

Lecture 15

# **More Recursion**

# Announcements for This Lecture

---

## Prelim 1

---

- Prelim 1 back **today!**
  - Access in *Gradescope*
  - Solution posted in CMS
  - **Mean:** 71, **Median:** 74
  - Testing was *horrible*
- What are letter grades?
  - **A:** 80 (consultant level)
  - **B:** 60-79 (major level)
  - **C:** 30-55 (passing)

## Assignments and Labs

---

- Need to be working on A4
  - Instructions are posted
  - Just reading it takes a while
  - Slightly longer than A3
  - Problems are harder
- **Lab Today:** lots of practice!
  - First 4 functions mandatory
  - Many optional ones too
  - Exam questions on Prelim 2

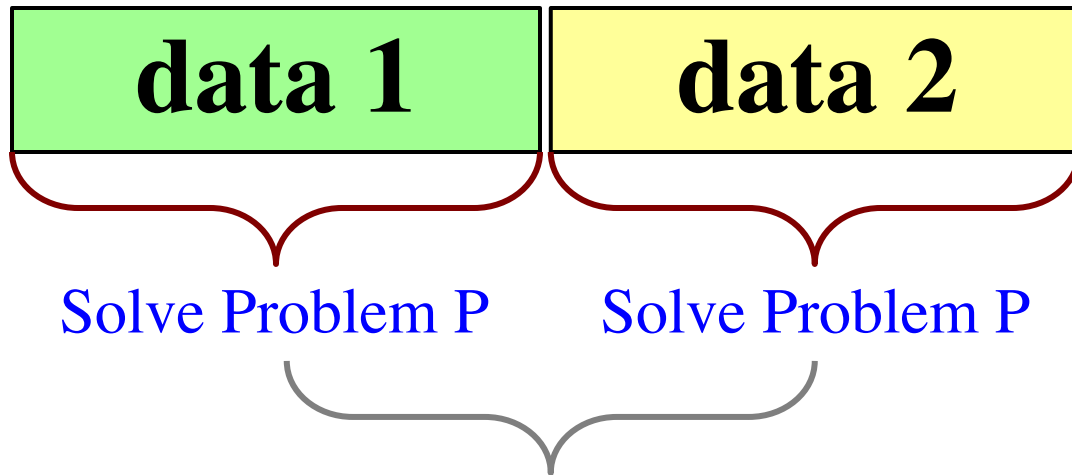
# Recall: Divide and Conquer

---

**Goal:** Solve problem P on a piece of data



**Idea:** Split data into two parts and solve problem



**Combine Answer!**

# Example: Reversing a String

```
def reverse(s):
```

```
    """Returns: reverse of s
```

```
    Precondition: s a string"""
```

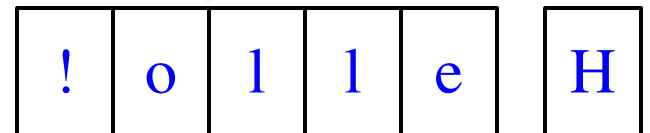
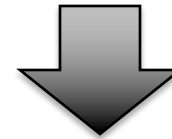
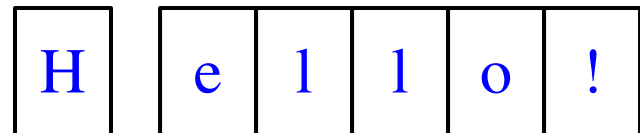
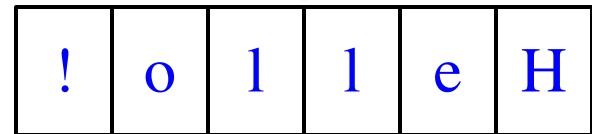
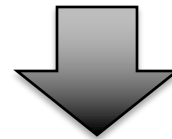
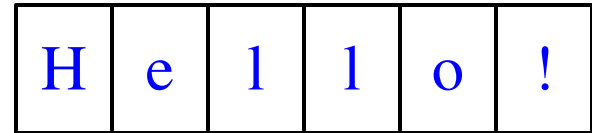
```
    # 1. Handle small data
```

```
    if len(s) <= 1:
```

```
        return s
```

```
    # 2. Break into two parts
```

```
    # 3. Combine the result
```



# Example: Reversing a String

```
def reverse(s):
```

```
    """Returns: reverse of s
```

```
    Precondition: s a string"""
```

```
    # 1. Handle small data
```

```
    if len(s) <= 1:
```

```
        return s
```

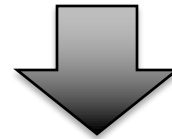
```
    # 2. Break into two parts
```

```
    left = s[0]
```

```
    right = reverse(s[1:])
```

```
    # 3. Combine the result
```

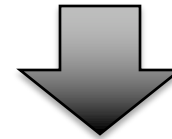
|   |   |   |   |   |   |
|---|---|---|---|---|---|
| H | e | l | l | o | ! |
|---|---|---|---|---|---|



|   |   |   |   |   |   |
|---|---|---|---|---|---|
| ! | o | l | l | e | H |
|---|---|---|---|---|---|



|   |   |   |   |   |   |
|---|---|---|---|---|---|
| H | e | l | l | o | ! |
|---|---|---|---|---|---|



|   |   |   |   |   |   |
|---|---|---|---|---|---|
| ! | o | l | l | e | H |
|---|---|---|---|---|---|

# Example: Reversing a String

```
def reverse(s):
```

```
    """Returns: reverse of s
```

```
    Precondition: s a string"""
```

```
    # 1. Handle small data
```

```
    if len(s) <= 1:
```

```
        return s
```

```
    # 2. Break into two parts
```

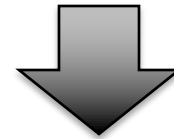
```
    left = s[0]
```

```
    right = reverse(s[1:])
```

```
    # 3. Combine the result
```

```
    return right+left
```

