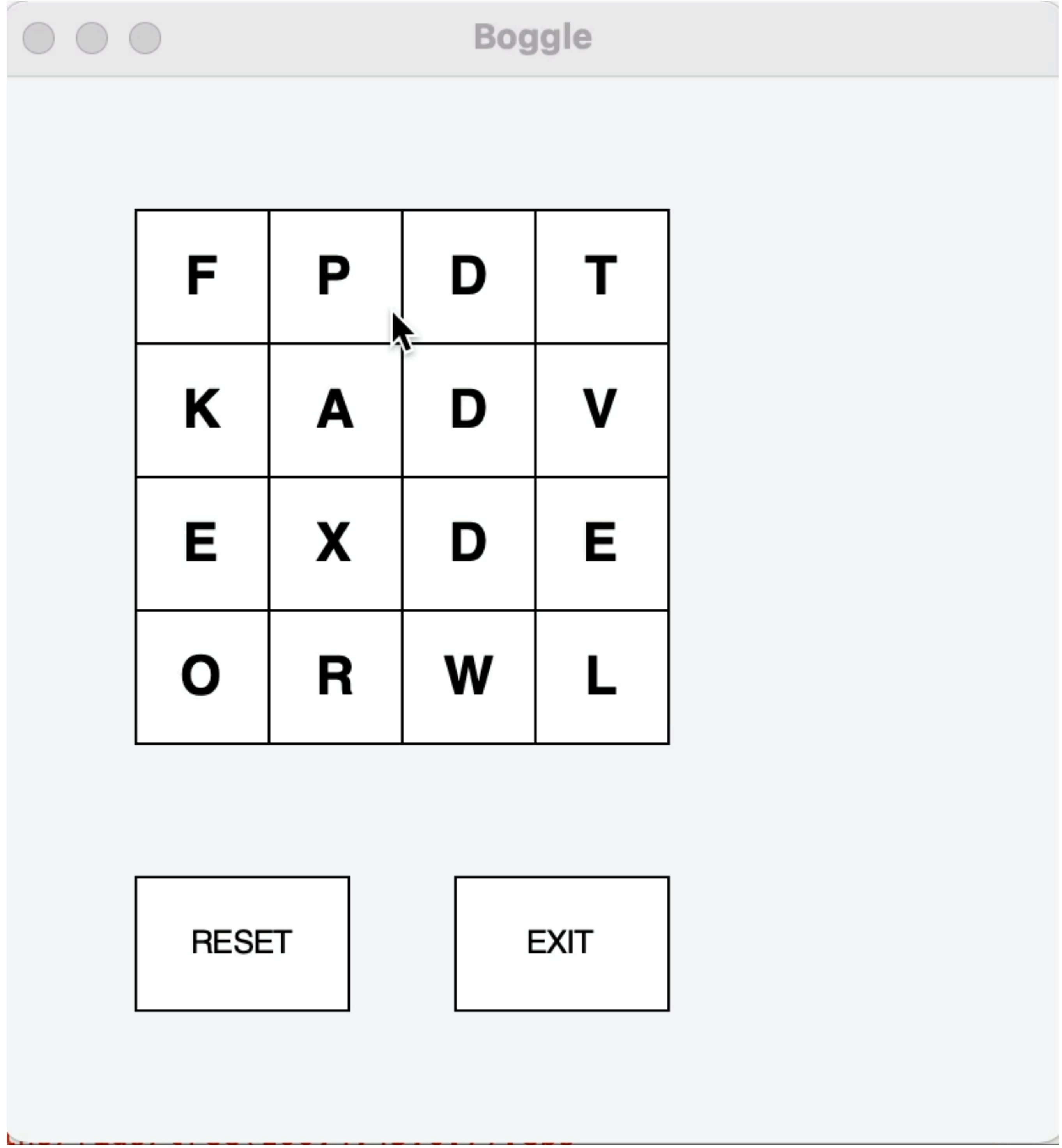
CS 134:
Special Methods & Linked Lists

Announcements & Logistics

- **Lab 7 and 8** feedback coming soon
- **HW 8** due tonight at 11pm (please don't forget the week!)
- **Lab 9 Boggle**
  - **Parts 1 & 2 (BoggleLetter & BoggleBoard)** due Wed/Thur
  - We will run our tests and return automated feedback, but we won't assign grades
  - **Part 3 (BoggleGame)** due May 4/5

Do You Have Any Questions?

