

Computational Structures in Data Science

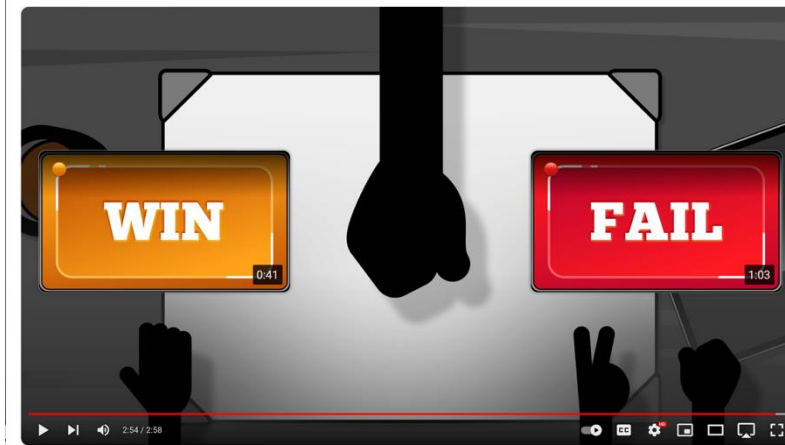
Data Structures: Linked Lists

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Fun Video: CGP Grey Rock Paper Scissors

- How many rounds of Rock Paper Scissors is a 1 in 1,000,000,000 chance of winning?
- Each video leads to another set of videos.
- This is technically a *tree*, but we'll come back to that later.



One-in-a-Million YouTube Game: Can YOU Win?
CGP Grey 6.01M subscribers

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Where We're Going

- For now – we've learned *most* of the basics of Python!
 - There are plenty of Python we don't see in CS88
- We'll be applying OOP principles to explore new topics.
- We're going to focus on storing / organizing data
 - Lists, Tuples, and Dictionaries: Data Structures you already know!
- **BUT: How do we build our own?**
 - We'll build our own lists first, then talk about trees and other ways of organizing data
- **Last few lectures: Switch to SQL**

Why "Data Structures"? (Next Few lectures)

- Data Structures
 - OOP helps us organize our *programs*
 - Data Structures help us organize our data!
 - Can be implemented using OOP
 - You already know lists and dictionaries!
 - We'll see a new one today
- Enjoy this stuff? Take CS 61B!
- Find it challenging? Don't worry! It's a different way of thinking.

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Linked Lists

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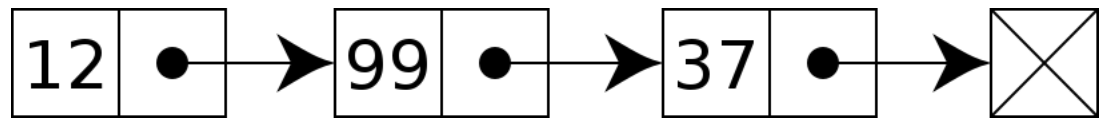


Data Structures

- A data structure is a way to organize or group a bunch of independent pieces of data.
 - Lists (arrays), Dictionaries, Tuples
- A class, on its own, is **not** necessarily a data structure, it represents a new data type.
 - a "car" or a "person" is an instance of that data type.
 - Lists, Dicts, etc are also data types; their goal is to organize other data.
- These are common patterns that can be used to solve a wide variety of problems.
- Sometimes we're giving structure to make it easier as a programmer, sometimes we're trying to be fast or efficient.

