

Recursion

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Outline

Recursion

Coin Problem

Hanoi Towers

Line to Louvre



By Edal Anton Lefterov, <https://commons.wikimedia.org/w/index.php?curid=11806863>

Computing Queue Length

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Computing Queue Length

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- She wants to know the number of people before her in the line
- She asks a person (call him Bob) standing before her in the line: Could you please tell me the number of people before you?
- Now, Bob faces **exactly the same problem**
- Bob somehow computes that the number of people before him is 239
- Now, Alice knows that the number of people before her is 240

Recursive Program

```
numberOfPeopleBefore(A):  
  if there is nobody before A:  
    return 0  
   $B \leftarrow$  person right before A  
  return numberOfPeopleBefore( $B$ ) + 1
```

Factorial Function

Definition

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Recursive definition

$$n! = \begin{cases} 1 & \text{if } n = 1 \\ n \times (n-1)! & \text{if } n > 1 \end{cases}$$

Iterative Program

```
def factorial(n):  
    assert(n > 0)  
    result = 1  
    for i in range(1, n + 1):  
        result *= i  
    return result
```

Recursive Program

```
def factorial(n):  
    assert(n > 0)  
    if n == 1:  
        return 1  
    else:  
        return n * factorial(n - 1)
```

Termination

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- This is usually achieved by decreasing some parameter until it reaches a **base case**
 - Line length: the line of the length decreases by 1 with each recursive call, until it becomes 1
 - Factorial: n decreases to 1

Example of Infinite Recursion

```
def infinite(n):  
    if n == 1:  
        return 0  
    return n * infinite(n + 1)
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- In theory, will never stop: the parameter increases to infinity
- In practice, will cause an error message like `stack overflow` or `maximum recursion depth exceeded`

More Examples of Infinite Recursion

- No base case:

```
def factorial(n):  
    return n * factorial(n - 1)
```

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```

- Parameter does not change:

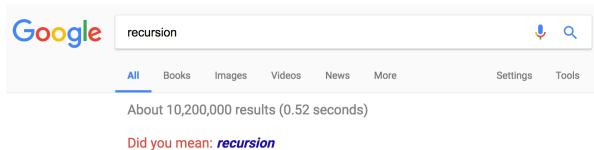
```
def infinite(n):  
    if n == 1:  
        return 0  
    return 1 + infinite(n)
```


More (Jokey) Examples

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- By Google:



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Prove that any monetary amount starting from 8 can be paid using coins of denominations 3 and 5.

- Looks plausibly: $8 = 3 + 5$, $9 = 3 + 3 + 3$, $10 = 5 + 5$, $11 = 3 + 3 + 5$
- But how can we be sure that it is **always** possible?

Speculating

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- Then, 14, 17, 20, etc
- Similarly, 9 gives 12, 15, 18, 21, etc
- While 10 gives 13, 16, 19, 22, etc

Recursive Program

```
def change(amount):  
    assert(amount >= 8)  
    if amount == 8:  
        return [3, 5]  
    if amount == 9:  
        return [3, 3, 3]  
    if amount == 10:  
        return [5, 5]  
  
