CMPUT 175 Introduction to Foundations of Computing

Queue, bounded Queue, Circular Queue

Post-test

You should view the vignettes:

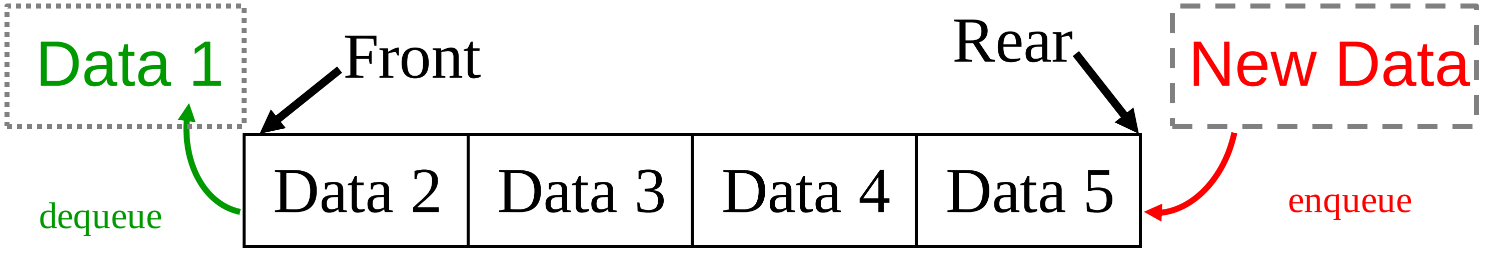
Queues

Objectives

- In this lecture we will learn about another linear structure called Queue.
- We will learn about how to implement the Queue data structure in python.
- We will discuss Other implementations such as bounded Queues and circular Queues.

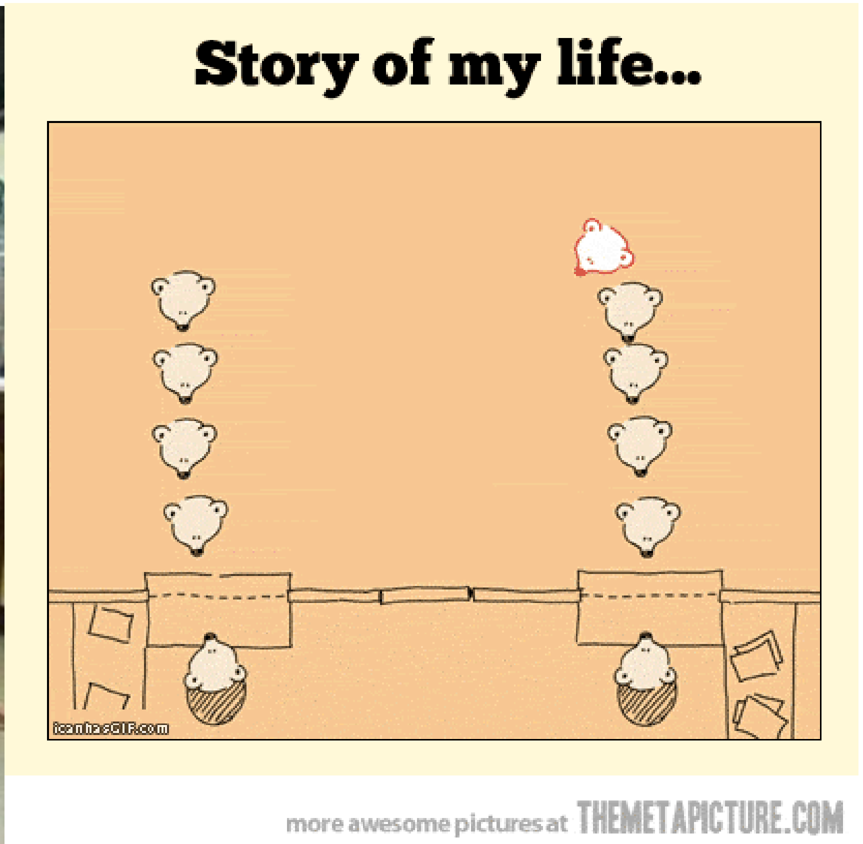
Queues

- Ordered collection where items are added at one end (called rear or tail) and removed at the other end (called front or head)



- First in - first out (FIFO)
  - Add element: enqueue (from rear of queue)
  - Remove element: dequeue (from front of queue)
  - is empty
  - check size

Funny Queues



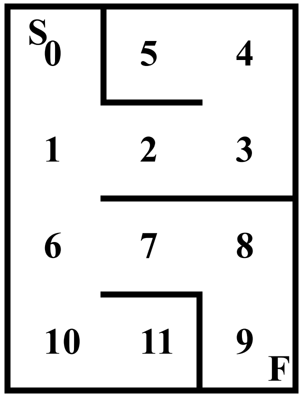
How useful are Queues

We will see some examples:

- Printing queue for waiting printing tasks
- Computing processes waiting list
- Keyboard buffer
- Traversing a maze
- …

Queue Example - Maze Algorithm

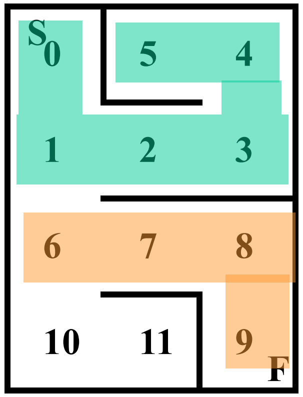
- Like Stacks, Queues can also be used to store unsearched paths.
- Repeat as long as the current square is not null and is not the finish square:
  - “Visit” the square and mark it as visited.
  - Enqueue one square on the queue for each unvisited legal move from the current square.
  - Dequeue the queue into the current square or bind the current square to null if the queue is empty.
- If the current square is the goal we are successful, otherwise there is no solution



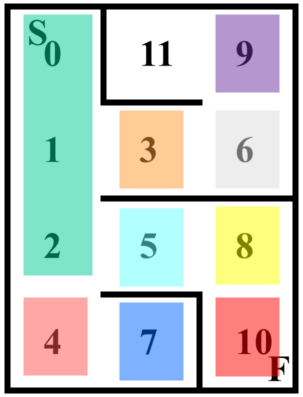
Queue Example - Searching

- The algorithm seems the same so what is the difference between using a Stack and a Queue?
- When a Stack is used, the search goes as deep along a single path as possible, before trying another path.
- When a Queue is used, the search expands a frontier of nodes equidistant from the start.

