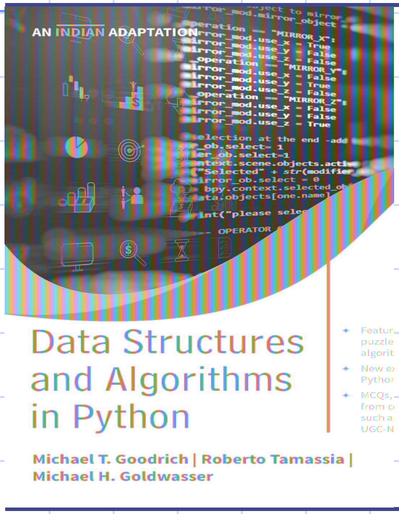
AN INDIAN ADAPTATION
Data Structures and Algorithms in Python
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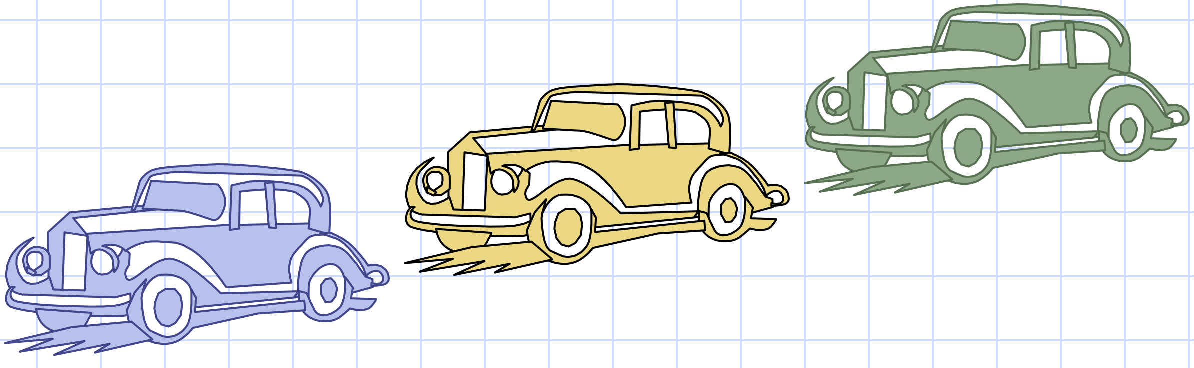
Adapted by Subhrakanta Panda