Demo!



Last Time

- Finished implementation of Tic Tac Toe game
    - (Fun?) Application of object-oriented design and inheritance
- Designed to help with the Boggle lab
- Advice as you make your way through the lab:
    - Isolate functionality and test often (use `__str__` to print values as needed)
    - Check individual methods
    - **Discuss logic with partner before writing any code**
    - Worry about common cases first, but don't forget the "edge" cases

Today's Plan

- We will build a **recursive list class**
  - Our own implementation of list
- On the way, we will learn how to implement some **special (aka magic) methods** which override the behavior of existing operators/functions in Python
  - We have already seen some examples: `__str__`
  - Automatically called when we use the `str()` or `print()` function
- Today we will see:
  - `__len__` (called when you use `len` function)
  - `__contains__` (called when we use `in` operator)
  - `__getitem__` (called when we index into a sequence using `[]`)
  - Many more!

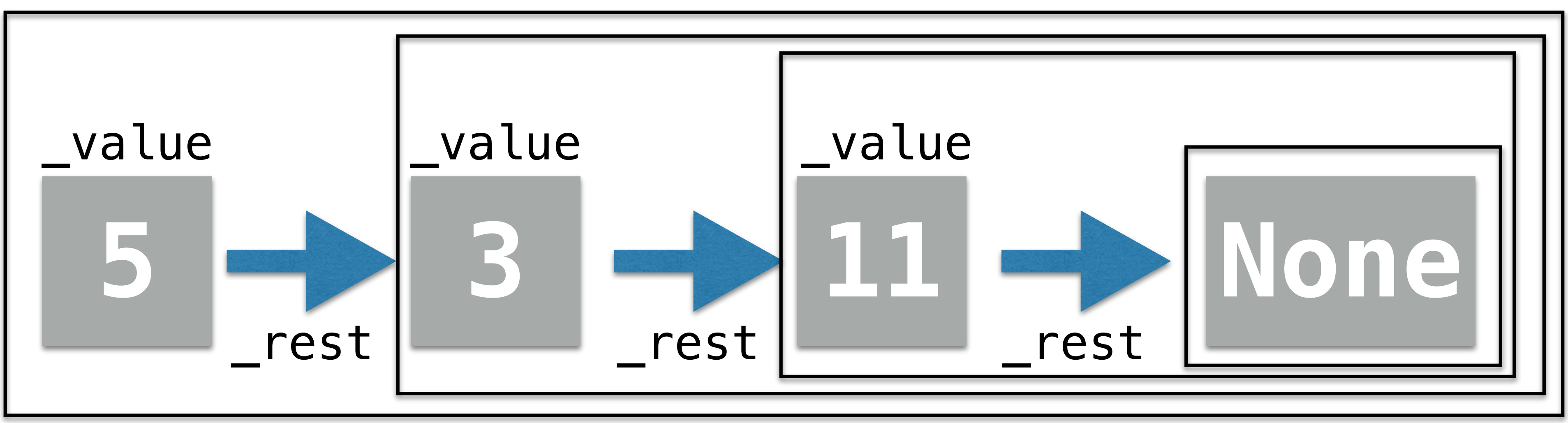
Python's Built-in list Class

- A class with methods (that someone else implemented)
- `pydoc3 list`

```
Help on class list in module builtins:

class list(object)
 |  list(iterable=(), /)
 |
 |  Built-in mutable sequence.
 |
 |  If no argument is given, the constructor creates a new empty list.
 |  The argument must be an iterable if specified.
 |
 |  Methods defined here:
 |
 |  __add__(self, value, /)
 |      Return self+value.
 |
 |  __contains__(self, key, /)
 |      Return key in self.
 |
 |  __delitem__(self, key, /)
 |      Delete self[key].
 |
 |  __eq__(self, value, /)
 |      Return self==value.
 |
 |  __ge__(self, value, /)
 |      Return self>=value.
 |
 |  __getattribute__(self, name, /)
 |      Return getattr(self, name).
 |
 |  __getitem__(...)
 |      x.__getitem__(y) <==> x[y]
 |
 |  __gt__(self, value, /)
:
```

