# CSc 120
## Introduction to Computer Programming II

Abstract Data Types

Stacks and Queues

# Abstract Data Types

# Abstract Data Types

An *abstract data type (ADT)* describes a set of data values and associated operations that are specified independent of any particular implementation.

An ADT is a logical description of how we view the data and the operations allowed on that data.

- describes *what* the data represents
- not *how* is the data represented

The data is *encapsulated*.

# Abstract Data Types

Because the data is *encapsulated* we can change the underlying implementation without affecting the *logical* way the ADT behaves.

- the logical description remains the same
- the operations remain the same

Example:

- lists
  - Python built-in lists
  - linked lists

# Abstract Data Types

Consider the ADT definition of a list.

Lists:

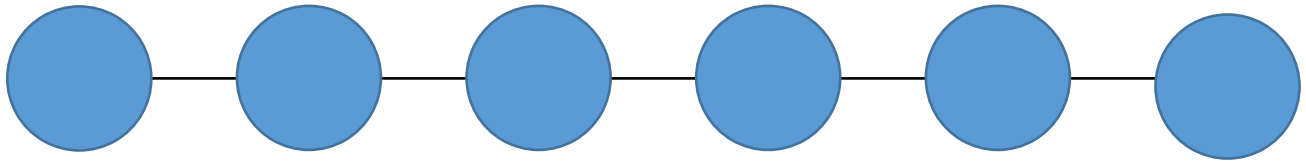
- logical description
  - linear ordering of elements
  - elements can be inserted or deleted from any location
- operations
  - len, indexing, slicing, in, concatenation, insert, delete, ...

# linear data structures

# Linear data structures

A *linear* data structure is a collection of objects with a straight-line ordering among them

- each object in the collection has a *position*
- for each object in the collection, there is a notion of the object *before* it or *after* it



# Data structures we've seen

| Linear | Not linear |
| --- | --- |
| • Python lists<br>• Linked lists | • Dictionaries<br>• Sets |

# Today's topic

| Linear | Not linear |
| --- | --- |
| • Python lists | • Dictionaries |
| • Linked lists | • Sets |
| • Stacks | |
| • Queues | |
| • Dequeues | |

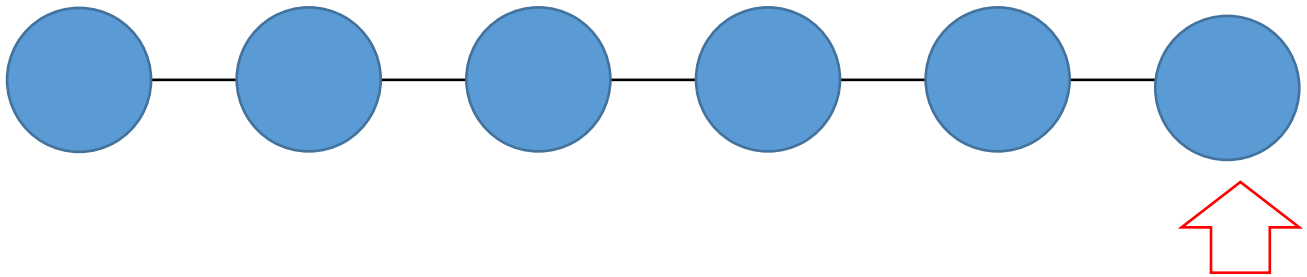
Key property: the way in which objects are added to, and removed from, the collection

# stacks

# The Stack ADT

A *stack* is a linear data structure where objects are inserted or removed only at one end

- all insertions and deletions happen at one particular end of the data structure
- this end is called the *top* of the stack
- the other end is called the *bottom* of the stack



insertions and deletions happen at one end

# Stacks: insertion of values

Insertion of a sequence
of values into a stack:

5 17 33 9 43

stack top None

stack bottom None

# Stacks: insertion of values

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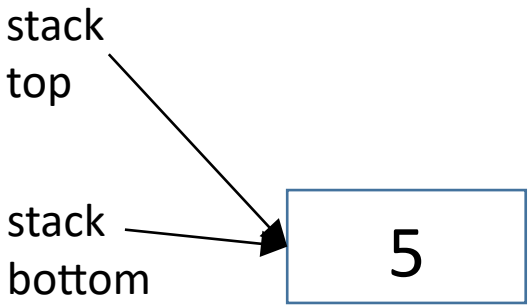
5 17 33 9 43



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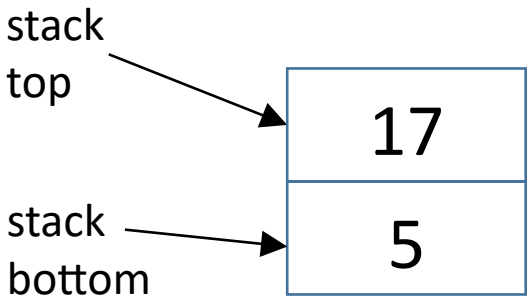

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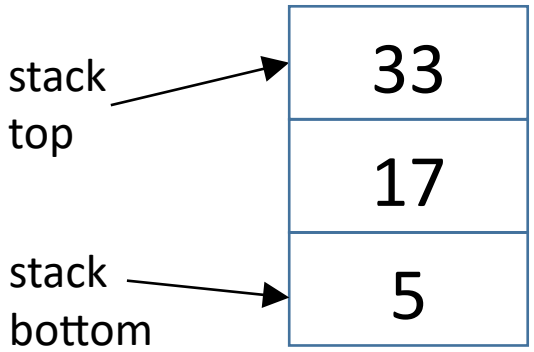

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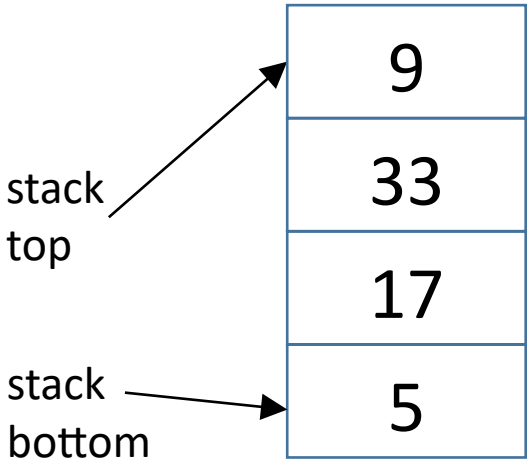

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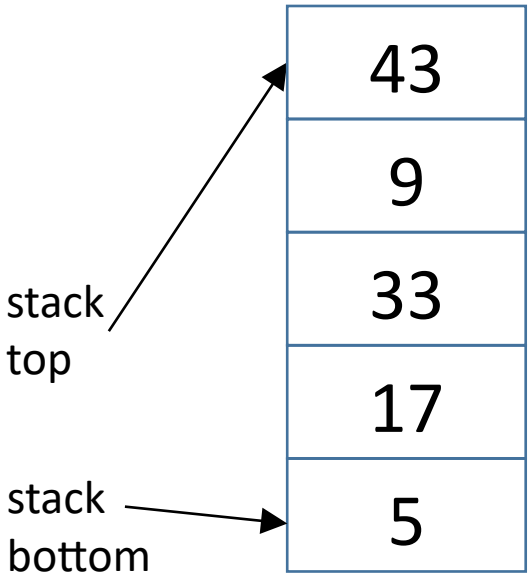
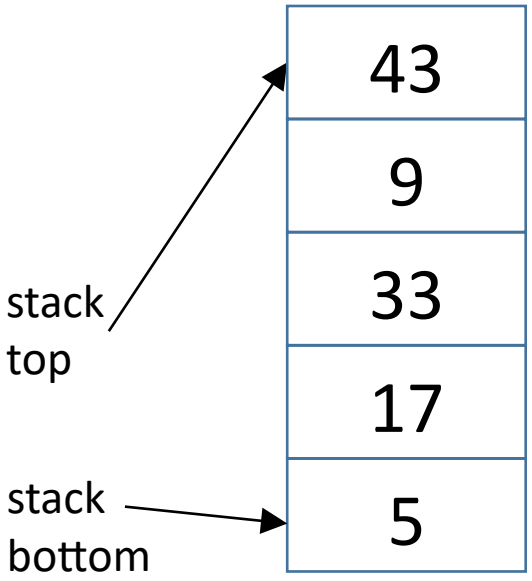


# Stacks: insertion of values

5 17 33 9 43

*order in which values were inserted*



# Stacks: removal of values

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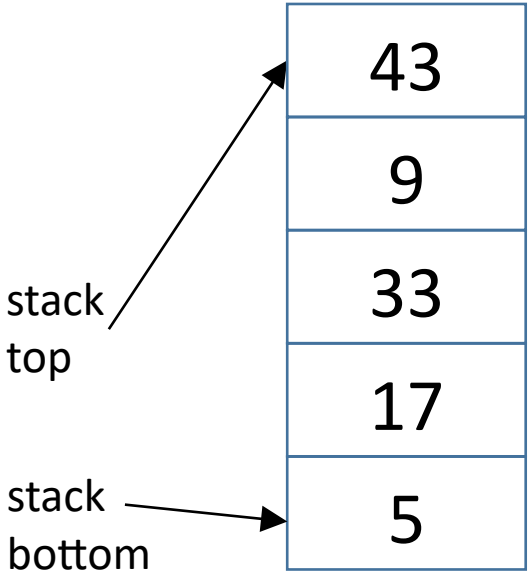
*order in which values were inserted*

Removing values from the stack:



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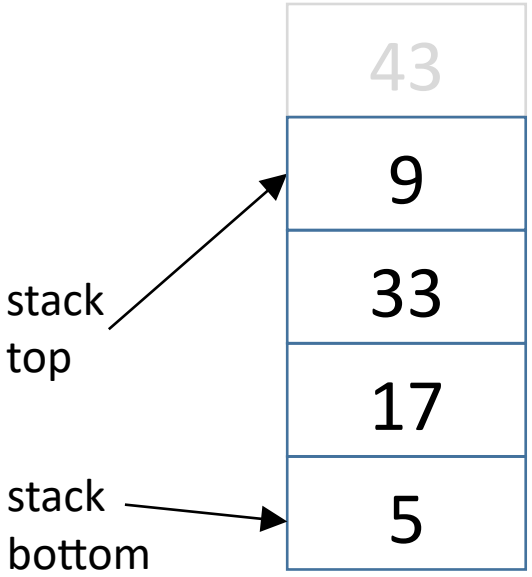
*order in which values were inserted*