Chapter 7

Queues

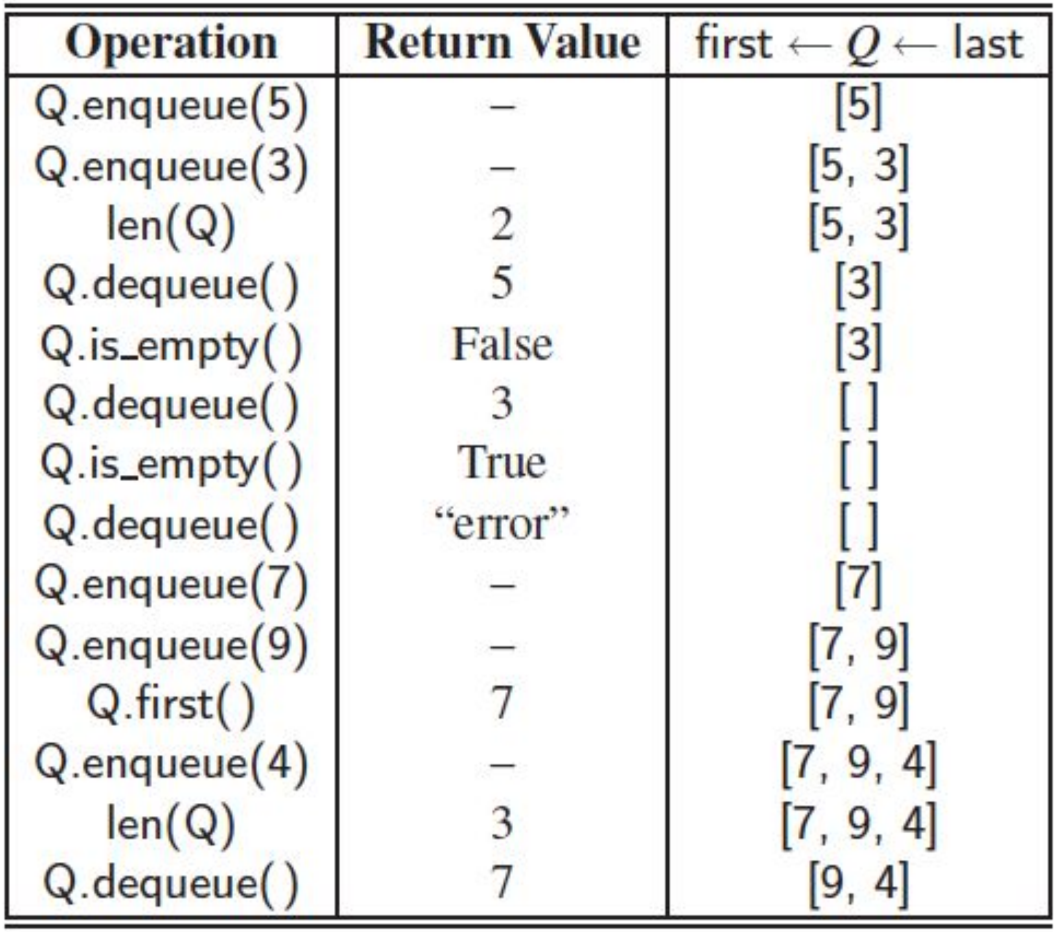
Queues



The Queue ADT

- The Queue ADT stores arbitrary objects
- Insertions and deletions follow the first-in first-out scheme
- Insertions are at the rear of the queue and removals are at the front of the queue
- Main queue operations:
  - enqueue(object): inserts an element at the end of the queue
  - object dequeue(): removes and returns the element at the front of the queue
- Auxiliary queue operations:
  - object first(): returns the element at the front without removing it
  - integer len(): returns the number of elements stored
  - boolean is_empty(): indicates whether no elements are stored
- Exceptions
  - Attempting the execution of dequeue or front on an empty queue throws an EmptyQueueException

Example



Operation	Return Value	first ← Q ← last
Q.enqueue(5)	–	[5]
Q.enqueue(3)	–	[5, 3]
len(Q)	2	[5, 3]
Q.dequeue( )	5	[3]
Q.is_empty( )	False	[3]
Q.dequeue( )	3	[ ]
Q.is_empty( )	True	[ ]
Q.dequeue( )	“error”	[ ]
Q.enqueue(7)	–	[7]
Q.enqueue(9)	–	[7, 9]
Q.first( )	7	[7, 9]
Q.enqueue(4)	–	[7, 9, 4]
len(Q)	3	[7, 9, 4]
Q.dequeue( )	7	[9, 4]

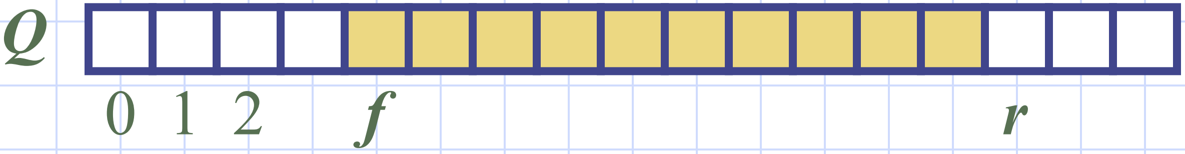
Applications of Queues

- Direct applications
  - Waiting lists, bureaucracy
  - Access to shared resources (e.g., printer)
  - Multiprogramming
- Indirect applications
  - Auxiliary data structure for algorithms
  - Component of other data structures

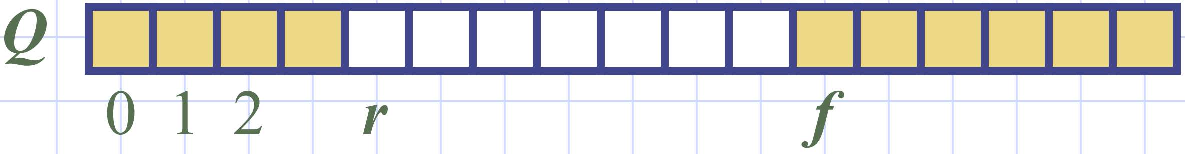
Array-based Queue

- Use an array of size N in a circular fashion
- Two variables keep track of the front and rear
  - f index of the front element
  - r index immediately past the rear element
- Array location r is kept empty