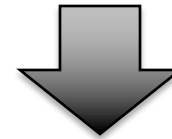
|   |   |   |   |   |   |
|---|---|---|---|---|---|
| H | e | l | l | o | ! |
|---|---|---|---|---|---|



|   |   |   |   |   |   |
|---|---|---|---|---|---|
| ! | o | l | l | e | H |
|---|---|---|---|---|---|



|   |   |   |   |   |   |
|---|---|---|---|---|---|
| H | e | l | l | o | ! |
|---|---|---|---|---|---|



|   |   |   |   |   |   |
|---|---|---|---|---|---|
| ! | o | l | l | e | H |
|---|---|---|---|---|---|

# Example: Reversing a String

---

```
def reverse(s):
```

```
    """Returns: reverse of s
```

```
    Precondition: s a string"""
```

```
    # 1. Handle small data
```

```
    if len(s) <= 1:
```

```
        return s
```

```
    # 2. Break into two parts
```

```
    left = s[0]
```

```
    right = reverse(s[1:])
```

```
    # 3. Combine the result
```

```
    return right+left
```

Base Case

Recursive  
Case

# Example: Reversing a String

```
def reverse(s):  
    """Returns: reverse of s  
    Precondition: s a string"""  
    # 1. Handle small data  
    if len(s) <= 1:  
        return s  
    # 2. Break  
    left = s[0]  
    right = reverse(s[1:])  
    # 3. Combine the result  
    return right+left
```

Remove  
recursive call

Base Case

Recursive  
Case



# How to Break Up a Recursive Function?

---

```
def commafy(s):
```

```
    """Returns: string with commas every 3 digits
```

```
    e.g. commafy('5341267') = '5,341,267'
```

```
    Precondition: s represents a non-negative int"""
```

## Approach 1

5

341267

# How to Break Up a Recursive Function?

---

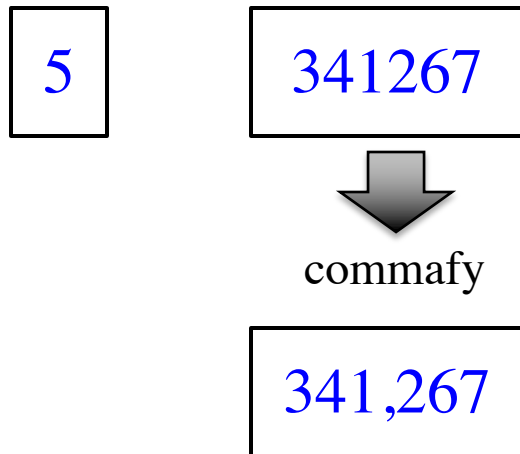
```
def commafy(s):
```

```
    """Returns: string with commas every 3 digits
```

```
    e.g. commafy('5341267') = '5,341,267'
```

```
    Precondition: s represents a non-negative int"""
```

## Approach 1



# How to Break Up a Recursive Function?

---

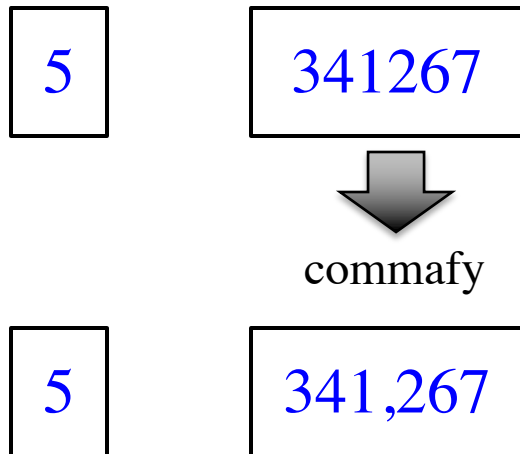
```
def commafy(s):
```

```
    """Returns: string with commas every 3 digits
```

```
    e.g. commafy('5341267') = '5,341,267'
```

```
    Precondition: s represents a non-negative int"""
```

## Approach 1



# How to Break Up a Recursive Function?

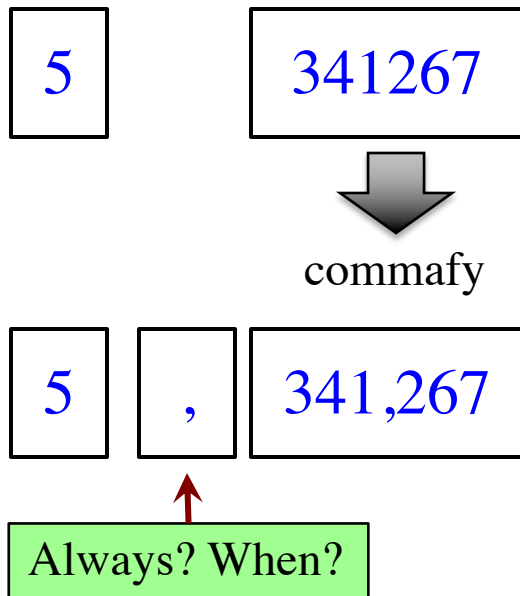
```
def commafy(s):
```

```
    """Returns: string with commas every 3 digits
```

```
    e.g. commafy('5341267') = '5,341,267'
```

```
    Precondition: s represents a non-negative int"""
```

## Approach 1



# How to Break Up a Recursive Function?

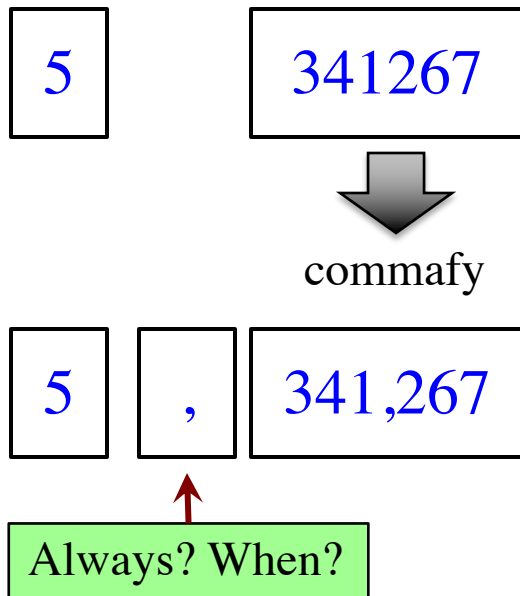
```
def commafy(s):
```

```
    """Returns: string with commas every 3 digits
```

