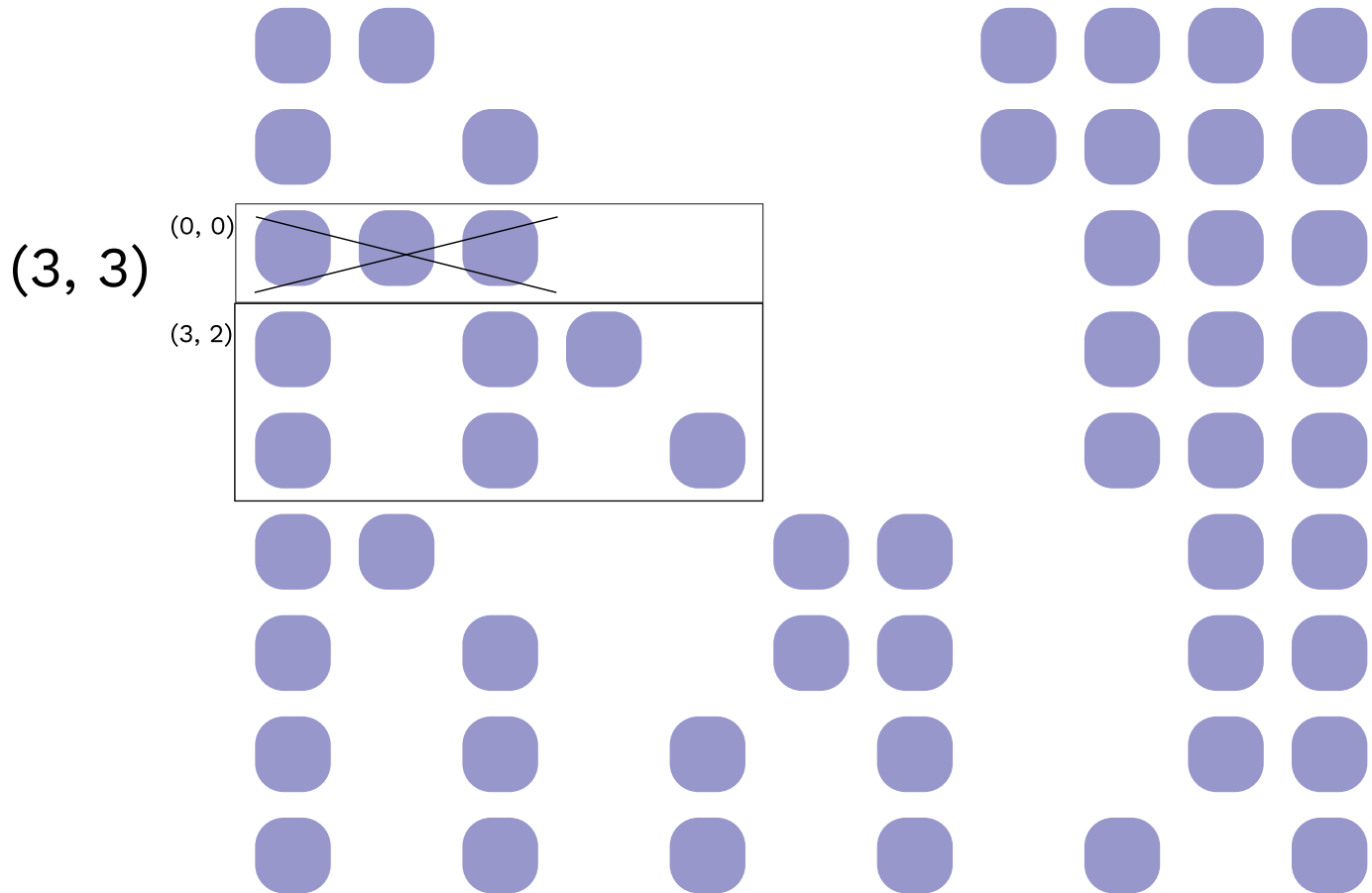
# Variant visualization



