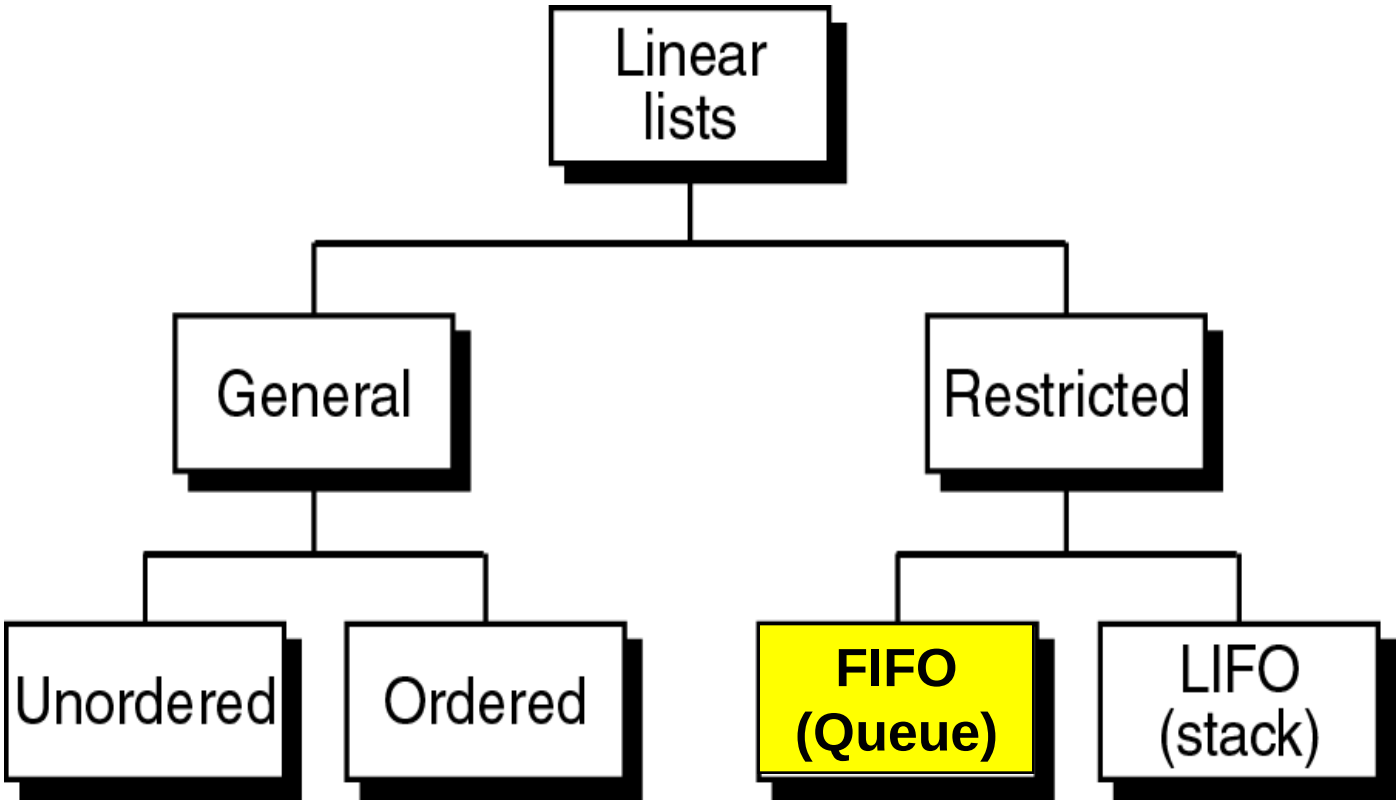
Chapter 3 - QUEUE

- Definition of Queue
- Specifications for Queue
- Implementations of Queue
- Linked Queue
- Contiguous Queue
- Applications of Queue

Linear List Concepts



Queue - FIFO data structure

- Queues are one of the most common of all data-processing structures.
- Queues are used where someone must wait one's turn before having access to something.
- Queues are used in every operating system and network: processing system services and resource supply: printer, disk storage, use of the CPU,...
- Queues are used in business online applications: processing customer requests, jobs, and orders.

Queue ADT

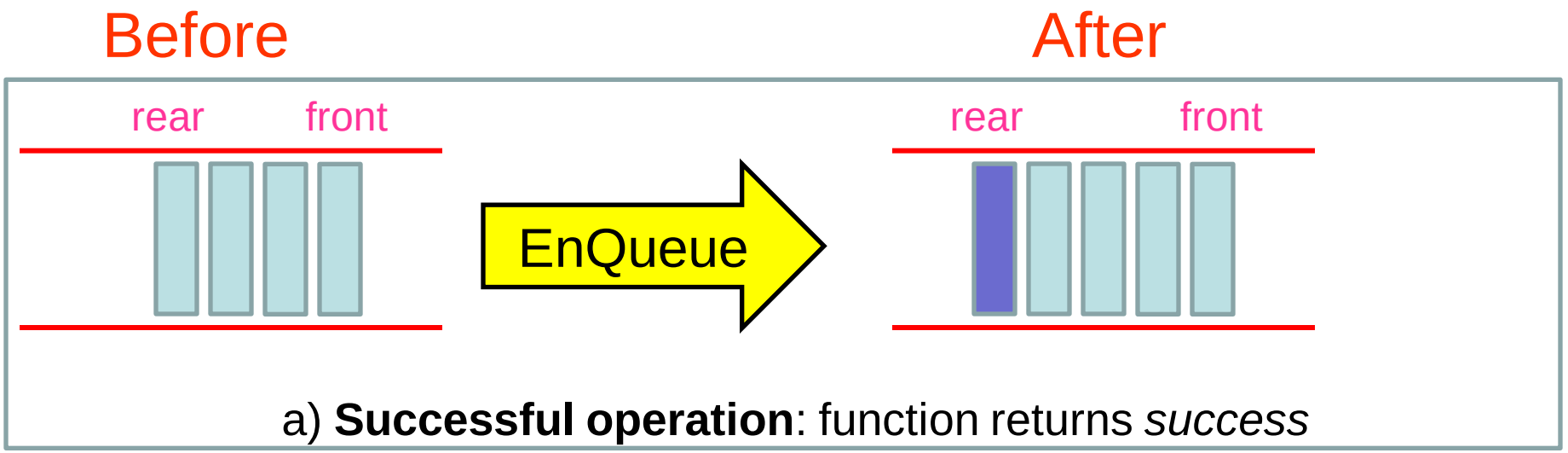
DEFINITION: A Queue of elements of type T is a finite sequence of elements of T, in which data can be inserted only at one end, called the rear, and deleted from the other end, called the front.

Queue is a First In - First Out (FIFO) data structure.

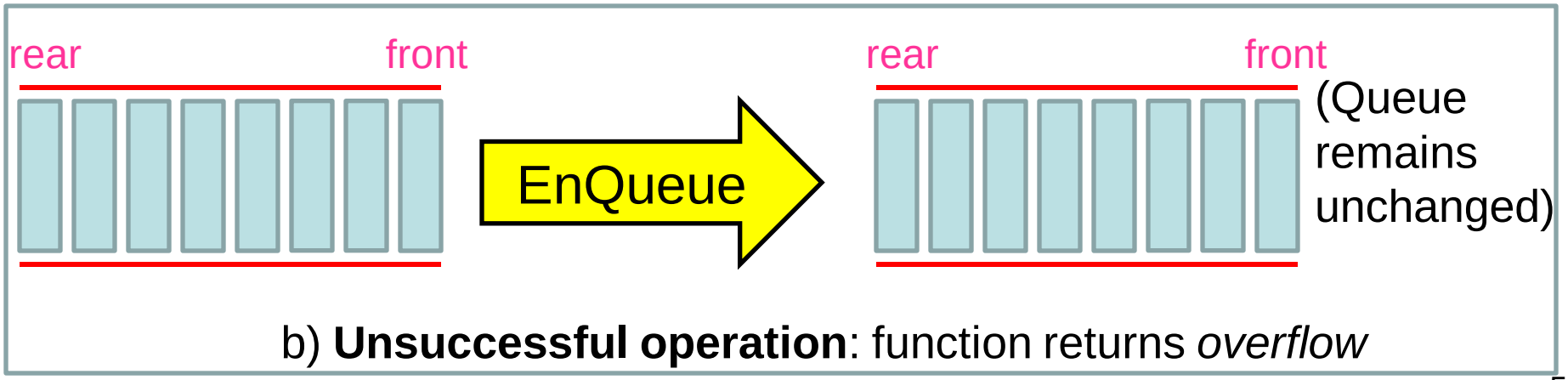
Basic operations:

- *Construct* a Queue, leaving it empty.
- *Enqueue* an element.
- *Dequeue* an element.
- *QueueFront.*
- *QueueRear.*

Basic operation of Queue (EnQueue)

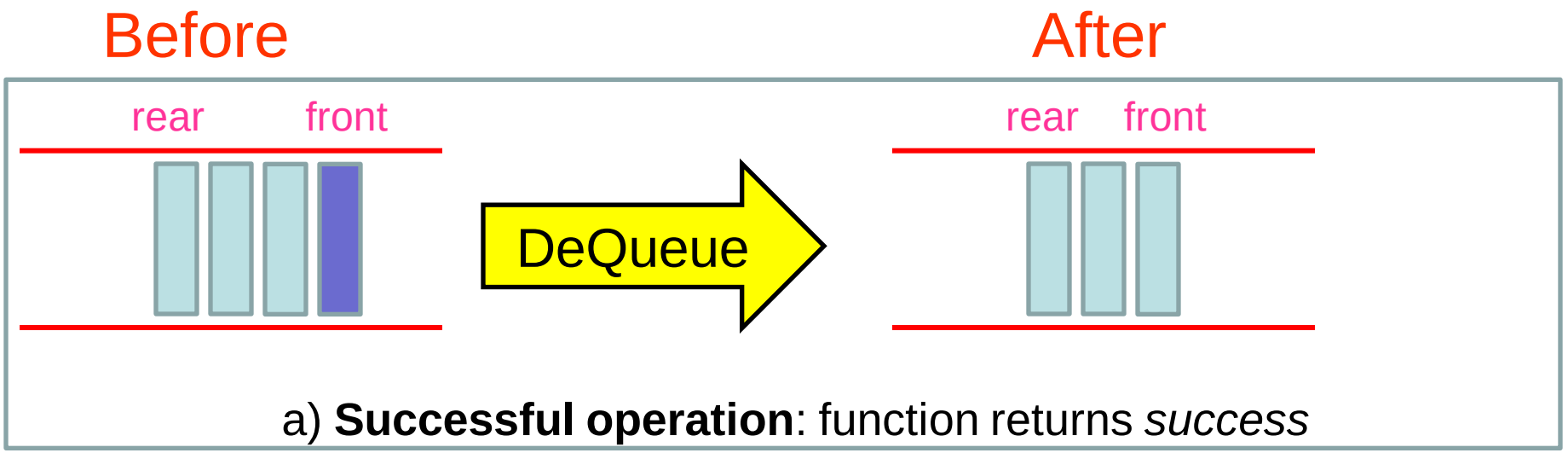


a) **Successful operation**: function returns *success*

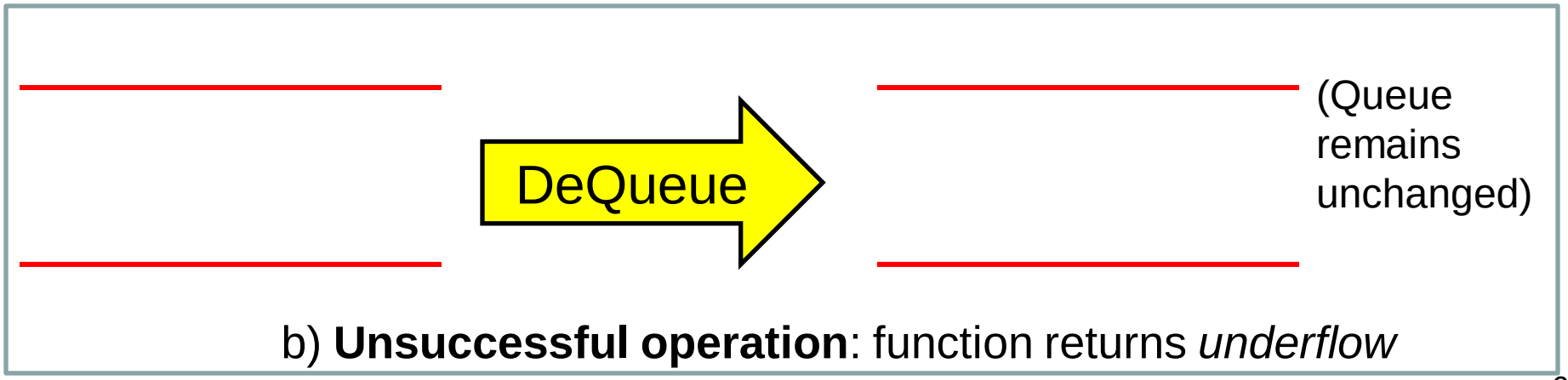


b) **Unsuccessful operation**: function returns *overflow*

Basic operation of Queue (DeQueue)