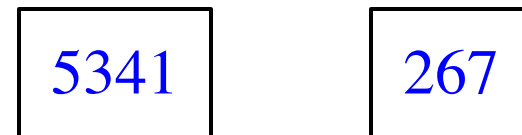
```
    e.g. commafy('5341267') = '5,341,267'
```

```
    Precondition: s represents a non-negative int"""
```

## Approach 1



## Approach 2



# How to Break Up a Recursive Function?

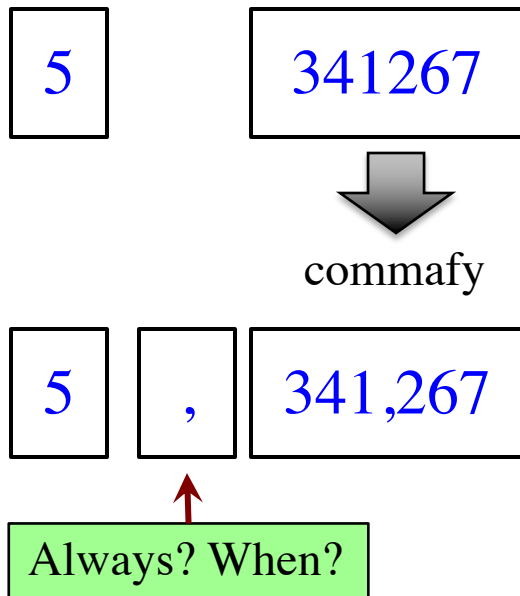
```
def commafy(s):
```

```
    """Returns: string with commas every 3 digits
```

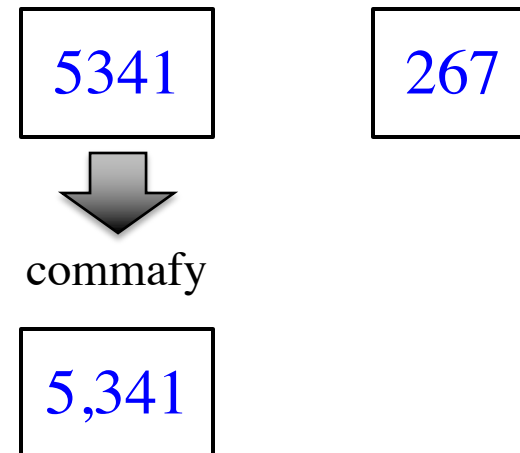
```
    e.g. commafy('5341267') = '5,341,267'
```

```
    Precondition: s represents a non-negative int"""
```

## Approach 1



## Approach 2



# How to Break Up a Recursive Function?

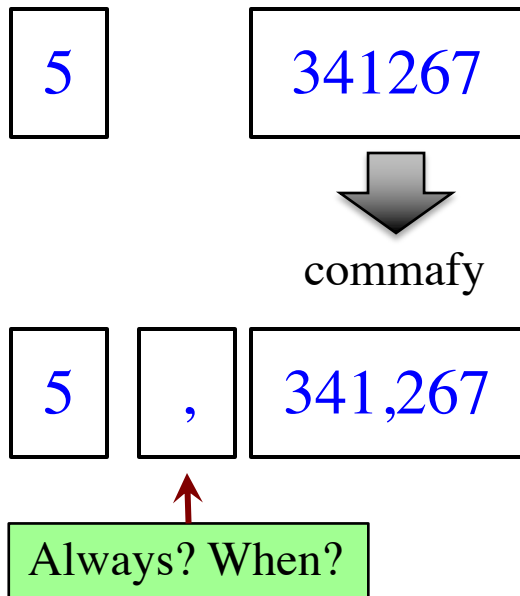
```
def commafy(s):
```

```
    """Returns: string with commas every 3 digits
```

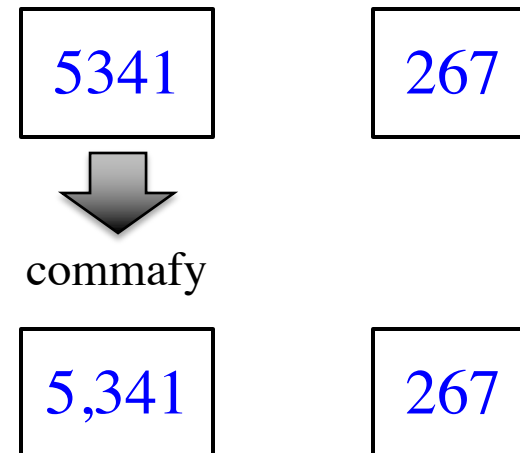
```
    e.g. commafy('5341267') = '5,341,267'
```

```
    Precondition: s represents a non-negative int"""
```

## Approach 1



## Approach 2



# How to Break Up a Recursive Function?

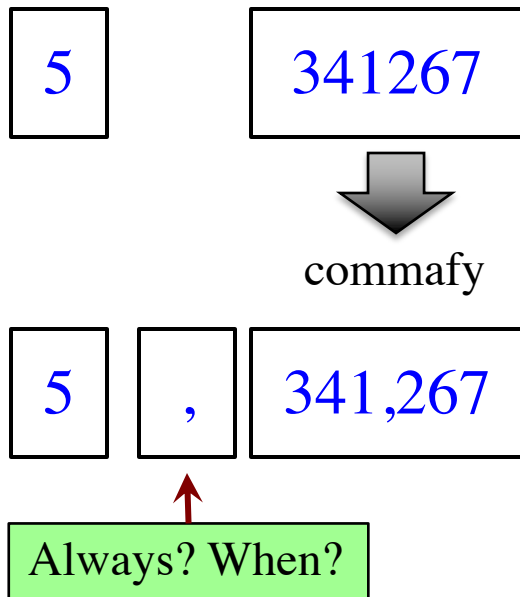
```
def commafy(s):
```

```
    """Returns: string with commas every 3 digits
```

```
    e.g. commafy('5341267') = '5,341,267'
```