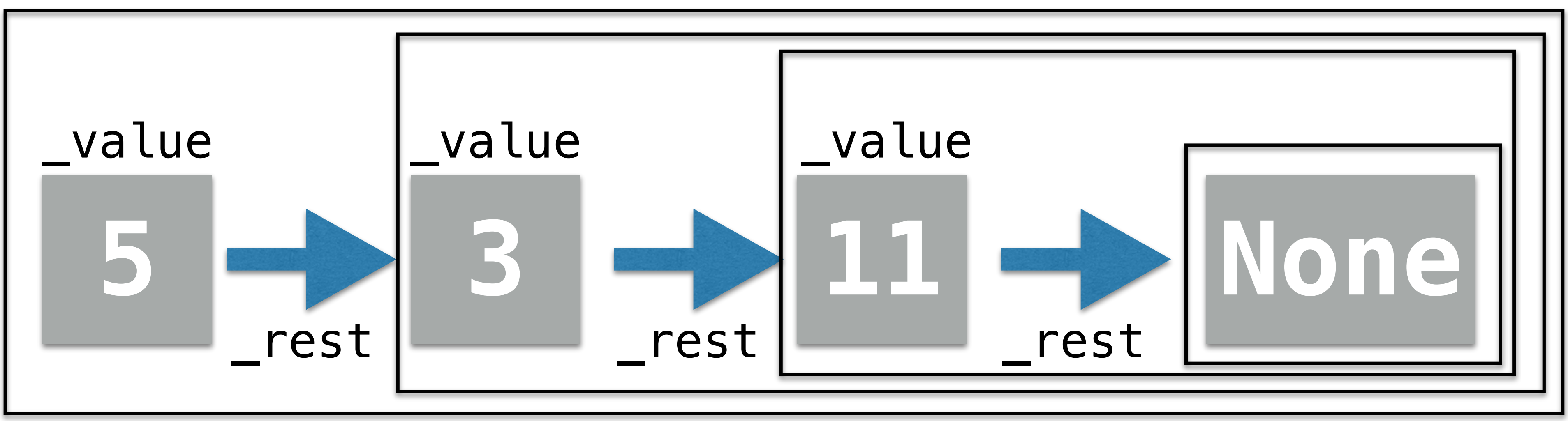
What exactly is a list?

- A container for a sequence of values
    - Recall that *sequence* implies an order
- Another way to think about this:
    - A chain of values, or a **linked list**
    - Each value has something after it: the rest of the sequence (recursion!)
- How do we know when we reach the end of our list?
    - Rest of the list is `None`



Our Own Class `LinkedList`

- Attributes:
  - `_value, _rest`
- **Recursive class**:
  - `_rest` points to another instance of the ***same class***
  - Any instance of a class that is created by using another instance of the class is a ***recursive class***



Initializing Our LinkedList

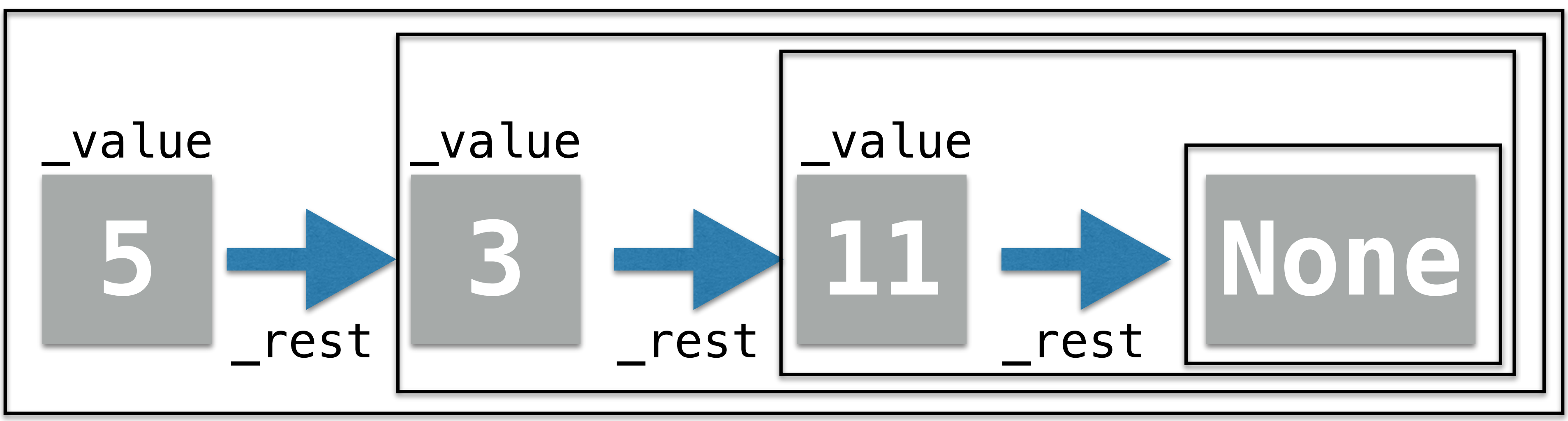
In [1]:
```python
class LinkedList:
    """Implements our own recursive list data structure"""
    __slots__ = ['_value', '_rest']

    def __init__(self, value=None, rest=None):
        self._value = value
        self._rest = rest
```