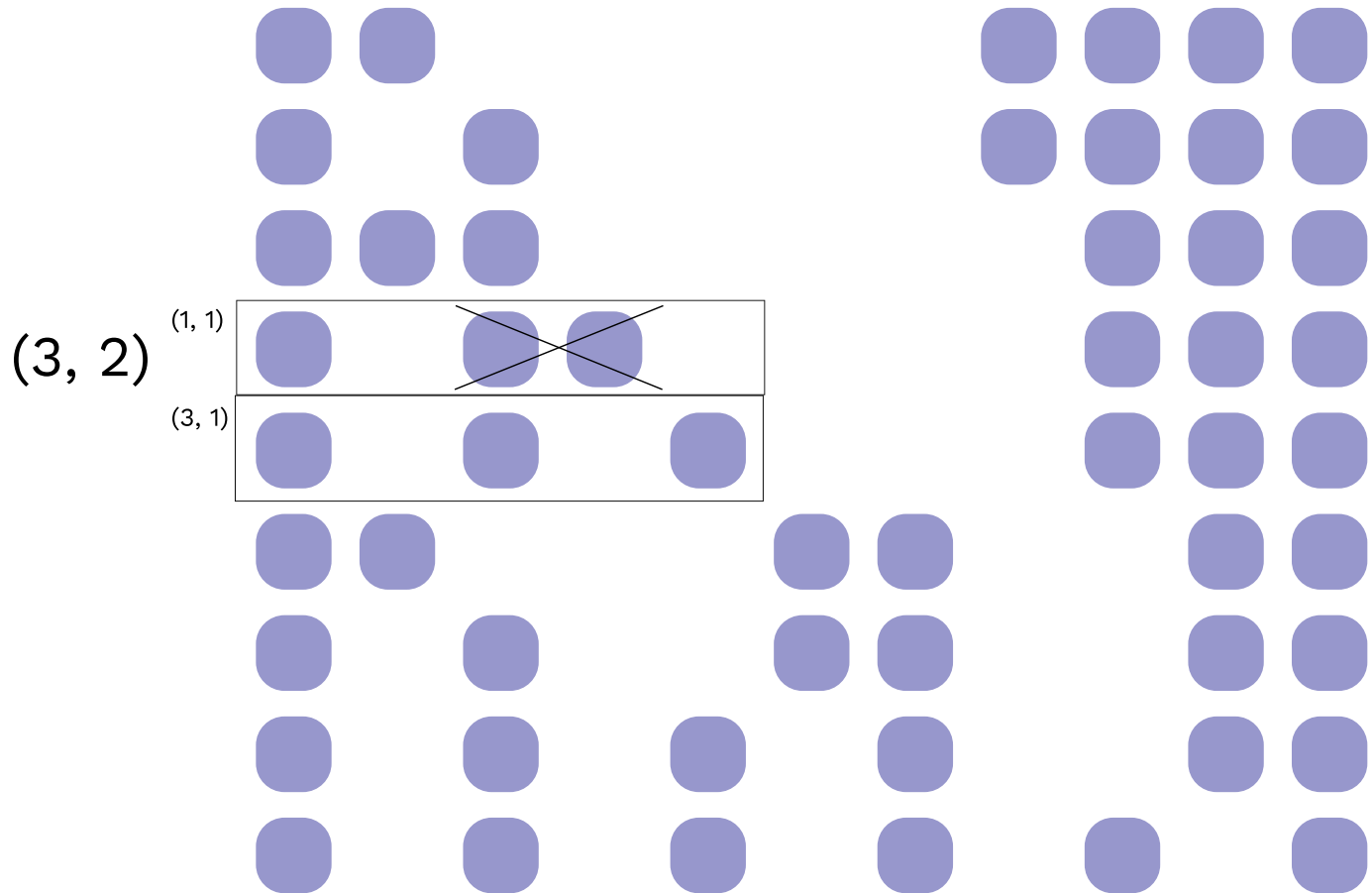
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