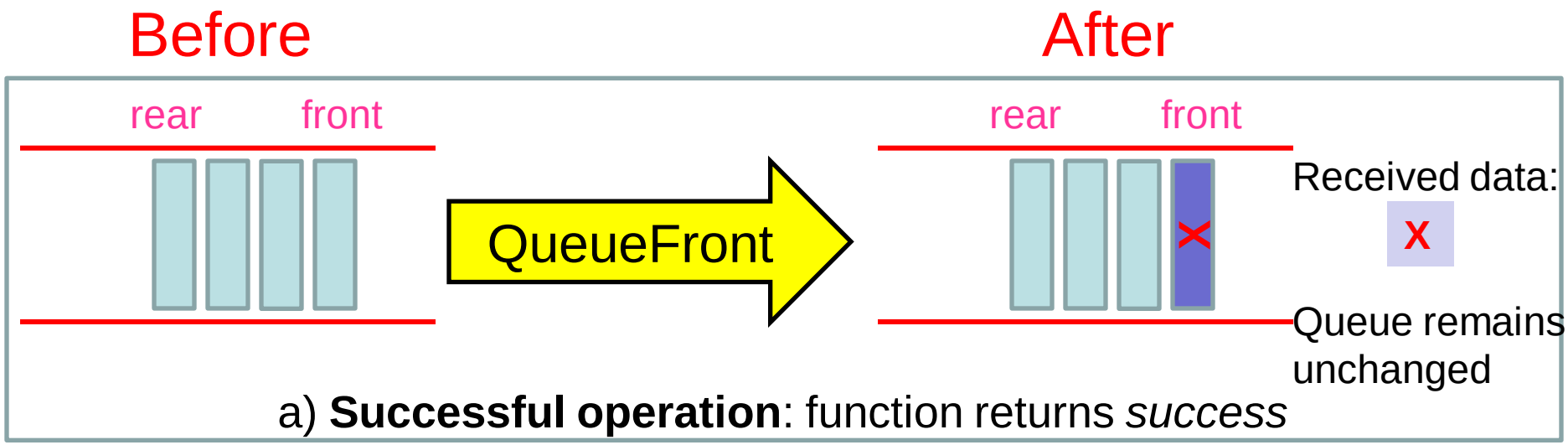


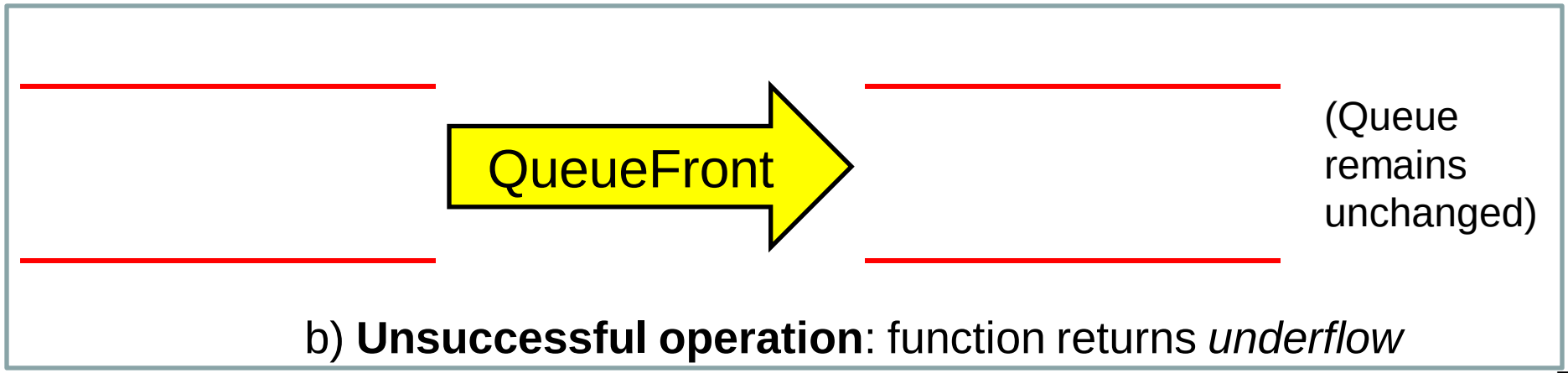
a) **Successful operation**: function returns *success*



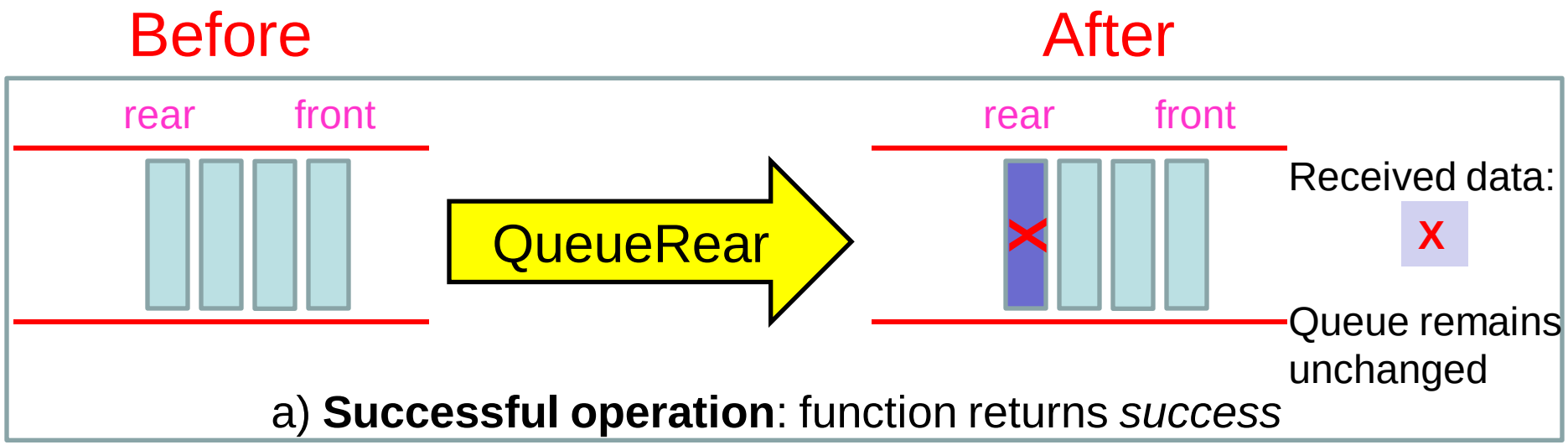
b) **Unsuccessful operation**: function returns *underflow*

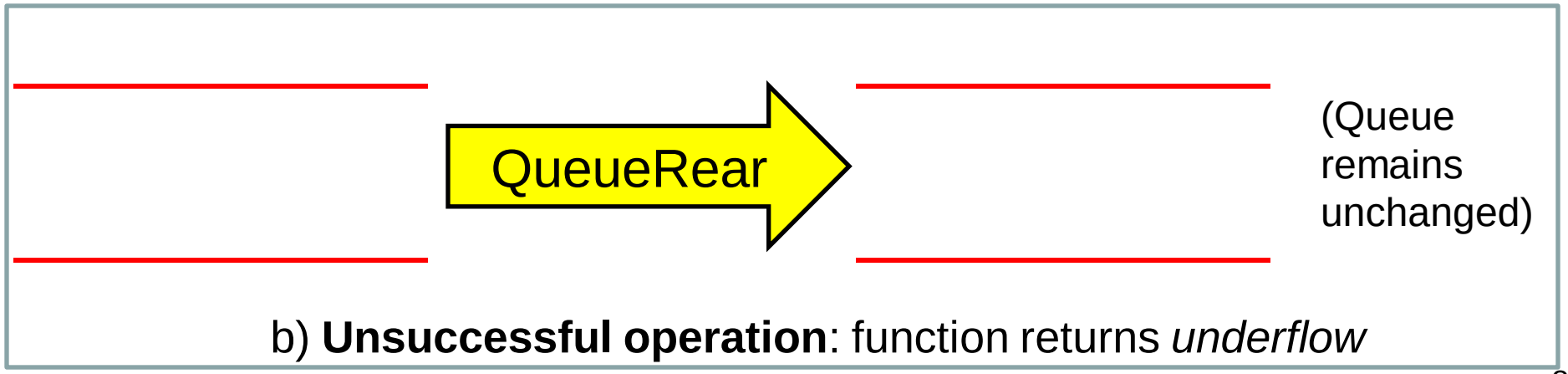
Basic operation of Queue (QueueFront)





Basic operation of Queue (QueueRear)





Queue ADT (cont.)

Extended operations:

- Determine whether the queue is *empty* or not.
- Determine whether the queue is *full* or not.
- Find the *size* of the queue.
- *Clear* the queue to make it empty.
- Determine the total number of elements that have ever been placed in the queue.
- Determine the average number of elements processed through the queue in a given period.
- …

Specifications for Queue ADT

<void> Create()

<ErrorCode> EnQueue (val DataIn <DataType>)

<ErrorCode> DeQueue ()

<ErrorCode> QueueFront (ref DataOut <DataType>)

<ErrorCode> QueueRear (ref DataOut <DataType>)

<boolean> isEmpty ()

<boolean> isFull ()

<void> Clear ()

<integer> Size () // the current number of elements in the queue.