Removing values from the stack:

43



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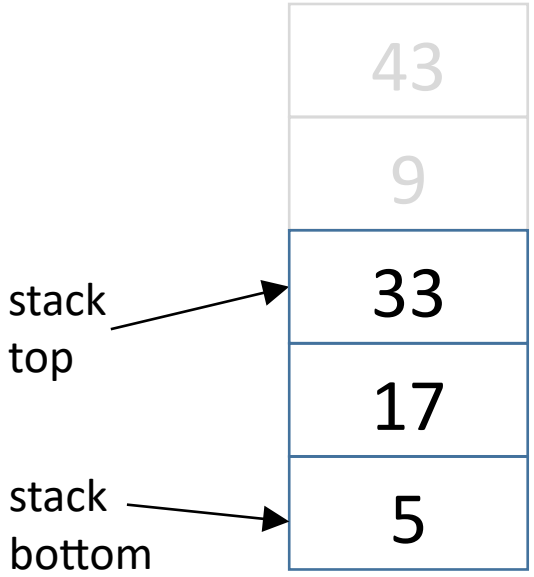
*order in which values were inserted*

Removing values from the stack:

43 9



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*order in which values were inserted*

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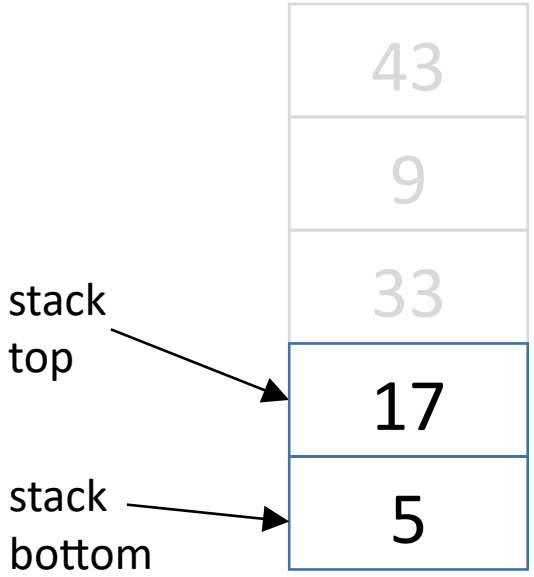

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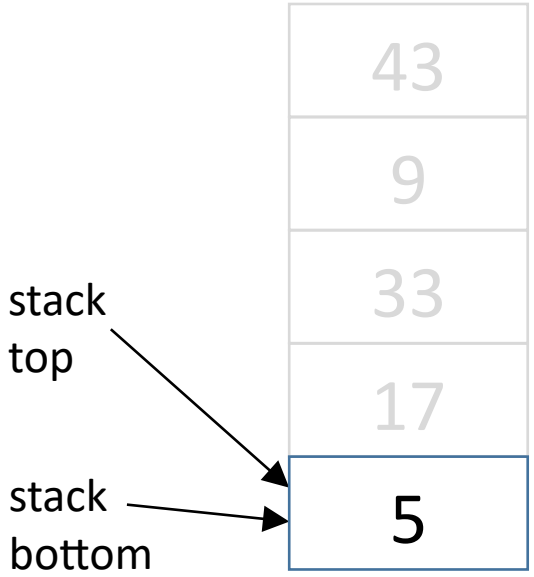
*order in which values were inserted*

Removing values from the stack:

43 9 33 17



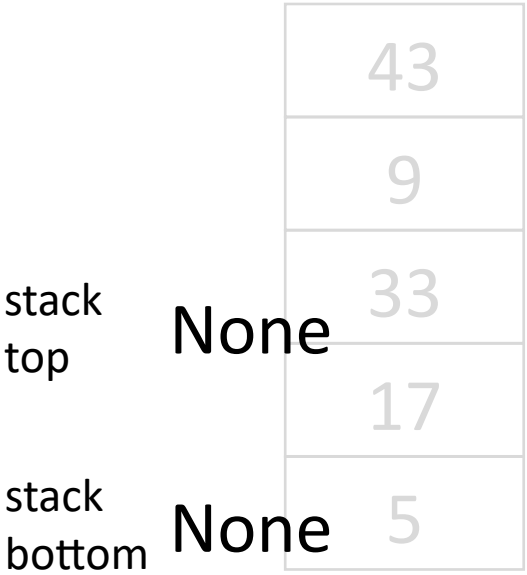
# Stacks: removal of values

5 17 33 9 43

*order in which values were inserted*

Removing values from the stack:

43 9 33 17 5



# Stacks: removal of values

5 17 33 9 43

*order in which values were inserted*

Removing values from the stack:

43 9 33 17 5

*order in which values were removed*

# Stacks: LIFO property

5 17 33 9 43

*order in which values were inserted*

Removing values from the stack:

43 9 33 17 5

*order in which values were removed*

values are removed in reverse order from the order of insertion

"LIFO order"
Last in, First out

# The Stack ADT

A *stack* is a linear data structure where objects are inserted or removed only at one end

- all insertions and deletions happen at one particular end of the data structure
- this end is called the *top* of the stack
- the other end is called the bottom of the stack

Operations

- insert at the top (called push)
- delete from the top (called pop)

# Methods for a Stack class

- Stack() : creates a new empty stack
- push(*item*) : adds *item* to the top of the stack
  - returns nothing
  - modifies the stack
- pop() : removes the top item from the stack
  - returns the removed item
  - modifies the stack
- is_empty() : checks whether the stack is empty
  - returns a Boolean

# EXERCISE

```
>>> s = Stack()
>>> s.push(4)
>>> s.push(17)
>>> s.push(5)
>>> x = s.pop()
>>> y = s.pop()
```

← *what does the stack* s *look like here?*
*what are the values of* x *and* y*?*

# EXERCISE

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>>> s.push(x)
>>> s.push(y)
```

← *what does the stack* s *look like here?*

# EXERCISE

*Implement the Stack class below. Use a Python list to hold the data.*

```
class Stack:
    # create a Stack
    def __init__(self):
        self._items = ?

    # adds item to the "top"
    def push(self, item):
        ?

    # removes the last item from the Stack
    def pop(self):
        ?
```

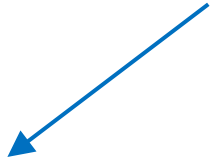
# Implementing a Stack class

```
class Stack:
    # the top of the stack is the last item in the list
    def __init__(self):
        self._items = []

    def push(self, item):
        self._items.append(item)

    def pop(self):
        return self._items.pop()
```

*removes and returns the last item in a list*



# stacks: applications

# An application: balancing parens

IDLE (the Python shell) matches up left and right parens ( ), brackets [ ], and braces { }

