APA 254
Data Structures

Lecture 6.1
(Queues)

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Queues

- Like a stack, special kind of linear list
- One end is called front
- Other end is called rear
- Additions (insertions or enqueue) are done at the rear only
- Removals (deletions or dequeue) are made from the front only

Queue ADT

AbstractDataType queue {

instances

ordered list of elements; one end is the front; the other is the rear;

operations

empty():	Return true if queue is empty, return false otherwise
size():	Return the number of elements in the queue
front():	Return the front element of queue
back():	Return the back (rear) element of queue
pop():	Remove an element from the queue // **dequeue**
push(x):	Add element x to the queue // **enqueue**

}

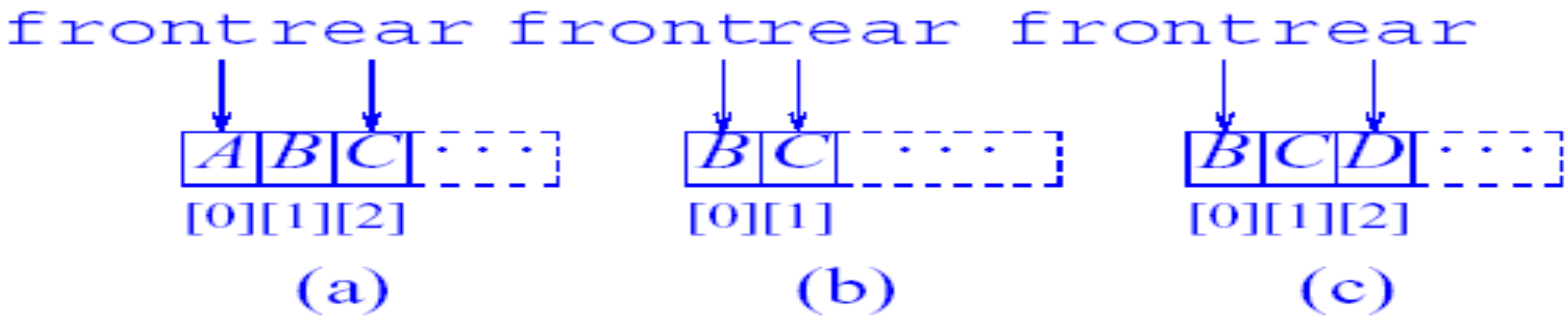
It is also possible to represent Queues using

1. Array-based representation
2. Linked representation

The Abstract Class queue

```
template <class T>  // Program 9.1
class queue
{
  public:
    virtual ~queue() {}
    virtual bool empty() const = 0;
    virtual int size() const = 0;
    virtual T& front() = 0;
    virtual T& back() = 0;
    virtual void pop() = 0;
    virtual void push(const T& theElement) = 0;
};
```

Array-based Representation of Queue



- Using simple formula equation

  location(i) = i – 1

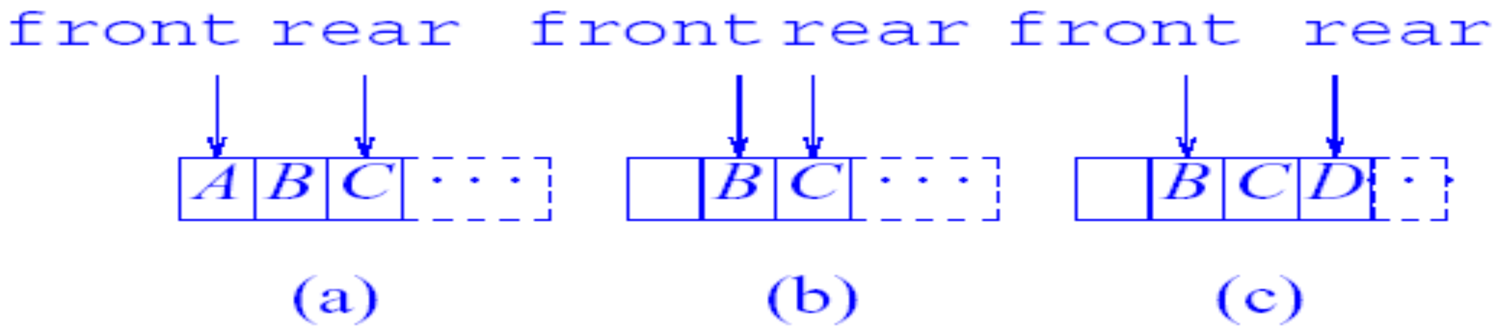
  - The first element is in queue[0], the second element is in queue[1], and so on
  - Front always equals zero, back (rear) is the location of the last element, and the **queue size** is **rear + 1**
  - How much time does it need for pop()?