Variants:

ErrorCode DeQueue (ref DataOut <DataType>)

…

Built Queue ADT

Queue may be fully inhirited from a List, inside its operations calling List's operations.

```
<ErrorCode> EnQueue (val DataIn <DataType>)
Call List::InsertTail(DataIn)
    or
Call List::Insert(DataIn, Size()) // insert after last lement
end EnQueue
```

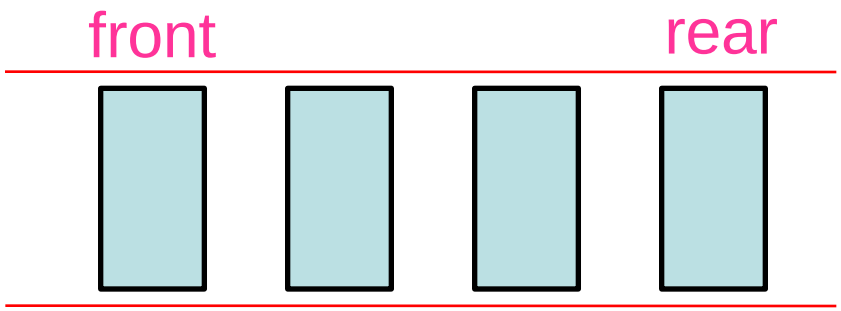
```
<ErrorCode> DeQueue (val DataOut <DataType>)
Call List::RemoveHead(DataOut)
    or
Call List::Remove(DataOut, 0) // remove element from the 1st position
end EnQueue
```

Similar for other operations of Queue…

Implementations of Queue

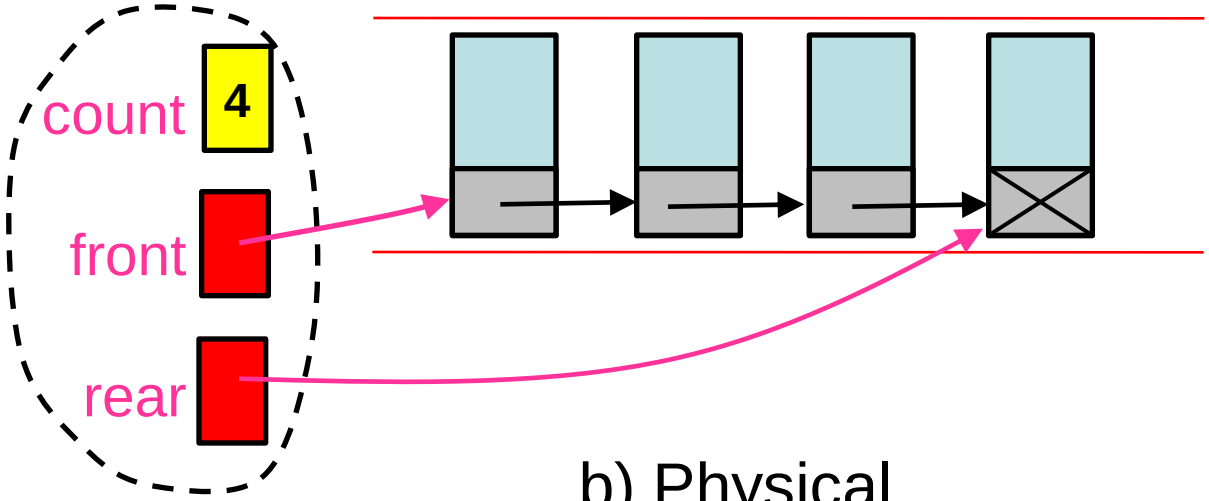
- ✓ Contiguous Implementation.
- ✓ Linked Implementation.

Linked Queue



a) Conceptual

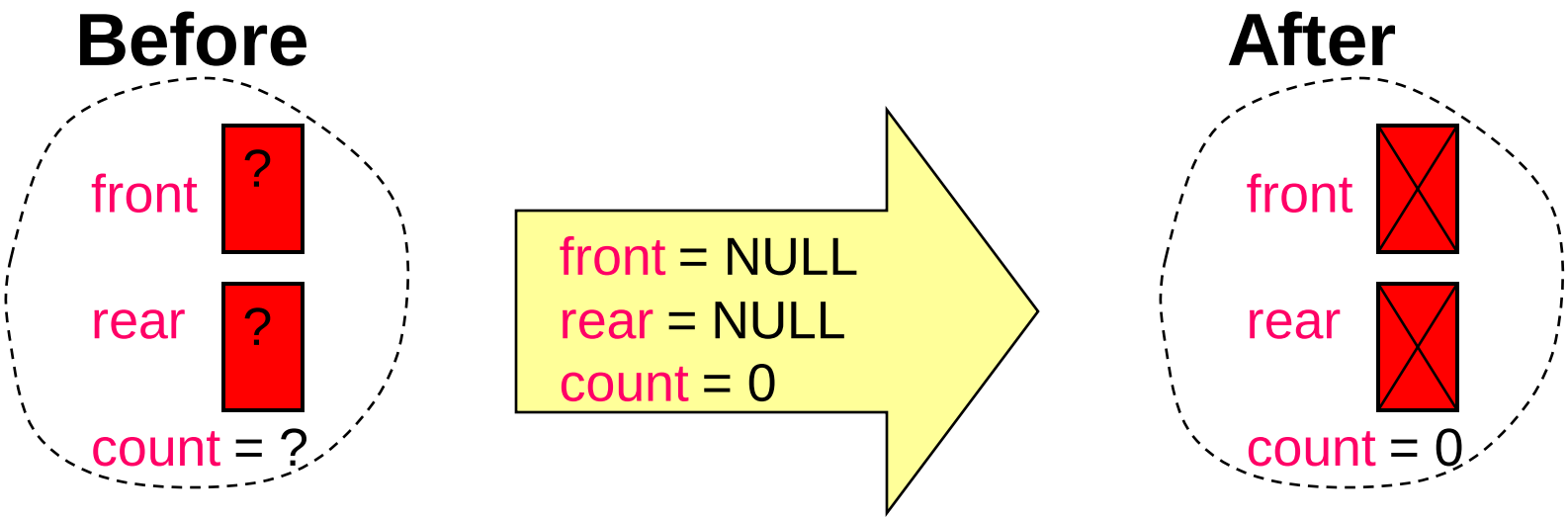
```
Node
   Data <DataType>
   link <pointer>
end Node
```



b) Physical

```
Queue
   front <pointer>
   rear <pointer>
   count <integer>
end Queue
```

Create an Empty Linked Queue



Create Linked Queue

<void> **Create**()

Creates an empty linked queue

Pre none

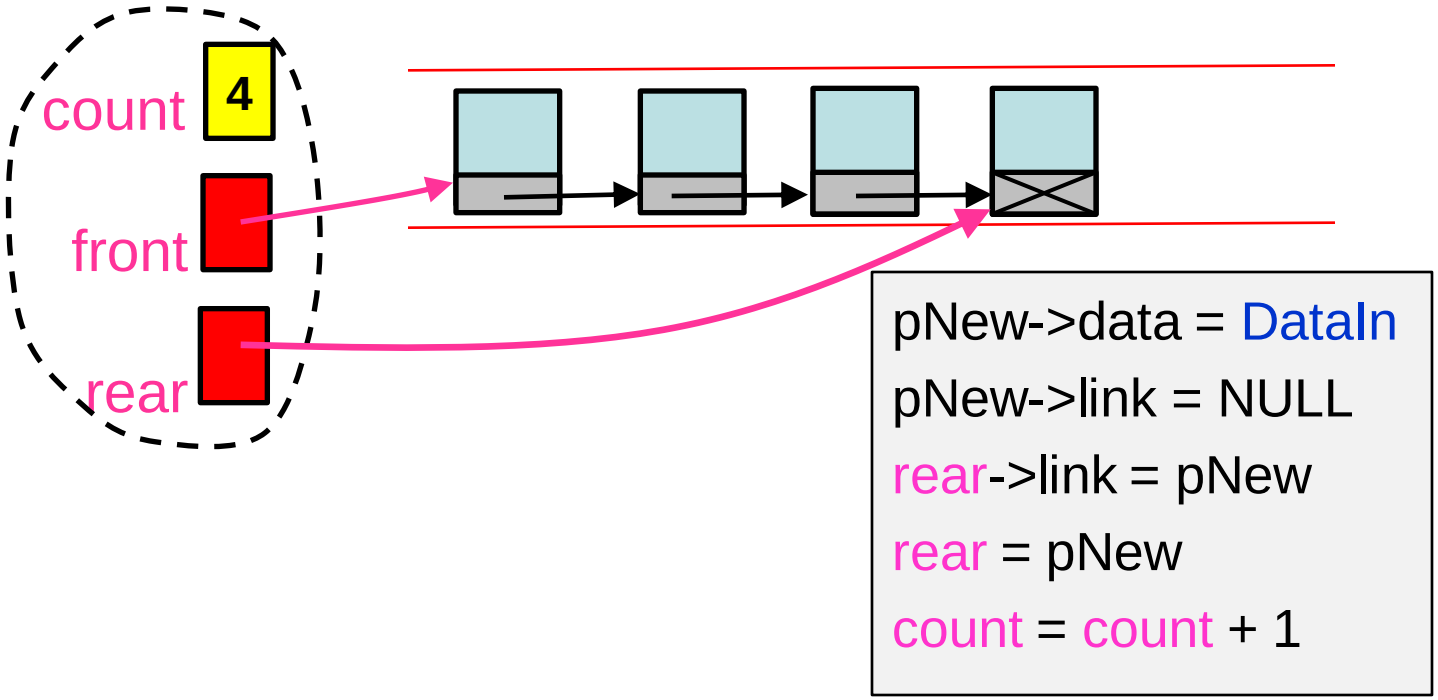
Post An empty linked queue has been created.

1. front = NULL
2. rear = NULL
3. count = 0
4. Return

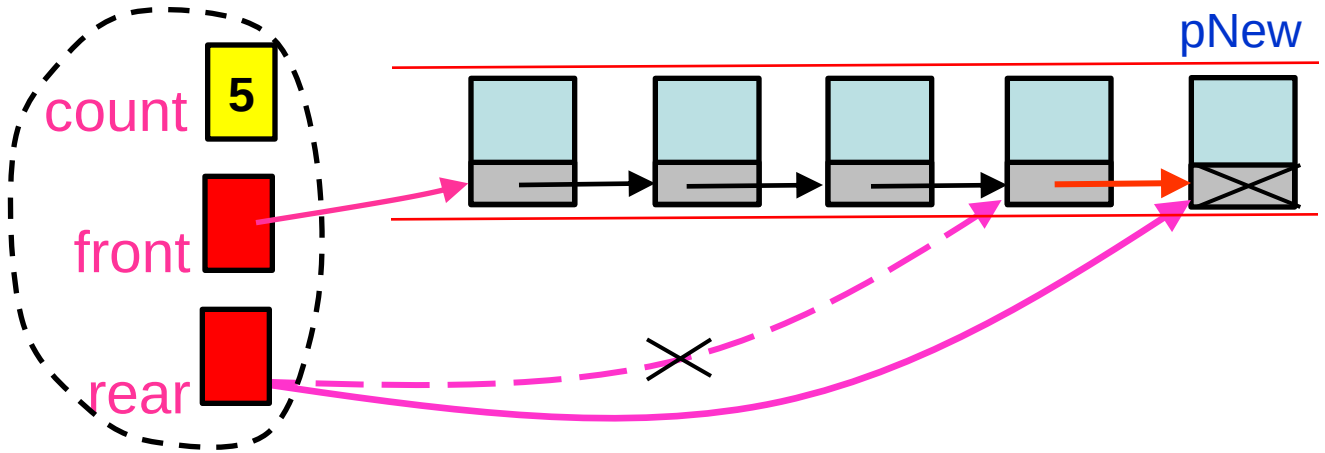
end Create

EnQueue

Before:

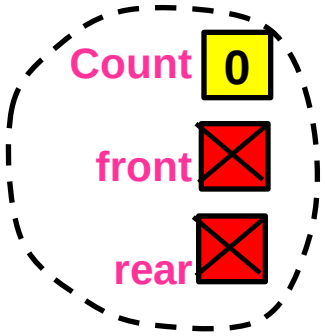


After:



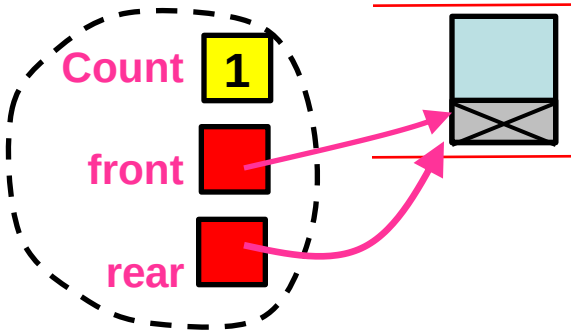
EnQueue (cont.)