    coins = change(amount - 3)  
    coins.append(3)  
    return coins
```

Outline

Recursion

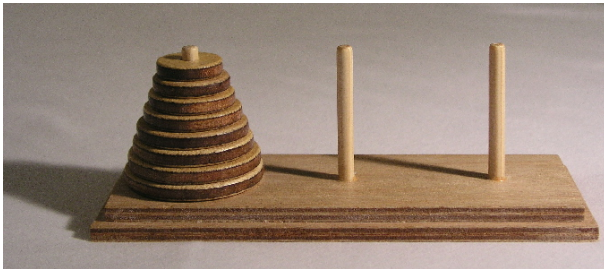
Coin Problem

Hanoi Towers

Hanoi Towers

Puzzle

There are three sticks with n discs sorted by size on one of the sticks. The goal is to move all n discs to another stick subject to two constraints: move one disc at a time and don't place a larger disc on a smaller one.



<https://commons.wikimedia.org/w/index.php?curid=228623>

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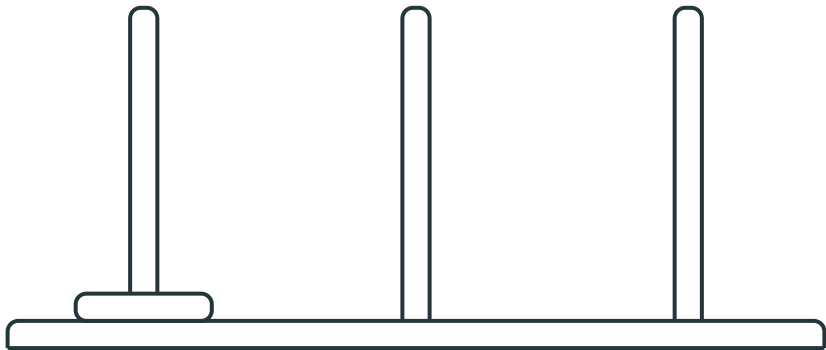
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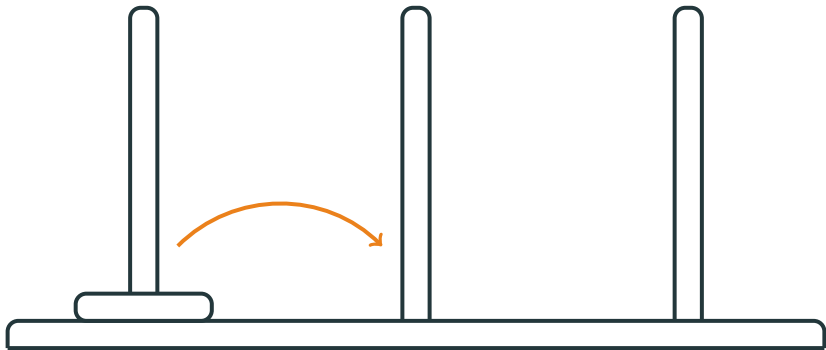
Is It Even Possible?

- For what n this is possible?
- For all!
- But how can we be sure?
- We will design a recursive program that will solve the puzzle for every n

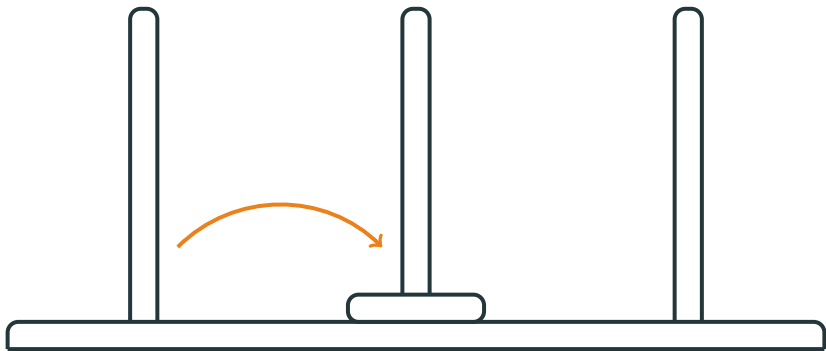
Simplest Possible Scenario