Derive from ArrayLinearList

- When front is left end of list and rear is right end:
  - Queue.empty() → ArrayLinearList.empty() **O(1)**
  - x = Queue.front() → ArrayLinearList.get(0) **O(1)**
  - x = Queue.back() → ArrayLinearList.get(length) **O(1)**
  - Queue.push(x) → ArrayLinearList.insert(length, x) **O(1)**
  - Queue.pop() → ArrayLinearList.erase(0) **O(length)**

- To perform every operation in O(1) time, we need a customized array representation

Array-based Representation of Queue



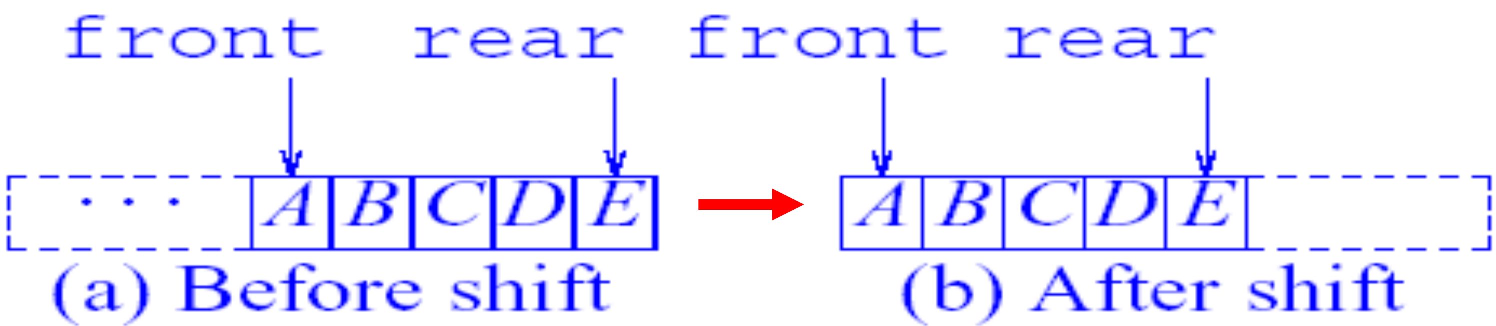
- Using modified formula equation

  $$location(i) = location(1) + i - 1$$

  - No need to shift the queue one position left each time an element is deleted from the queue
  - Instead, each deletion causes front to move right by 1
  - Front = location(1), rear = location(last element), and empty queue has rear > front
  - What do we do when **rear = Maxsize –1** and **front > 0**?

Array-based Representation of Queue

- Shifting a queue
  - To continue adding to the queue, we shift all elements to the left end of the queue
  - But shifting increases the worst-case add time from Θ(1) to Θ(*n*)
  - ➔ Need a better method!



Shifting a Queue

https://www.geeksforgeeks.org/queue-data-structure/

Array-based Representation of Queue

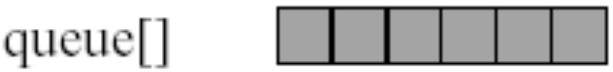
- Remedy in modified formula equation that can provide the worst-case add and delete times in $\Theta(1)$:

$$location(i) = (location(1) + i - 1) \% Maxsize$$

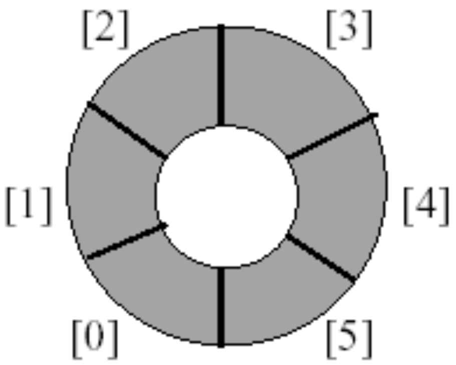
➔This is called a **Circular Queue**

Custom Array Queue

- Use a 1D array queue

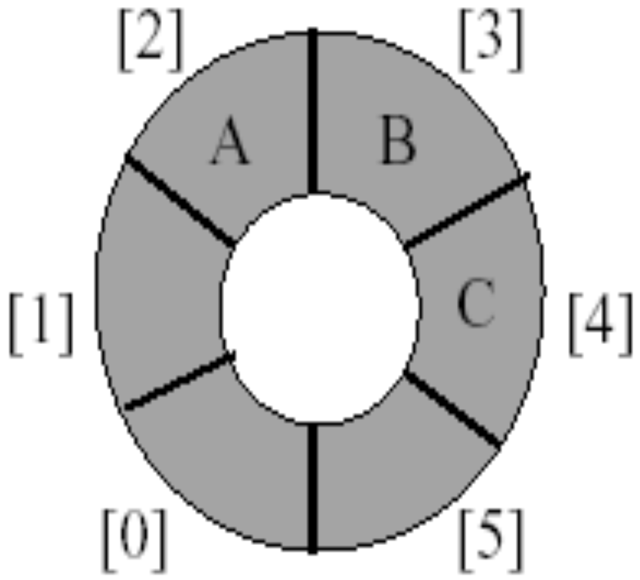


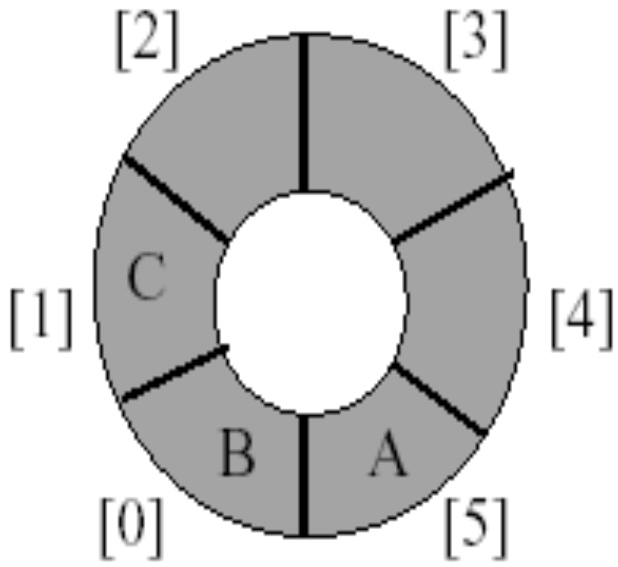
- Circular view of array



Custom Array Queue

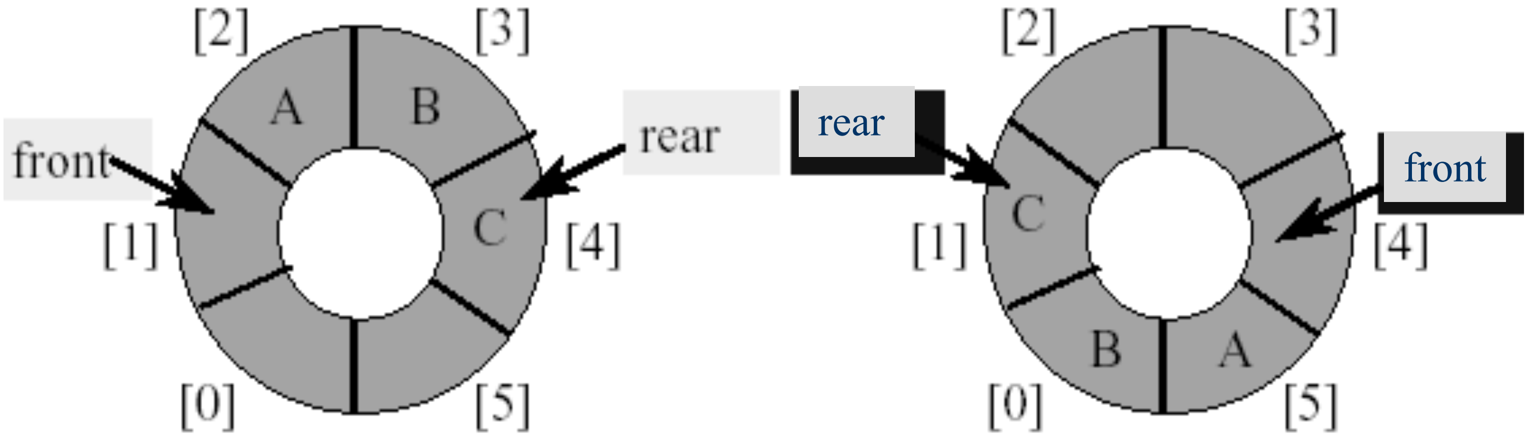
- Possible configurations with three elements.