normal configuration



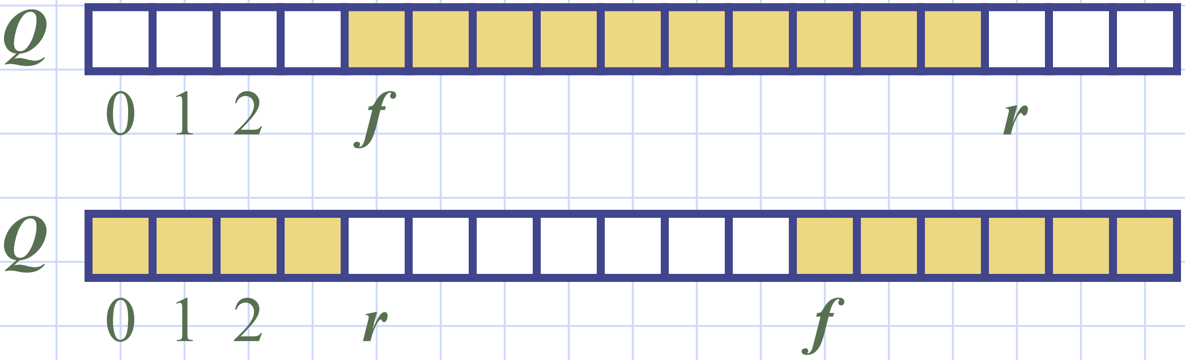
wrapped-around configuration



Queue Operations

- We use the modulo operator (remainder of division)

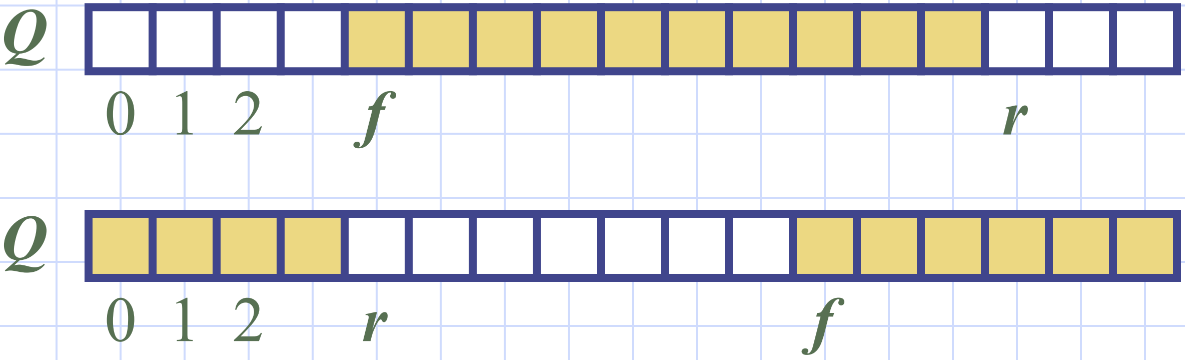
```
Algorithm size()
    return $(N - f + r) \bmod N$

Algorithm isEmpty()
    return $(f = r)$
```



Queue Operations (cont.)

- Operation enqueue throws an exception if the array is full
- This exception is implementation-dependent

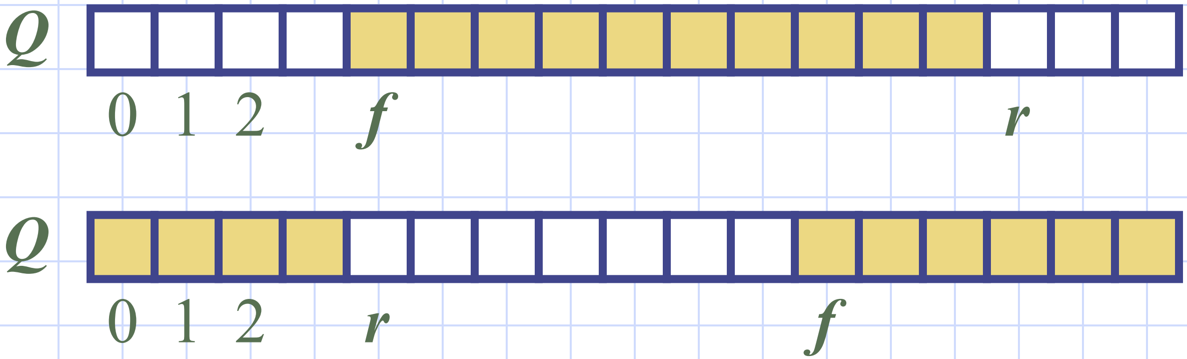
```
Algorithm enqueue(o)
    if size() = N − 1 then
        throw FullQueueException
    else
        Q[r] ← o
        r ← (r + 1) mod N
```



Queue Operations (cont.)