rest is another instance of our LinkedList class

In [2]:
```python
myList = LinkedList(5, LinkedList(3, LinkedList(11)))
```

In [3]:
```python
type(myList)
```

Out[3]:
```
__main__.LinkedList
```



Special Methods (Review)

- **`__init__(self, val)`**
  - When is it called?
    - When we ***create*** an instance (object) of the class
  - Can also call it as `obj.__init__(val)` (where `obj` is an instance of the class)
- **`__str__(self)`**
  - When is it called?
    - When we ***print*** an instance of the class using `print(obj)`
    - Also called whenever we convert an instance of the class to str, that is, when we call `str` function on it: `str(obj)`
    - Can also call it as `obj.__str__()`

Recursive Implementation: `__str__`

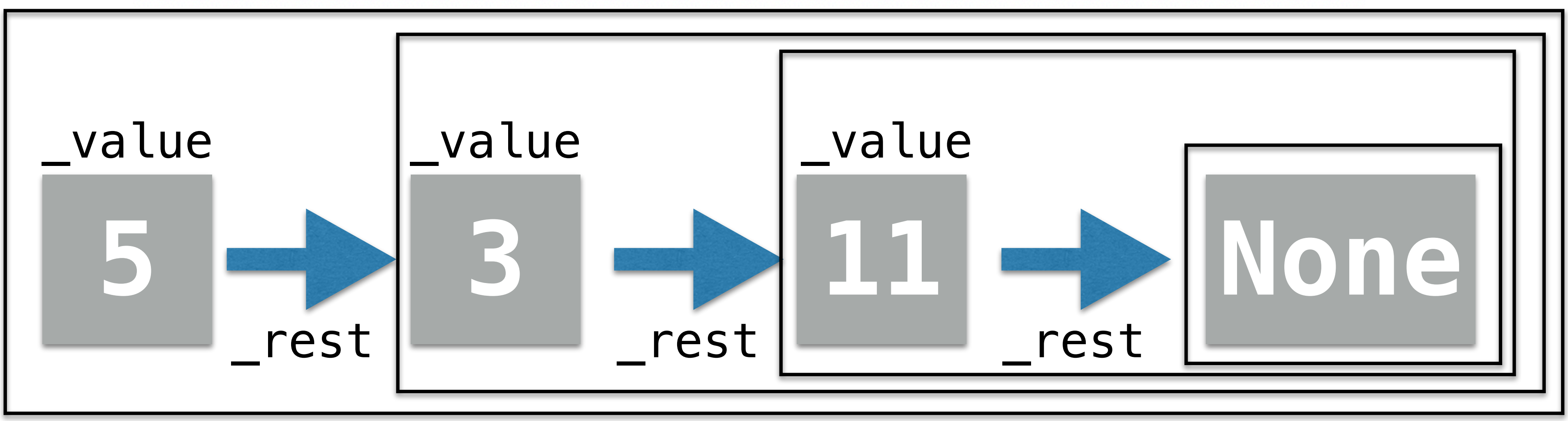
This is recursion! Since str calls itself. The base case is implicit when self._rest is **None**

```python
# str() function calls __str__() method
def __str__(self):
    if self._rest is None:
        return str(self._value)
    else:
        return str(self._value) + ", " + str(self._rest)
```

```python
myList = LinkedList(5, LinkedList(3, LinkedList(11)))
```

```python
print(myList) # testing __str__
```

```
5, 3, 11
```