Before:



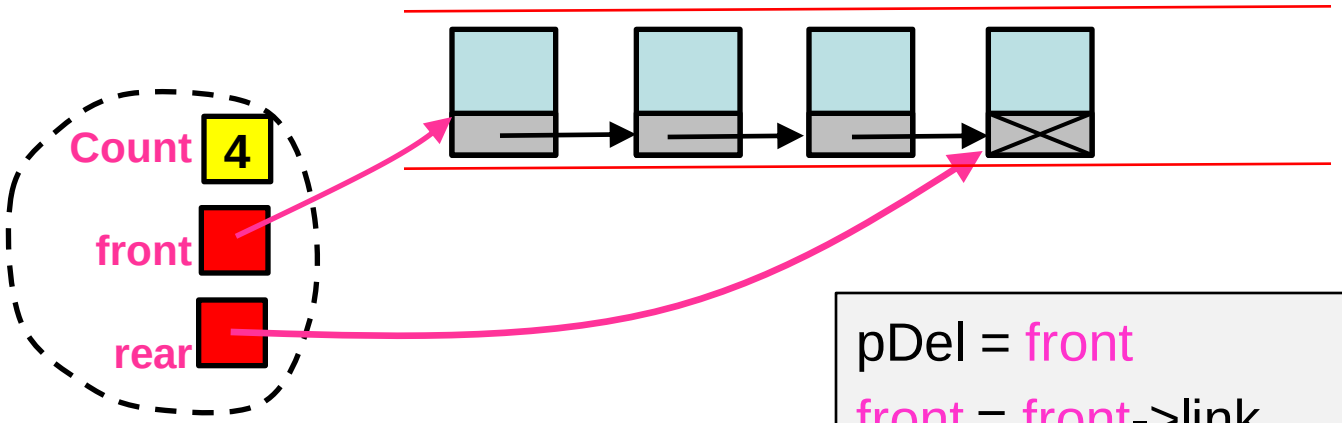
pNew->data = DataIn
pNew->link = NULL
front = pNew
rear = pNew
count = count + 1

After:



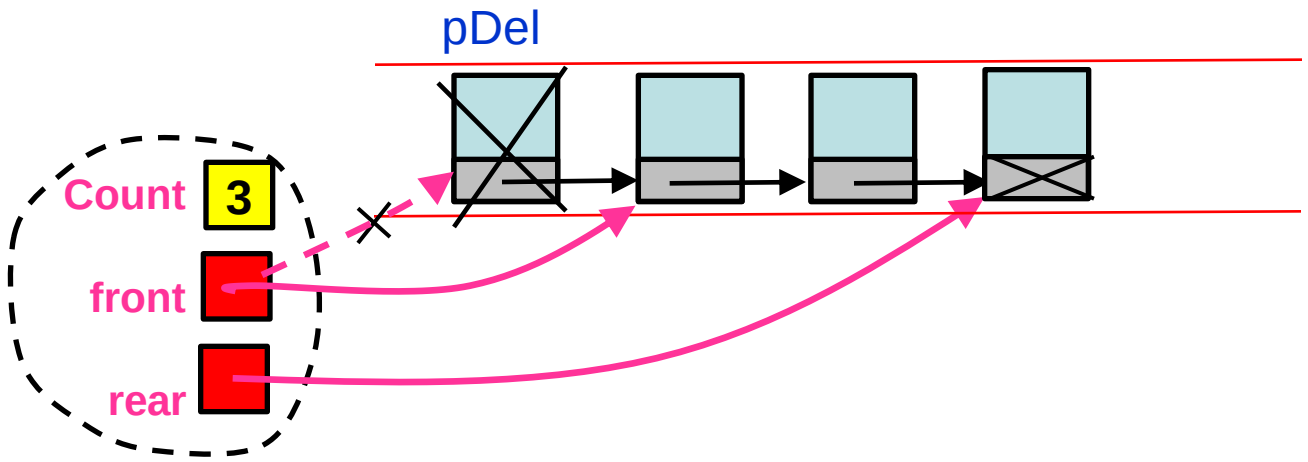
DeQueue

Before:



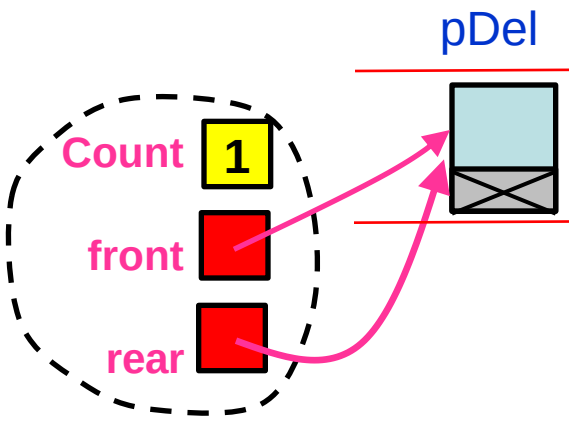
pDel = front
front = front->link
recycle pDel
count = count - 1

After:



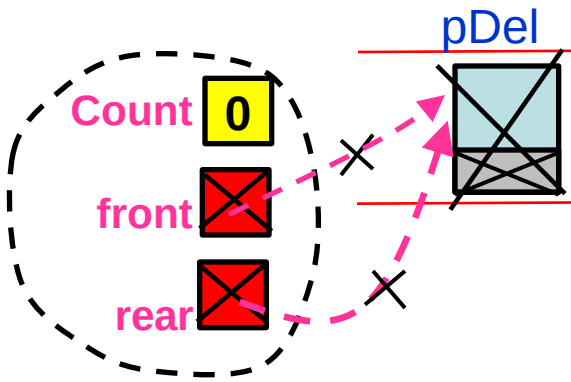
DeQueue

Before:



pDel= front
front = NULL
rear = NULL
recycle pDel
count = count - 1

After:



EnQueue & DeQueue Algorithm

Linked Implementation

- EnQueue is successful when queue is not full.
- DeQueue successful when queue is not empty.
- ***Regular cases***:
  - EnQueue: only rear must be updated (*points to new element*).
  - DeQueue: only front must be updated (*points to next element if exists*).
- ***Irregular cases***:
  - EnQueue an element to an empty queue: both rear and front must be updated (*point to new element*).
  - DeQueue a queue having only one element: both rear and front must be updated (*receive NULL value*).
- In any successful case, count must be updated.

EnQueue Algorithm

<ErrorCode> **EnQueue** (val DataIn <DataType>)

Inserts one element at the rear of the queue.

Pre DataIn contains data to be inserted.

Post If queue is not full, DataIn has been inserted at the rear of the queue; otherwise, queue remains unchanged.

Return *success* or *overflow*.

EnQueue Algorithm (cont.)

<ErrorCode> **EnQueue** (val DataIn <DataType>)

// For Linked Queue

1. Allocate pNew
2. If (allocation was successful)
    1. pNew->data = Data
    2. pNew->link = NULL
    3. if (count = 0)
        1. front = pNew
    4. else
        1. rear->link = pNew
    5. rear = pNew
    6. count = count + 1
    7. return *success*
3. Else
    1. return *overflow*

end EnQueue

Empty queue:

pNew->data = DataIn
pNew->link = NULL
front = pNew
rear = pNew
count = count + 1

Not empty queue:

pNew->data = DataIn
pNew->link = NULL
rear->link = pNew
rear = pNew
count = count + 1

DeQueue Algorithm

<ErrorCode> DeQueue()

Deletes one element at the front of the queue.

Pre none

Post If the queue is not empty, the element at the front of the queue has been removed; otherwise, the queue remains unchanged.

Return *success* or *underflow*.

DeQueue Algorithm (cont.)

```
<ErrorCode> DeQueue()
// For Linked Queue
1. If (count > 0)
    1. pDel = front
    2. front = front->link
    3. if (count = 1)
        1. rear = NULL
    4. recycle pDel
    5. count = count - 1
    6. return success
2. else
    1. return underflow
3. end DeQueue
```

Queue has more than one element:

```
pDel = front
front = front->link
recycle pDel
count = count - 1
```

Queue has only one element:

```
pDel= front
front = NULL // = front->link
rear = NULL
recycle pDel
count = count - 1
```

QueueFront Algorithm

<ErrorCode> QueueFront (ref DataOut <DataType>)

Retrieves data at the front of the queue without changing the queue.

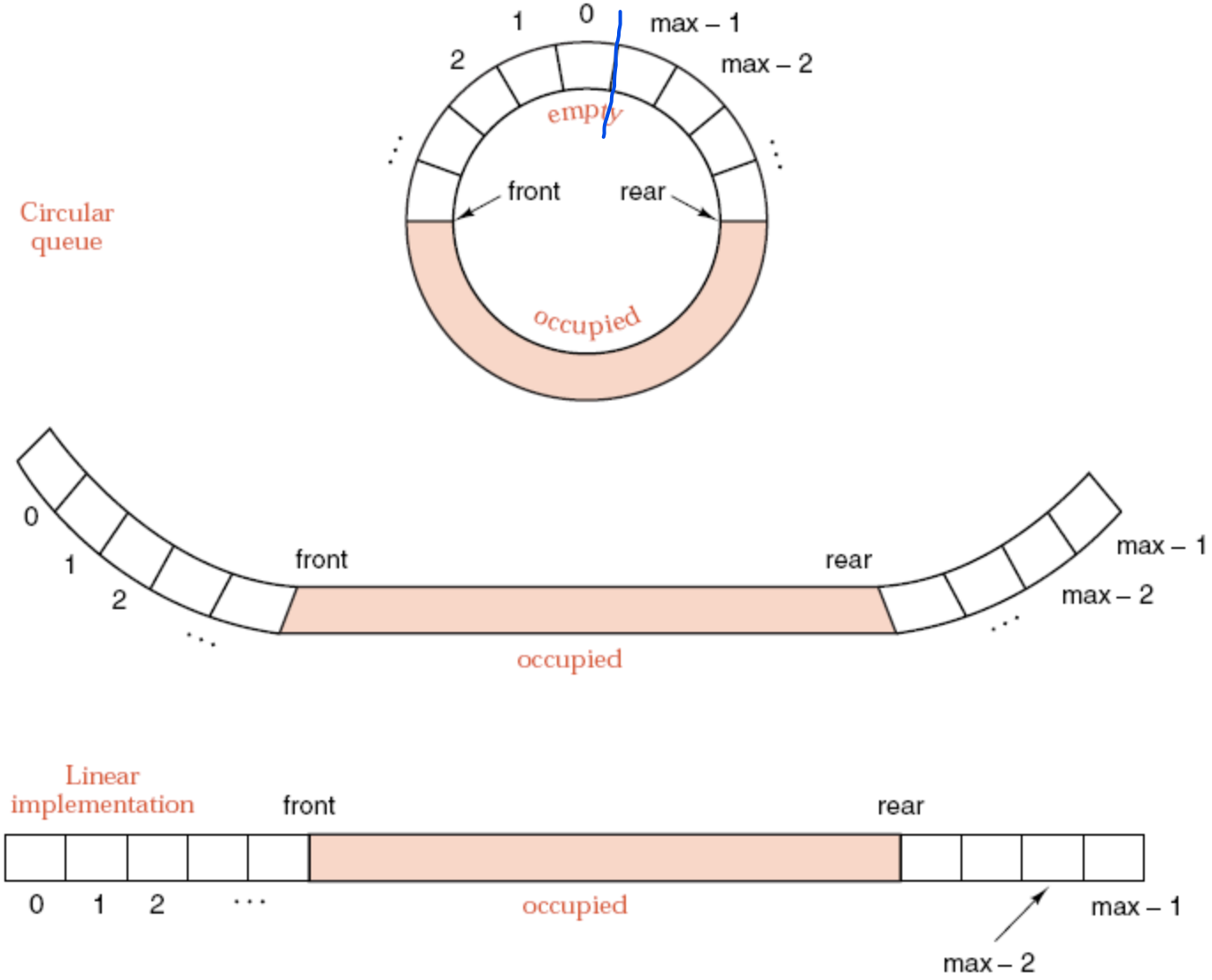
Pre none.