- Operation dequeue throws an exception if the queue is empty
- This exception is specified in the queue ADT

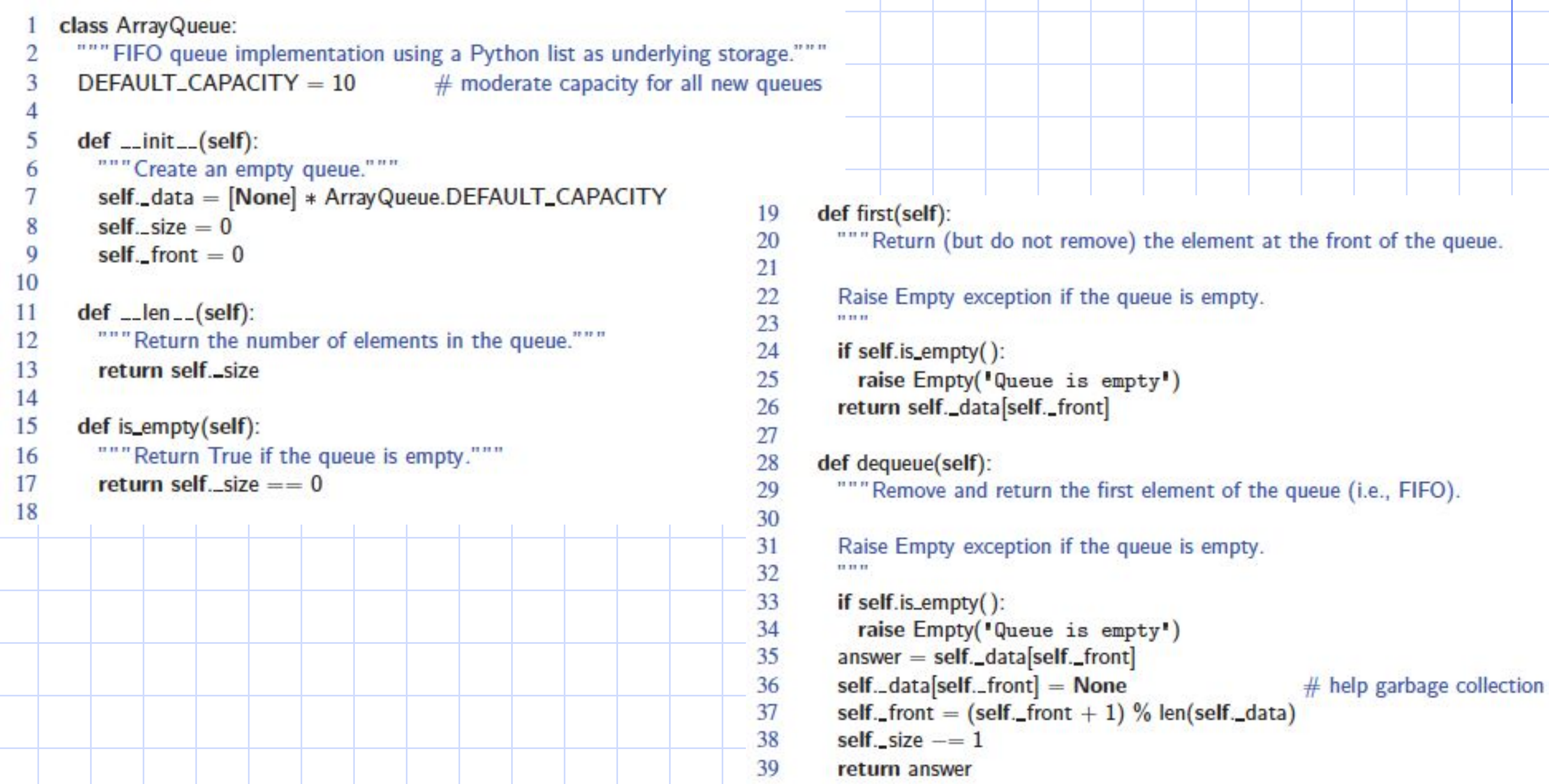
```
Algorithm dequeue()
    if isEmpty() then
        throw EmptyQueueException
    else
        $o \leftarrow Q[f]$
        $f \leftarrow (f + 1) \bmod N$
        return $o$
```