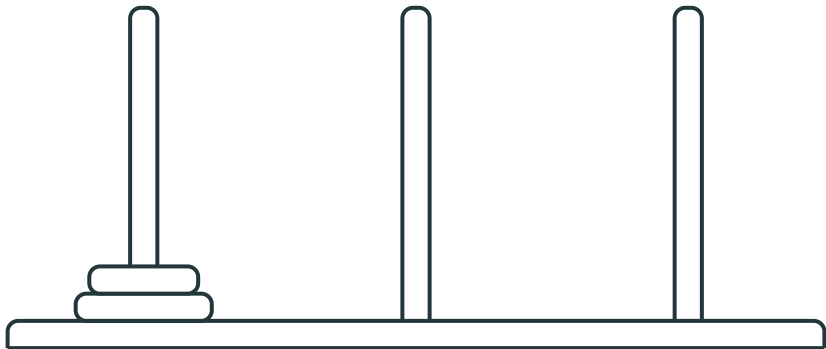
Simplest Possible Scenario



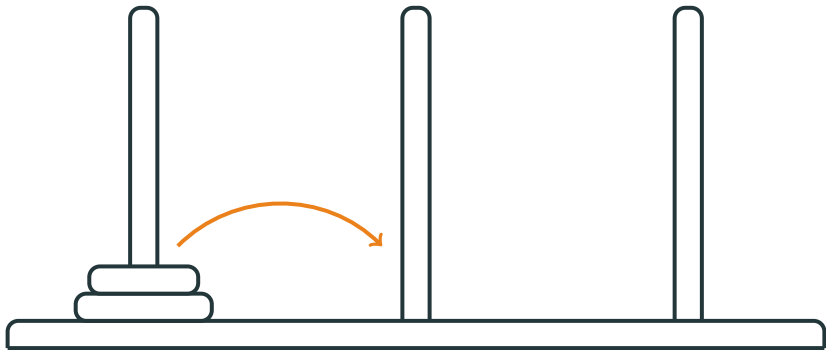
Simplest Possible Scenario



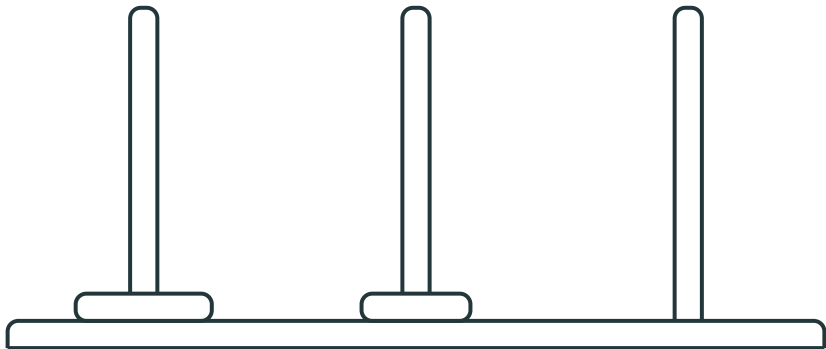
Two Discs



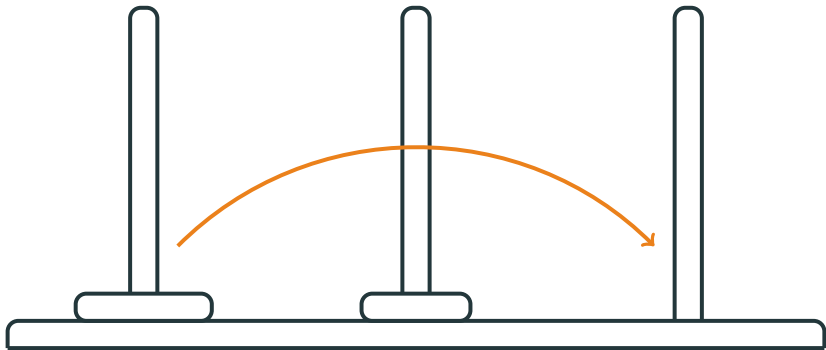
Two Discs



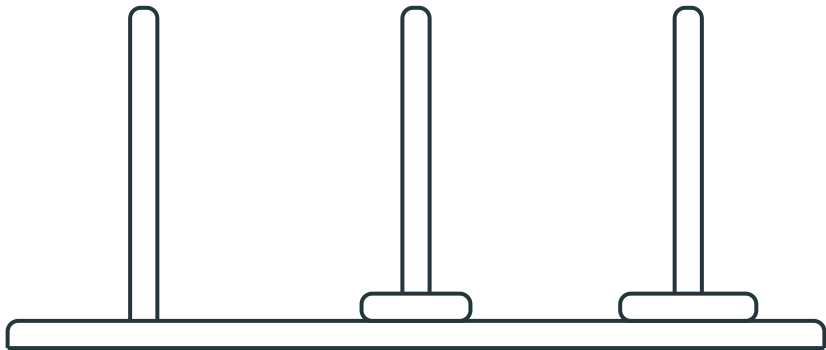
Two Discs



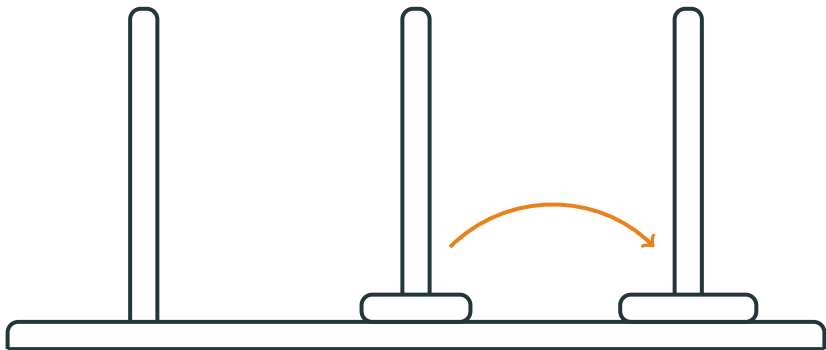
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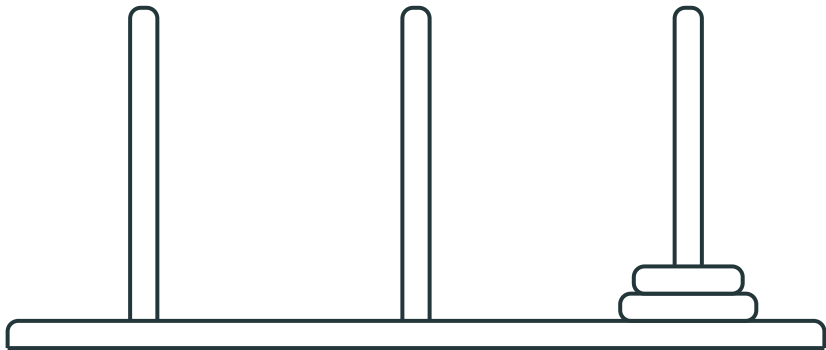
Two Discs