Post if the queue is not empty, DataOut receives data at its front. The queue remains unchanged.

Return *success* or *underflow*.

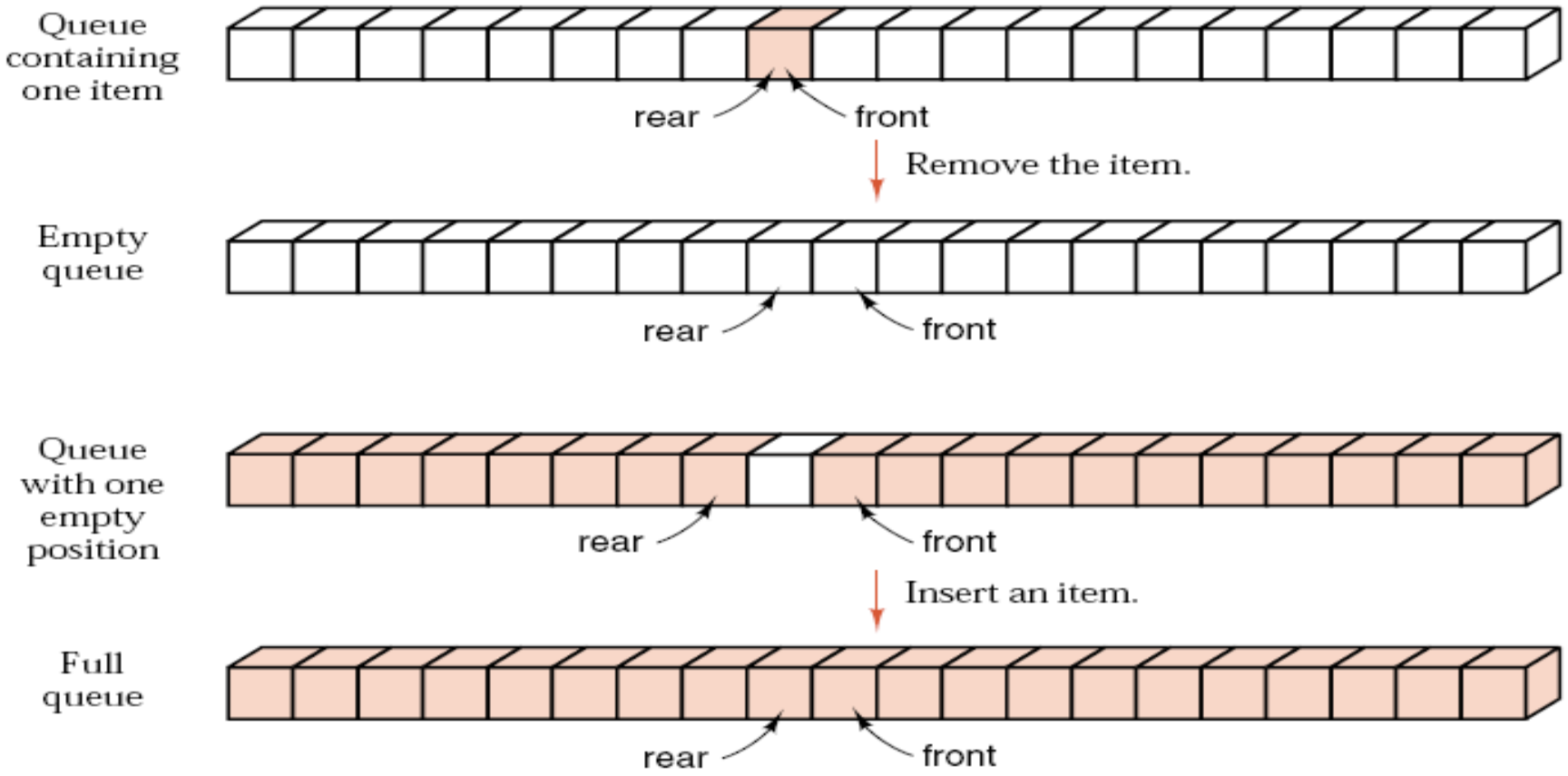
```
// For Linked Queue
1. If (count > 0)
   1. DataOut = front->data
   2. Return success
2. Else
   1. Return underflow
3. End QueueFront
```

Contiguous Implementation Of Queue



Contiguous Implementation Of Queue (cont.)

Boundary conditions

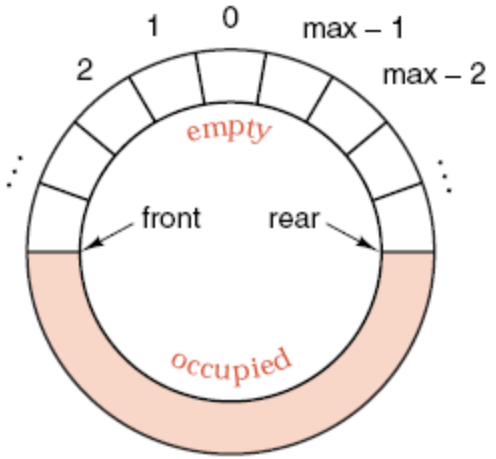


Contiguous Implementation Of Queue (cont.)

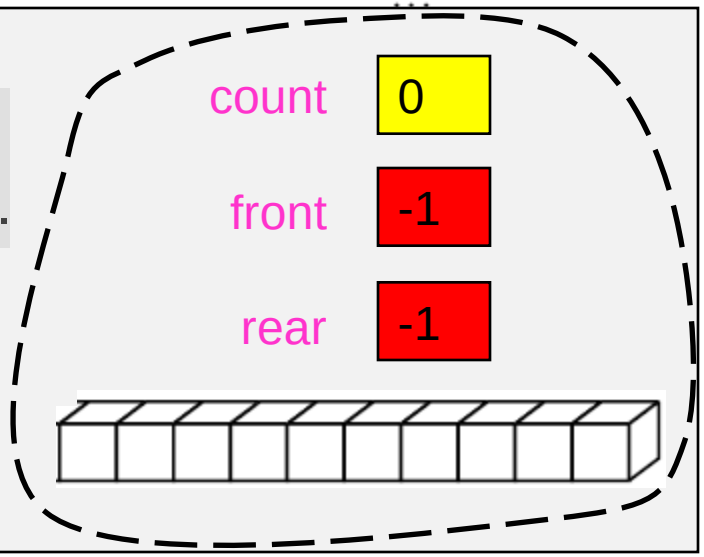
- *The physical model*: a linear array with the front always in the first position and all elements moved up the array whenerver the front is deleted.
- *A linear array* with two indices always increasing.
- *A circular array* with front and rear indices and one position left vacant.
- *A circular array* with front and rear indices and a Boolean flag to indicate fullness (or emptiness).
- *A circular array* with front and rear indices and an integer counter of elements

Contiguous Implementation Of Queue (cont.)

```
Queue
    front <integer>
    rear <integer>
    data <array of <DataType>>
    count <integer>
End Queue //Automatically Allocated Array
```




```
<void> Create()
Pre     none.
Post    An empty queue has been created.
1.  count = 0
2.  front = -1
3.  rear = -1
end Create
```



EnQueue & DeQueue Algorithm

Contiguous Implementation

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  - DeQueue: only front must be updated (*increases by 1*)
- ***Irregular cases***:
  - EnQueue an element to an empty queue: both rear and front must be updated (*receive 0 value – 1st position in array*).
  - DeQueue a queue having only one element: both rear and front must be updated (*receive -1 value*).
- In any successful case, count must be updated.

Queuing Theory

- A field of applied mathematics that is used to predict the performance of queues.
- Two types of queues:
  - Single-server queue: provides service to only one customer at a time.
  - Multi-server queue: provides service to many customers at a time.

Queuing Theory

- The two factors that most dramatically affect the queue:
  - Arrival rate: the rate at which customers arrive in the queue for service.
  - Service time: the average time required to complete the processing of a customer request.

Queuing Theory

- Performance of a queue is measured by:
  - Queue time: the average length of time customers wait in the queue.
  - Response time = queue time + service time
  - The average size of the queue.
  - The maximal queue size

Queuing Theory

- For a banking queue:
  - If the average service time is reduced by 15%, how many fewer tellers would we need?.
  - Given a growing system that is currently under capacity, how long will it be before we need to add another service.

Queue Applications

- Polynomial Arithmetic
- Categorizing Data
- Evaluate a Prefix Expression
- Radix Sort
- Queue Simulation

Polynomial Arithmetic

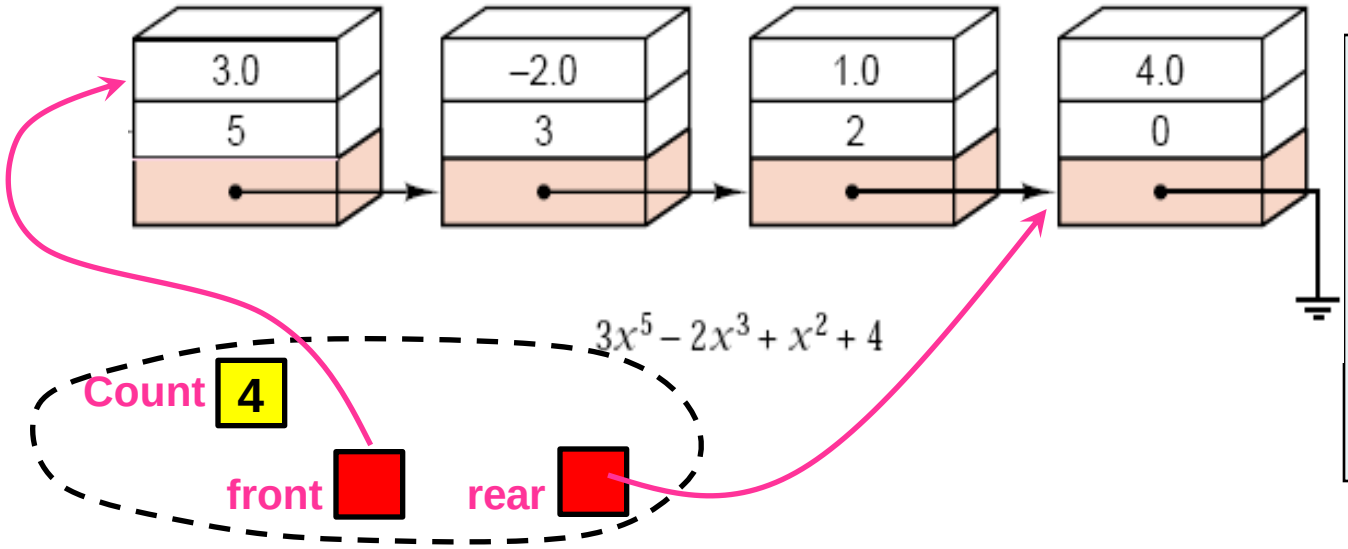
void PolynomialSum(val p1<Queue>,val p2<Queue>,
ref q<Queue>)

Calculates q = p1 + p2

Pre p1 and p2 are two polynomials , each element in them consists of a coefficient and an exponent. Elements in a polynomial appear with descending exponents.