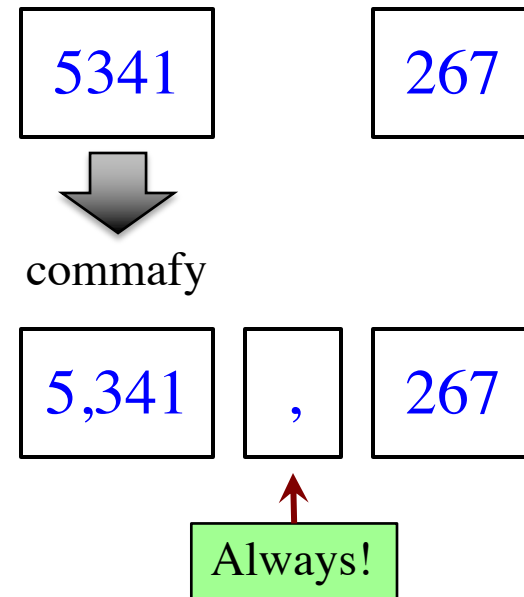
```
    Precondition: s represents a non-negative int"""
```

## Approach 1



10/16/18

## Approach 2



More Recursion

16



# How to Break Up a Recursive Function?

```
def commafy(s):
```

```
    """Returns: string with commas every 3 digits
```

```
    e.g. commafy('5341267') = '5,341,267'
```

```
    Precondition: s represents a non-negative int"""
```

```
    # 1. Handle small data.
```

```
    if len(s) <= 3:
```

```
        | return s
```

```
    # 2. Break into two parts
```

```
    left = commafy(s[:-3])
```

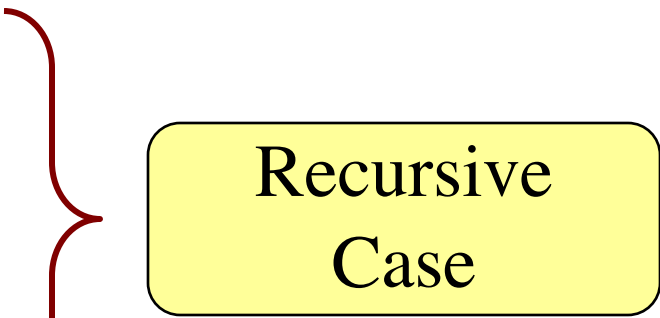
```
    right = s[-3:] # Small part on RIGHT
```

```
    # 3. Combine the result
```

```
    return left + ',' + right
```



Base Case



Recursive Case

# How to Break Up a Recursive Function?

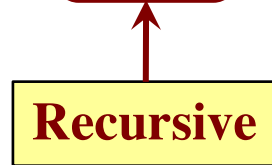
```
def exp(b, c)
```

```
    """Returns: bc
```

```
    Precondition: b a float, c ≥ 0 an int"""
```

## Approach 1

$$12^{256} = 12 \times (12^{255})$$



$$b^c = b \times (b^{c-1})$$

## Approach 2

$$12^{256} = (12^{128}) \times (12^{128})$$



$$b^c = (b \times b)^{c/2} \text{ if } c \text{ even}$$

# Raising a Number to an Exponent

---

## Approach 1

---

```
def exp(b, c)
    """Returns:  $b^c$ 
    Precond: b a float,  $c \geq 0$  an int"""
    #  $b^0$  is 1
    if c == 0:
        | return 1

    #  $b^c = b(b^{c-1})$ 
    left = b
    right = exp(b,c-1)

    return left*right
```

## Approach 2

---

```
def exp(b, c)
    """Returns:  $b^c$ 
    Precond: b a float,  $c \geq 0$  an int"""
    #  $b^0$  is 1
    if c == 0:
        | return 1

    #  $c > 0$ 
    if c % 2 == 0:
        | return exp(b*b,c//2)

    return b*exp(b*b,(c-1)//2)
```

# Raising a Number to an Exponent

## Approach 1

```
def exp(b, c)
    """Returns: bc
    Precond: b a float, c ≥ 0 an int"""
    # b0 is 1
    if c == 0:
        | return 1

    # bc = b(bc-1)
    left = b
    right = exp(b,c-1)

    return left*right
```

## Approach 2

```
def exp(b, c)
    """Returns: bc
    Precond: b a float, c ≥ 0 an int"""
    # b0 is 1
    if c == 0:
        | return 1

    # c > 0
    if c % 2 == 0:
        | return exp(b*b,c//2)
    else:
        | return b*exp(b*b,(c-1)//2)
```