```
>>> x = [1,2,[3,4,[5],7],8]
```

How does it figure out how far back to highlight?

# An application: balancing parens

Basic idea: Match each ] with corresponding [

- similarly for ( … ) and { … } pairs

- Idea:
  - maintain a stack
  - on seeing '[' : push
  - on seeing ']' : pop the matching symbol

Example: [ 1, 2, [ 3, [ 4 ], 5 , [ 7 ] ] ]

Stack (empty)

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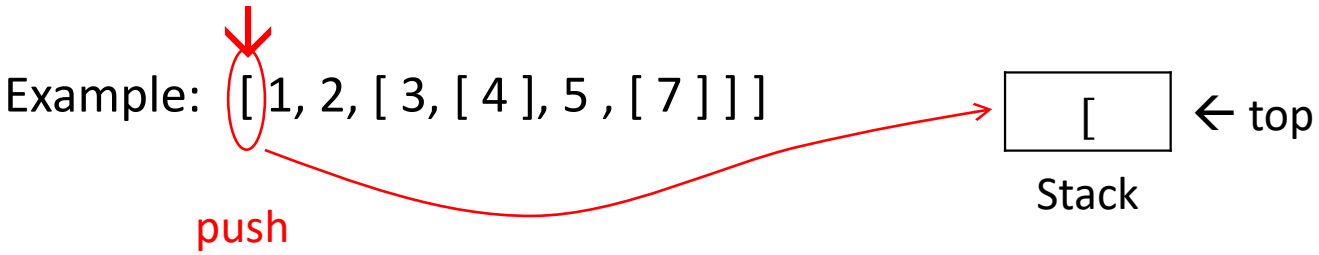

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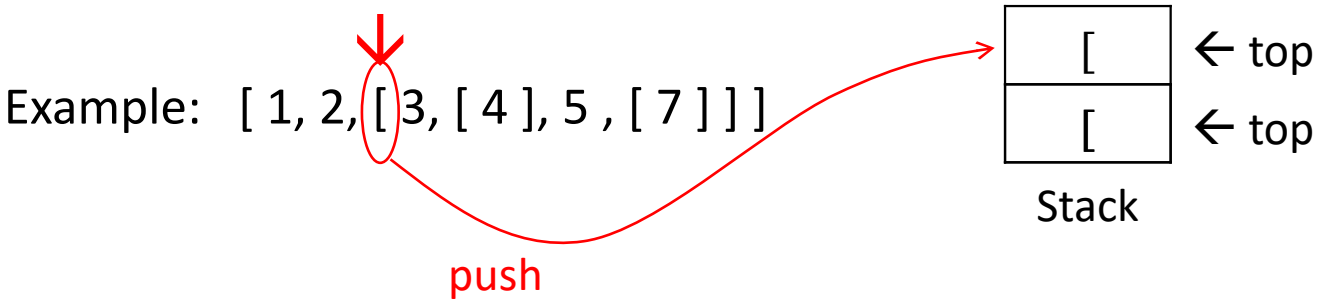

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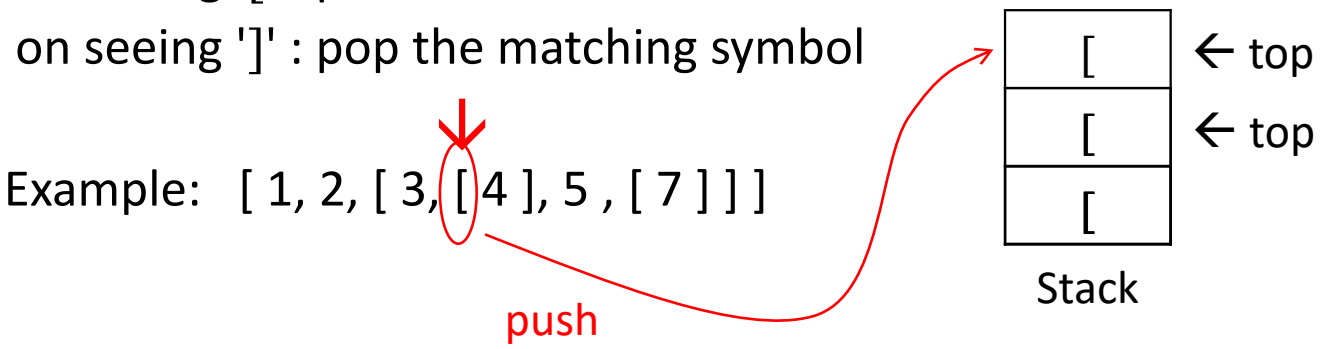

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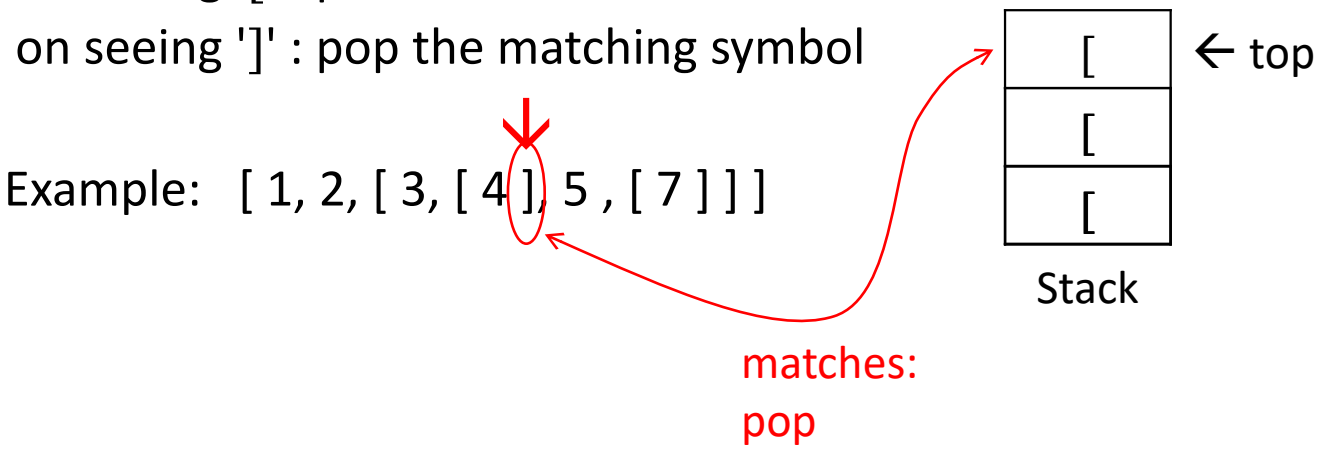

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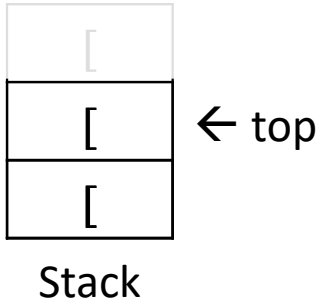

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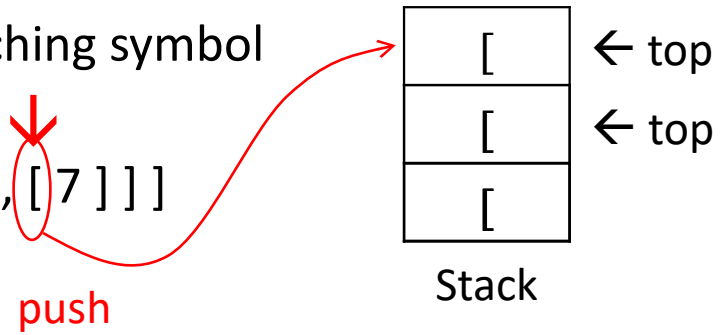

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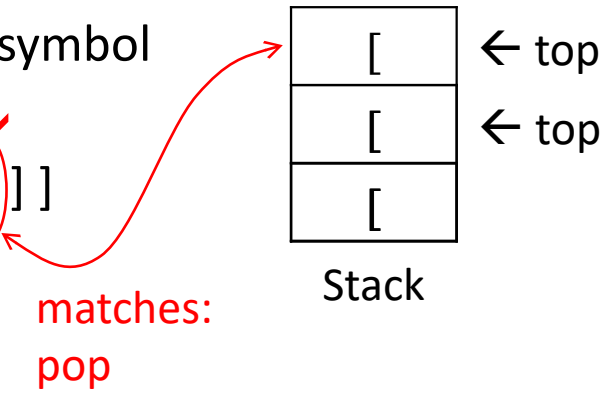

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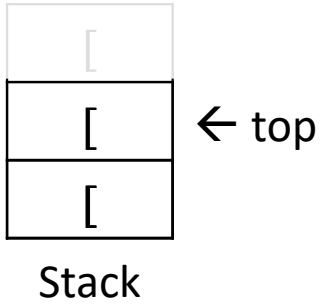

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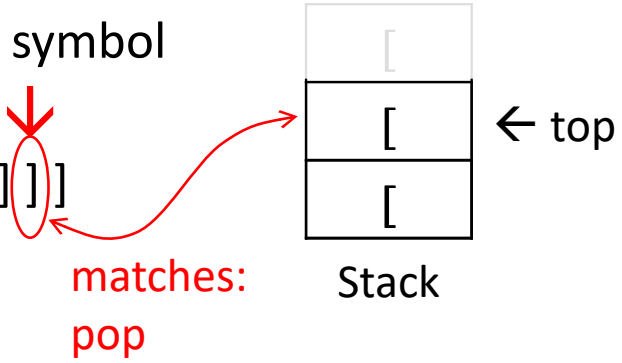

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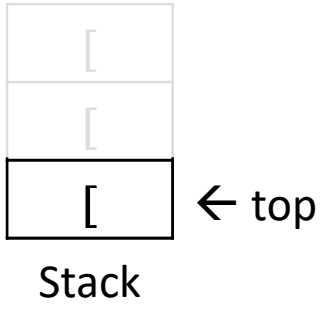

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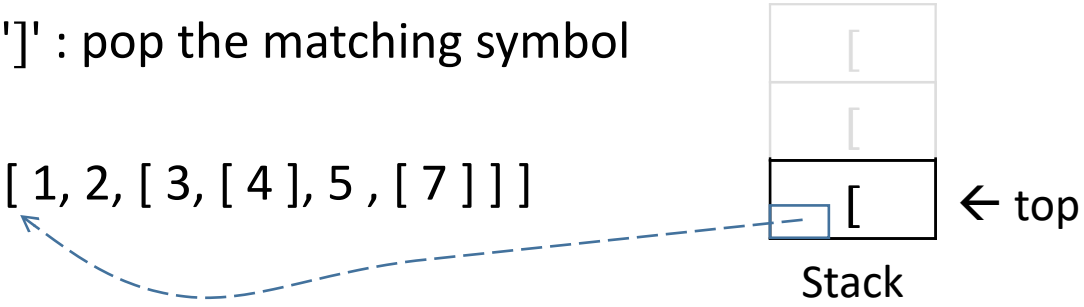



Elaboration: Have each stack element keep track of the position of its [

# EXERCISE

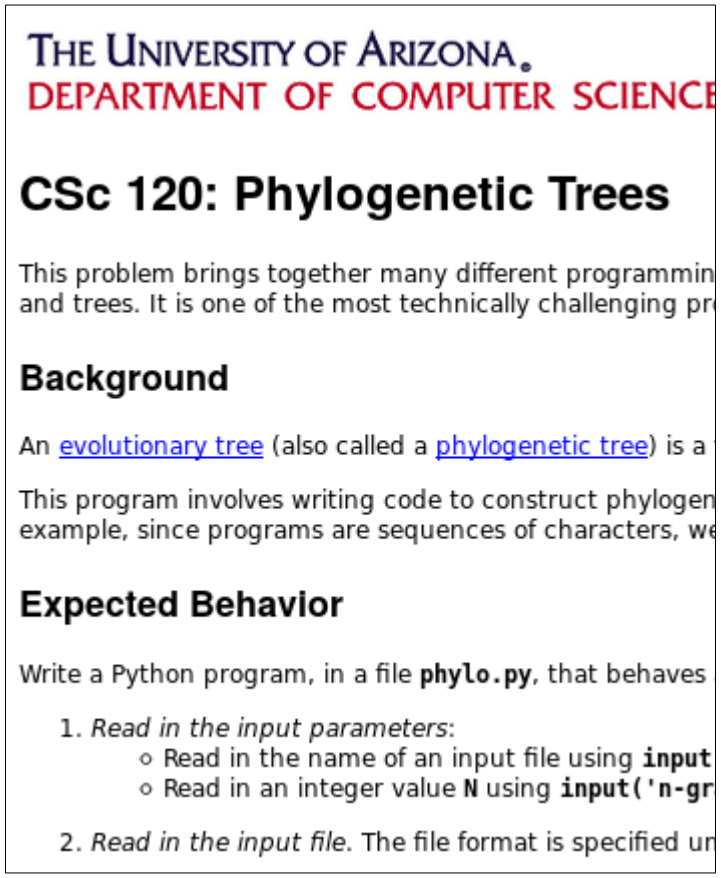
*Given the Stack class, write a function `balanced(s)` that returns True if the string `s` is balanced with respect to '[' and ']' and False otherwise.*