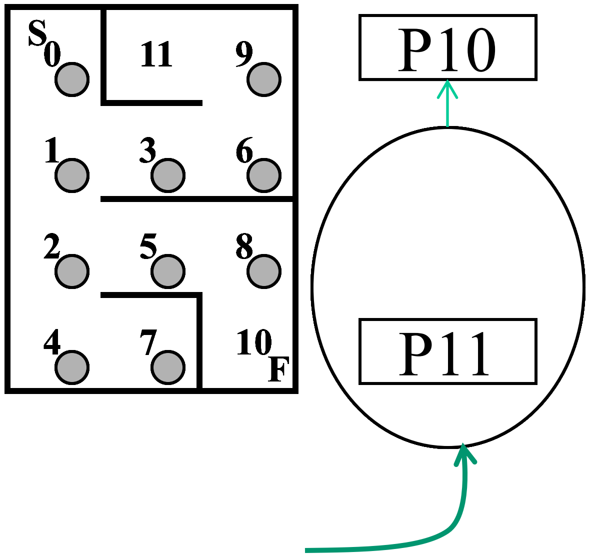
Stack Search



Queue Search



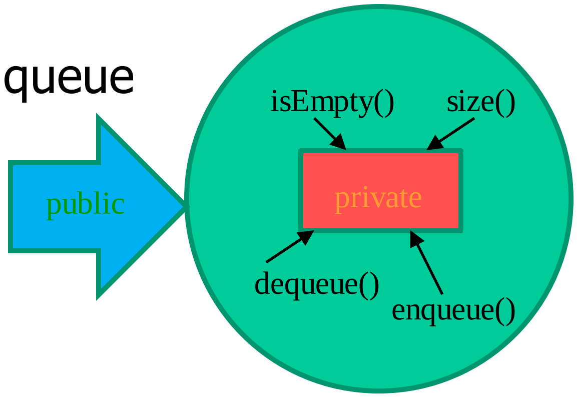
Queue Example - Maze Trace



Success!

Queue Abstract data Type

- **Queue()**
  - Create a new queue that is empty.
  - It needs no parameters and returns an empty queue
- **enqueue(item)**
  - Adds a new item to the rear of the queue.
  - It needs an item and returns nothing
- **dequeue()**
  - Remove the front item from the queue
  - It needs no parameters and returns the item.
  - The queue is modified.
- **isEmpty()**
  - Test to see whether the queue is empty
  - It needs no parameters and returns a Boolean value
- **size()**
  - Returns the number of items on the queue
  - It needs no parameters and returns an integer

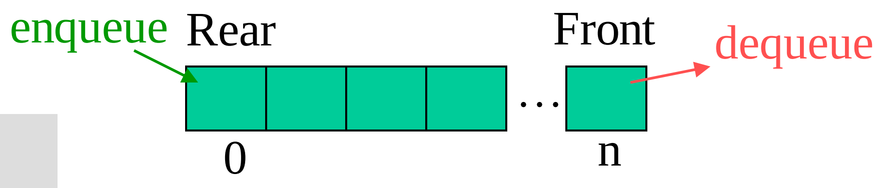


Queue Implementation in Python

- How to store the elements in the queue and allow the queue to grow and shrink one element at a time?
  - Using a python List
  - We chose the front (head) and rear (tail) of the queue to correspond to some fixed end of the list
- Implement each and every method as specified in the Queue ADT (enqueue, dequeue, isEmpty, size)
- Implement the class and instance constructor

Implementation

- Assuming we chose to have the rear on the left (position 0) of the list and the front on the right of a list.



Queue using List

```
class Queue:
    def __init__(self):
        self.items = []

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

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

```
def isEmpty(self):
        return self.items == []

def size(self):
        return len(self.items)
```

Printing the queue

- How to display the queue instance?
- The queue is implemented as a list and python knows how to display it.
- It is better to define a method to display the queue. Let’s call it show()

```
def show(self):
      print (self.items)
```

```
def __str__(self):
      return str(self.items)
```

Converts the object into a string

Let’s test it

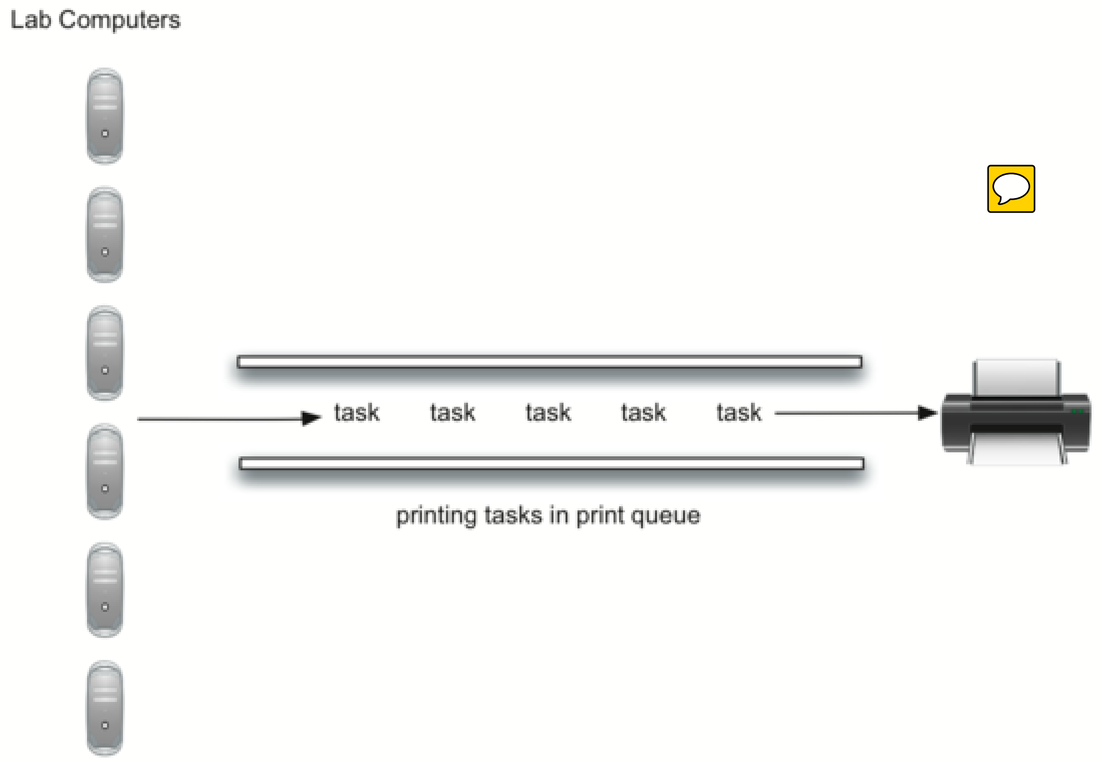
```
q=Queue()
q.show()
print (q.isEmpty())
q.enqueue("bob")
q.show()
print (q.isEmpty())
q.enqueue("eva")
q.enqueue("paul")
q.show()
print (q.size())
item=q.dequeue()
q.show()
print (item,"was first in the queue")
print (q.size())
```

