11 – Advanced Structures and STL library

Lecturer:

Contact:

Faculty of Computer Science and Engineering
Hochiminh city University of Technology

Contents

Doubling Linked List

Doubly Linked List

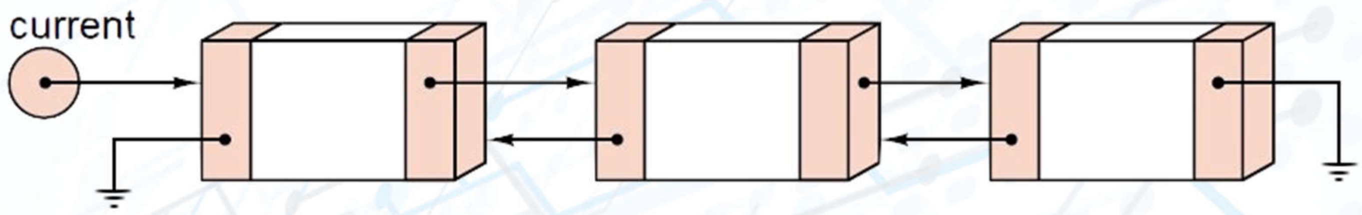


Figure 1: Doubly Linked List allows going forward and backward.

```
node
    data <dataType>
    next <pointer>
    previous <pointer>
end node
```

```
list
    current <pointer>
end list
```

Doubly Linked List

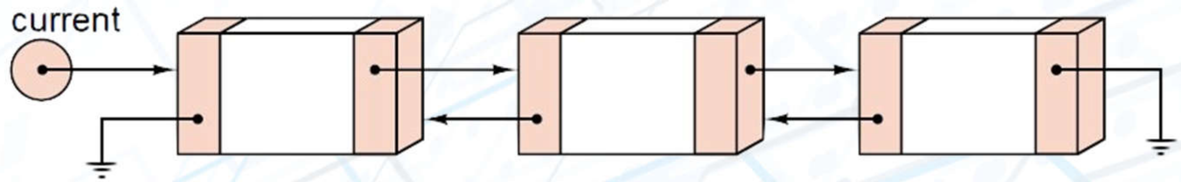


Figure 2: Doubly Linked List allows going forward and backward.

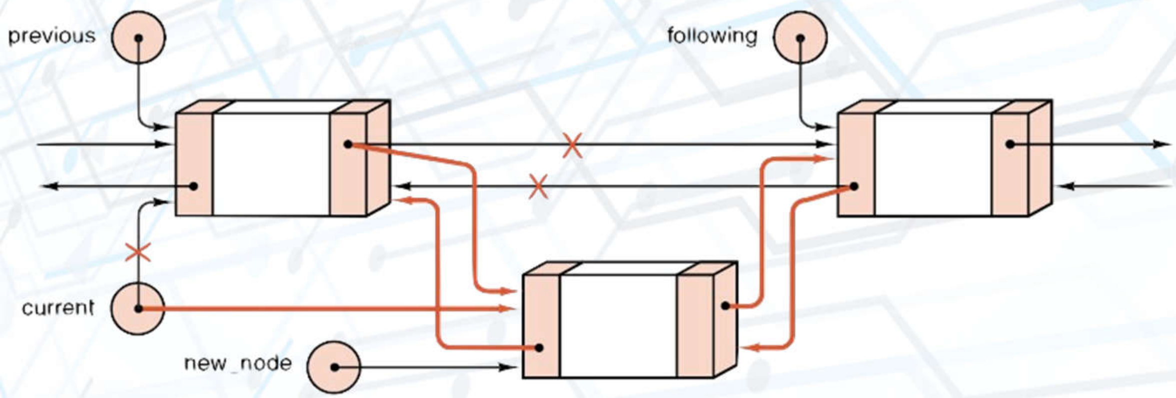
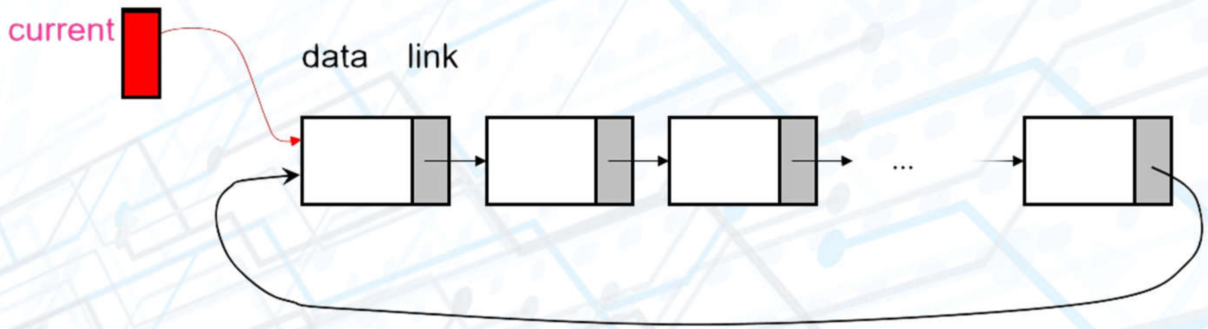


Figure 3: Insert an element in Doubly Linked List.