Recursive Implementation: `__str__`

- What if we want to enclose the elements in the square brackets `[ . ]`
- It helps to have a helper method that does the same thing as `__str__()` on the previous slide, and then call that helper between concatenating the square brackets

```
def __strElements(self):
    if self._rest is None:
        return str(self._value)
    else:
        return str(self._value) + ", " + self._rest.__strElements()

def __str__(self):
    return "[" + self.__strElements() + "]"
```

```
myList = LinkedList(5, LinkedList(3, LinkedList(11)))
```

```
print(myList) # testing __str__
```

```
[5, 3, 11]
```

An Aside: `__repr__`

- In Labs 8 and 9, we included `__repr__` methods in your starter code
- You do not need to worry about them! (Just ignore these methods in Lab 9!)
- For your reference, here is a quick summary:
  - Like `__str__()`, `__repr__()` returns a string, useful for debugging
  - Unlike `__str__()`, the format of the string is very specific
  - `__repr__()` returns a string representation of an instance of a class that can be used to recreate the object

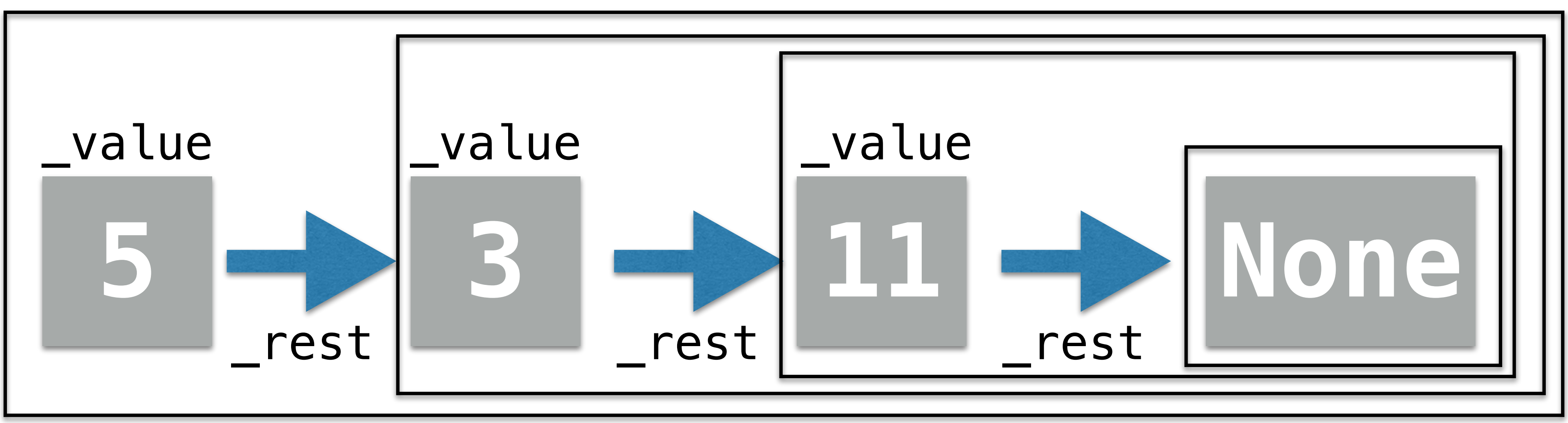
```python
# repr() function calls __repr__() method
# return value should be a string that is a valid Python
# expression that can be used to recreate the LinkedList
def __repr__(self):
    return "LinkedList({}, {})".format(self._value, repr(self._rest))
```

```
In [62]: myList = LinkedList(5, LinkedList(3, LinkedList(11)))

In [64]: myList  # testing __repr__

Out[64]: LinkedList(5, LinkedList(3, LinkedList(11, None)))
```