Post q is the sum of p1 and p2

Uses Queue ADT



data
coefficient <int>
degree <int>
end data

```
void PolynomialSum (val p1 <Queue>, val p2 <Queue>, ref q <Queue>)
1. q.Clear()
2. loop ( NOT p.isEmpty()   OR  NOT q.isEmpty() )
    1. p1.QueueFront(p1Data)
    2. p2.QueueFront(p2Data)
    3. if (p1Data.degree > p2Data.degree)
        1. p1.DeQueue()
        2. q.EnQueue(p1Data)
    4. else if (p2Data.degree > p1Data.degree)
        1. p2.DeQueue()
        2. q.EnQueue(p2Data)
    5. else
        1. p1.DeQueue()
        2. p2.DeQueue()
        3. if (p1Data.coefficient + p2Data.coefficient <> 0)
            1. qData.coefficient  = p1Data.coefficient  + p2Data.coefficient
            2. qData.degree = p1Data.degree
            3. q.EnQueue(qData)
End PolynomialSum
```

```
data
        coefficient <int>
        degree <int>
end data
```

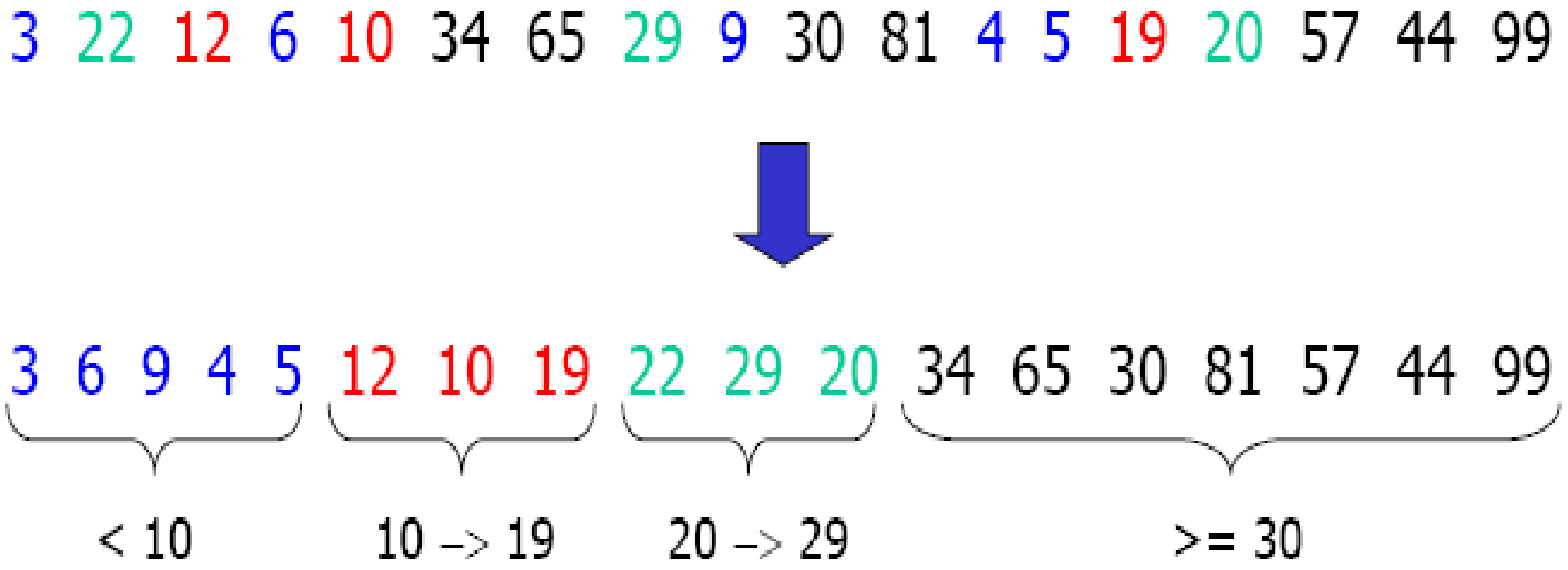
Categorizing Data

- ✓ Sometimes data need to rearrange without destroying their basic sequence.
- ✓ Samples:
  - Ticket selling: several lines of people waiting to purchase tickets and each window sell tickets of a particular flight.
  - Delivery center: packages are arranged into queues base on their volumes, weights, destinations,...

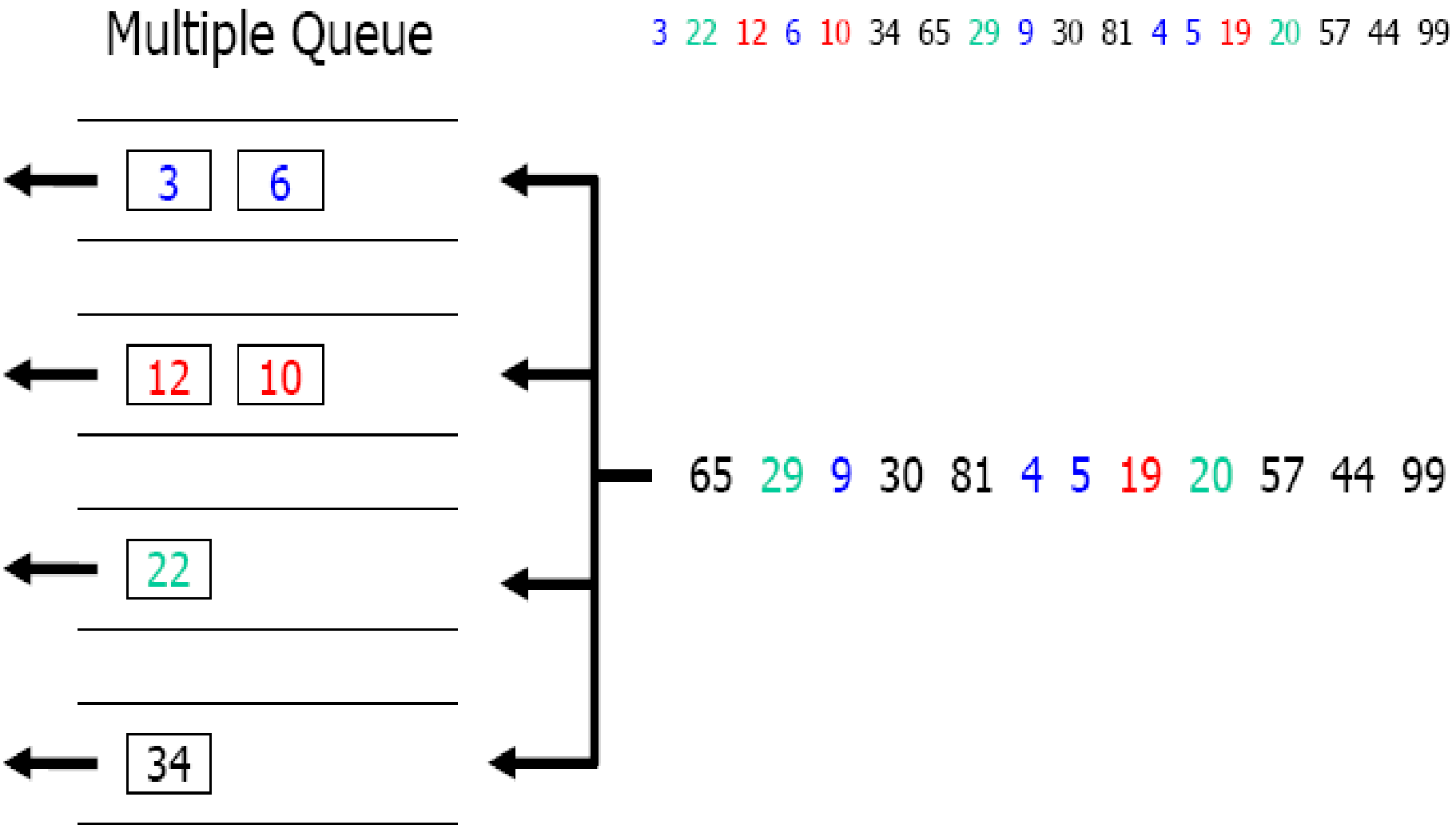
Multiple Queue Application

Categorizing Data (cont.)

Rearrange data without destroying their basic sequence.



Categorizing Data (cont.)



Categorizing Data (cont.)

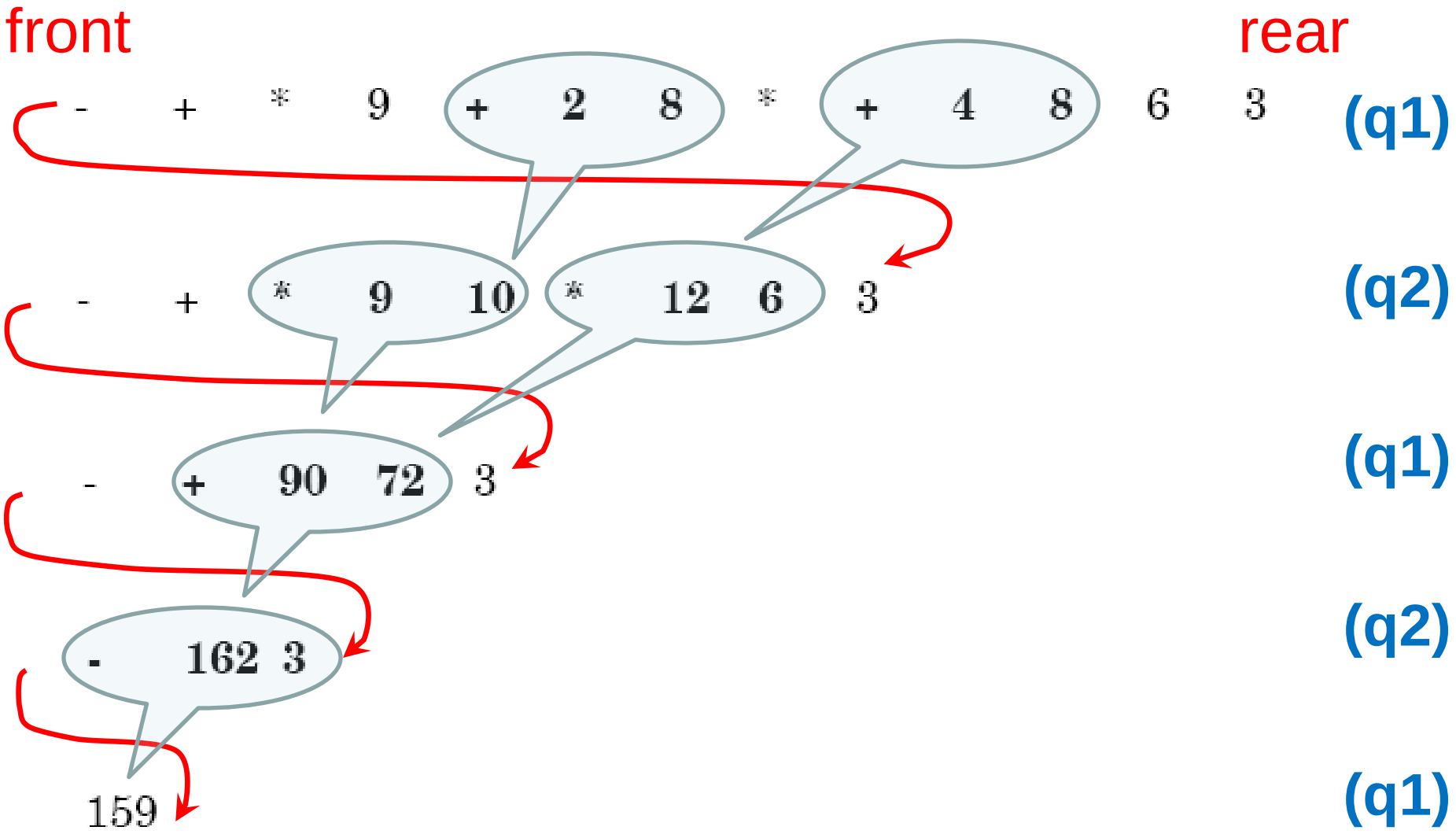
Algorithm Categorize

Groups a list of numbers into four groups using four queues.