```
class Stack:
    def __init__(self):
        self._items = []

    def push(self, item):
        self._items.append(item)
    def pop(self):
        return self._items.pop()
    def is_empty():
        return self._items == []
```

# Related: Displaying web pages

**Web page**



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## CSc 120: Phylogenetic Trees

This problem brings together many different programmin
and trees. It is one of the most technically challenging pr

### Background

An evolutionary tree (also called a phylogenetic tree) is a

This program involves writing code to construct phylogen
example, since programs are sequences of characters, we

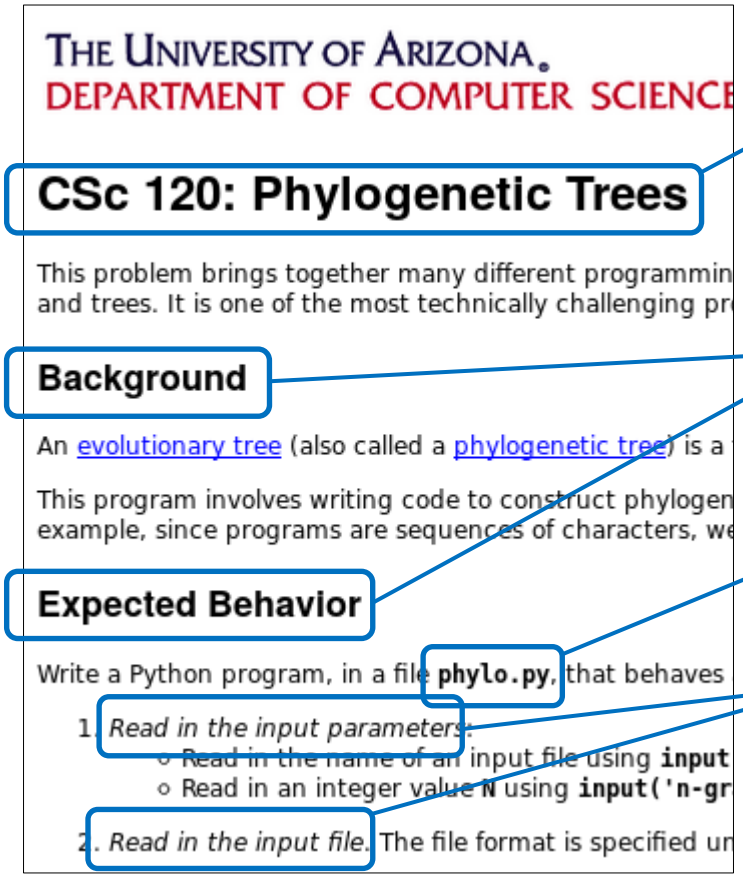
### Expected Behavior

Write a Python program, in a file **phylo.py**, that behaves

1. *Read in the input parameters*:
   - Read in the name of an input file using **input**
   - Read in an integer value **N** using **input('n-gr**
2. *Read in the input file*. The file format is specified un

# Related: Displaying web pages

**Web page**




**Display considerations**

main header: large font, bold

secondary header: medium font, bold

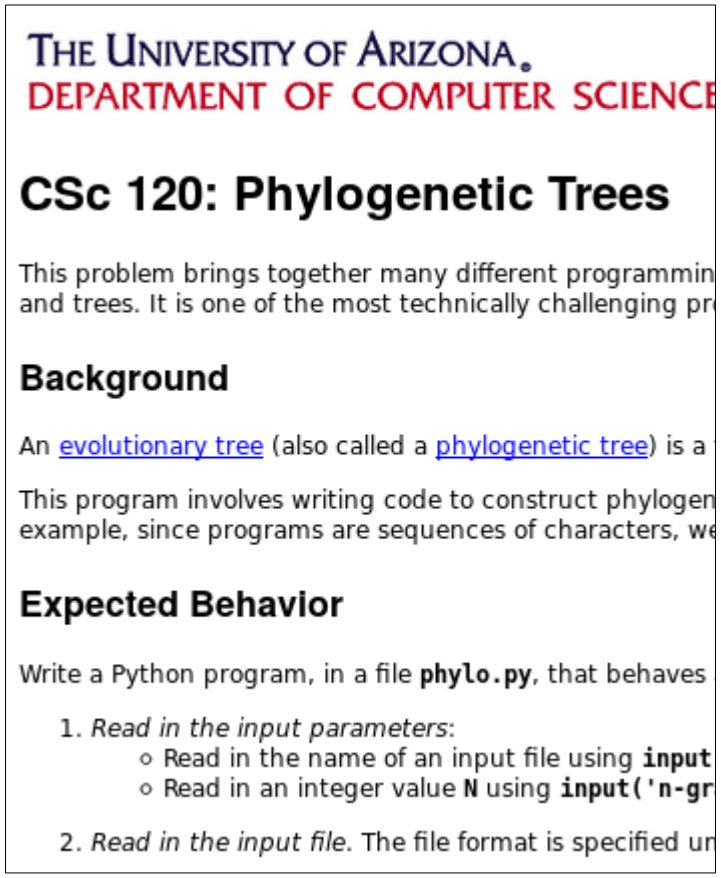
bold font

italics font

**Question**: how does the web browser figure out how much a given display format should include?
E.g., which text is in boldface, how much is in italics, etc.

# Related: Displaying web pages

**Web page**



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**HTML source**

```
</head>
<body bgcolor="white">
<p>
<img src="../../IMGS/uadcs.gif" alt="University of Arizona, Depa
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<h1>CSc 120: Phylogenetic Trees</h1>

This problem brings together many different programming construc
techniques we covered over the course of the semester including:
manipulation, (Python) lists, dictionaries, tuples, classes,
list comprehensions, and trees.  It is one of the most
technically challenging programs assigned in this class this sem
think it's also one of the most interesting.

<h2>Background</h2>
An <a href="http://evolution.berkeley.edu/evolibrary/article/phy
  evolutionary tree</a> (also called a
<a href="https://en.wikipedia.org/wiki/Phylogenetic_tree"
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evolutionary relationships between a set of organisms.
<p/>
This program involves writing code to construct phylogenetic tre
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<h2>Expected Behavior</h2>
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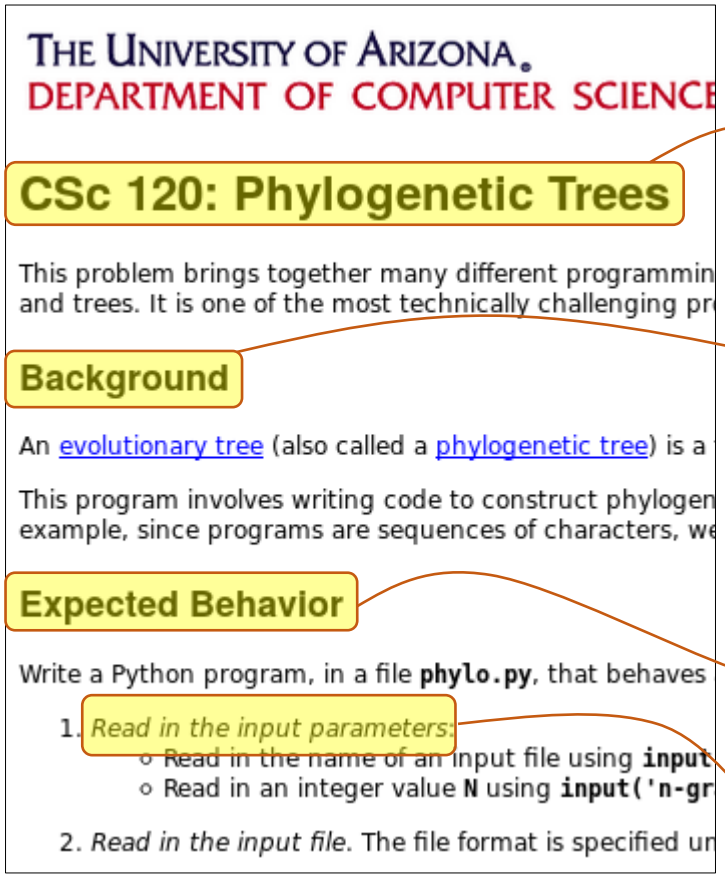


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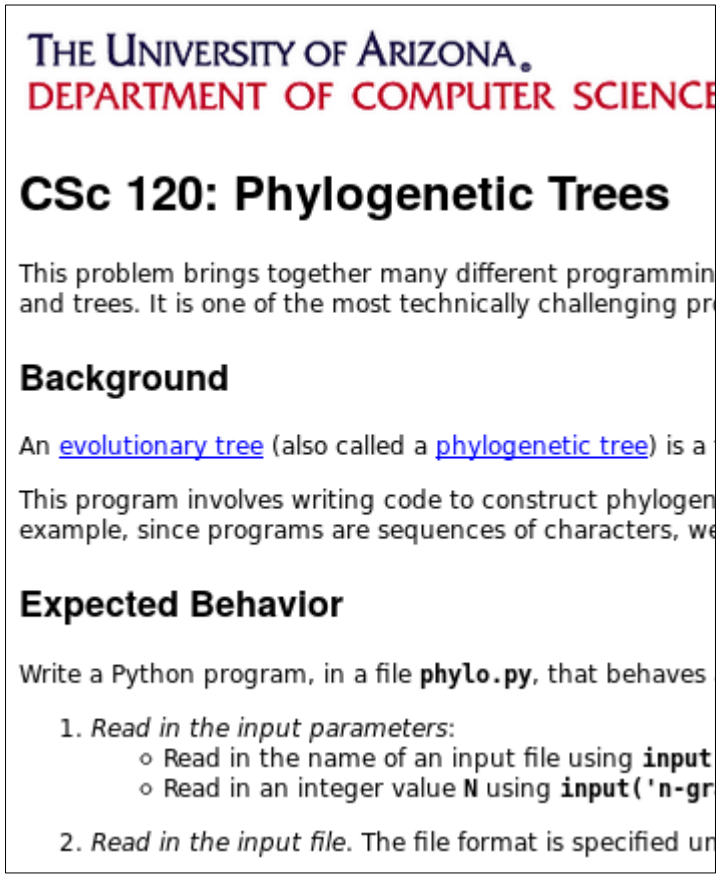
```

# Related: Displaying web pages

**Web page**



THE UNIVERSITY OF ARIZONA
DEPARTMENT OF COMPUTER SCIENCE

## CSc 120: Phylogenetic Trees

This problem brings together many different programmin
and trees. It is one of the most technically challenging pr

### Background

An evolutionary tree (also called a phylogenetic tree) is a

This program involves writing code to construct phylogen
example, since programs are sequences of characters, we

### Expected Behavior

Write a Python program, in a file **phylo.py**, that behaves

1. *Read in the input parameters*:
   - Read in the name of an input file using **input**
   - Read in an integer value **N** using **input('n-gr**
2. *Read in the input file*. The file format is specified un

**HTML source**

```
</head>
<body bgcolor="white">
<p>
<img src="../../IMGS/uadcs.gif" alt="University of Arizona, Depa
</p>

<h1>CSc 120: Phylogenetic Trees</h1>

This problem brings together many different programming construc
techniques we covered over the course of the semester including:
manipulation, (Python) lists, dictionaries, tuples, classes,
list comprehensions, and trees.  It is one of the most
technically challenging programs assigned in this class this sem
think it's also one of the most interesting.