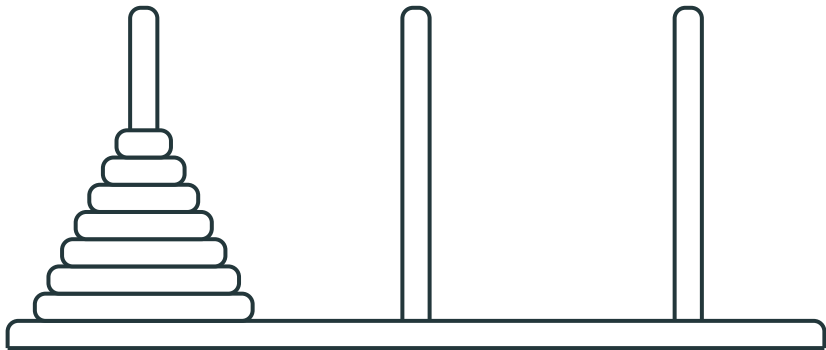
Two Discs



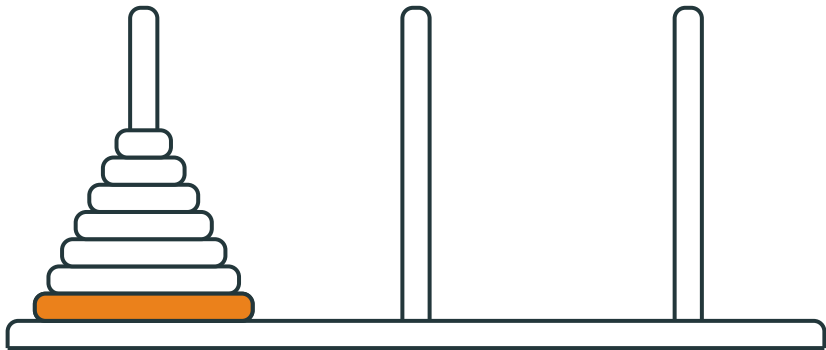
Two Discs



Speculating

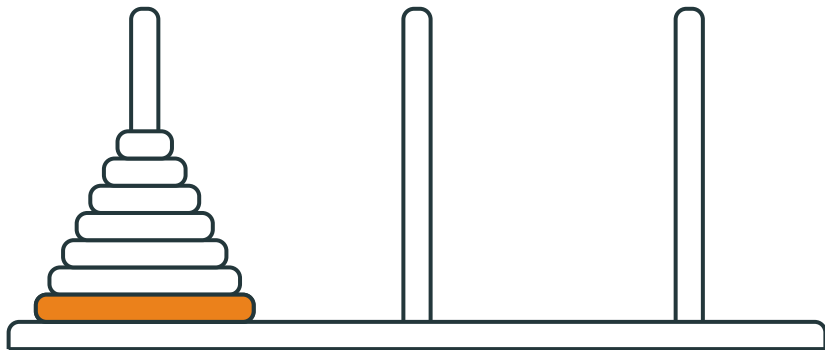


Speculating



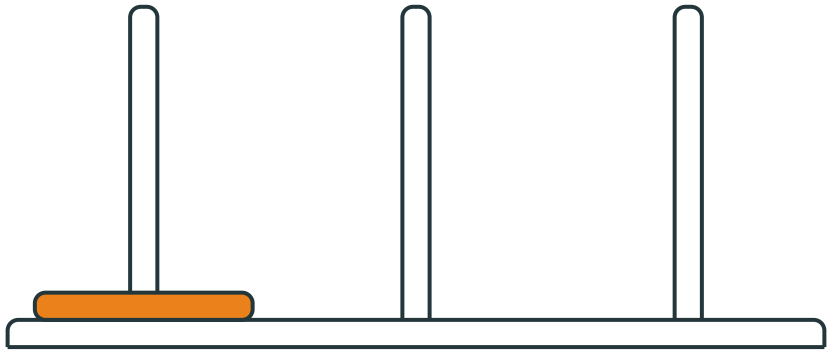
consider the largest disc

Speculating



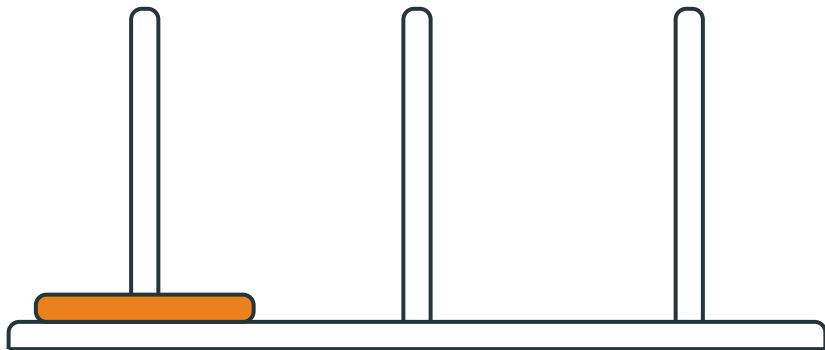
when can we move it?

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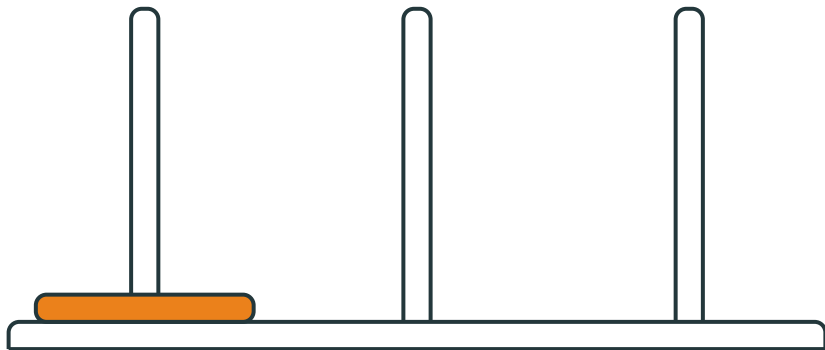
when there are no other discs on this stick!