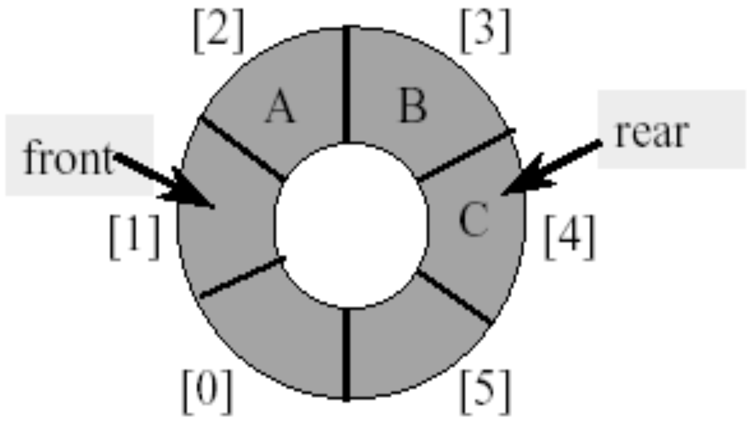
Custom Array Queue

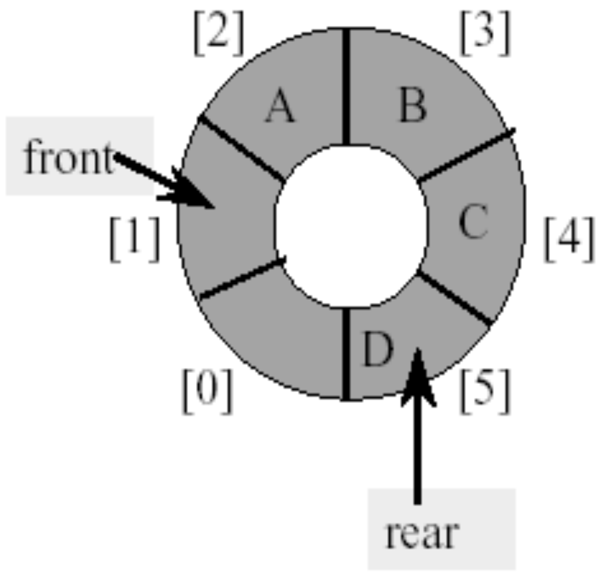
- Use integer variables ‘front’ and ‘rear’.
  - ‘front’ is one position counter-clockwise from first element
  - ‘rear’ gives the position of last element



Custom Array Queue

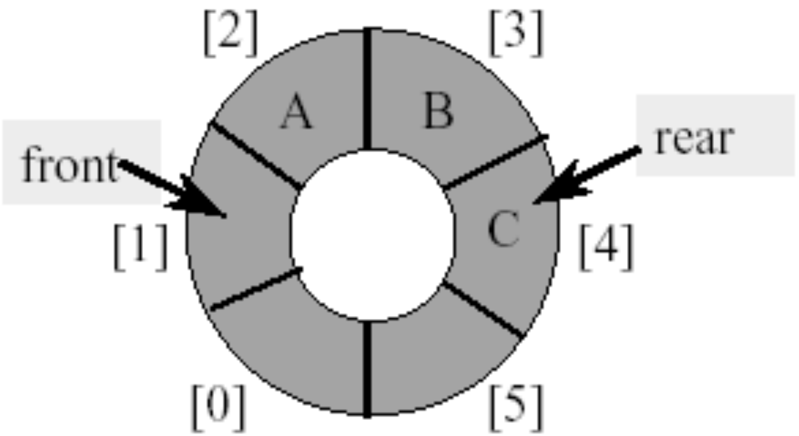
- Add an element
  - Move ‘rear’ one clockwise.
  - Then put an element into queue[rear].