```
[]
True
['bob']
False
['paul', 'eva', 'bob']
3
['paul', 'eva']
bob was first in the queue
2
```

It seems to work as designed but these are very rudimentary tests. More stringent tests done in isolation are always required.

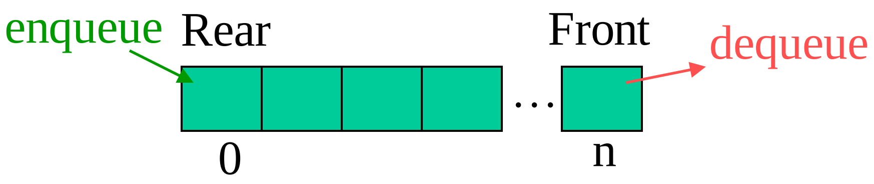
Printing Queue

- The textbook gives an illustrative example of use of Queues to manage printing tasks in a computing lab. and provides a simulation.

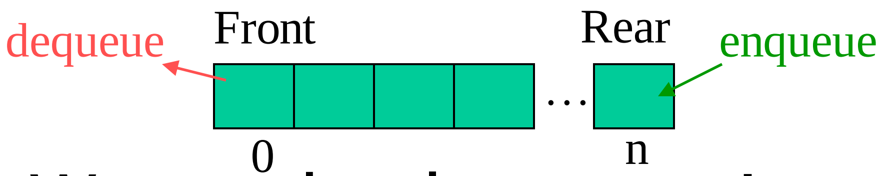


Implementation Options

- Using a list, we implemented the Queue by selecting the rear (tail) to be at position 0.



- We can opt to have the front (head) at position 0.



- We need only to rewrite enqueue() and dequeue().

```
class Queue:
    def __init__(self):
        self.items = []
    def isEmpty(self):
        return self.items == []

    def size(self):
        return len(self.items)
```

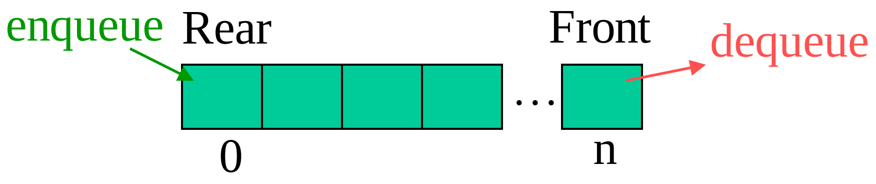
```
def enqueue(self, item):
    self.items.append(item)

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

Both implementations provide the same performance
One shifts elements on enqueue, the other shifts elements on dequeue

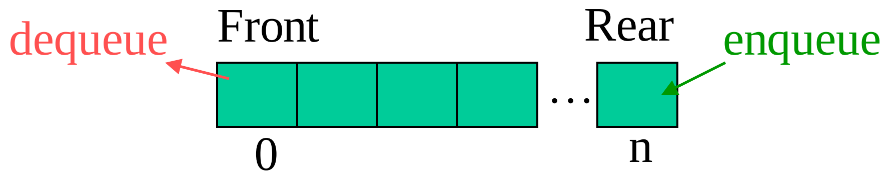
Comparision

- Rear at position 0.



- dequeue operation is O(1)
- enqueue operation is O(n)

- Front at position 0.



- dequeue operation is O(n)
- enqueue operation is O(1)

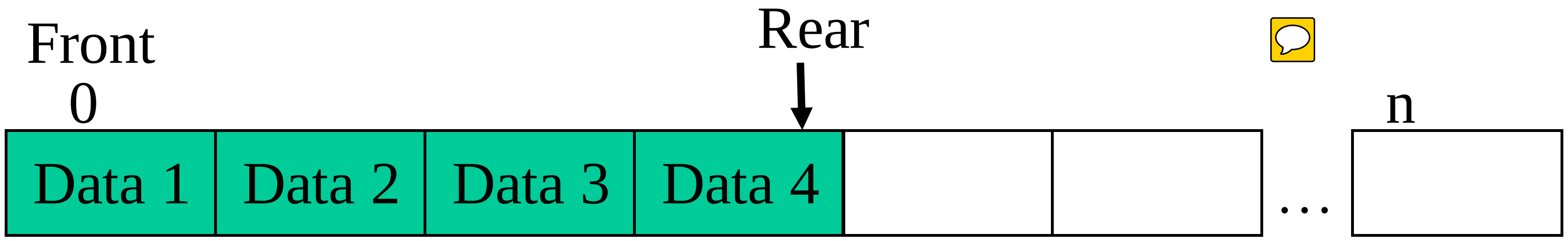
- There is an efficient implementation of the ADT queue that allows adding and removing element with O(1): Doubly-Linked-List
- We will see this data structure later after covering Linked Lists

Bounded Queues

- A bounded queue is a queue limited to a fixed number of items.
- The capacity is fixed at creation of the queue and can not be changed
- This is possible when we know a-priori the maximum size of the queue we would need.
- We can impose the front to be at position 0 of the list and have an index for the rear that we slide along the list.

Bounded Queues Visual

- This queue of capacity n has 4 elements.
- Front is always at position 0
- Current Rear is at position 3



- The implementation with python will remain as a lab exercise

Bounded Queue ADT

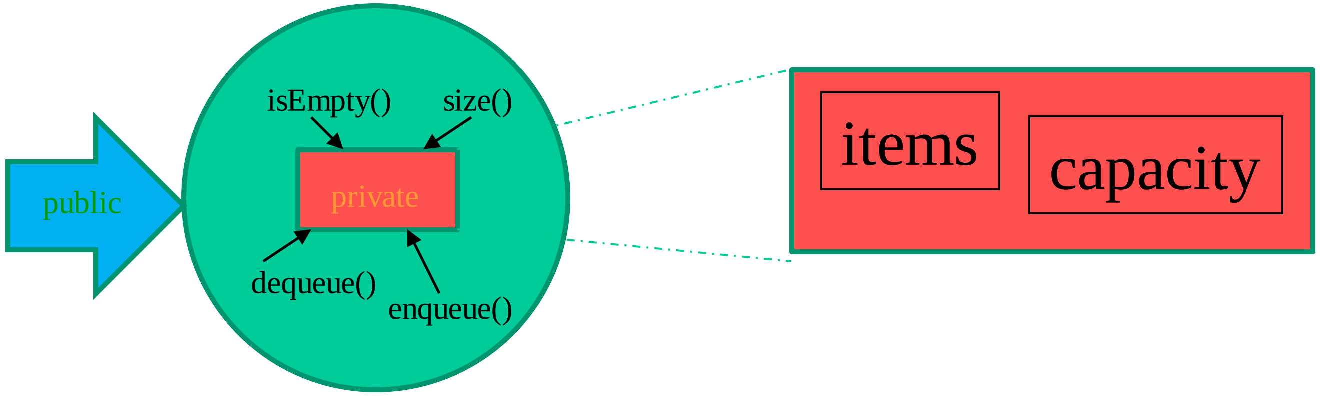
- **BQueue(capacity)**
  - Create a new queue of size *capacity* that is empty.
- **enqueue(item)**
  - Adds a new item *item* to the rear of the queue (if there is room).
- **dequeue()**
  - Remove the front item from the queue and return it.
- **peek()**
  - Return the front item from the queue without removing it
- **isEmpty()**
  - Test to see whether the queue is empty and return a Boolean value
- **isFull()**
  - Test to see whether the queue reached full capacity and return a Boolean value
- **size()**
  - Return the number of items on the queue
- **capacity()**
  - Return the capacity of the queue
- **clear()**
  - Empty the queue.