Queue in Python

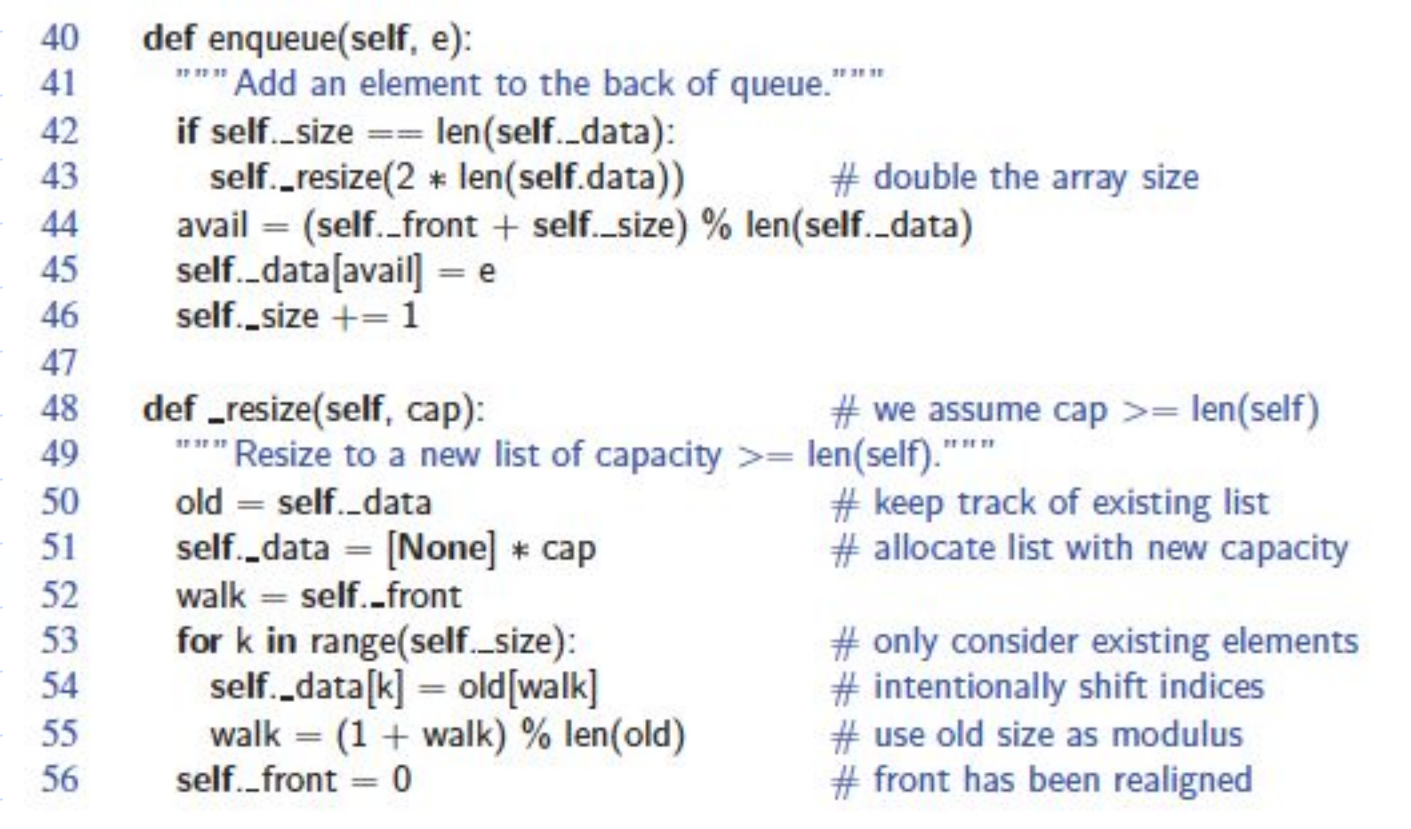
- Use the following three instance variables:
  - _data: is a reference to a list instance with a fixed capacity.
  - _size: is an integer representing the current number of elements stored in the queue (as opposed to the length of the data list).
  - _front: is an integer that represents the index within data of the first element of the queue (assuming the queue is not empty).