Notice we did not say print(myList) here

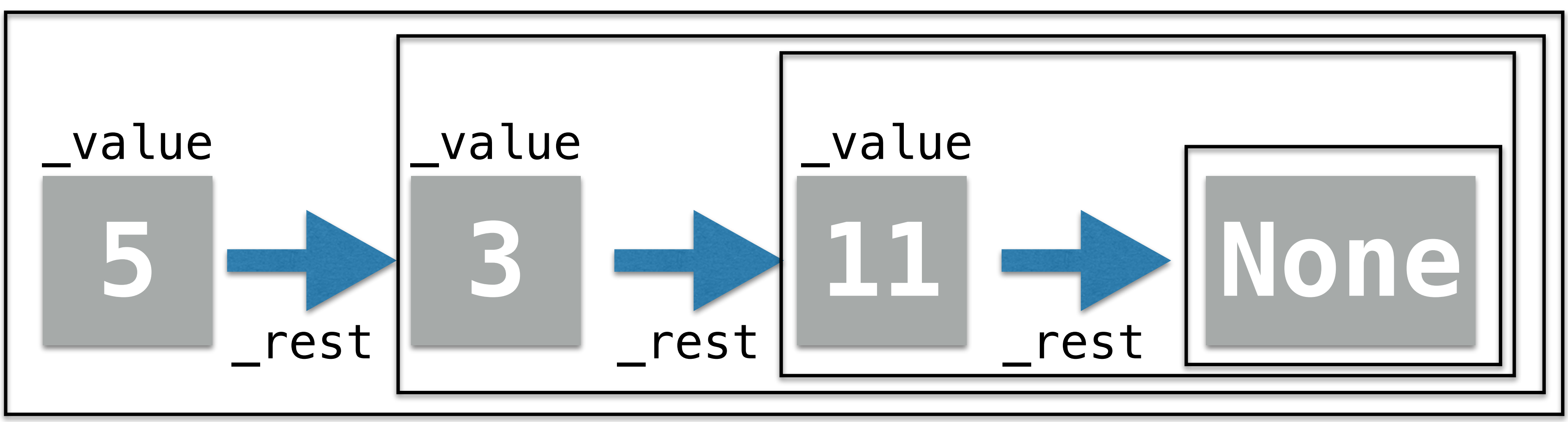
Special Method: `__len__`

- `__len__(self)`
  - Called when we use the built-in function `len()` in Python on an object `obj` of the class: `len(obj)`
  - We can call `len` function on any object whose class has the `__len__` special method implemented
- We want to implement this special method so it tells us the number of elements in our linked list, e.g. 3 elements in the list below



Implementing Recursively

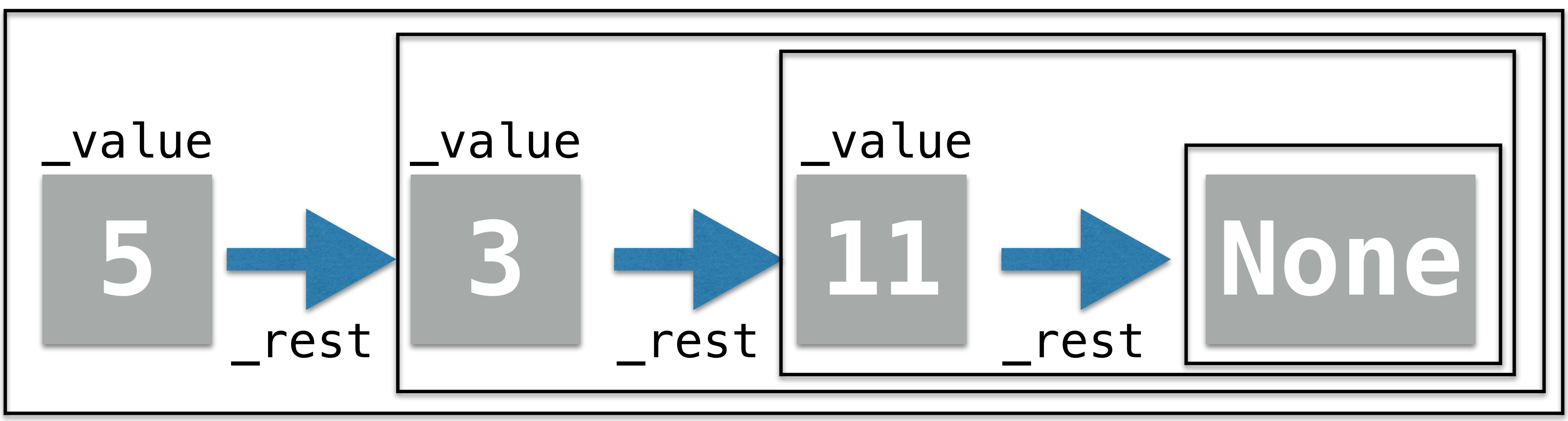
- As our **`LinkedList`** class is defined recursively, let's implement the **`__len__`** method recursively
    - Example of fruitful recursion that returns an int (num of elements)
- What is the base case?
- What about the recursive case?
    - Count self (so, +1), and then call **`len()`** on the rest of the list!