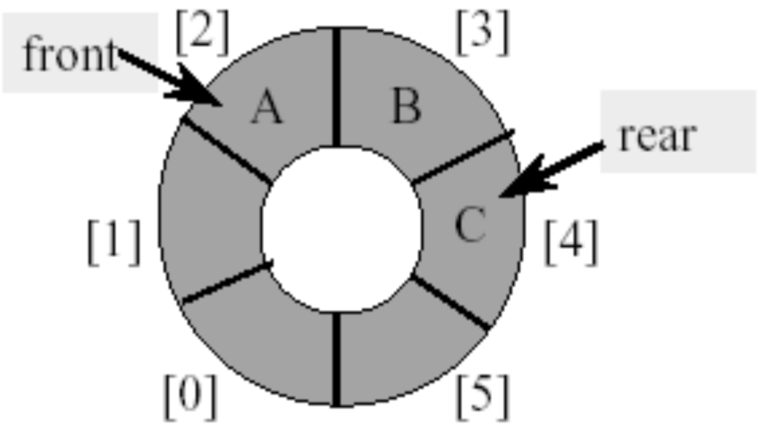




Custom Array Queue

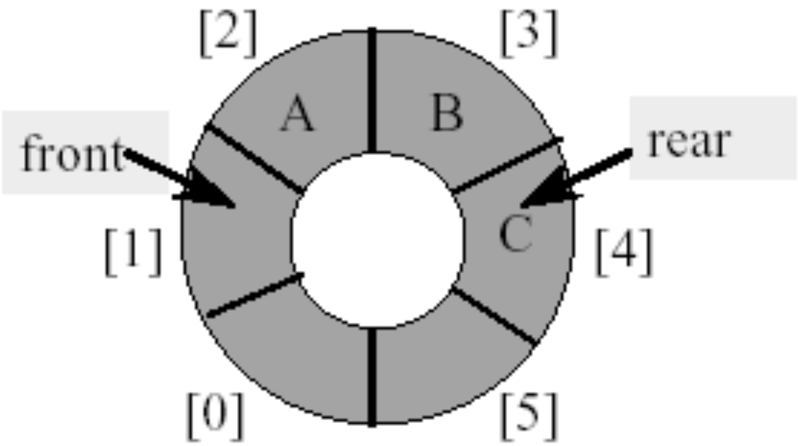
- Remove an element
  - Move front one clockwise.
  - Then extract from queue[front].





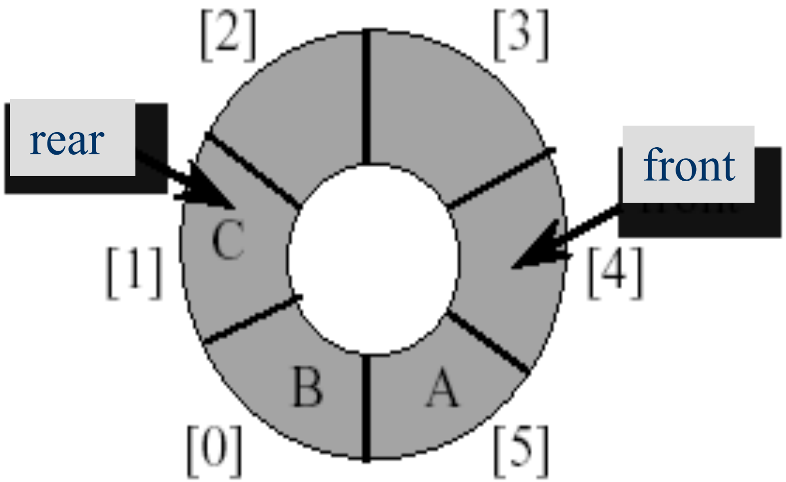
Custom Array Queue

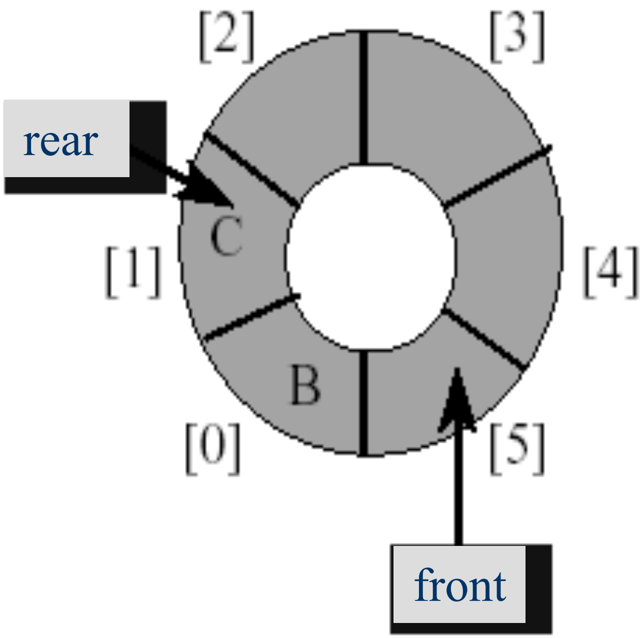
- Moving clockwise
  - rear++;
    if (rear == queue.length) rear = 0;
  - rear = (rear + 1) % queue.length;