# Raising a Number to an Exponent

```
def exp(b, c)
    """Returns: bc
    Precond: b a float, c ≥ 0 an int"""
    # b0 is 1
    if c == 0:
        return 1

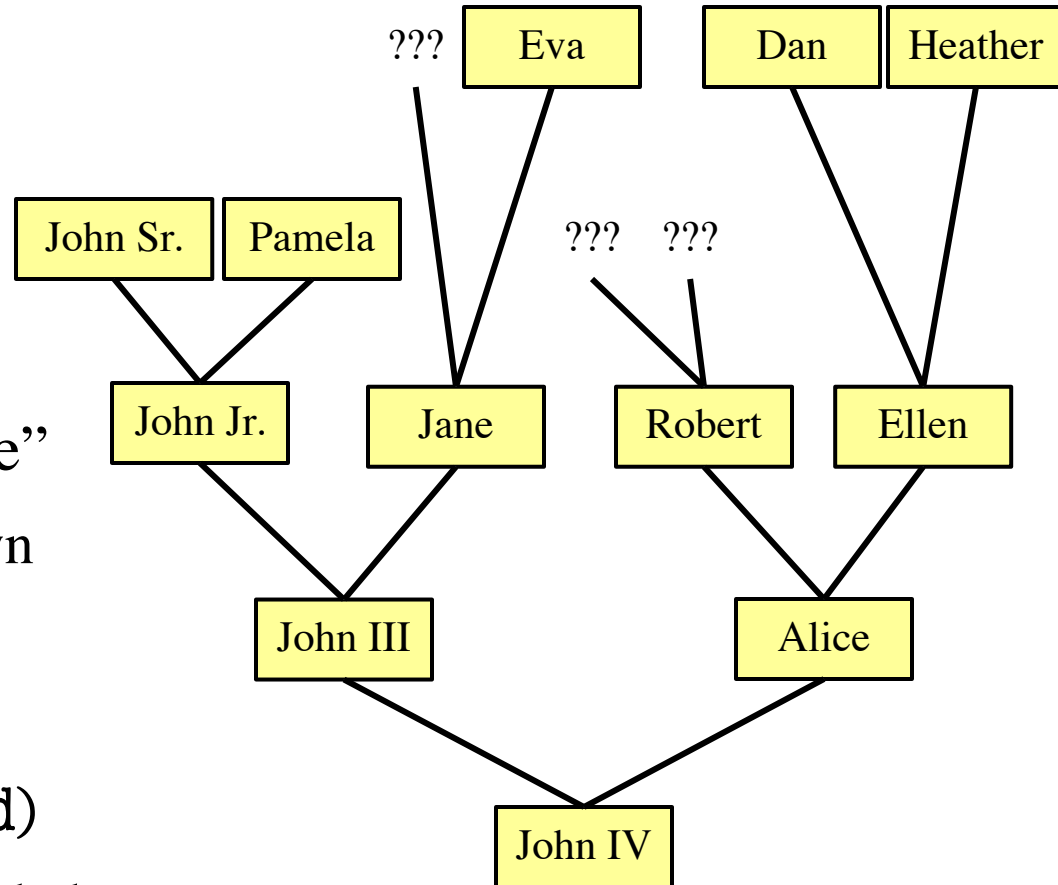
    # c > 0
    if c % 2 == 0:
        return exp(b*b,c//2)
    return b*exp(b*b,(c-1)//2)
```

| c              | # of calls |
|----------------|------------|
| 0              | 0          |
| 1              | 1          |
| 2              | 2          |
| 4              | 3          |
| 8              | 4          |
| 16             | 5          |
| 32             | 6          |
| 2 <sup>n</sup> | n + 1      |

32768 is 2<sup>15</sup>  
b<sup>32768</sup> needs only 215 calls!

# Recursion and Objects

- Class Person (person.py)
  - Objects have 3 attributes
  - **name**: String
  - **mom**: Person (or None)
  - **dad**: Person (or None)
- Represents the “family tree”
  - Goes as far back as known
  - Attributes mom and dad are None if not known
- **Constructor**: Person(n,m,d)
  - Or Person(n) if no mom, dad



# Recursion and Objects

```
def num_ancestors(p):
```

```
    """Returns: num of known ancestors
```

```
    Pre: p is a Person"""
```

```
    # 1. Handle small data.
```

```
    # No mom or dad (no ancestors)
```

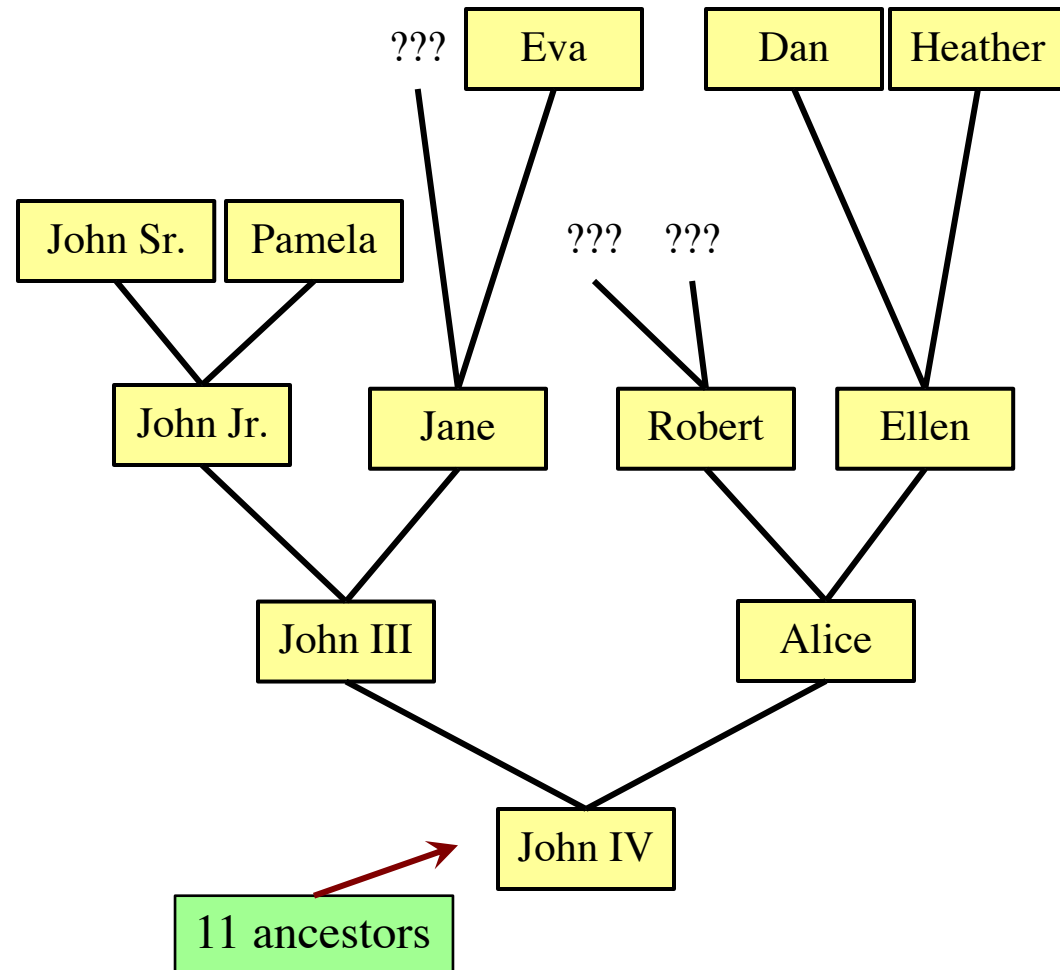
```
    # 2. Break into two parts
```

```
    # Has mom or dad
```

```
    # Count ancestors of each one
```