1. queue1, queue2, queue3, queue4 <Queue>
2. loop (not EOF)
    1. read (number)
    2. if (number < 10)
        1. queue1.EnQueue(number)
    3. else if (number < 20)
        1. queue2.EnQueue(number)
    4. else if (number < 30)
        1. queue3.EnQueue(number)
    5. else
        1. queue4.EnQueue(number)
3. *// Takes data from each queue.*
4. End Categorize

Evaluate a Prefix Expression

Use two queues in turns to evaluate a prefix expression

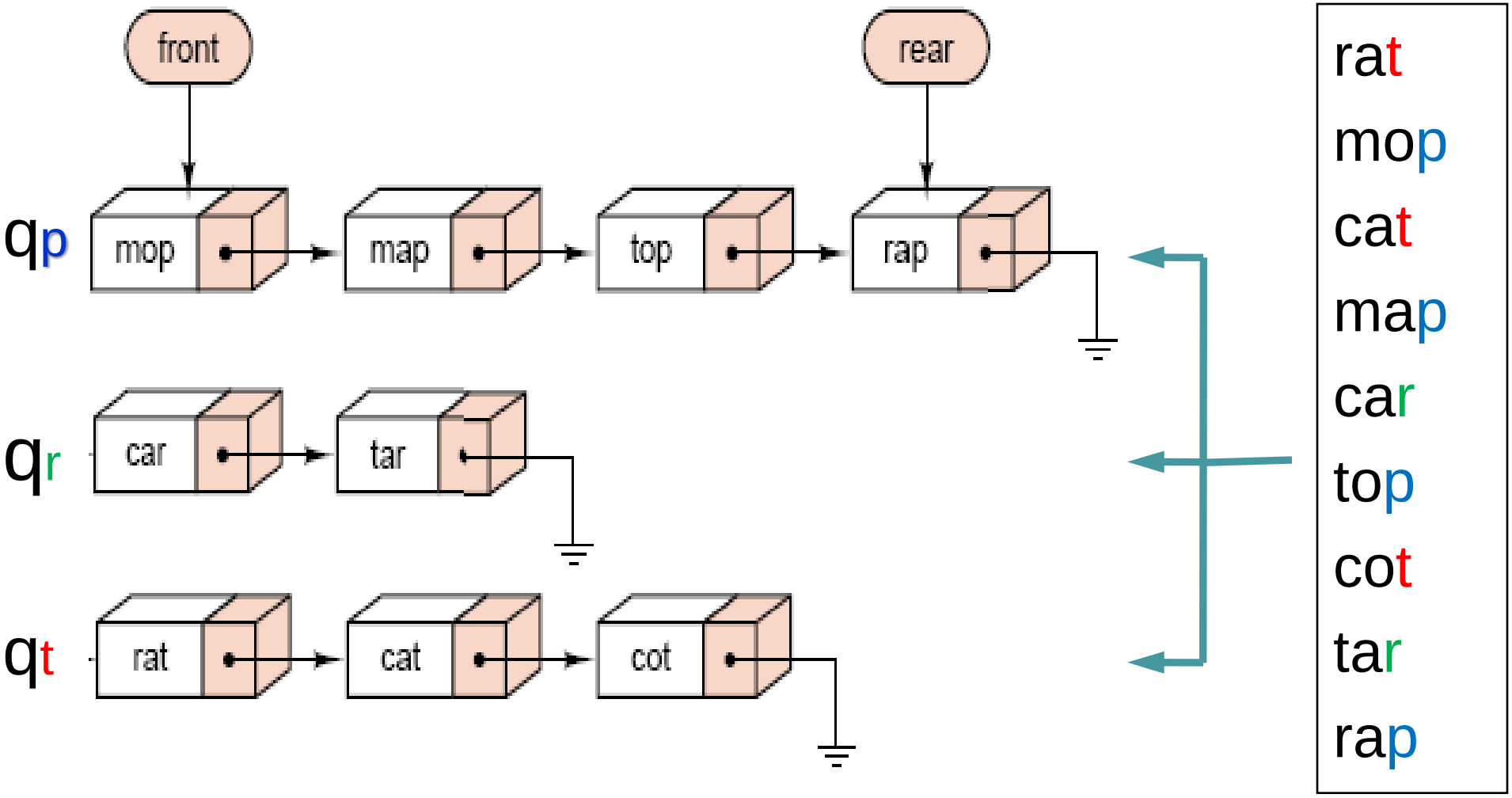


Radix Sort

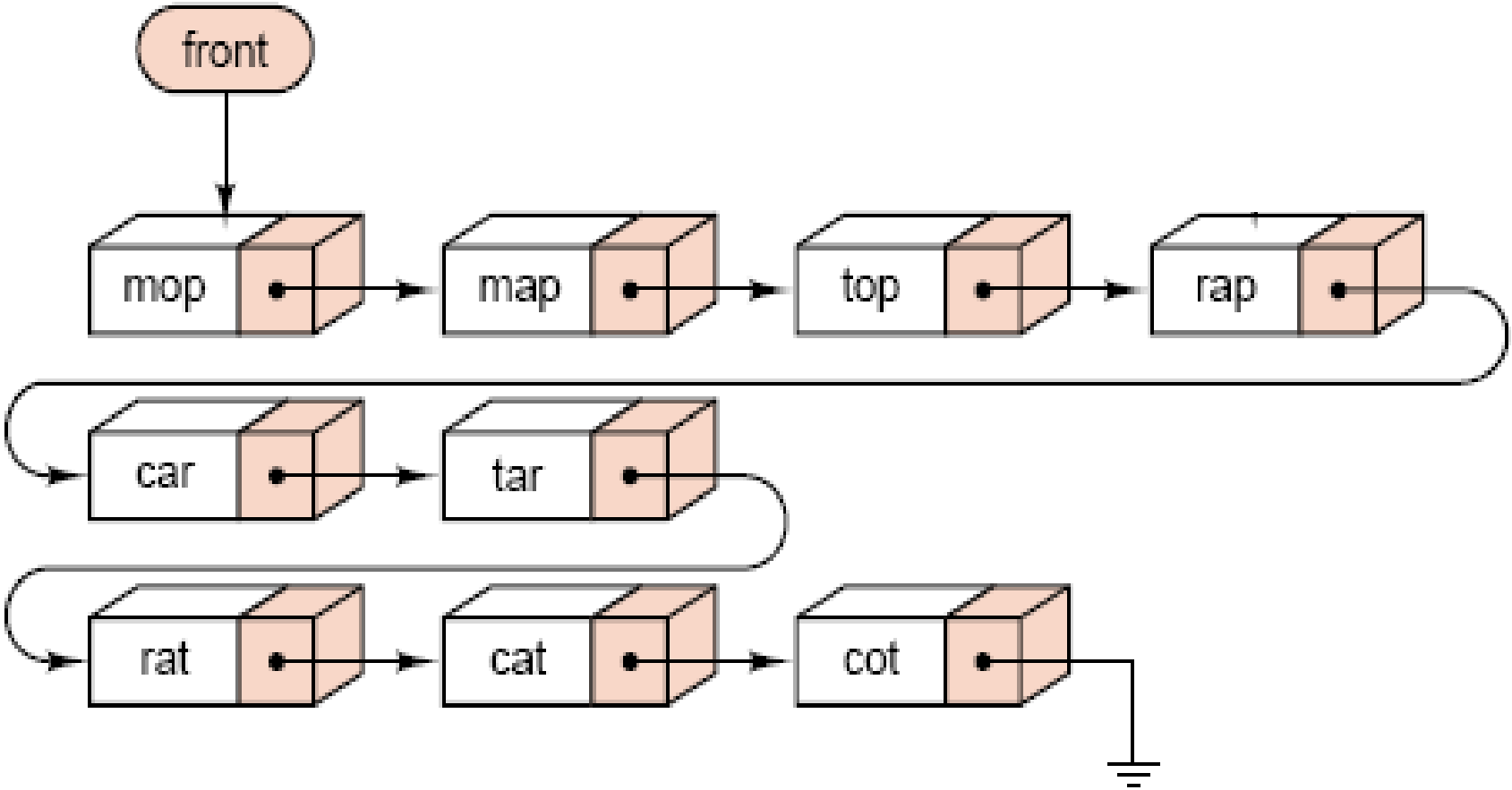
- ✓ Algorithm applied to data that use character string as key.
- ✓ Very efficient sorting method that use linked queues.
- ✓ Consider the key one character at a time
- ✓ Devide the elements into as many sublists as there are possibilities for given character from the key.
- ✓ To eleminate multiplicity of sublists, consider characters in the key from right to left.