Speculating



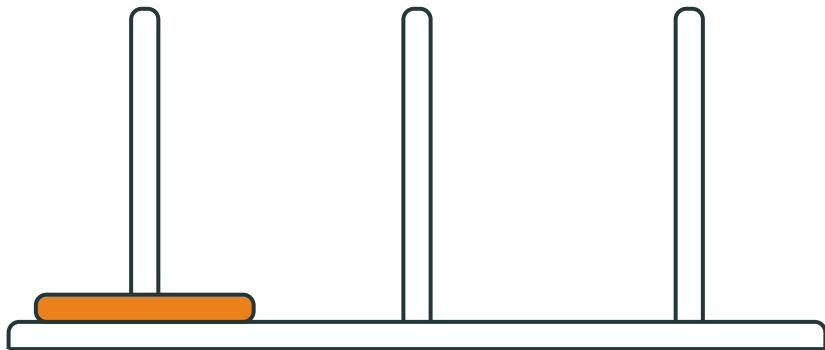
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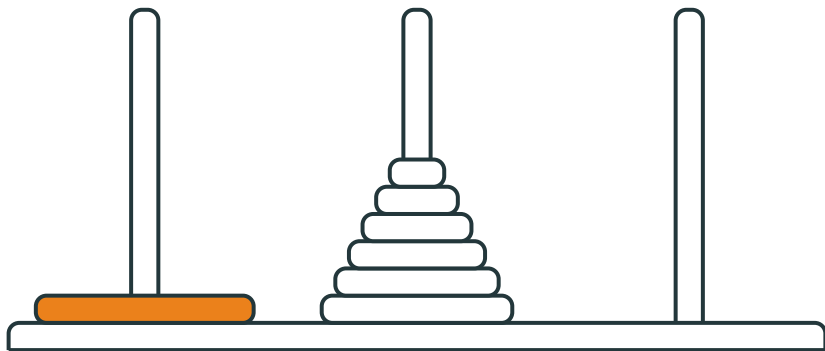
only to an empty stick!

Speculating



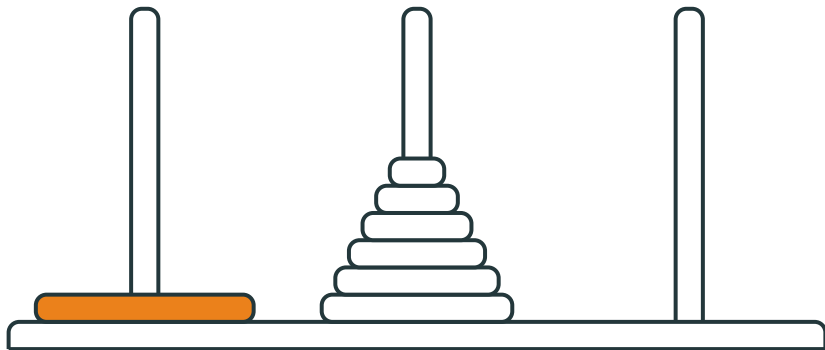
all other discs should be at another stick

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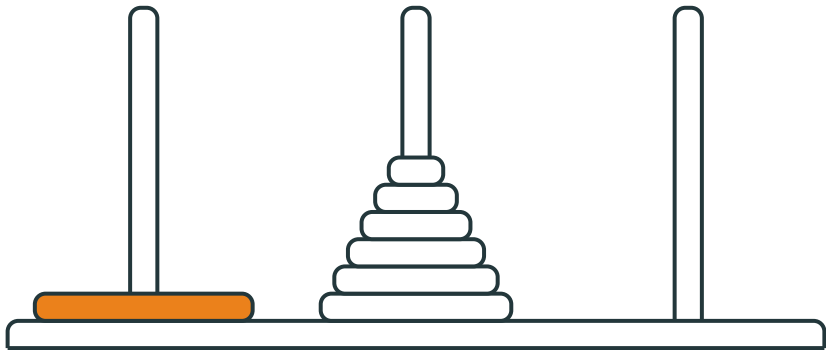
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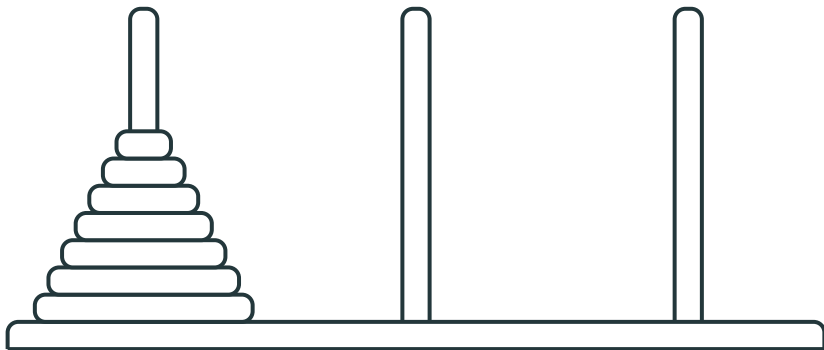