We need to raise exceptions when enqueue and reaching capacity or dequeue when queue is empty

Bounded Queue Constructor

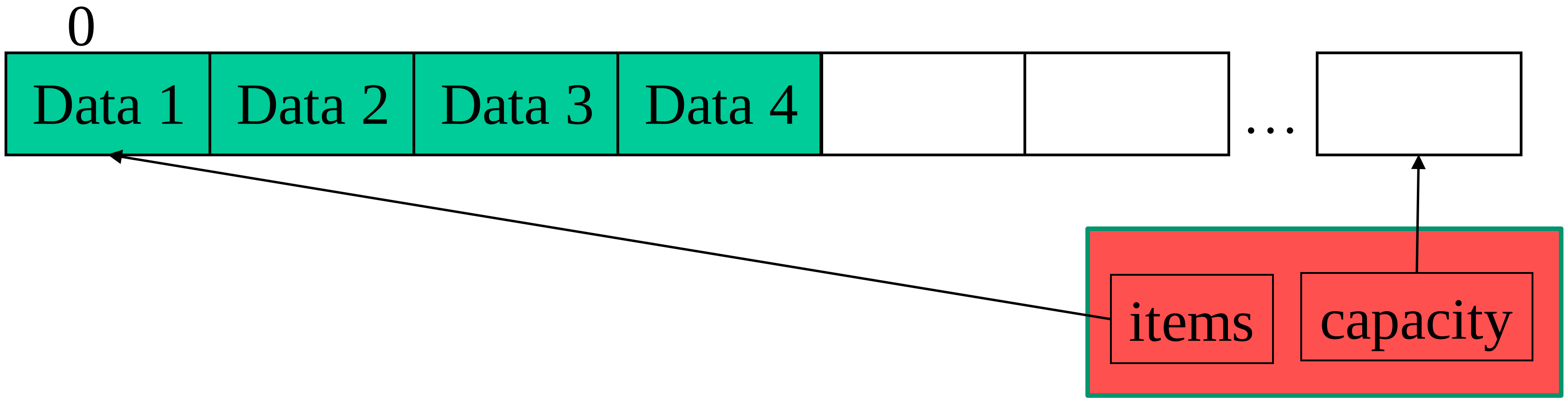
```
class BoundedQueue:
    # Constructor, which creates a new empty queue:
    def __init__(self, capacity):
        assert isinstance(capacity, int), ('Error: Type error: %s' % (type(capacity)))
        assert capacity >= 0, ('Error: Illegal capacity: %d' % (capacity))

        self.__items = []
        self.__capacity = capacity
```



Bounded Queue enqueue()

```
# Adds a new item to the back of the queue, and returns nothing:
def enqueue(self, item):
    if len(self.__items) >= self.__capacity:
        raise Exception('Error: Queue is full')
     self.__items.append(item)
```



Bounded Queue dequeue() and peek()

```
# Removes and returns the front-most item in the queue.
# Returns nothing if the queue is empty.
def dequeue(self):
     if len(self.__items) <= 0:
         raise Exception('Error: Queue is empty')
     return self.__items.pop(0)

# Returns the front-most item in the queue, and DOES NOT change the queue.
def peek(self):
    if len(self.__items) <= 0:
        raise Exception('Error: Queue is empty')

    return self.__items[0]
```

Bounded Queue isEmpty(), IsFull(), size() and capacity()

```
# Returns True if the queue is empty, and False otherwise:
def isEmpty(self):
        return len(self.__items) == 0

# Returns True if the queue is full, and False otherwise:
def isFull(self):
      return len(self.__items) == self.__capacity
```

```
# Returns the number of items in the queue:
def size(self):
      return len(self.__items)

# Returns the capacity of the queue:
def capacity(self):
      return self.__capacity
```