Recursive Implementation: `__len__`

```
# len() function calls __len__() method
def __len__(self):
    # base case: i'm the last item
    if self._rest is None:
        return 1
    else:
        # same as return 1 + self.rest.__len__()
        return 1 + len(self._rest)
```

Note: It is preferred to use `is` or `is not` operators (as opposed to `==` or `!=`) when comparing a user-defined object to a `None` value. This is because `__eq__` and `__ne__` are also special methods that can be made to behave differently for classes.



What About Other Special Methods?

- What other functionality does the built-in list have in Python that we can incorporate into our own class?
  - Can check if an item is in the list (`in` operator): `__contains__`
  - Concatenate two lists using `+ : __add__`
  - Index a list with `[ ] : __getitem__`
  - **Set** an item to another val, e.g. myList `[2] =` "hello" : `__setitem__`
  - Compare the values of two lists for equality using `==` : `__eq__`
  - **Reverse/sort** a list
  - **Append** an item to the list: `append method`
  - Many others!
- Let's try to add some of these features to our `LinkedList`

`in` Operator: `__contains__`

- **`__contains__(self, val)`**
  - When we say `if elem in seq` in Python:
    - Python calls the `__contains__` special method on `seq`
    - That is, `seq.__contains__(elem)`
- Thus if we want the `in` operator to work for the objects of our class, we can do so by implementing the `__contains__` special method
- Basic idea:
    - "Walk" along list checking values
    - If we find the value we're looking for, return True
    - If we make it to the end of the list without finding it, return False
    - We'll do this recursively!

in Operator: `__contains__`

- `__contains__(self, val)`
  - When we say `if elem in seq` in Python:
    - Python calls the `__contains__` special method on `seq`
    - That is, `seq.__contains__(elem)`
- Thus if we want the `in` operator to work for the objects of our class, we can do so by implementing the `__contains__` special method

```
# in operator calls __contains__() method
def __contains__(self, val):
    if self._value == val:
        return True
    elif self._rest is None:
        return False
    else:
        # same as calling self.__contains__(val)
        return val in self._rest
```

+ Operator: `__add__`

- **`__add__(self, other)`**
  - When using lists, we can concatenate two lists together into one list using the **+** operator (this always returns a new list)
  - To support the **+** operator in our `LinkedList` class, we need to implement `__add__` special method
  - Make the end of our first list point to the beginning of the other
  - Basic idea:
    - Walk along first list until we reach the end
    - Set _rest to be the beginning of second list
    - More recursion!

+ Operator: `__add__`

- **`__add__(self, other)`**
  - When using lists, we can concatenate two lists together into one list using the **+** operator (this always returns a new list)
  - To support the **+** operator in our `LinkedList` class, we need to implement `__add__` special method
  - Make the end of our first list point to the beginning of the other

```
# + operator calls __add__() method
# + operator returns a new instance of LinkedList
def __add__(self, other):
    # other is another instance of LinkedList
    # if we are the last item in the list
    if self._rest is None:
        # set _rest to other
        self._rest = other
    else:
        # else, recurse until we reach the last item
        self._rest.__add__(other)
    return self
```

self is the "head" or beginning of the list. Note that it didn't change!

[] Operator: `__getitem__`, `__set_item__`

- **`__getitem__(self, index)` and `__setitem__(self, index, val)`**
  - When using lists, we can get or set the item at a specific index by using the `[]` operator (e.g., val = mylist[1] or mylist[2] = newVal)
  - To support the `[]` operator in our `LinkedList` class, we need to implement `__getitem__` and `__setitem__`
  - Basic idea:
    - Walk out to the element at `index`
    - Get or set value at that index accordingly
    - Recursive!