need to move $n - 1$ discs

Speculating

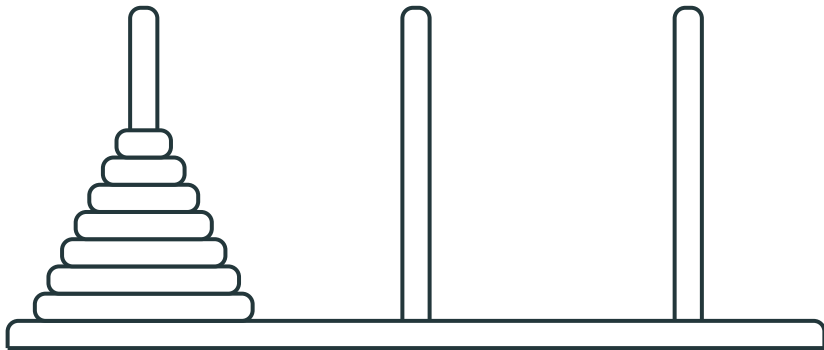


this is the same problem!

Recursive Solution

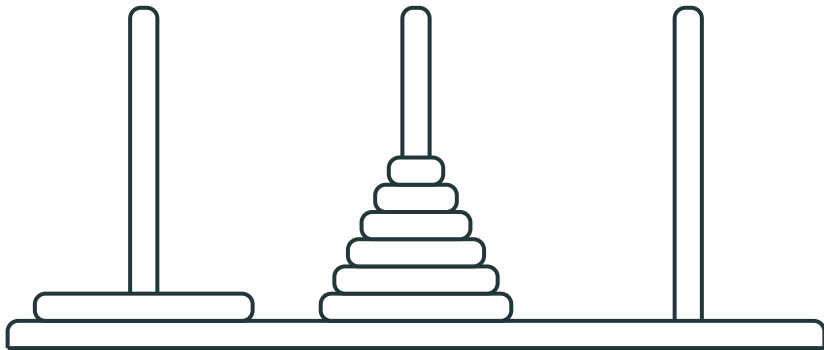


Recursive Solution



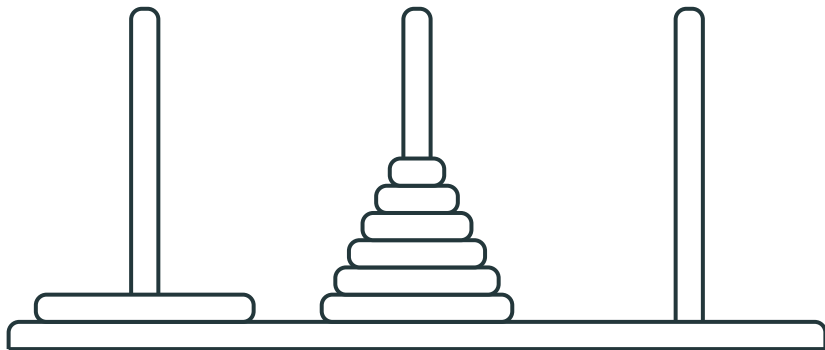
move $n - 1$ discs recursively

Recursive Solution



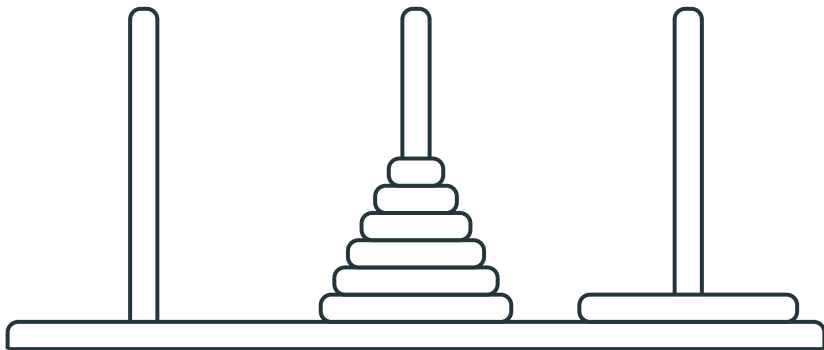
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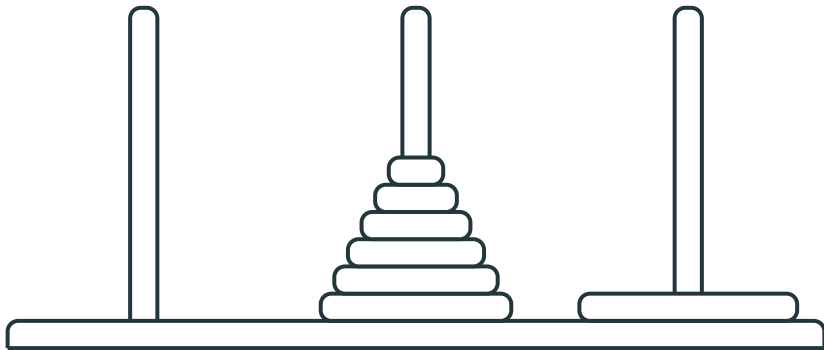
move the largest disk

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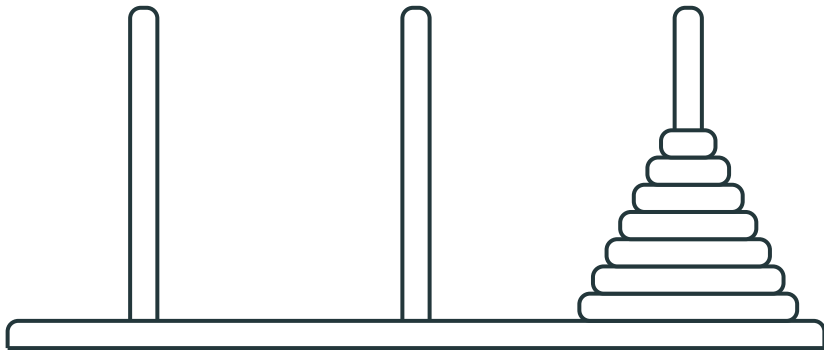
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Recursive Solution



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Summary

- We've constructed a solution for all n :
 - Base case: it is possible for $n = 1$
 - Hence, it is possible for $n = 2$
 - Hence, it is possible for $n = 3$
 - ...
- We'll later learn a related notion of induction