<h2>Background</h2>
An <a href="http://evolution.berkeley.edu/evolibrary/article/phy
  evolutionary tree</a> (also called a
<a href="https://en.wikipedia.org/wiki/Phylogenetic_tree"
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evolutionary relationships between a set of organisms.
<p/>
This program involves writing code to construct phylogenetic tre
the genome sequences of a set of organisms.  (Of course, there i
inherently genetic about the techniques we use and the code we w
example, since programs are sequences of characters, we could ju
apply this approach to sets of programs.)

<h2>Expected Behavior</h2>
Write a Python program, in a file <b><tt>phylo.py</tt></b>, that
behaves as specified below.
<p/>
<ol>
  <li>
    <i>Read in the input parameters</i>:
```

# Related: Displaying web pages

"tags"

<h1> : "open header 1"

</h1> : "close header 1"

<h2> : "open header 2"

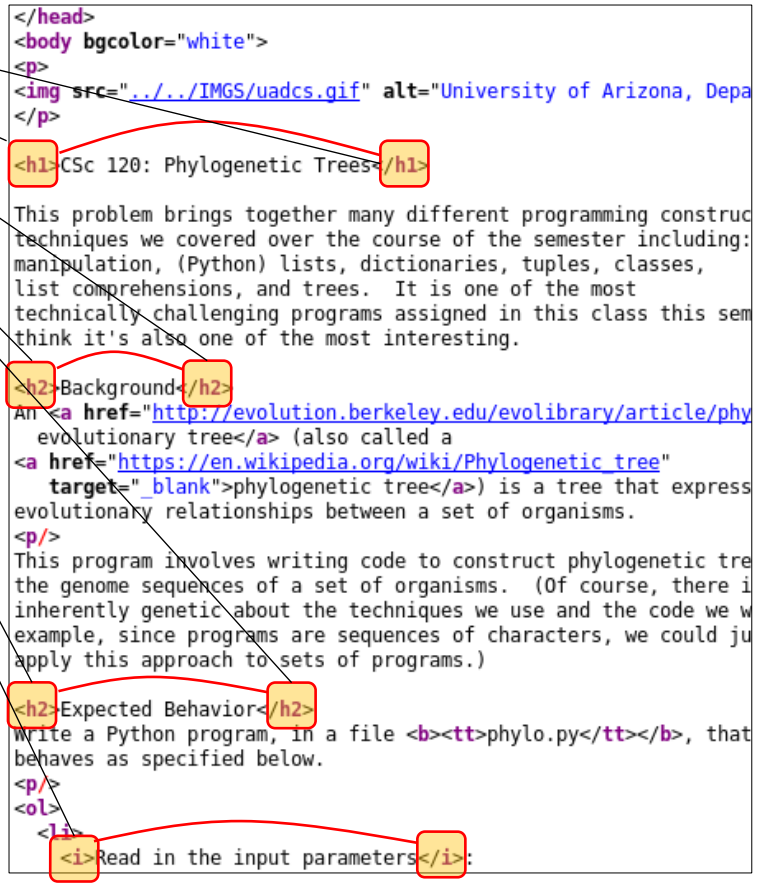
</h2> : "close header 2"

 : "open italics"

 : "close italics"

…

**HTML source**



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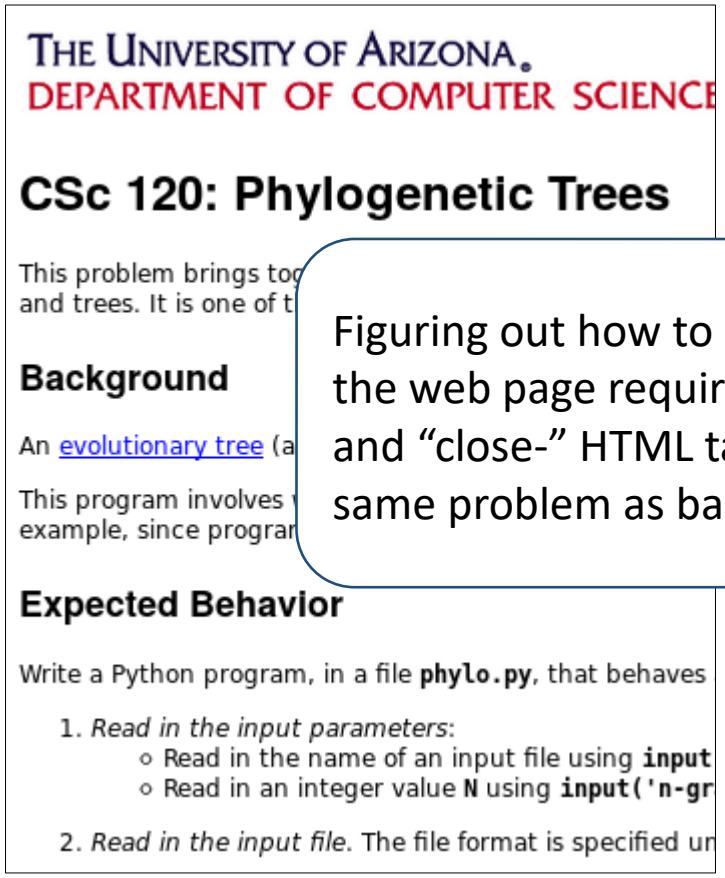
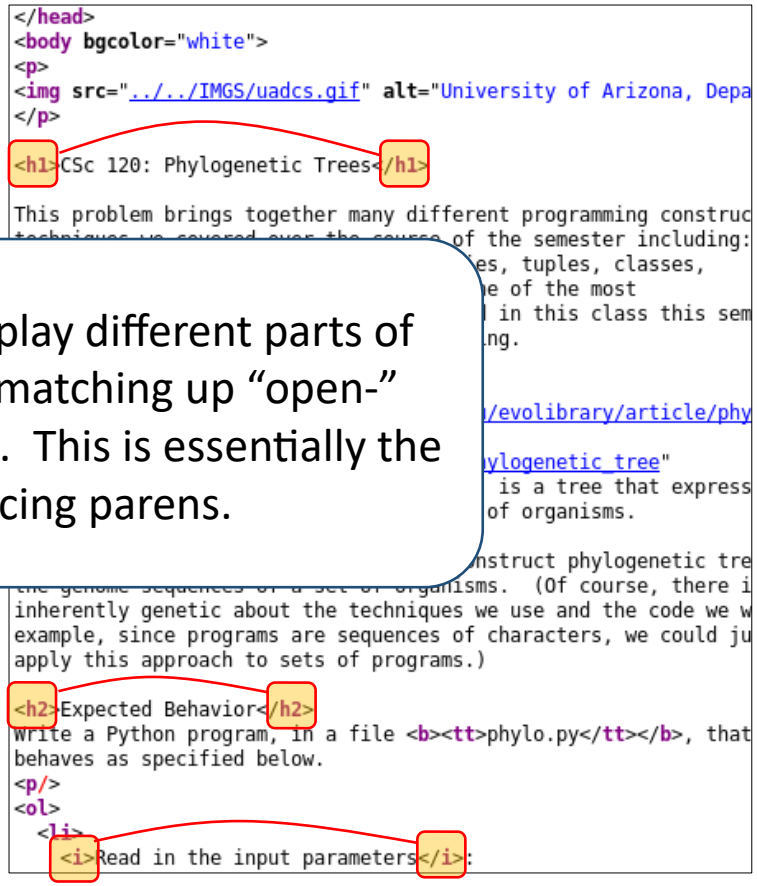



**HTML source**




Figuring out how to display different parts of the web page requires matching up “open-” and “close-” HTML tags. This is essentially the same problem as balancing parens.

# EXERCISE