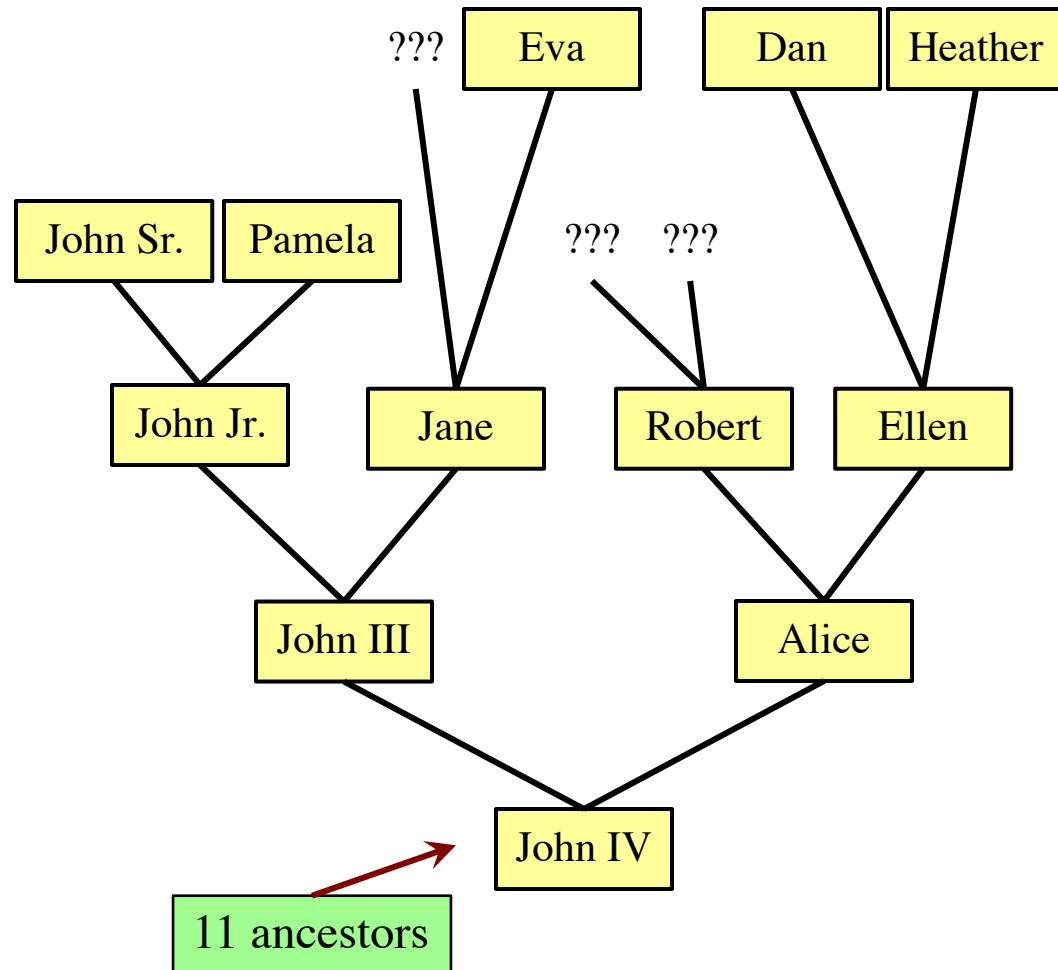
```
    # (plus mom, dad themselves)
```

```
    # 3. Combine the result
```



# Recursion and Objects

```
def num_ancestors(p):  
    """Returns: num of known ancestors  
    Pre: p is a Person"""  
    # 1. Handle small data.  
    if p.mom == None and p.dad == None:  
        | return 0  
  
    # 2. Break into two parts  
    moms = 0  
    if not p.mom == None:  
        | moms = 1+num_ancestors(p.mom)  
    dads = 0  
    if not p.dad== None:  
        | dads = 1+num_ancestors(p.dad)  
  
    # 3. Combine the result  
    return moms+dads
```





# Is All Recursion Divide and Conquer?

---

- Divide and conquer implies two halves “equal”
  - Performing the same check on each half
  - With some optimization for small halves
- Sometimes we are given a **recursive definition**
  - Math formula to compute that is recursive
  - String definition to check that is recursive
  - Picture to draw that is recursive
  - **Example:**  $n! = n (n-1)!$
- In that case, we are just implementing definition

# Example: Palindromes

---

- String with  $\geq 2$  characters is a palindrome if:
  - its first and last characters are equal, and
  - the rest of the characters form a palindrome

- **Example:**

have to be the same

AMANAPLANACANALPANAMA

has to be a palindrome

- **Function to Implement:**

```
def ispalindrome(s):
```

```
    """Returns: True if s is a palindrome"""
```

# Example: Palindromes

- String with  $\geq 2$  characters is a palindrome if:
  - its first and last characters are equal, and
  - the rest of the characters form a palindrome

```
def ispalindrome(s):
```

```
    """Returns: True if s is a palindrome"""
```

```
    if len(s) < 2:
```

```
        return True
```

**Base case**

```
    # Halves not the same; not divide and conquer
```

```
    ends = s[0] == s[-1]
```

```
    middle = ispalindrome(s[1:-1])
```

**Recursive case**

```
    return ends and middle
```

Recursive  
Definition

# Recursive Functions and Helpers

---

```
def ispalindrome2(s):  
    """Returns: True if s is a palindrome  
    Case of characters is ignored."""  
    if len(s) < 2:  
        | return True  
    # Halves not the same; not divide and conquer  
    ends = equals_ignore_case(s[0], s[-1])  
    middle = ispalindrome(s[1:-1])  
    return ends and middle
```

# Recursive Functions and Helpers

---

```
def ispalindrome2(s):
```

```
    """Returns: True if s is a palindrome
```

```
    Case of characters is ignored. """
```

```
    if len(s) < 2:
```

```
        | return True
```

```
    # Halves not the same; not divide and conquer
```

```
    ends = equals_ignore_case(s[0], s[-1])
```

```
    middle = ispalindrome(s[1:-1])
```

```
    return ends and middle
```

# Recursive Functions and Helpers

```
def ispalindrome2(s):
```

```
    """Returns: True if s is a palindrome
```

```
    Case of characters is ignored. """
```

```
    if len(s) < 2:
```

```
        | return True
```

```
    # Halves not the same; not divide and conquer
```

```
    ends = equals_ignore_case(s[0], s[-1])
```

```
    middle = ispalindrome(s[1:-1])
```

```
    return ends and middle
```

Use helper functions!