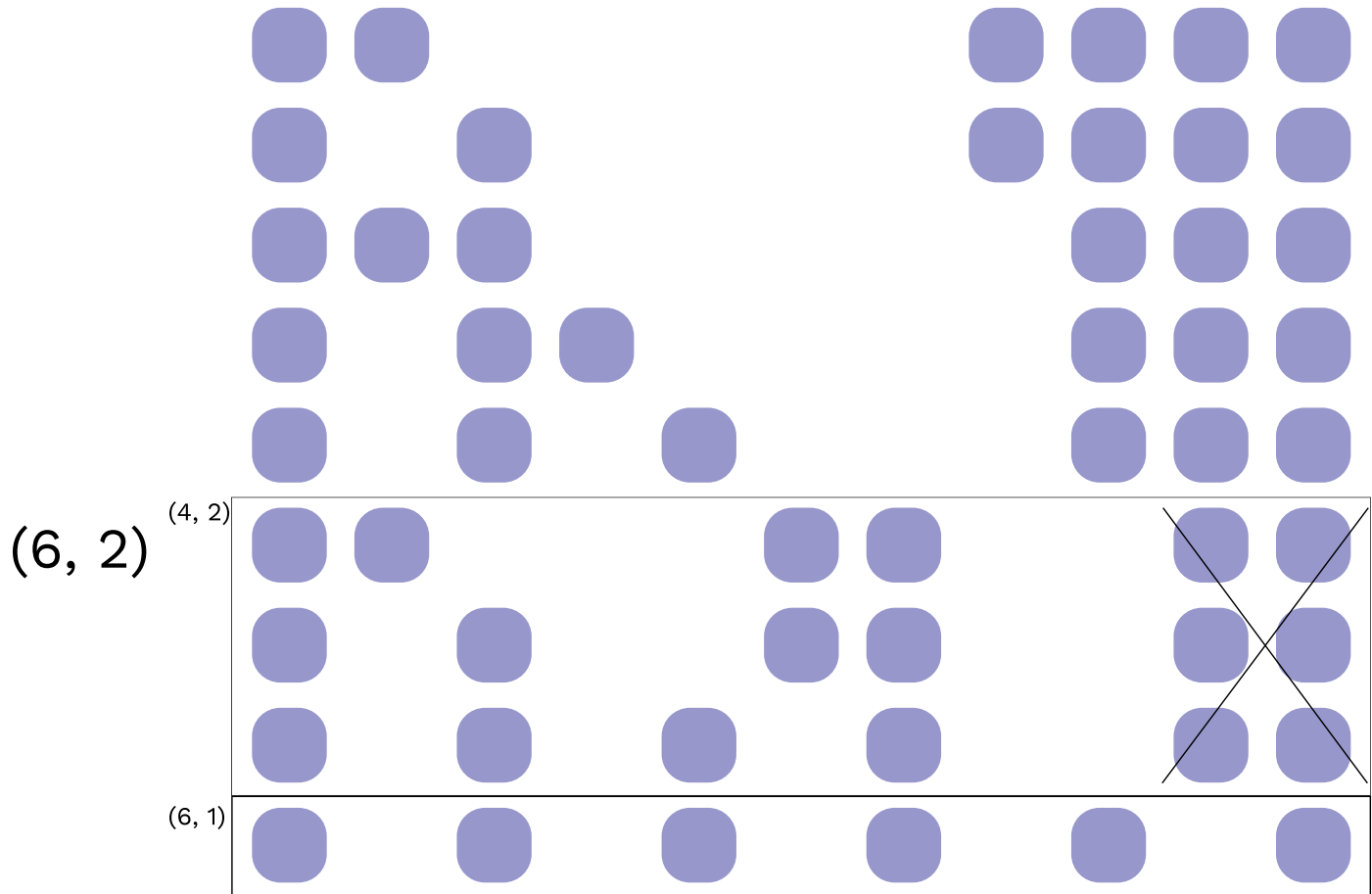


# Variant visualization

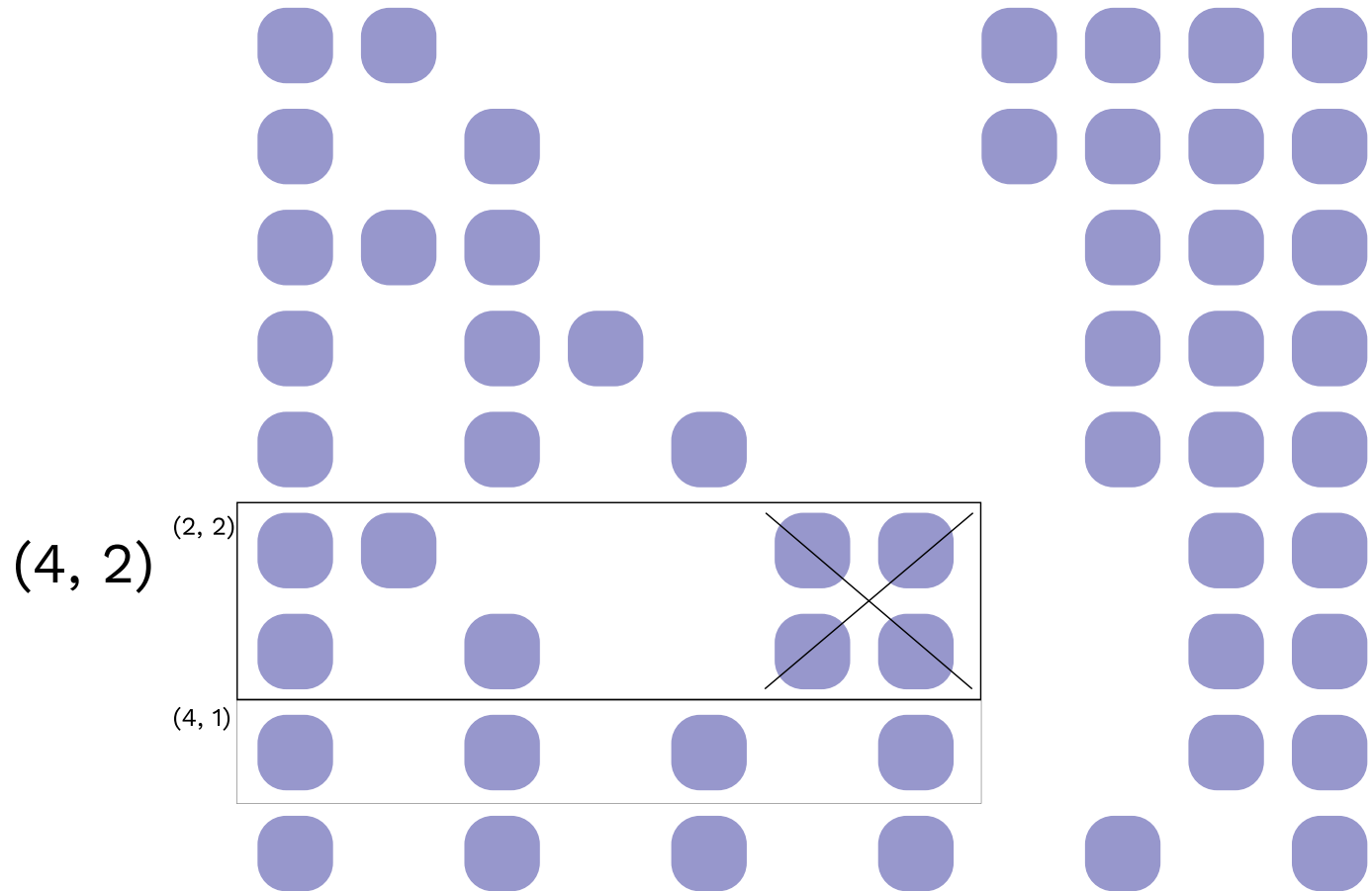




# Variant visualization



# Variant visualization



# Variant visualization