```
>>> s1 = Stack()
>>> s1.push(4)
>>> s1.push(17)
>>> s2 = Stack()
>>> s2.push(s1.pop())
>>> s2.push(s1.pop())
>>> s1.push(s2.pop())
>>> s1.push(s2.pop())
```

← *what does the stack* s1 *look like here?*

# EXERCISE

*Hypothetical: Python 7 has just been released and built-in lists are inefficient. In fact, all operations are $O(n^2)$.*

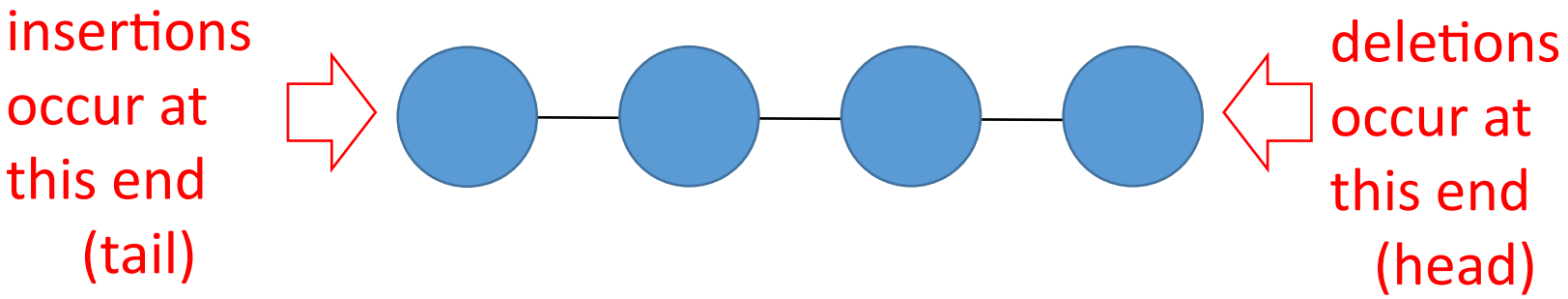
*Avoid these inefficiencies by implementing the Stack class using LinkedLists.*

# queues

# A Queue ADT

A *queue* is a linear data structure where insertions and deletions happen at different ends

- insertions happen at one end (the queue's "back“, or “tail”)
- deletions happen at the other end (the queue's "front“, or “head”)



# Queues: insertion of values

Insertion of a sequence of values into a queue: 5 17 33 9 43

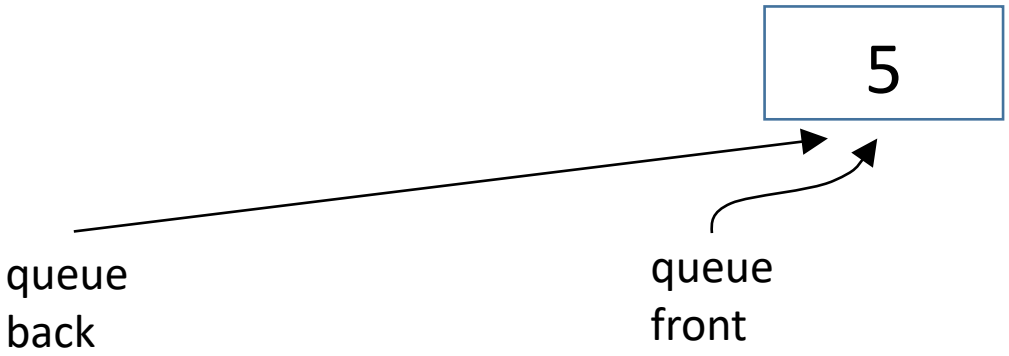
queue back None

queue front None

# Queues: insertion of values

Insertion of a sequence of values into a queue:

5 17 33 9 43



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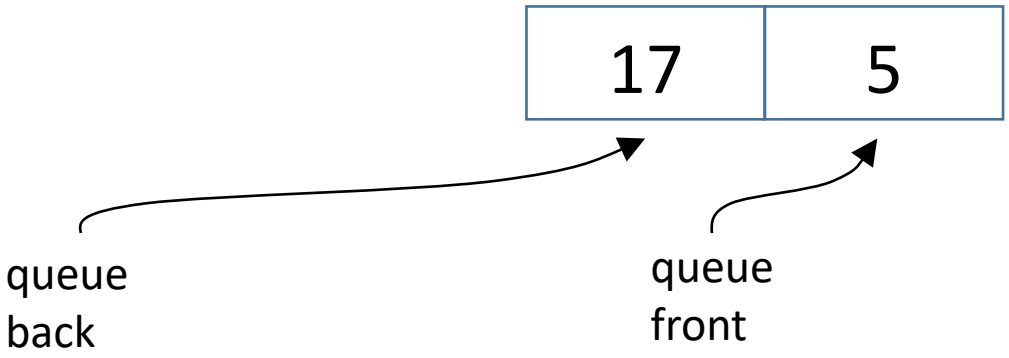
Insertion of a sequence of values into a queue:

5 17 33 9 43



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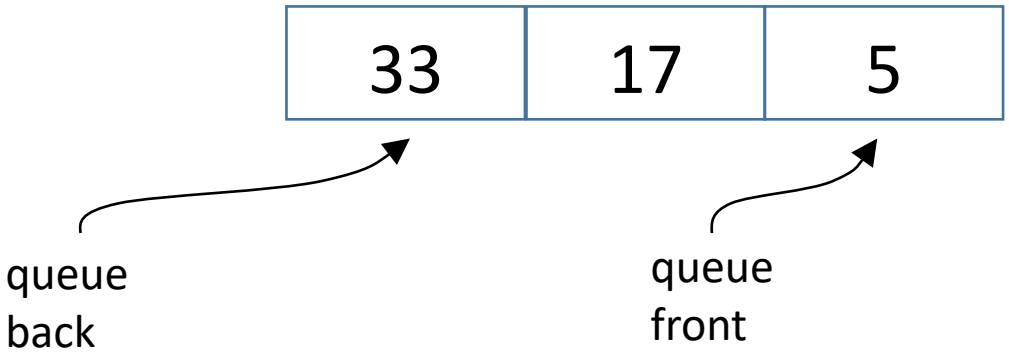
5 17 33 9 43



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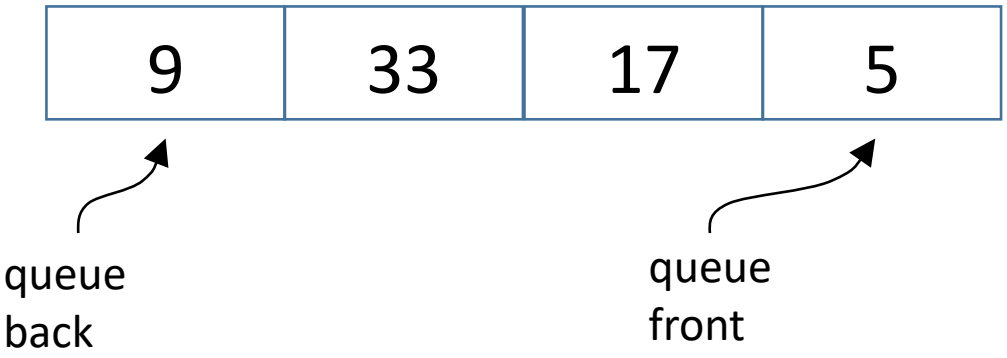
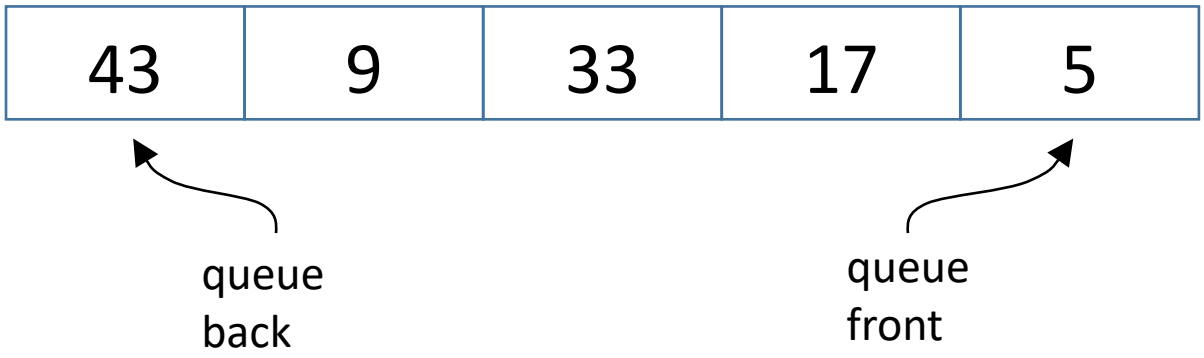


# Queues: insertion of values

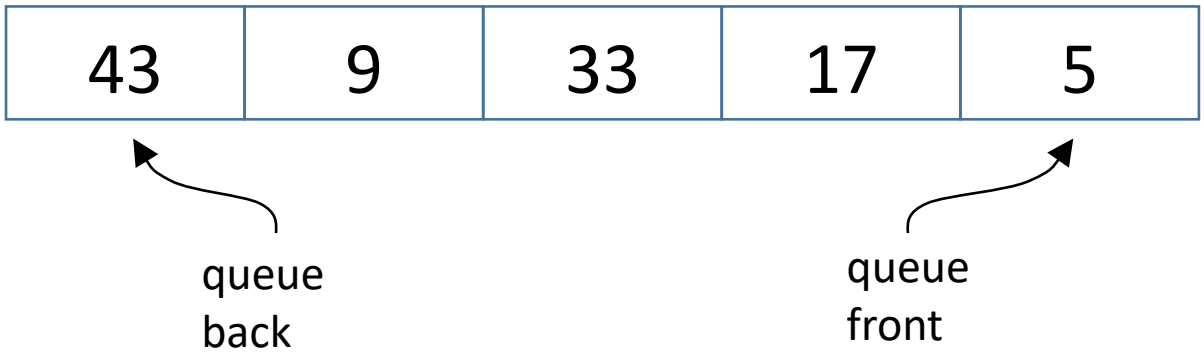
Insertion of a sequence of values into a queue:

5 17 33 9 43