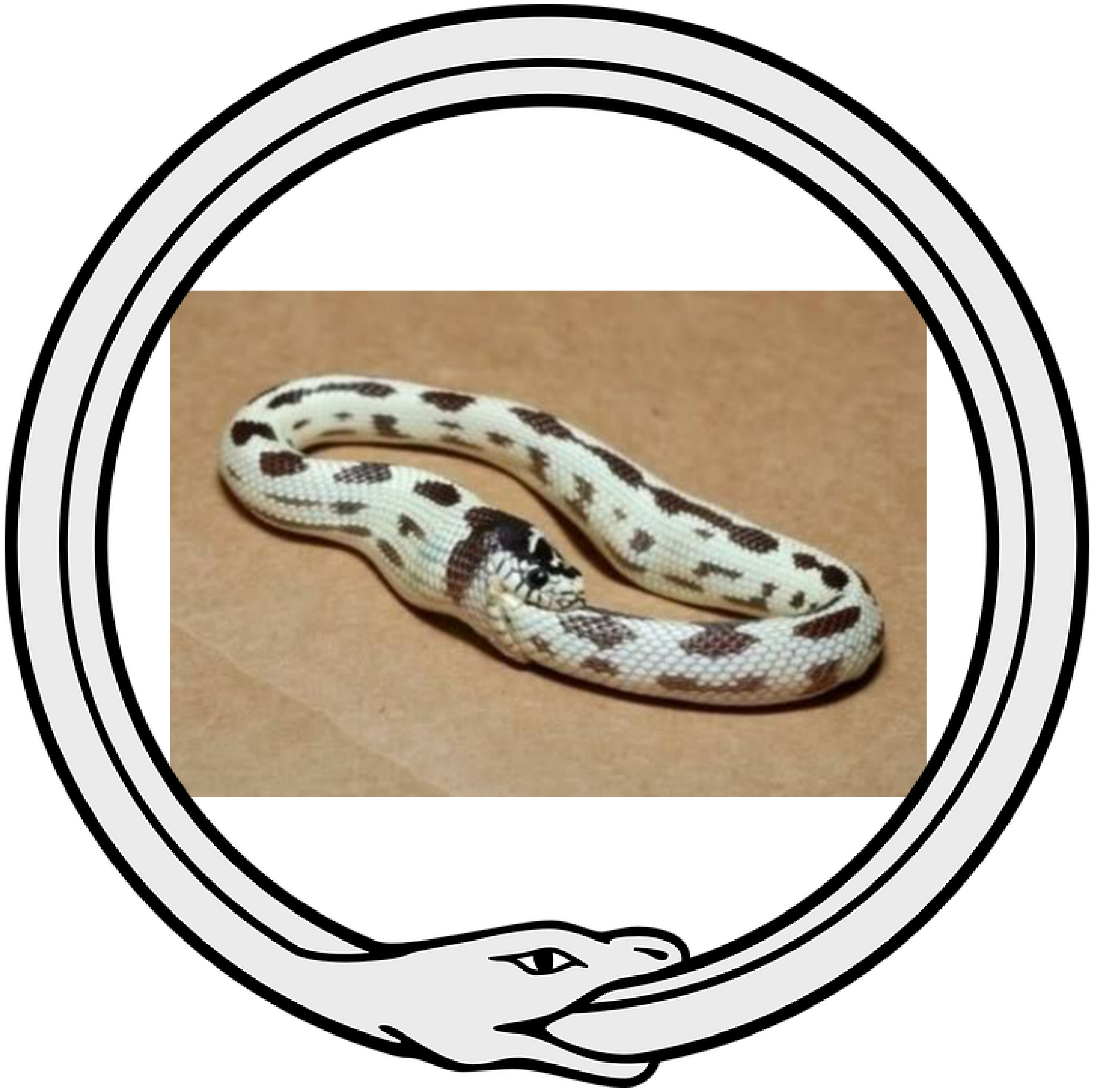
Bounded Queue clear() and str()

```
# Removes all items from the queue, and sets the size to 0
# clear() should not change the capacity
def clear(self):
      self.__items = []

# Returns a string representation of the queue:
def __str__(self):
   str_exp = ""
   for item in self.__items:
      str_exp += (str(item) + " ")
   return str_exp
```

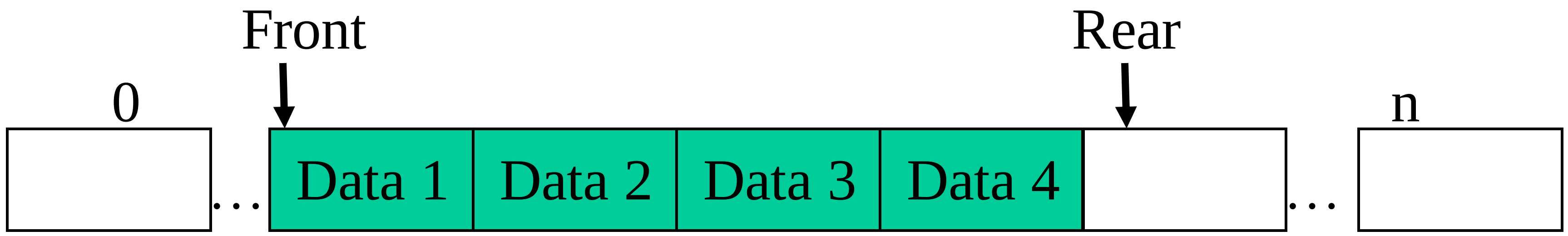
```
# Returns a string representation of the object
# bounded queue:
def __repr__(self):
   return  str(self) + " Max=" + str(self.__capacity)
```

```
1,2,3,4,5 Max=100
```

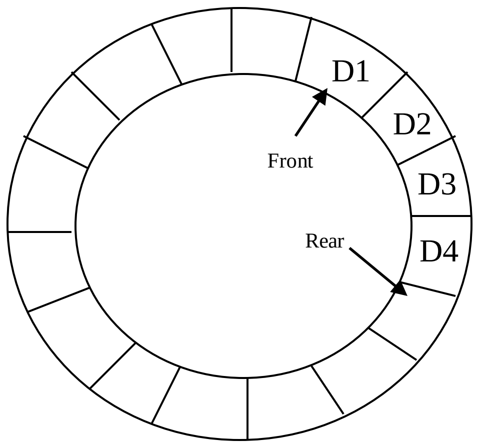


Circular Queues

- A circular queue is a bounded queue but instead of pinning the front (head) at position 0, both rear and front have indexes that slide

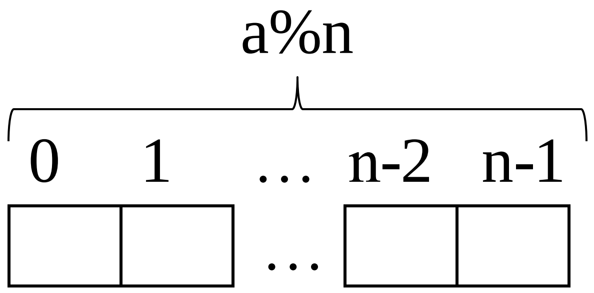


- Front is “chasing” rear modulo the capacity. This is why we call it circular



Let's talk about Modulus

- The modulo operation finds the remainder after division of one number *a* by another *n*
- *a* modulo *n* or *a* mod *n* or *a* % *n*
- *Remainder of a/n*
- *a%n is always between 0 and n-1*