- Pull out anything not part of the recursion
- Keeps your code simple and easy to follow

```
def equals_ignore_case(a, b):
```

```
    """Returns: True if a and b are same ignoring case"""
```

```
    return a.upper() == b.upper()
```

# Example: More Palindromes

---

```
def ispalindrome3(s):
```

```
    """Returns: True if s is a palindrome
```

```
    Case of characters and non-letters ignored."""
```

```
    return ispalindrome2(depunct(s))
```

```
def depunct(s):
```

```
    """Returns: s with non-letters removed"""
```

```
    if s == ":
```

```
        | return s
```

```
    # Combine left and right
```

```
    if s[0] in string.letters:
```

```
        | return s[0]+depunct(s[1:])
```

```
    # Ignore left if it is not a letter
```

```
    return depunct(s[1:])
```

Use helper functions!

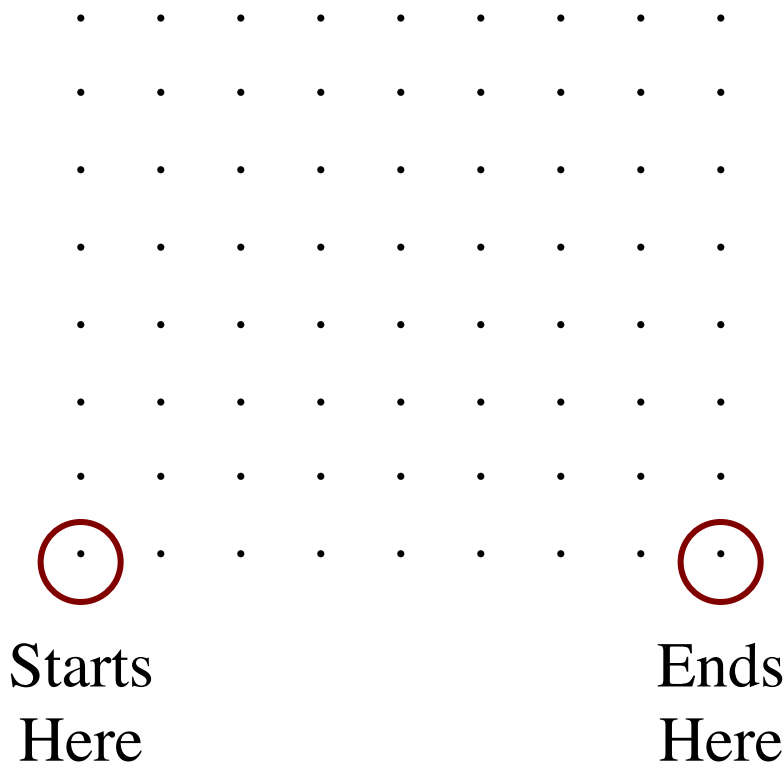
- Sometimes the helper is a recursive function
- Allows you break up problem in smaller parts

# Example: Space Filling Curves

---

## Challenge

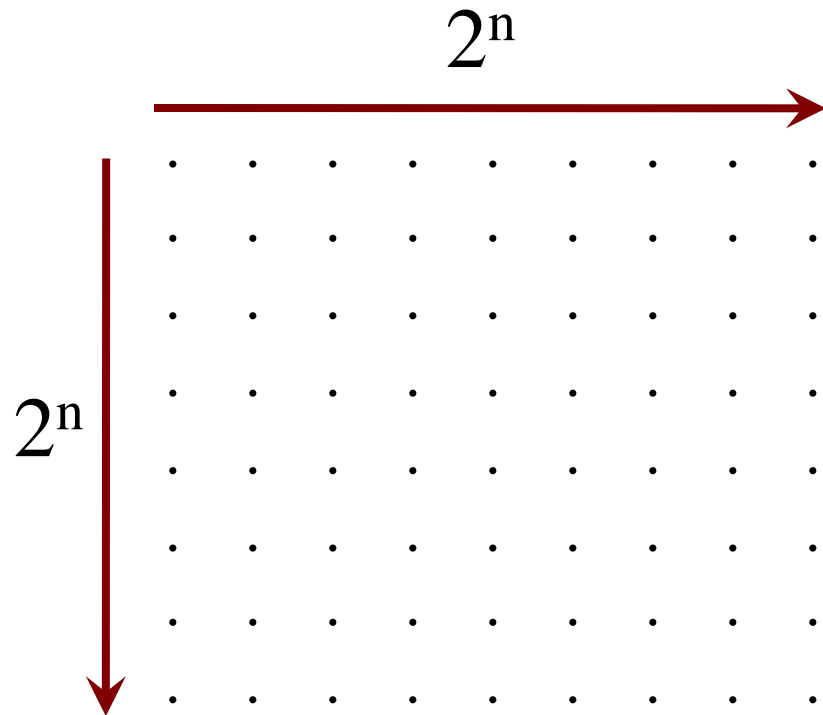
---



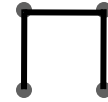
- Draw a curve that
  - Starts in the left corner
  - Ends in the right corner
  - Touches every grid point
  - Does not touch or cross itself anywhere
- Useful for analysis of 2-dimensional data