# Queues: insertion of values

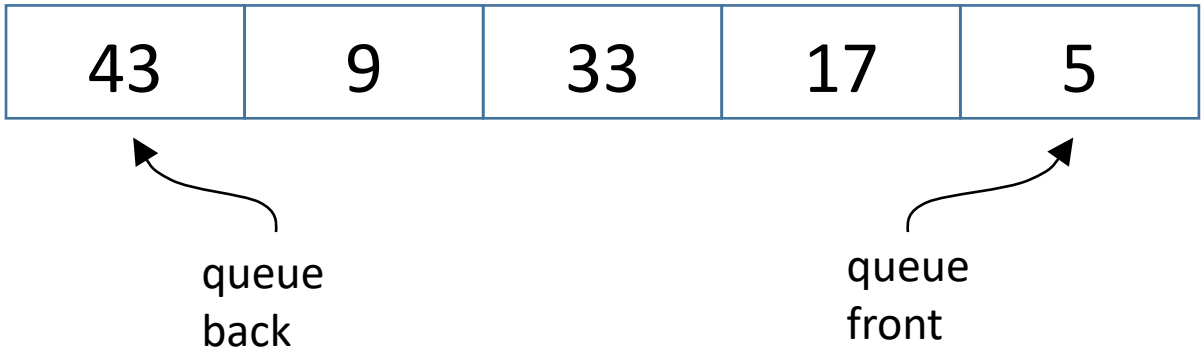
*order of insertion* → 5 17 33 9 43



# Queues: removal of values

*order of insertion* → 5 17 33 9 43

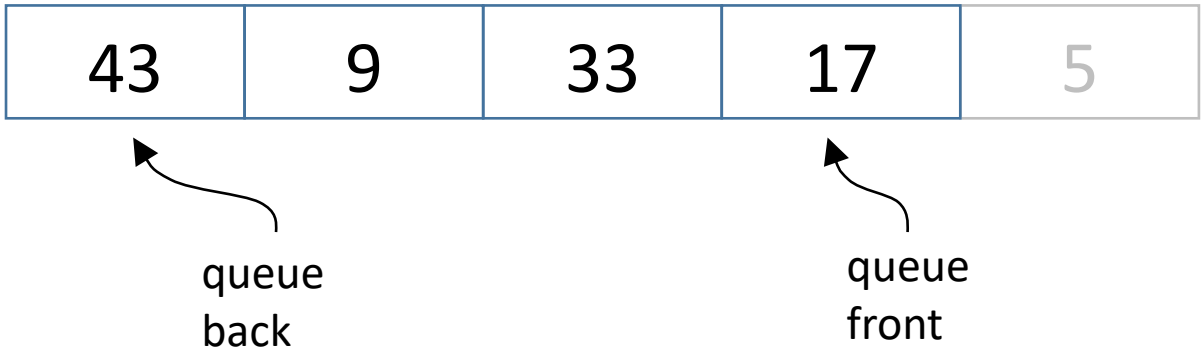
Removing values
from this queue:



# Queues: removal of values

*order of insertion* → 5 17 33 9 43

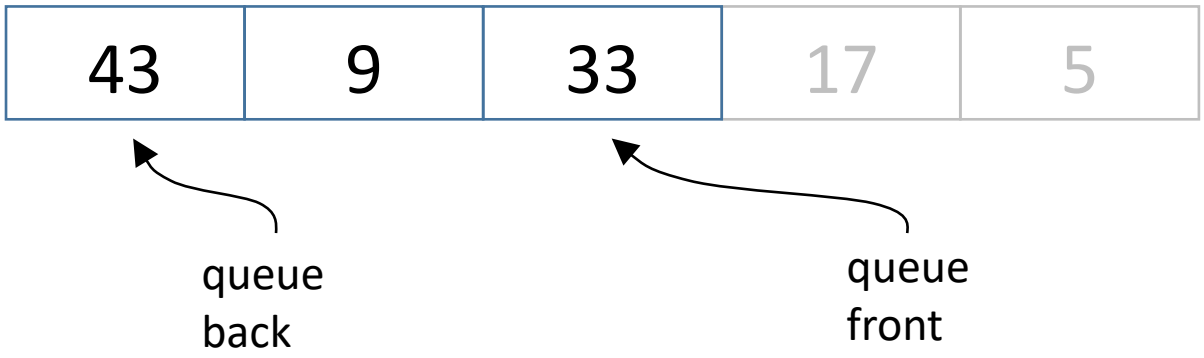
Removing values from this queue: 5



# Queues: removal of values

*order of insertion* → 5 17 33 9 43

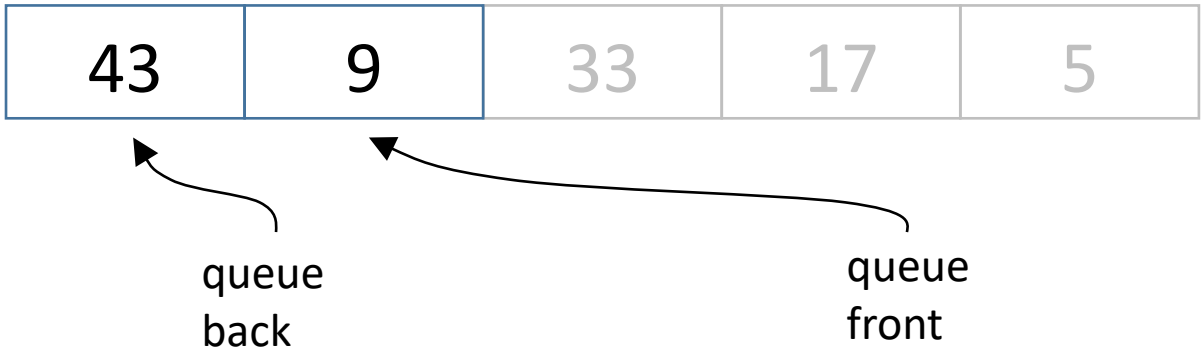
Removing values from this queue: 5 17



# Queues: removal of values

*order of insertion* → 5 17 33 9 43

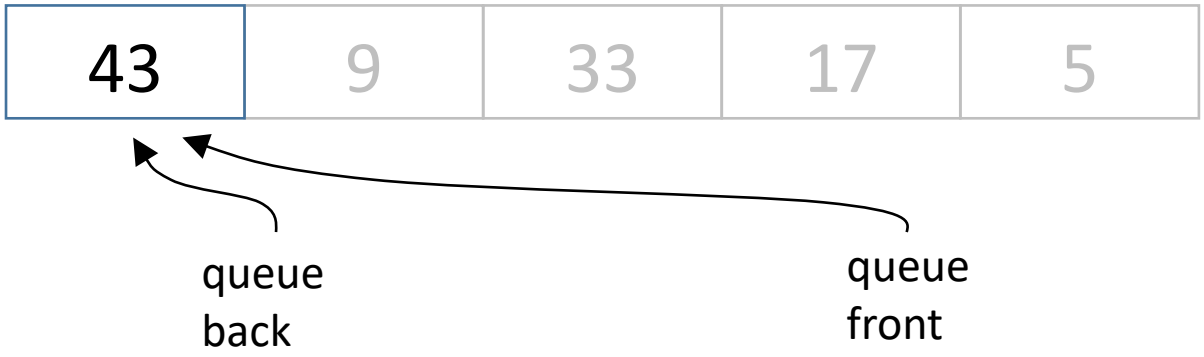
Removing values from this queue: 5 17 33



# Queues: removal of values

*order of insertion* → 5 17 33 9 43

Removing values from this queue: 5 17 33 9



# Queues: removal of values

*order of insertion* → 5 17 33 9 43

Removing values from this queue: 5 17 33 9 43


queue back None

queue front None

# Queues: removal of values

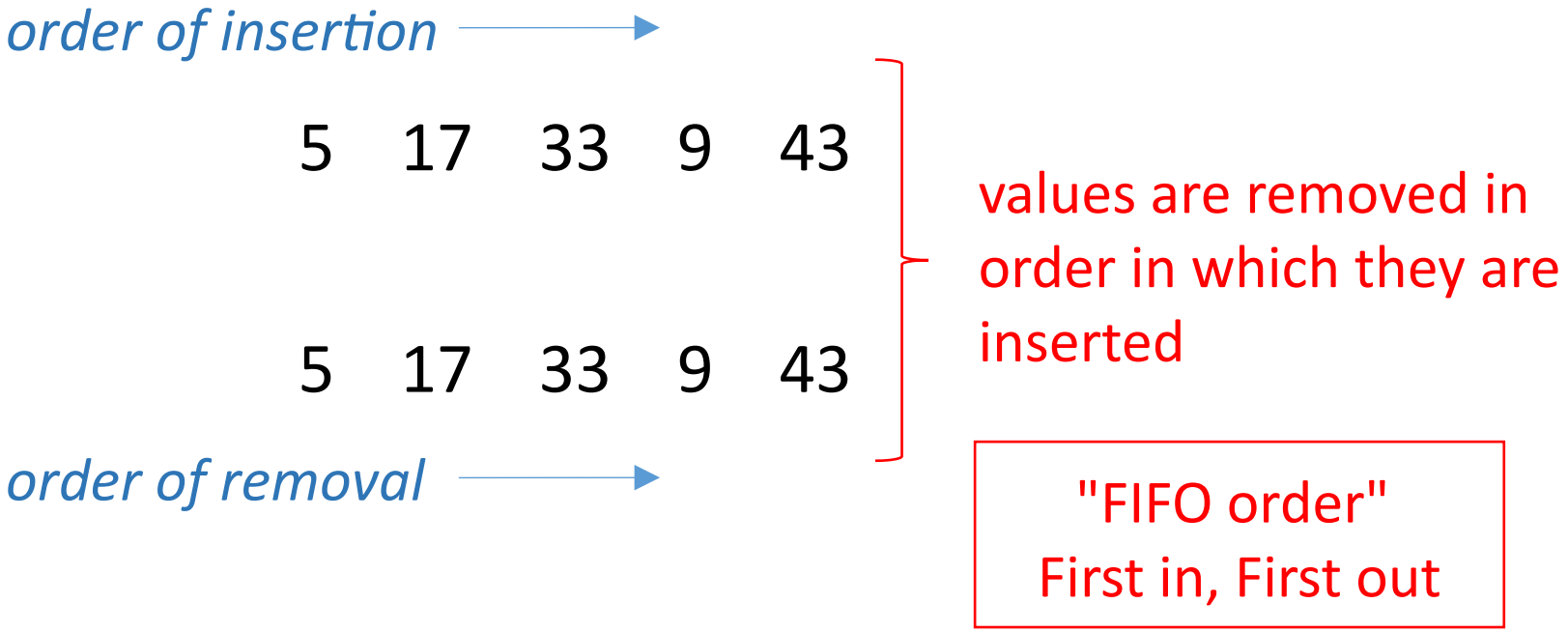
*order of insertion* →

5 17 33 9 43

5 17 33 9 43

*order of removal* →

# Queues: FIFO property



# Methods for a queue class

- Queue(): creates a new empty queue
- enqueue(*item*): adds *item* to the back of the queue
  - modifies the queue
  - returns nothing
- dequeue(): removes and returns the item at the front of the queue
  - returns the removed item
  - modifies the queue
- is_empty(): checks whether the queue is empty
  - returns a Boolean
- size(): returns the size of the queue
  - returns an integer

# EXERCISE