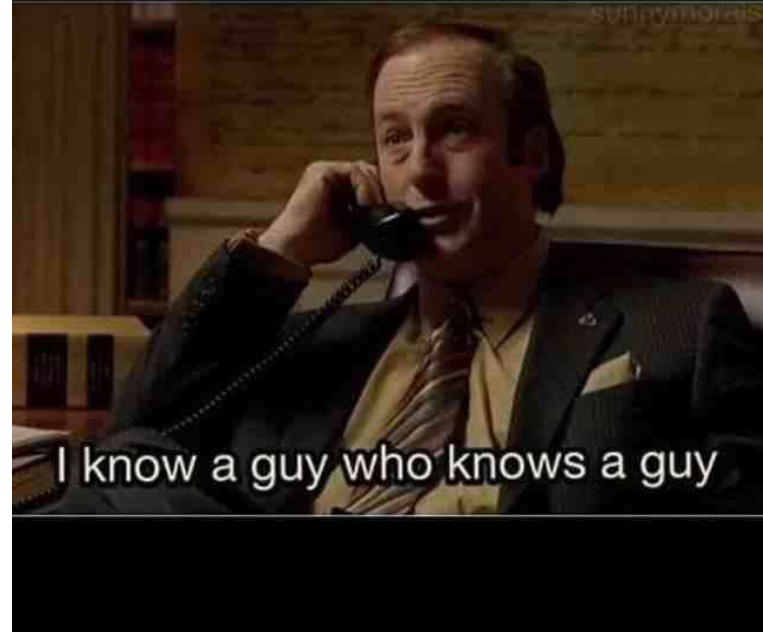
Linked Lists

- A Recursive List, sometimes called a "rlist"
- Linked lists contain other linked lists
- A series of items with two pieces:
 - A value, usually called "first"
 - A "pointer" to the rest of the items in the list.



- We'll use a very small Python class "Link" to model this.
- `Link(12, Link(99, Link(37, Link.empty)))`

Linked List data structures be like:



What's Needed For a Linked List?

- `first`
- `rest`
- An idea of “empty”
- **Nothing else is *necessary***
- `__repr__`, `__len__` methods are all useful shortcuts and useful recursion practice.

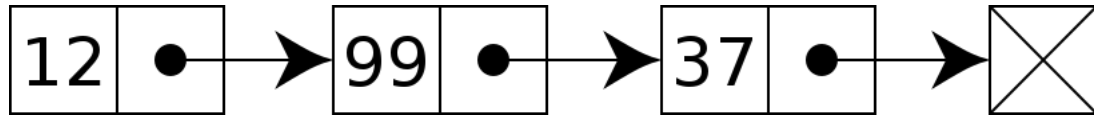
The Link Class

```
class Link:
    empty = ()
    def __init__(self, first, rest=empty):
        self.first = first
        self.rest = rest
```

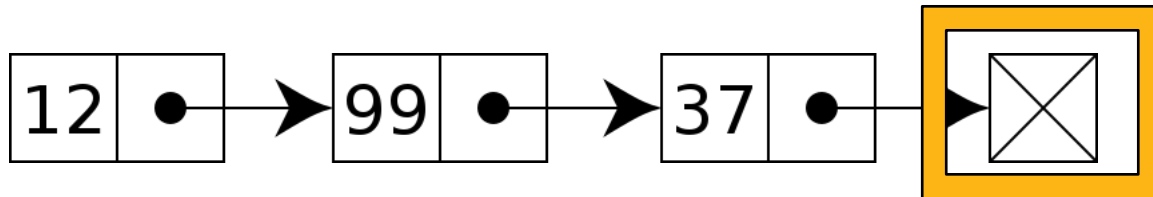
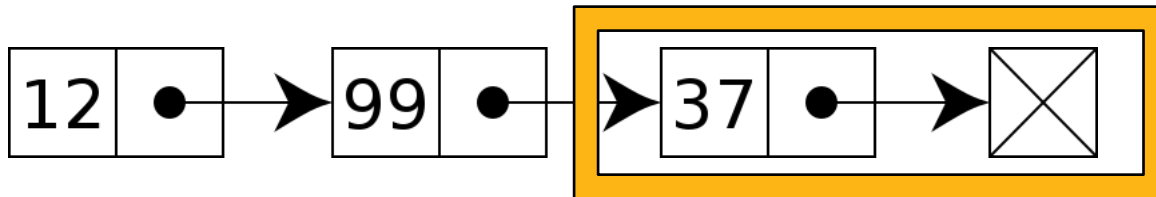
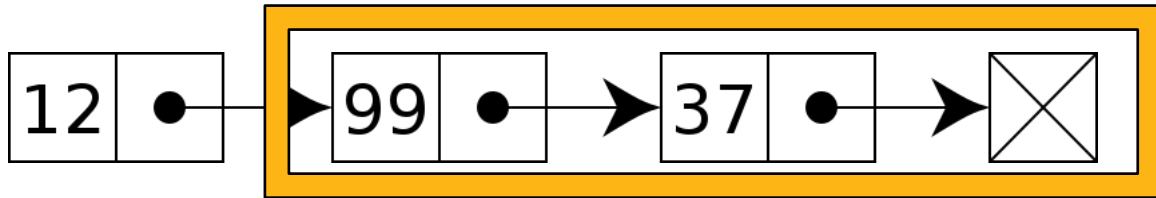
That's all we need!