Custom Array Queue

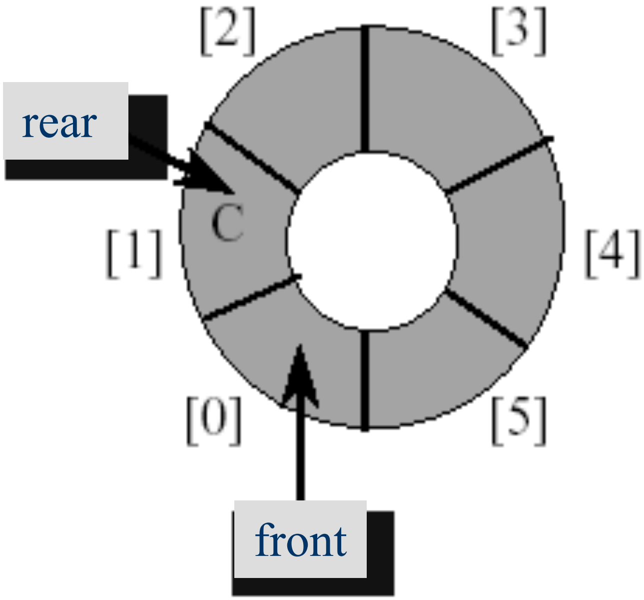
- Empty that queue

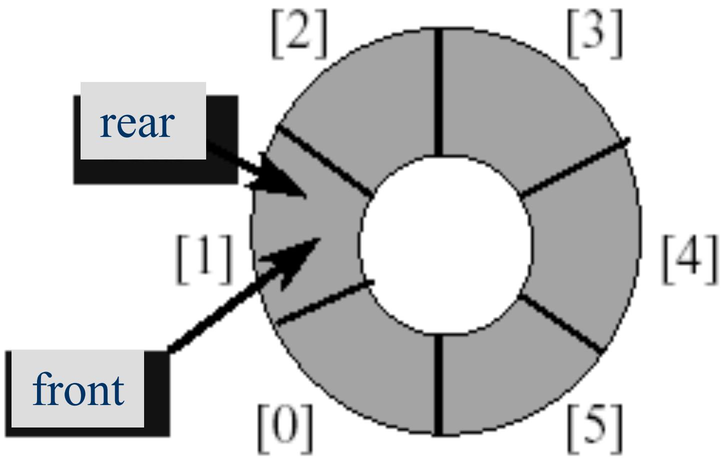




Custom Array Queue

- Empty that queue



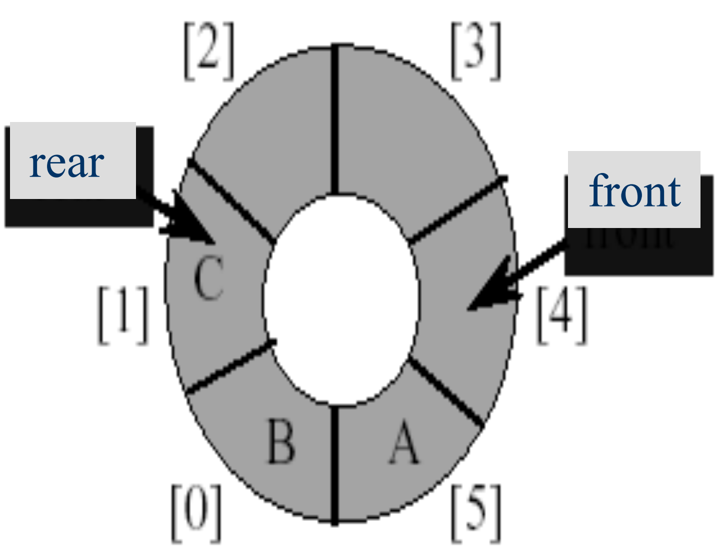


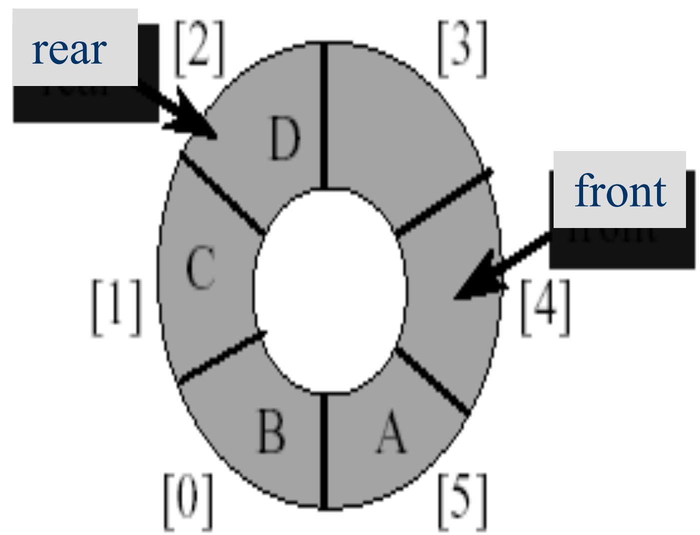
Custom Array Queue

- Empty that queue
  - When a series of removals causes the queue to become empty, front = rear.
  - When a queue is constructed, it is empty.
  - So initialize front = rear = 0.