[] Operator: `__getitem__, __set_item__`

- **`__getitem__(self, index)` and `__setitem__(self, index, val)`**
  - When using lists, we can get or set the item at a specific index by using the `[]` operator (e.g., val = mylist[1] or mylist[2] = newVal)

```
# [] list index notation calls __getitem__() method
# index specifies which item we want
def __getitem__(self, index):
    # if index is 0, we found the item we need to return
    if index == 0:
        return self._value
    else:
        # else we recurse until index reaches 0
        # remember that this implicitly calls __getitem__
        return self._rest[index - 1]
```

[] Operator: `__getitem__, __set_item__`

- **`__getitem__(self, index)` and `__setitem__(self, index, val)`**
  - When using lists, we can get or set the item at a specific index by using the `[]` operator (e.g., val = mylist[1] or mylist[2] = newVal)

```
# [] list index notation also calls __setitem__() method
# index specifies which item we want, val is new value
def __setitem__(self, index, val):
    # if index is 0, we found the item we need to update
    if index == 0:
        self._value = val
    else:
        # else we recurse until index reaches 0
        # remember that this implicitly calls __setitem__
        self._rest[index - 1] = val
```

`==` Operator: `__eq__`

- **`__eq__(self, other)`**
    - When using lists, we can compare their values using the `==` operator
    - To support the `==` operator in our `LinkedList` class, we need to implement `__eq__`
    - We want to walk the lists and check the values
    - Make sure the sizes of lists match, too

== Operator: `__eq__`

- **`__eq__(self, other)`**
  - When using lists, we can compare their values using the **==** operator
  - To support the **==** operator in our `LinkedList` class, we need to implement `__eq__`

```
# == operator calls __eq__() method
# if we want to test two LinkedLists for equality, we test
# if all items are the same
# other is another LinkedList
def __eq__(self, other):
    # If both lists are empty
    if self._rest is None and other.getRest() is None:
        return True

    # If both lists are not empty, then value of current list elements
    # must match, and same should be recursively true for
    # rest of the list
    elif self._rest is not None and other.getRest() is not None :
        return self._value == other.getValue() and self._rest == other.getRest()

    # If we reach here, then one of the lists is empty and other is not
    return False
```

Many Other Special Methods

- Examples:
    - `__eq__ (self, other): x == y`
    - `__ne__ (self, other): x != y`
    - `__lt__ (self, other): x < y`
    - `__gt__ (self, other): x > y`
    - `__add__(self, other) : x + y`
    - `__sub__(self, other): x - y`
    - `__mul__(self, other): x * y`
    - `__truediv__(self, other): x / y`
    - `__pow__(self, other): x ** y`
    - …

Useful List Method: `append`

- **`append(self, val)`**
  - When using lists, we can add an element to the end of an existing list by calling append (mutates our list)
  - Thus `append` is similar to `__add__`, except we are only adding a single element rather than an entire list (so it's a bit easier to accomplish)
  - Basic idea:
    - Walk to end of list
    - Create a new `LinkedList(val)` and add it to end

Useful List Method: `append`

- **`append(self, val)`**
  - When using lists, we can add an element to the end of an existing list by calling append (mutates our list)
  - Thus **append** is similar to **__add__**, except we are only adding a single element rather than an entire list (so it's a bit easier to accomplish)

```python
# append is not a special method, but it is a method
# that we know and love from the Python list class.
# unlike __add__, we do not return a new LinkedList instance
def append(self, val):
    # if am at the list item
    if self._rest is None:
        # add a new LinkedList to the end
        self._rest = LinkedList(val)
    else:
        # else recurse until we find the end
        self._rest.append(val)
```

Making our List an Iterable

- We can iterate over a Python list in a `for loop`
- It would be nice if we could iterate over our LinkedList in a for loop
- This won't quite work right now

```
In [108]: for item in myList:
              print(item)

5
3
11

---------------------------------------------------------------------------
TypeError                                 Traceback (most recent call last)
<ipython-input-108-4bf86db75685> in <module>
----> 1 for item in myList:
      2     print(item)

<ipython-input-104-8a5ab5d1919c> in __getitem__(self, index)
     68             # else we recurse until index reaches 0
     69             # remember that this implicitly calls __getitem__
---> 70             return self._rest[index - 1]
     71 
     72     # [] list index notation also calls __setitem__() method

TypeError: 'NoneType' object is not subscriptable
```

Making our List an Iterable

- We can iterate over a Python list in a `for loop`
- It would be nice if we could iterate over our LinkedList in a for loop
- This won't quite work right now
- What do we need?
  - Next time we will discuss the special method `__iter__`
  - We will look behind the scenes at a for loop and see how it works!