Radix Sort

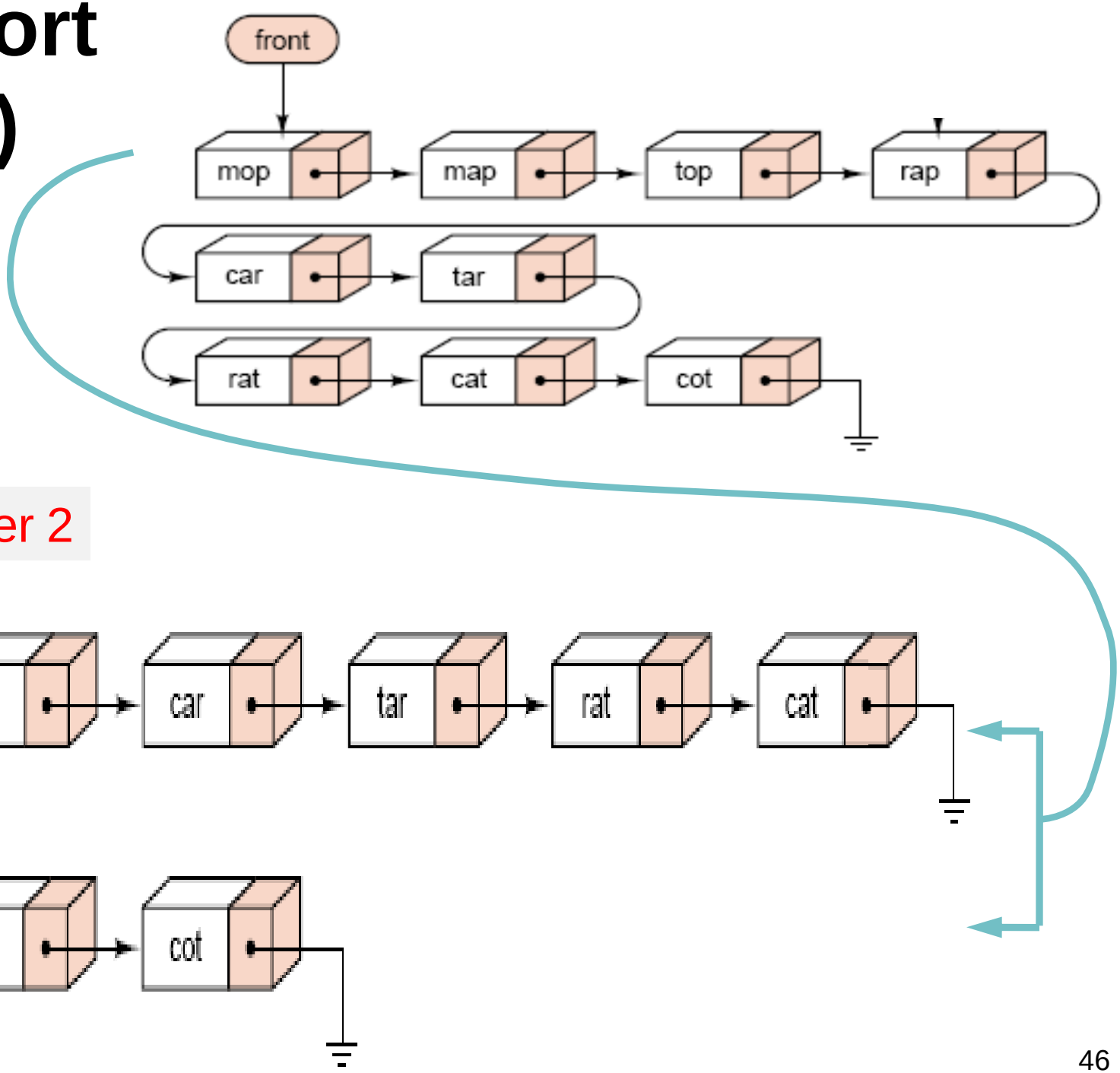
Sorted by letter 3



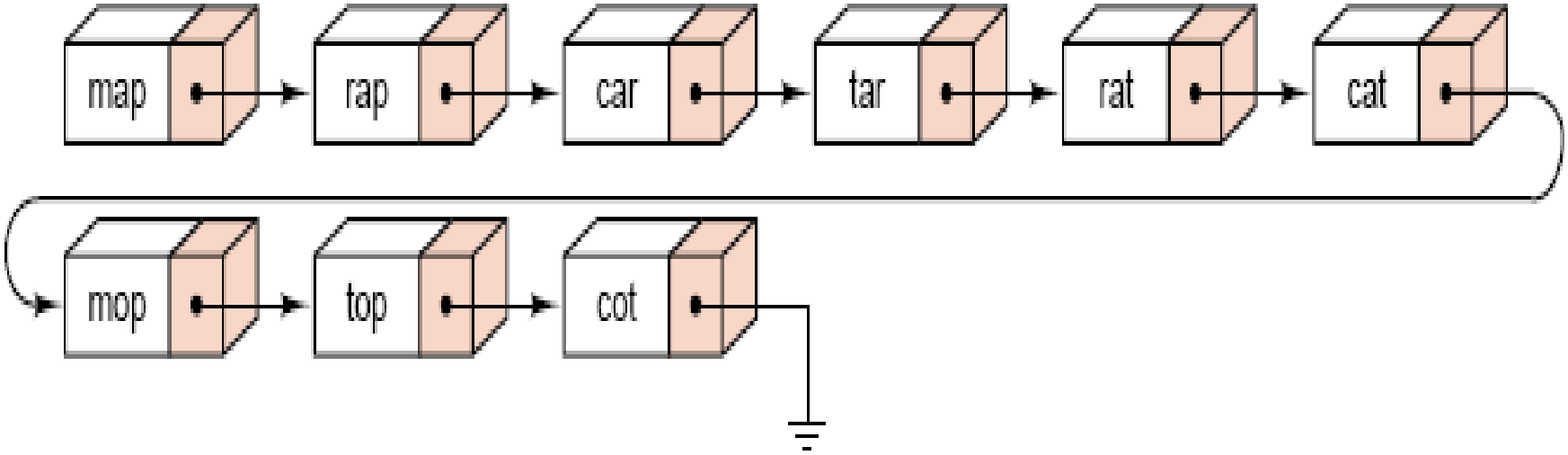
Radix Sort (cont.)



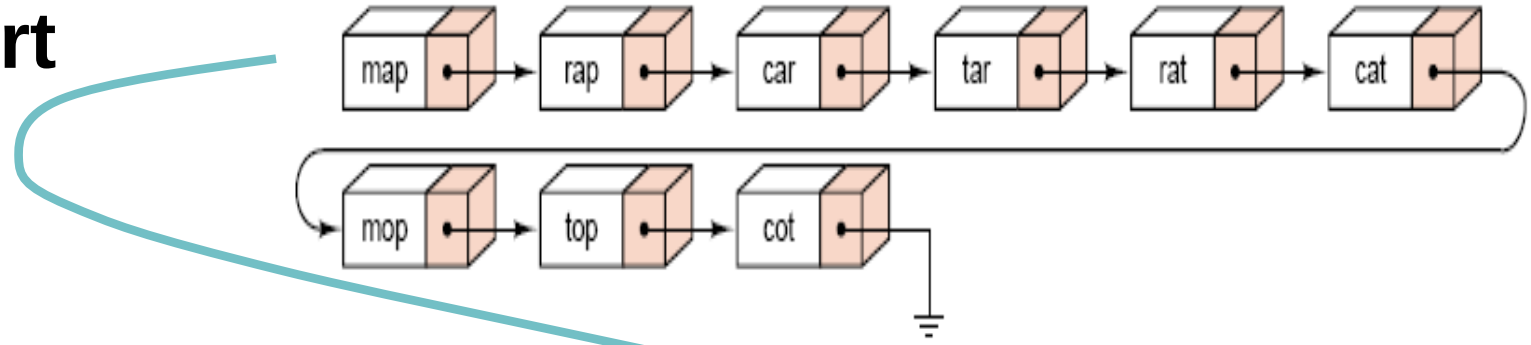
Radix Sort (cont.)



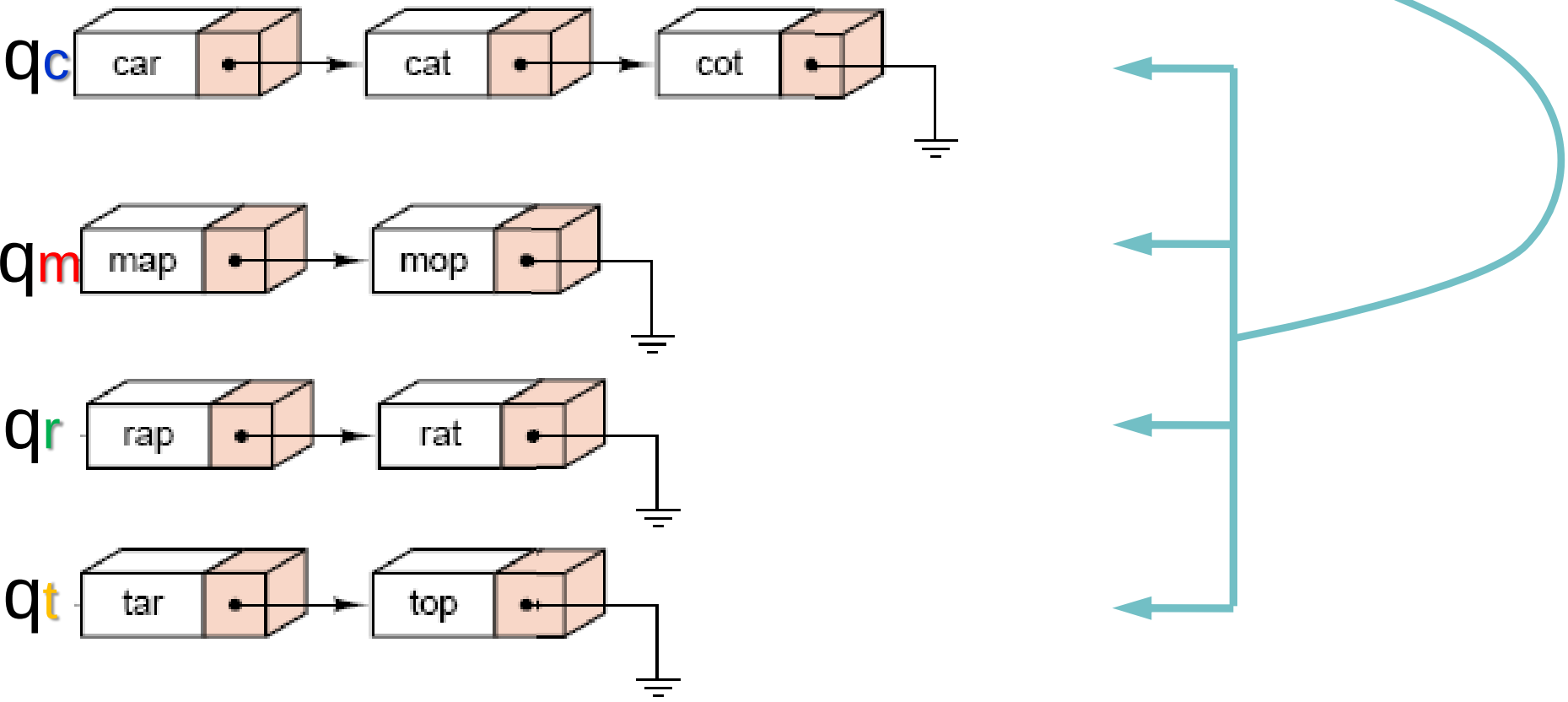
Radix Sort (cont.)



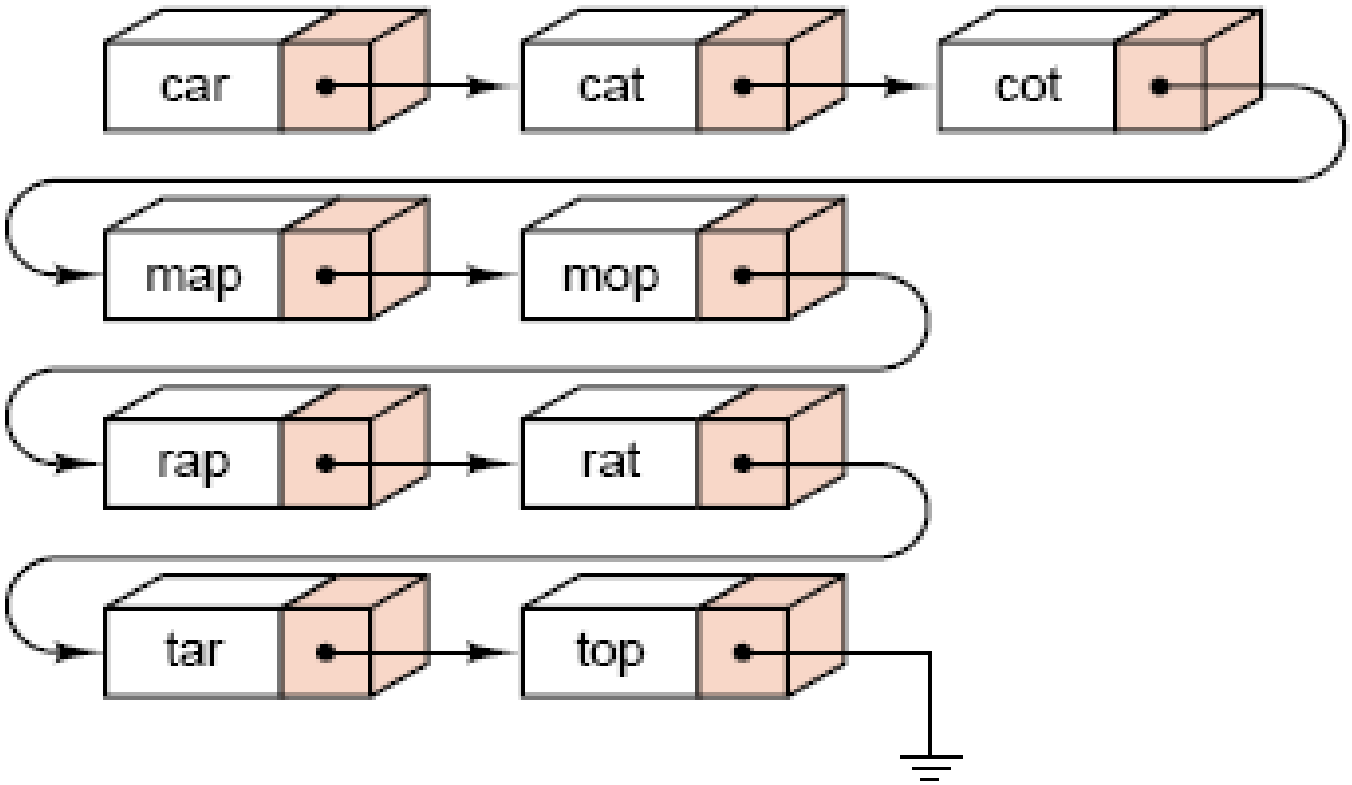
Radix Sort (cont.)



Sorted by letter 1



Radix Sort (cont.)



Sorted list

Queue Simulation

- A modelling activity to generate statistics about the performance of queues.

- Gilberg-Forouzan's textbook:
  - Queue simulation program