- We can add a `__repr__` method, `length`, etc.
- Use an `empty` tuple for clarity / easier than `None`.
 - `()` has lots of useful methods defined, like `len()`

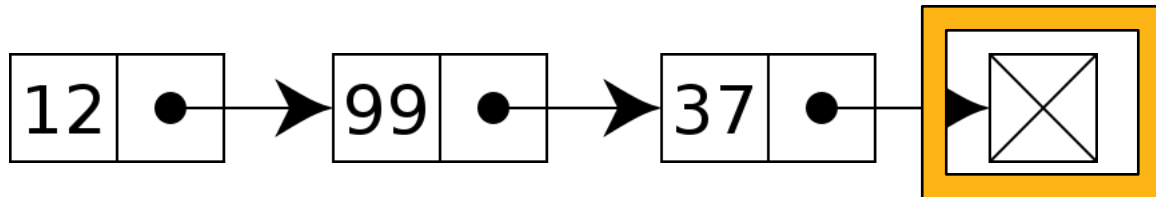
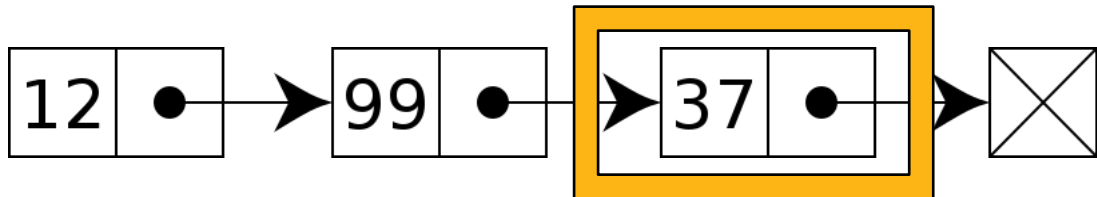
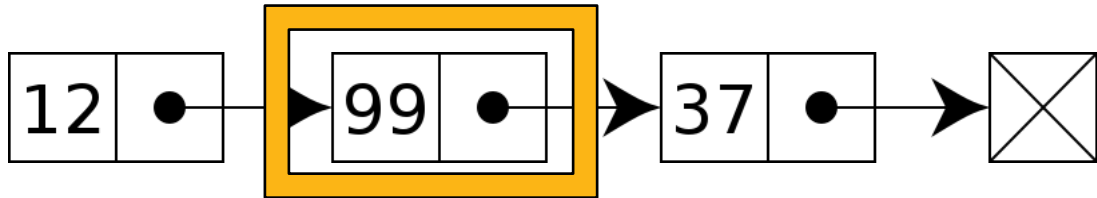
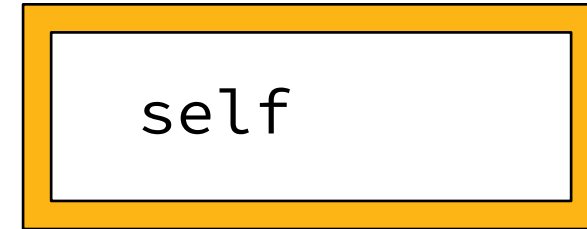
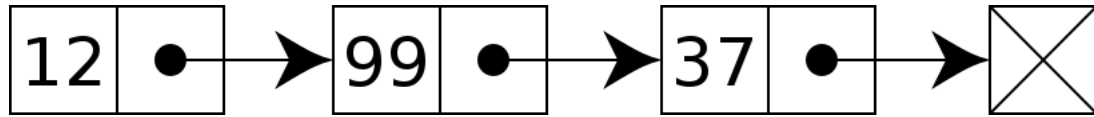
Recursion Is Implicit



`self.rest`



Different ways to think of a linked list: “relative” vs “recursive”



Iterating or Processing a Linked List

- Our base case or stopping condition?
 - Linked List is empty!
- We can use recursion or iteration.
 - Which is “better”?
 - Depends on the problem we are trying to solve!

Iterating Over All Items in Linked List

```
def print_link(link):  
    if not link:  
        return  
    print(link.first)  
    print_link(link.rest)
```

- Base Case: No more items
- Do Action
- Recurse on the rest of the list

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Iterating Over All Items in Linked List

```
def print_link(link):  
    if not link:  
        return  
    print(link.first)  
    print_link(link.rest)
```

- Base Case: No more items
- Do Action
- Recurse on the rest of the list

```
def print_link(link):  
    if not link:  
        return  
    item = link  
    while item:  
        print(item.first)  
        item = item.rest
```

- Handle the empty list
- Keep track of current item
- Update item to be the next in sequence.