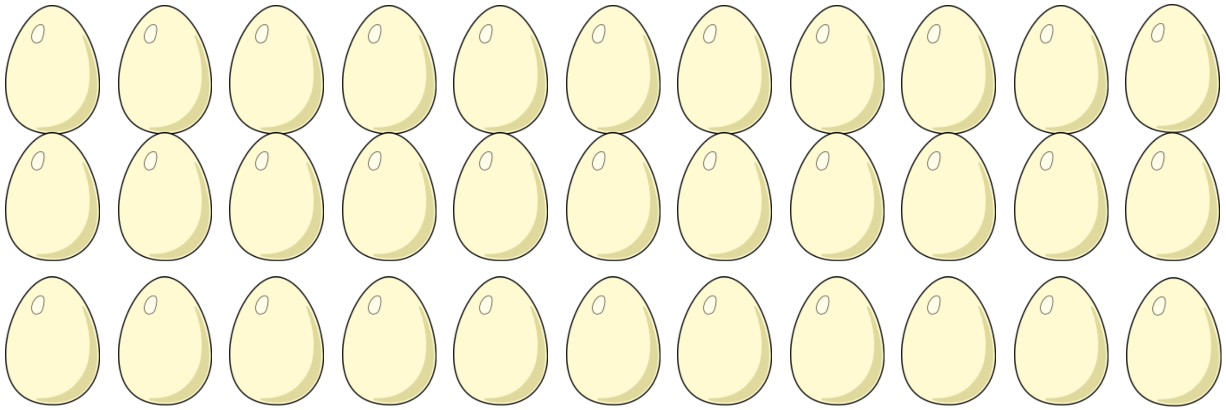
Visualize Modulus

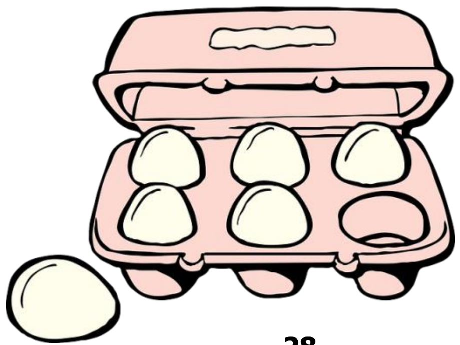
Clock is hour modulo 12

$$\underbrace{0,1,2,3,4,5,6,7,8,9,10,11}_{},\underbrace{0,1,2,3,4,5,6,7,8,9,10,11}_{},0,1,2\ldots$$

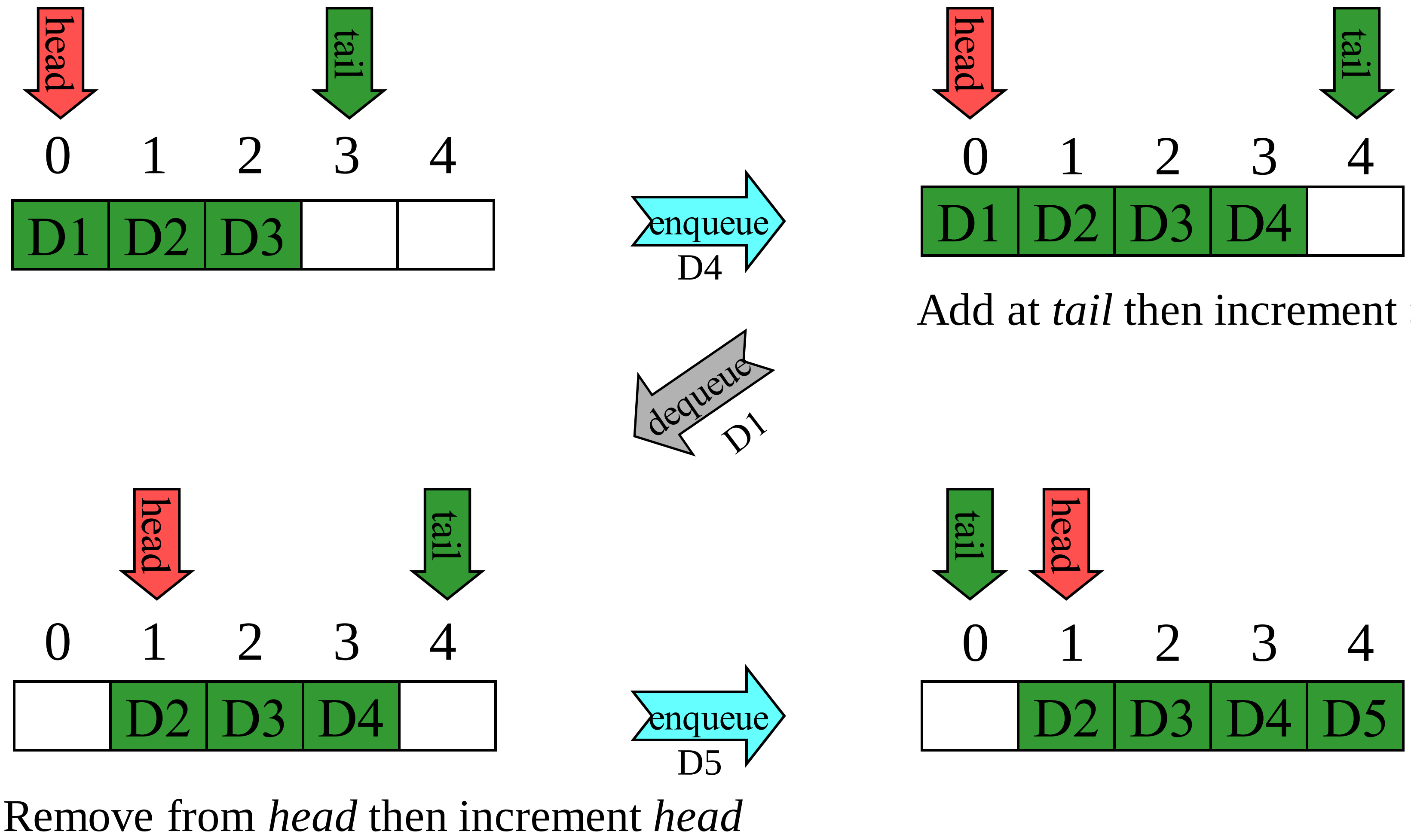
33 % 6 = ?