Custom Array Queue

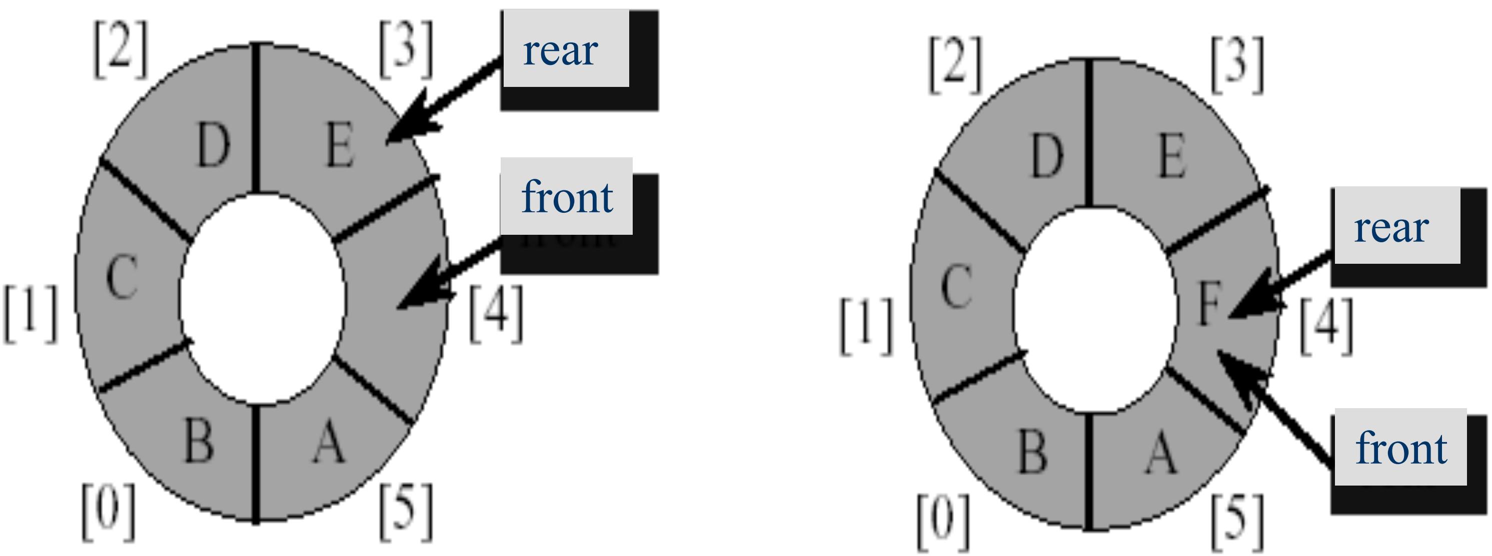
- A Full Tank Please





Custom Array Queue

- A Full Tank Please



Custom Array Queue

- A Full Tank Please
  - When a series of adds causes the queue to become full, front = rear.
  - So we cannot distinguish between a full queue and an empty queue.

- How to differentiate two cases: queue empty and queue full?

Custom Array Queue

- Remedies
  - Don't let the queue get full
    - **When the addition of an element will cause the queue to be full, increase array size**
  - Define a boolean variable lastOperationIsAdd
    - **Following each add operation set this variable to true.**
    - **Following each delete operation set this variable to false.**
    - **Queue is empty iff (front == rear) && !lastOpeartionIsAdd**
    - **Queue is full iff (front == rear) && lastOperationIsAdd**

Custom Array Queue

- Remedies (cont'd)
  - Define a variable NumElements
    - **Following each add operation, increment this variable**
    - **Following each delete operation, decrement this variable**
    - **Queue is empty iff (front == rear) && (!NumElements)**
    - **Queue is full iff (front == rear) && (NumElements)**