```
>>> q = Queue()
>>> q.enqueue(4)
>>> q.enqueue(17)
>>> x = q.dequeue()
>>> q.enqueue(5)
>>> y = q.dequeue()
```

← *what are the values of* x *and* y*?*

# EXERCISE

```
>>> q = Queue()
>>> q.enqueue(4)
>>> q.enqueue(17)
>>> x = q.dequeue()
>>> y = q.dequeue()
>>> q.enqueue(y)
>>> q.enqueue(x)
>>> q.enqueue(y)
```

← *what does the queue* q *look like here?*

# Implementing a queue class

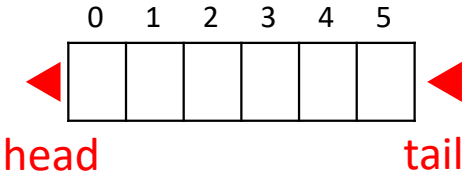
- Use a built-in list for the internal representation
  - Python lists can be added to from the front or the end
- First implementation:
  - the head is the $0^{th}$ element
  - the tail is the nth element
- Second implementation
  - the head is the nth element
  - the tail is the $0^{th}$ element

# Implementing a Queue class I

```
class Queue:
    # the front of the queue is the first item in the list
    def __init__(self):
        self._items = []

    def enqueue(self, item):
        self._items.append(item)

    def dequeue(self):
        return self._items.pop(0)
```




*removes and returns item 0 from the list*

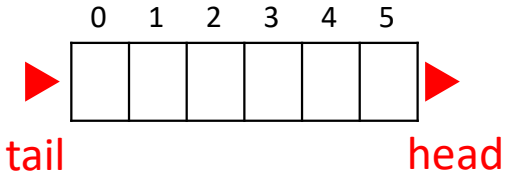
# EXERCISE-2

*Implement a queue with a Python list. Make the front of the queue the last item in the list*

```
class Queue:
    def _ _init_ _(self):


    def enqueue(self, item):


    def dequeue(self):
```

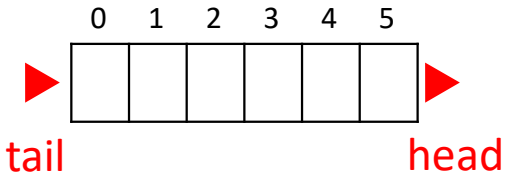


# Answer: implementation II

```
class Queue:
    # the front of the queue is the last item in the list
    def __init__(self):
        self._items = []

    def enqueue(self, item):
        self._items.insert(0, item)

    def dequeue(self):
        return self._items.pop()
```




*removes and returns the last item in the list*

# queues: applications

# Application 1: Simulation

- Typical applications simulate problems that require data to be managed in a FIFO manner
  - Hot potato
    - Kids stand in a circle and pass a “hot potato” around until told to stop. The person holding the potato is taken out of the circle. The process is repeated until only one person remains.
- Use a *simulation* to determine which person remains after num "passes" or rounds
  - Person at front of queue "holds" the potato
  - To pass the potato: simulate by dequeue/enqueue
  - After num passes, the person at the front is removed: simulate by dequeue
  - Let’s see this in action

# EXERCISE

Write a function hot_potato(q, num) that takes a queue q and the number of rounds of simulation num and eliminates the correct element after num rounds.

What operations take an element from the front of the queue and place it at the back of the queue?

# Solution

```
def hot_potato(q, num):

    for i in range(num):
        x = q.dequeue()
        q.enqueue(x)

    return q.dequeue()
```

# Application 1: Simulation

- Typical applications simulate problems that require data to be managed in a FIFO manner
  - Hot potato
  - Generalized: Given n elements, eliminate every kth element repeatedly until only 1 element is left. What was the original position of the remaining element?
  - Known as the Josephus problem:
    - for any n and any k, what original starting position will not be eliminated?

- Use a queue and a *simulation* to determine which element remains.

# EXERCISE

Problem: Given n, create a queue with n elements, then repeatedly eliminate every kth element until only 1 element is left. What was the original position of the remaining element?

use a queue to simulate the circle

n is the number of elements to put into the queue

while there is more than one element in the queue

    eliminate every kth element

# General solution for k=2

- Given n elements, eliminate every kth element repeatedly until only 1 element is left. What was the original position of the remaining element?
- When k = 2, the original position can be derived from the binary representation of n.

  Take the first digit of the binary representation.

  Move it to the end

  The result is the original position.

  Ex: n = 41, k=2

  In binary

  n = 101001

  Therefore, the original position (in binary) is

  010011

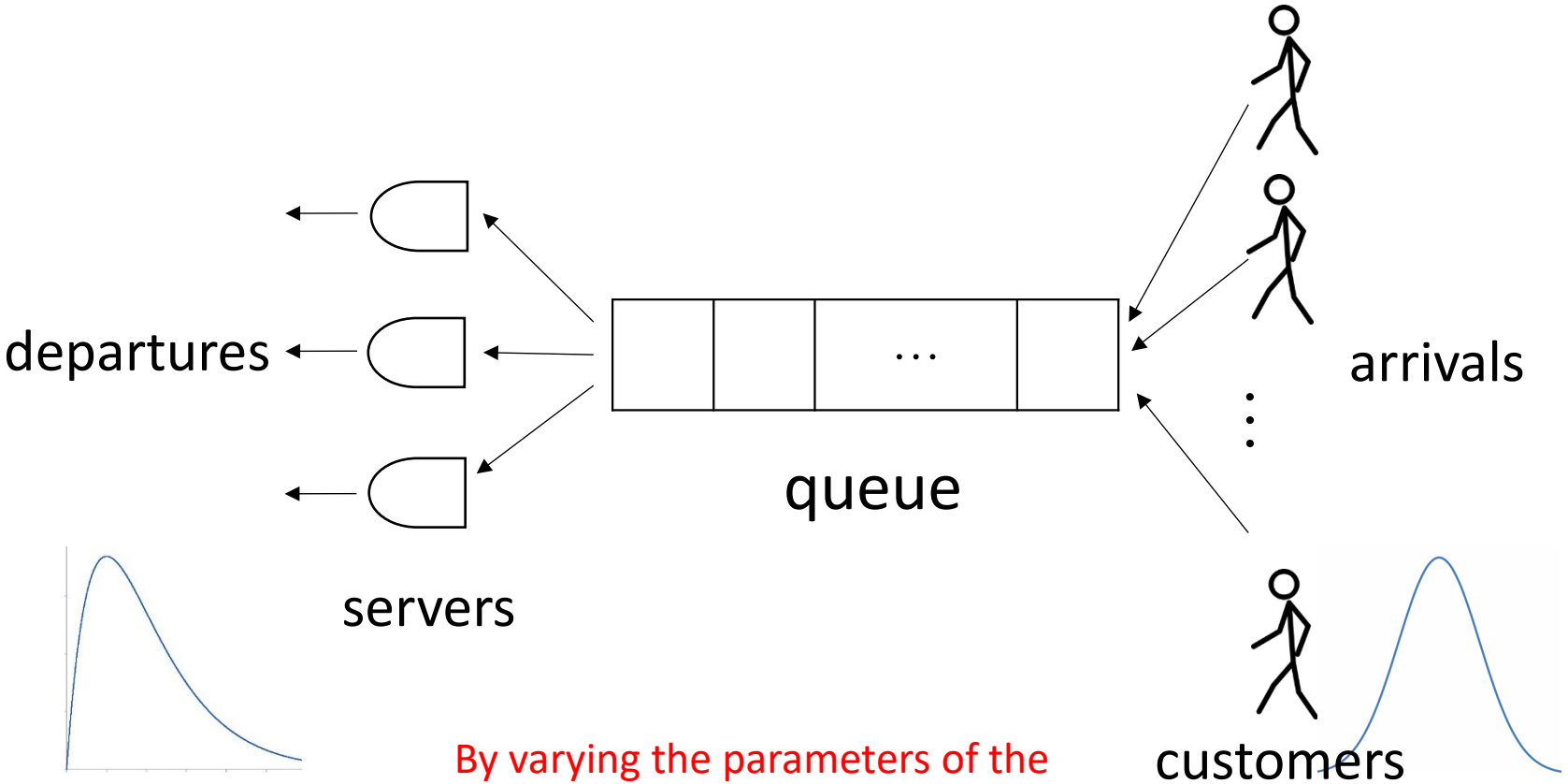
  and 010011 = $2^4 + 2^1 + 2^0 = 19$
- Let's check our simulation.

https://en.wikipedia.org/wiki/Josephus_problem#CITEREFDowdyMays1989

# Application 2 : Simulation

- Suppose we are opening a grocery store. How many checkout lines should we put in?
  - too few $\Rightarrow$ long wait times, unhappy customers
  - too many $\Rightarrow$ wasted money, space
- Use *simulations* of the checkout process to guide the decision
  - study existing stores to figure out typical shopping and checkout times
  - estimate no. of customers expected at the new location
  - run simulations to determine customer wait time and checkout line utilization under different scenarios

# Discrete event simulation




By varying the parameters of the simulation (arrival and departure rates, no. of servers) we can try out different scenarios

# Summary

- Stacks and queues are abstract data types (ADTs)
  - similar in that they are both *linear* data structures
  - items can be thought of as arranged in a line
  - each item has a position and a before/after relationship with the other items
- They differ in the way items are added and removed
  - stacks: items added and removed at one end
    - results in LIFO behavior
  - queues: items added at one end, removed at the other
    - results in FIFO behavior
- They find a wide range of applications in computer science