33 % 6 = 3





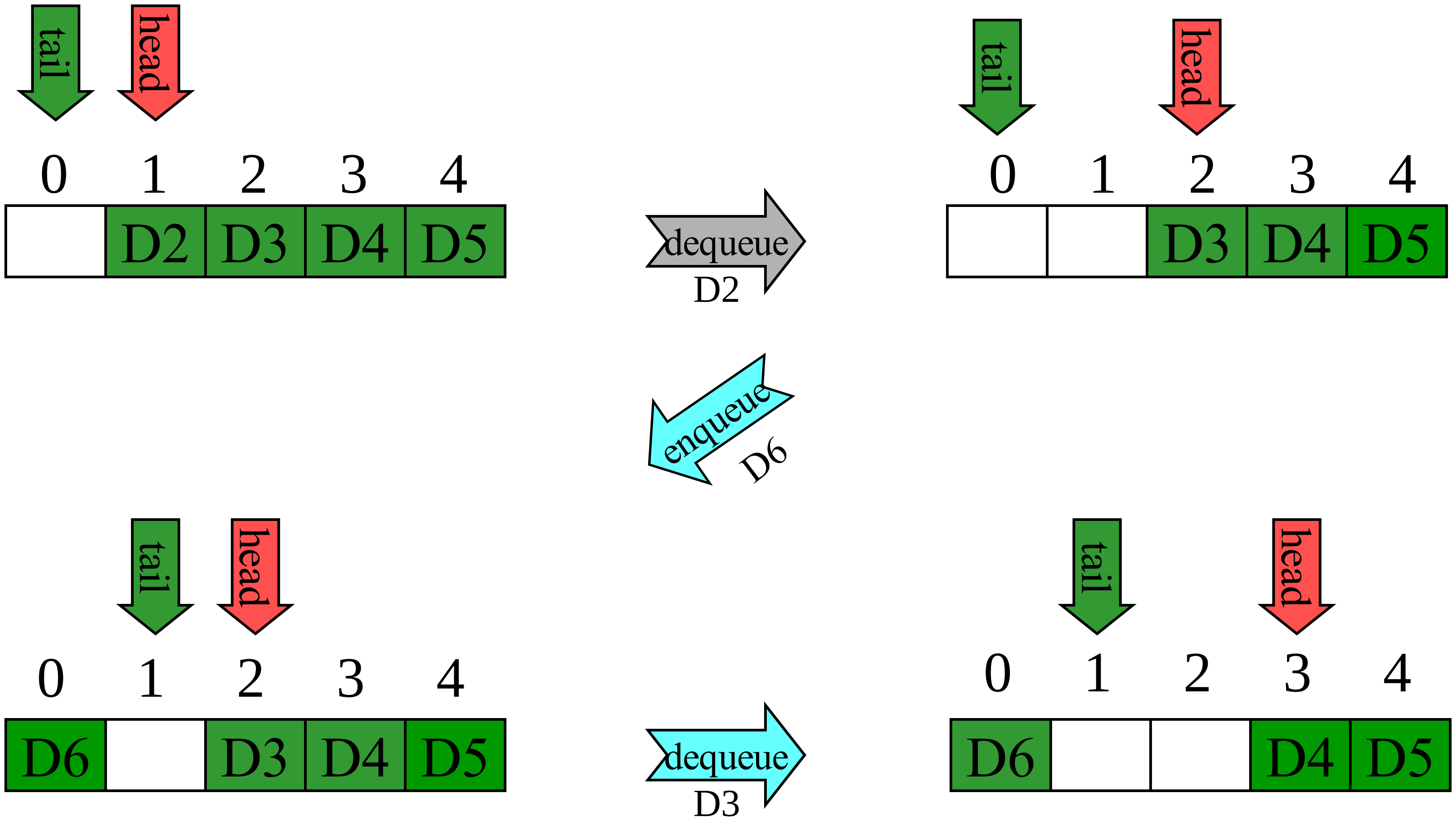
Sliding Indexes (slide 1)



Add at *tail* then increment *tail*

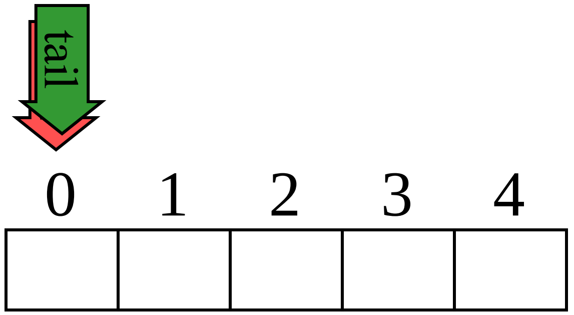
Remove from *head* then increment *head*

Sliding Indexes (slide 1)

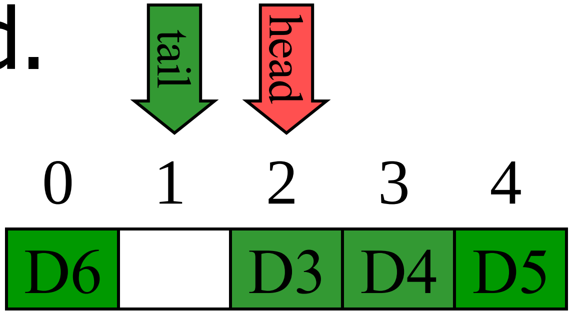


Circular Queues - Empty and Full

- We leave one empty entry in the Queue.
- The condition for an empty Queue is: head == tail.



- The condition for a full Queue is: tail is one "behind" head.

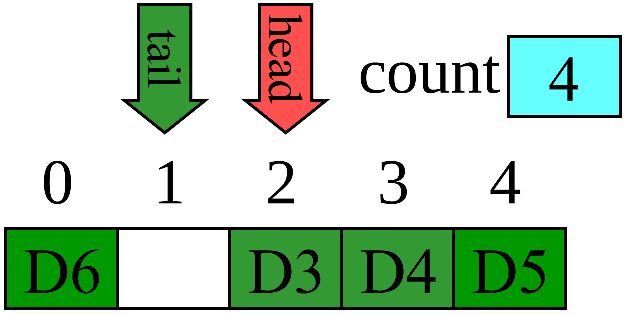


Circular Queues - Empty and Full

- We can avoid leaving one empty entry in the Queue by caching the current size of the queue
- The condition for an empty Queue is: the size is 0.
- The condition for a full Queue is: the size is equal to the queue maximum capacity.
- When enqueueing the cached size is incremented
- When dequeueing the cached size is decremented

Dequeue:
 remove from head
 increment head

Enqueue:
 add to tail
 increment tail



Circular Queue ADT

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  - Create a new queue of size *capacity* that is empty.
- **enqueue(item)**
  - Adds a new item *item* to the rear of the queue (if there is room).
- **dequeue()**
  - Remove the front item from the queue and return it.
- **peek()**
  - Return the front item from the queue without removing it
- **isEmpty()**
  - Test to see whether the queue is empty and return a Boolean value
- **isFull()**
  - Test to see whether the queue reached full capacity and return a Boolean value
- **size()**
  - Return the number of items on the queue
- **capacity()**
  - Return the capacity of the queue
- **clear()**
  - Empty the queue.