Demo – See the Notebook

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Linked Lists Practice with Simple Functions

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Linked Lists Practicing Recursion

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Making Range / Map / Filter

```
# Classic Lists:
```

```
square, odd = lambda x: x * x, lambda x: x % 2 == 1
```

```
list(map(square, filter(odd, range(1, 6)))) # [1, 9, 25]
```

```
# With Linked Lists:
```

```
map_link(square, filter_link(odd, range_link(1, 6)))
```

```
# → Link(1, Link(9, Link(25)))
```

```
def range_link(start, end):
```

```
def map_link(f, s):
```

```
def filter_link(f, s):
```

Range Link

```
def range_link(start, end):  
    """Return a Link containing consecutive integers from  
start to end.
```

```
>>> range_link(3, 6)  
Link(3, Link(4, Link(5)))  
"""
```

```
if start >= end:  
    return Link.empty  
else:  
    return _____
```

Making Range / Map / Filter

```
def range_link(start, end):  
    """Return a Link containing consecutive integers from  
    start to end.  
  
    >>> range_link(3, 6)  
    Link(3, Link(4, Link(5)))  
    """"  
    if start >= end:  
        return Link.empty  
    else:  
        return Link(start, range_link(start + 1, end))
```

Map Link

```
def map_link(f, s):  
    """Return a Link that contains f(x) for each x in Link  
s.
```

```
>>> map_link(square, range_link(3, 6))  
Link(9, Link(16, Link(25)))  
"""
```

```
if s is Link.empty:
```

```
    return s
```

```
else:
```

```
    return _____
```

Map Link

```
def map_link(f, s):  
    """Return a Link that contains f(x) for each x in Link  
s.
```

```
>>> map_link(square, range_link(3, 6))  
Link(9, Link(16, Link(25)))  
"""
```

```
if s is Link.empty:  
    return s  
else:  
    return Link(f(s.first), map_link(f, s.rest))
```

Filter Link

```
def filter_link(f, s):
    """Return a Link that contains only the elements x of
    Link s for which f(x) is a true value.
    >>> filter_link(odd, range_link(3, 6))
    Link(3, Link(5))
    """
    if s is Link.empty:
        return s

    -----
    if f(s.first):
        return -----
    else:
        return -----
```

Filter Link

```
def filter_link(f, s):
    """Return a Link that contains only the elements x of
    Link s for which f(x) is a true value.
    >>> filter_link(odd, range_link(3, 6))
    Link(3, Link(5))
    """
    if s is Link.empty:
        return s
    filtered_rest = _____
    if f(s.first):
        return Link(s.first, _____)
    else:
        return filtered_rest
```

Filter Link

```
def filter_link(f, s):
    """Return a Link that contains only the elements x of
    Link s for which f(x) is a true value.
    >>> filter_link(odd, range_link(3, 6))
    Link(3, Link(5))
    """
    if s is Link.empty:
        return s
    filtered_rest = filter_link(f, s.rest)
    if f(s.first):
        return Link(s.first, filtered_rest)
    else:
        return filtered_rest
```

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Linked Lists Wrap Up

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Uses for a Linked List

- Modeling a Polynomial Equation
 - each item is (coefficient, exponent, next_term)
- Items in a music Playlist
 - each item is a (song, next_song) pair
 - easy to add/remove items
 - Specifically: often want to remove the first item
- Model real-world relationships
 - Anything that is a "chain" is a good option
 - Next up: We'll extend this idea to "trees"

Why are linked lists useful?

- **Honestly, a regular list is easier *most* of the time**
 - Python handles all the hard details!
 - When data get large, there are lots of edge cases.
- In terms of ***efficiency***: Linked lists make it fast to move items around, insert, and delete **from the front and/or back** (depending on implementation)
 - But they are slower to finding any single item (“random access”) – **can’t index into a linked list**
- In **Ants** Project: You'll see a list of Place objects which are linked together via an entrance and an exit – they’re linked lists!

Lists

vs

Linked Lists

- Built into Python
- Create with `[]` or `list()`
- Can iterate through with loops
- Can use index to retrieve element (e.g. `lst[0]`)
- Not a recursive data structure

- `Link` class (created for C88C, isn't built into Python)
- Create with `Link(<first>, <rest>)`
- Can iterate through with loops
 - But not "directly" through a for loop
- Can't use indices to retrieve elements
- Is a recursive data structure

Efficiency of Linked Lists vs Lists

- Linked Lists generally use less memory.
- Linked Lists:
 - Once you've found an item, inserting / removing is easy, $O(1)$
 - Finding anything other than the first/last item is $O(n)$
- "Regular" Lists:
 - Inserting / Removing items, other than the last is $O(n)$ – due to internal copying
 - Finding any random item is $O(1)$.
- What if you need to iterate over all items in order?
 - $O(n)$ in both cases