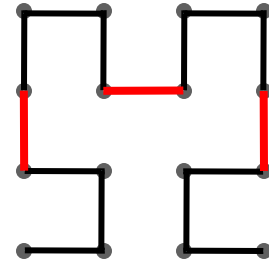
# Hilbert's Space Filling Curve



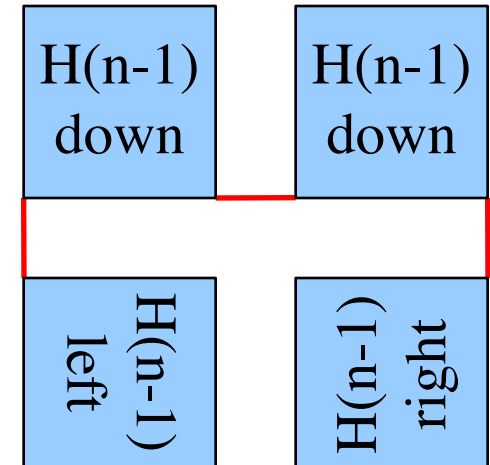
Hilbert(1):



Hilbert(2):



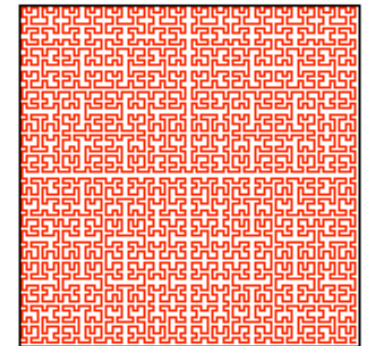
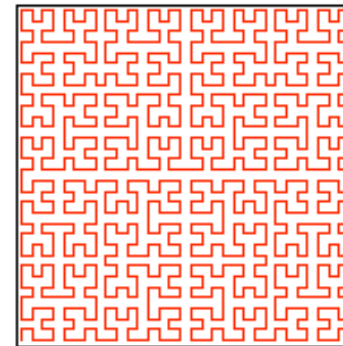
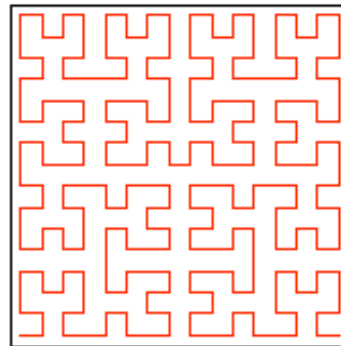
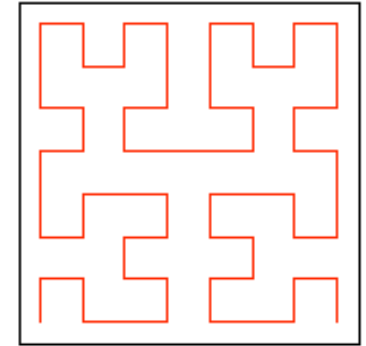
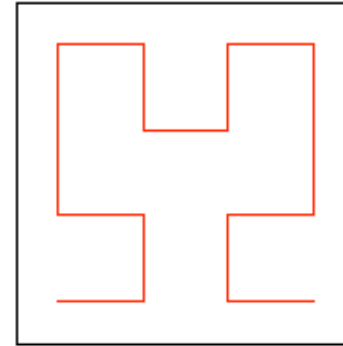
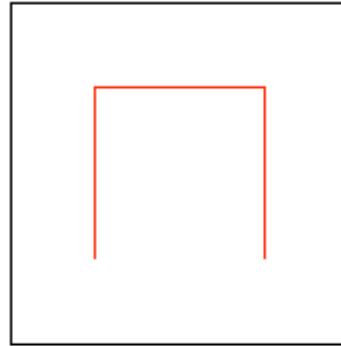
Hilbert(n):



# Hilbert's Space Filling Curve

## Basic Idea

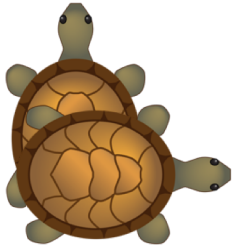
- Given a box
- Draw  $2^n \times 2^n$  grid in box
- Trace the curve
- As  $n$  goes to  $\infty$ , curve fills box



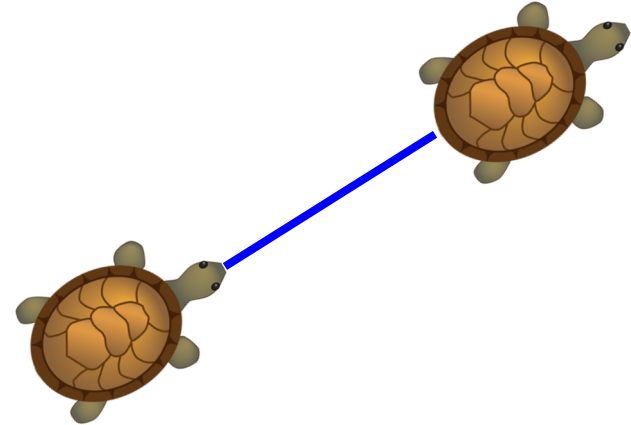
# “Turtle” Graphics: Assignment A4

---

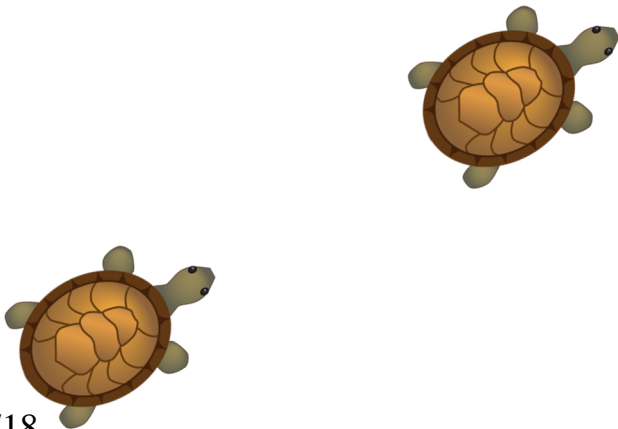
Turn



Draw Line



Move



Change Color