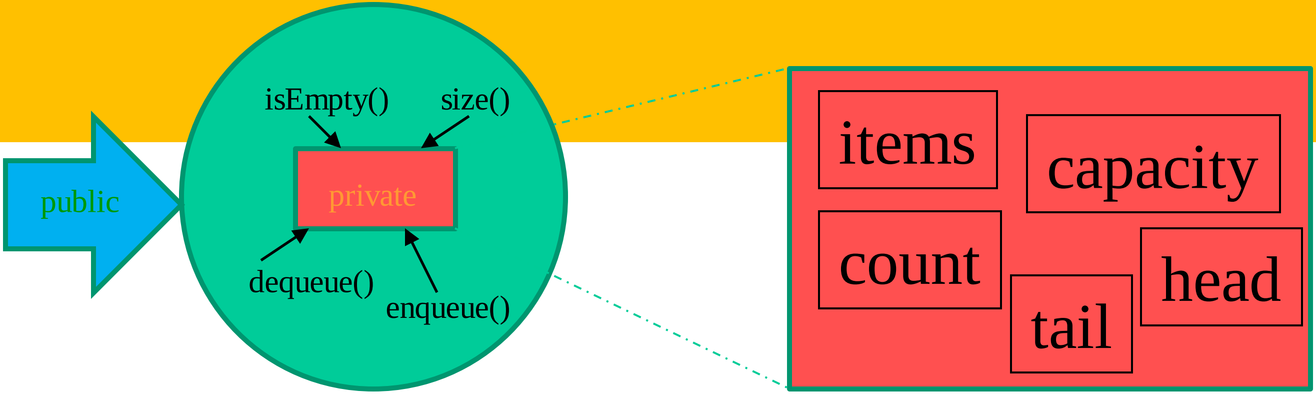
We need to raise exceptions when enqueue and reaching capacity or dequeue when queue is empty

Bounded Queue Constructor

```
class CircularQueue:
    # Constructor, which creates a new empty queue:
    def __init__(self, capacity):
        if  type(capacity) != int or capacity<=0:
            raise Exception ('Capacity Error')

        self.__items = []
        self.__capacity = capacity
        self.__count=0
        self.__head=0
        self.__tail=0
```

Different way to test input parameter

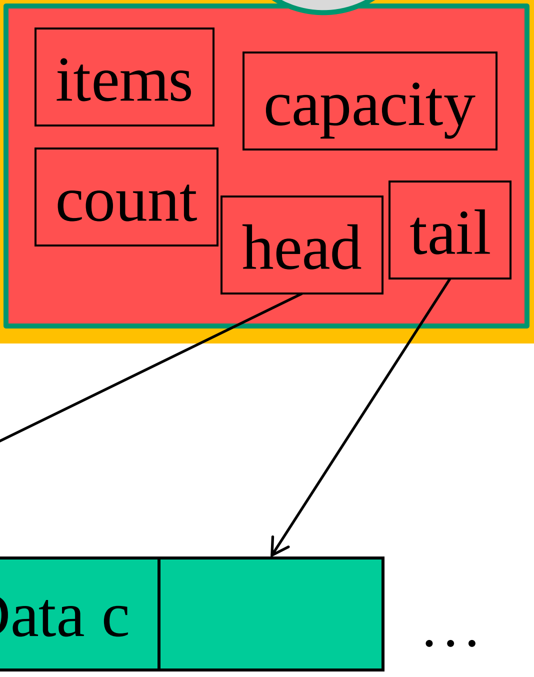


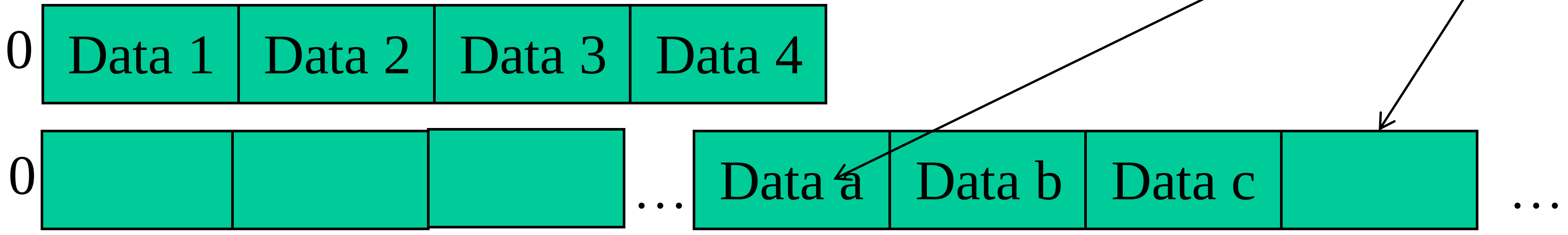
Circular Queue enqueue()

```
# Adds a new item to the back of the queue, and returns nothi
def enqueue(self, item):
    if self.__count== self.__capacity:
        raise Exception('Error: Queue is full')
    if len(self.__items) < self.__capacity:
        self.__items.append(item)
    else:
        self.__items[self.__tail]=item
    self.__count +=1
    self.__tail=(self.__tail +1) % self.__capacity
```

We could have avoided it if the constructor had:

```
for i in range(0, capacity):
    self.items.append(0)
```





Circular Queue dequeue() & peek()

```
# Removes and returns the front-most item in the queue.
# Returns nothing if the queue is empty.
def dequeue(self):
     if self.__count == 0:
         raise Exception('Error: Queue is empty')
     item= self.__items[self__head]
     self.__items[self.__head]=None
     self.__count -=1
     self.__head=(self.__head+1) % self.__capacity
     return item

# Returns the front-most item in the queue, and DOES NOT change the queue.
def peek(self):
    if self.__count == 0:
        raise Exception('Error: Queue is empty')

    return self.__items[self.__head]
```

Circular Queue isEmpty(), IsFull(), size() and capacity()

```
# Returns True if the queue is empty, and False otherwise:
def isEmpty(self):
        return self.__count == 0

# Returns True if the queue is full, and False otherwise:
def isFull(self):
      return self.__count == self.__capacity
```

```
# Returns the number of items in the queue:
def size(self):
      return self.__count

# Returns the capacity of the queue:
def capacity(self):
      return self.__capacity
```

Circular Queue clear() & str()

```
# Removes all items from the queue, and sets the size to 0
# clear() should not change the capacity
def clear(self):
        self.__items = []
        self.__count=0
        self.__head=0
        self.__tail=0

# Returns a string representation of the queue:
def __str__(self):
    str_exp = "]"
    i=self.__head
    for j in range(self.__count):
        str_exp += str(self.__items[i]) + " "
        i=(i+1) % self.__capacity
     return str_exp + "]"
```

```
]2 3 4 5 6 ]
```

Circular Queue repr()

```
# # Returns a string representation of the object  CircularQueue
def __repr__(self):
    return str(self.__items) + " H=“ + str(self.__head) + " T="+str(self.__tail) + " ("
+str(self.__count)+"/"+str(self.__capacity)+")"
```

```
[None, None, 2, 3, 4, 5, 6, None] H=2 T=7 (5/8)
```

```
[8, None, None, 3, 4, 5, 6, 7 ] H=3 T=1 (6/8)
```

Purpose of __str__ and __repr__

- Both are used to represent an object
- __str__ returns the informal string representation of an instance
- __str__ is called by the built-in function str() and by a print statement
- __repr__ returns an official string representation of an instance
- __repr__ is called by the built-in function repr()