- See Programs 9.2, 9.3, 9.4
- See Figure 9.7 for doubling array queue length

Linked Representation of Queue

- Can represent a queue using a chain
- Need two variables, front and rear, to keep track of the two ends of a queue
- Two options:

  1) assign head as front and tail as rear (see Fig 9.8 (a)), or

  2) assign head as rear and tail as front (see Fig 9.8 (b))

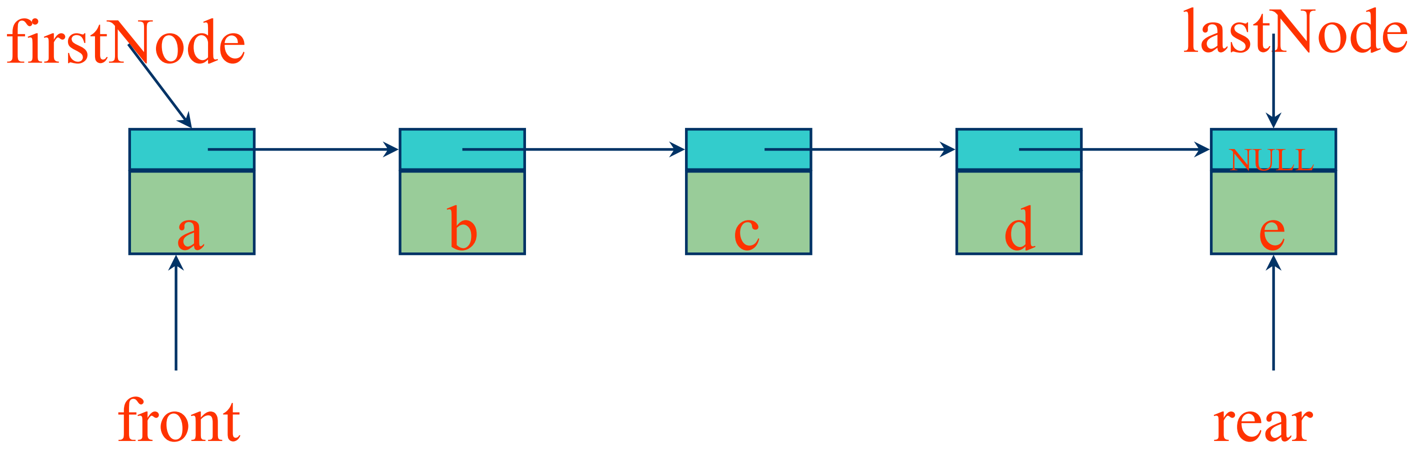
Which option is better and why?

→ See Figures 9.9 and 9.10

Linked Representation of Queue

- How can we implement a linked representation of queue?
- See Program 9.5 for implementing the push and pop methods of linkedQueue

Derive From ExtendedChain



- When front is left end of list and rear is right end:
  - empty() ➔ extendedChain::empty()
  - size() ➔ extendedChain::size()
  - front() ➔ get (0)
  - back() ➔ getLast() … new method
  - push(theElement) ➔ push_back(theElement)
  - pop() ➔ erase(0)

Revisit of Stack Applications

- Applications in which the stack **cannot be replaced** with a queue
  - Parentheses matching
  - Towers of Hanoi
  - Switchbox routing
  - Method invocation and return
- Application in which the stack **may be replaced** with a queue
  - Railroad Car Rearrangement
  - Rat in a maze

Application: Rearranging Railroad Cars

- Similar to problem of Section 8.5.3 using stacks
- This time holding tracks lie between the input and output tracks with the following same conditions:
  - Moving a car from a holding track to the input track or from the output track to a holding track is **forbidden**
- These tracks operate in a FIFO manner

  → can implement using **queues**
- We reserve track *Hk* for moving cars from the input track to the output track. So the number of tracks available to hold cars is *k-1.*

Rearranging Railroad Cars

- When a car is to be moved to a holding track, use the following selection method:
  - *Move a car c to a holding track that contains only cars with a smaller label*
  - *If multiple such tracks exist, select one with the largest label at its left end*
  - *Otherwise, select an empty track (if one remains)*
- What happens if no feasible holding track exists?

  ➔ rearranging railroad cars is NOT possible
- See Figure 9.11 and read its description

Implementing Rearranging Railroad Cars

- What should be changed in previous program (in Section 8.5.3)?
  1. Decrease the number of tracks (k) by 1
  2. Change the type of track to arrayQueue

- What is the time complexity of rearrangement?
  ➔ **O(numberOfCars * k)**

- See Programs 9.6 and 9.7