Queue in Python, Beginning



```
class ArrayQueue:
  """FIFO queue implementation using a Python list as underlying storage."""
  DEFAULT_CAPACITY = 10          # moderate capacity for all new queues

  def __init__(self):
    """Create an empty queue."""
    self._data = [None] * ArrayQueue.DEFAULT_CAPACITY
    self._size = 0
    self._front = 0

  def __len__(self):
    """Return the number of elements in the queue."""
    return self._size

  def is_empty(self):
    """Return True if the queue is empty."""
    return self._size == 0

  def first(self):
    """Return (but do not remove) the element at the front of the queue.

    Raise Empty exception if the queue is empty.
    """
    if self.is_empty():
      raise Empty('Queue is empty')
    return self._data[self._front]

  def dequeue(self):
    """Remove and return the first element of the queue (i.e., FIFO).

    Raise Empty exception if the queue is empty.
    """
    if self.is_empty():
      raise Empty('Queue is empty')
    answer = self._data[self._front]
    self._data[self._front] = None                  # help garbage collection
    self._front = (self._front + 1) % len(self._data)
    self._size -= 1
    return answer
```

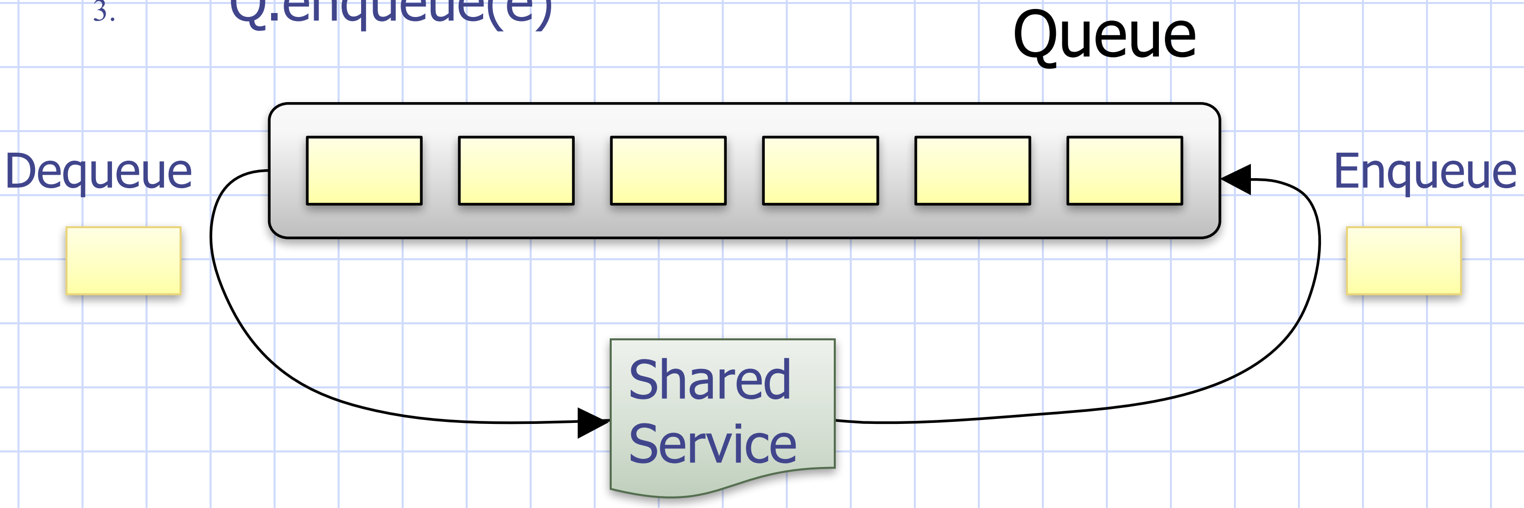
Queue in Python, Continued



```
  def enqueue(self, e):
    """Add an element to the back of queue."""
    if self._size == len(self._data):
      self._resize(2 * len(self.data))          # double the array size
    avail = (self._front + self._size) % len(self._data)
    self._data[avail] = e
    self._size += 1

  def _resize(self, cap):                       # we assume cap >= len(self)
    """Resize to a new list of capacity >= len(self)."""
    old = self._data                            # keep track of existing list
    self._data = [None] * cap                   # allocate list with new capacity
    walk = self._front
    for k in range(self._size):                 # only consider existing elements
      self._data[k] = old[walk]                 # intentionally shift indices
      walk = (1 + walk) % len(old)              # use old size as modulus
    self._front = 0                             # front has been realigned
```

Application: Round Robin Schedulers

- We can implement a round robin scheduler using a queue Q by repeatedly performing the following steps:
  1. e = Q.dequeue()
  2. Service element e
  3. Q.enqueue(e)


Queue
Dequeue
Enqueue
Shared Service