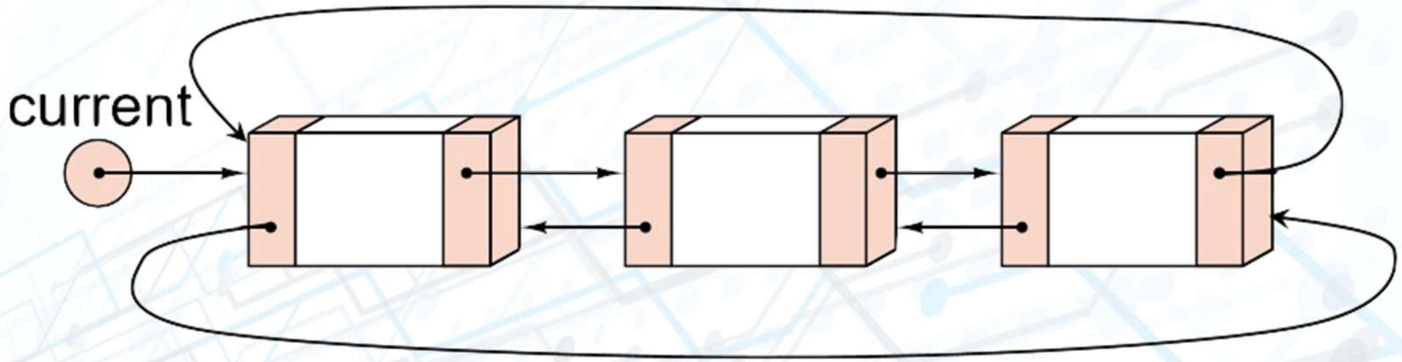
Circularly Linked List




```
node
   data <dataType>
   link <pointer>
end node
```

```
list
   current <pointer>
end list
```

Double circularly Linked List




```
node
    data <dataType>
    next <pointer>
    previous <pointer>
end node
```

```
list
    current <pointer>
end list
```

Basic operations of Stacks

Linear List Concepts

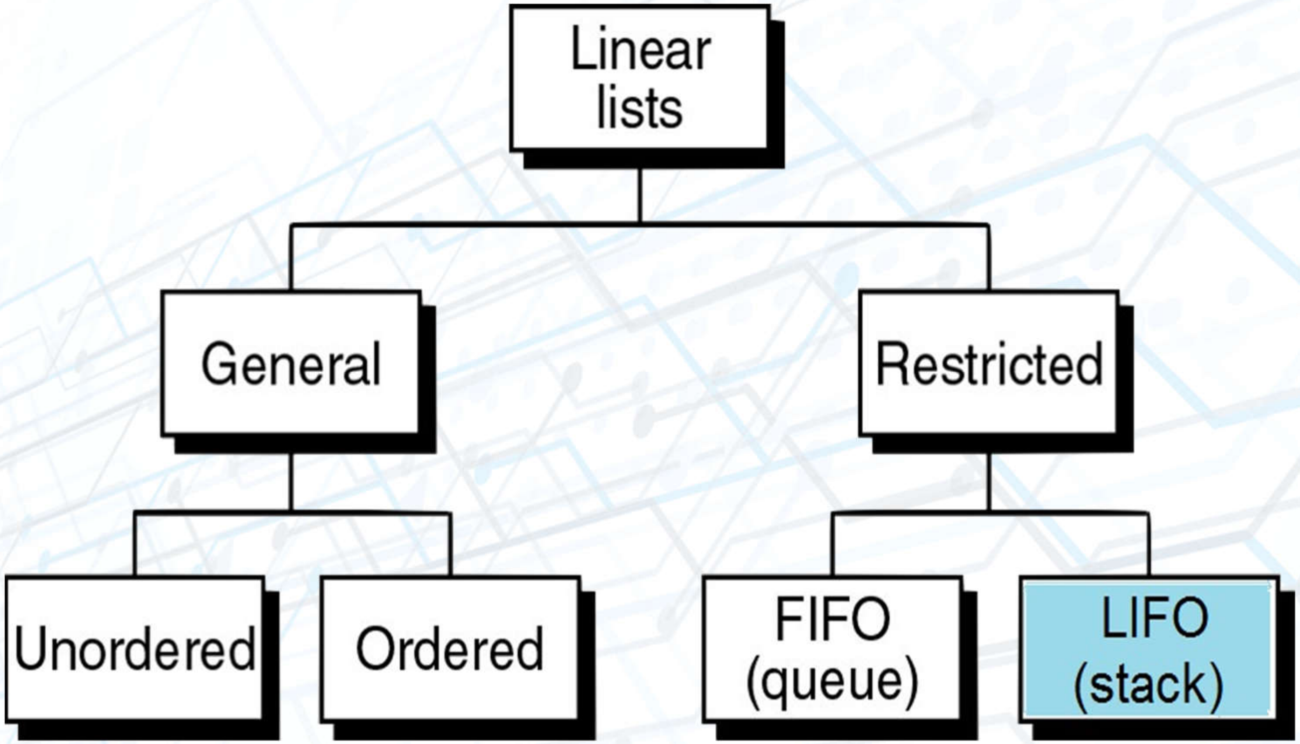
General list:

- No restrictions on which operation can be used on the list.
- No restrictions on where data can be inserted/deleted.

Restricted list:

- Only some operations can be used on the list.
- Data can be inserted/deleted only at the ends of the list.

Linear list concepts



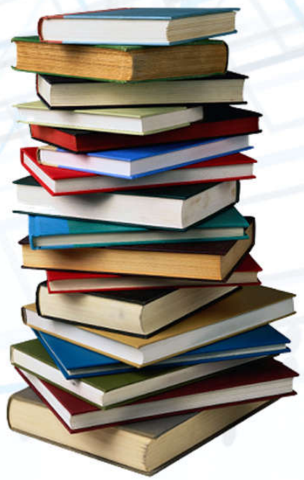
Stack

Definition

A stack of elements of type T is a finite sequence of elements of T, in which all insertions and deletions are restricted to one end, called the top.

Stack is a Last In - First Out (LIFO) data structure.

LIFO: The last item put on the stack is the first item that can be taken off.



Basic operations of Stacks

Basic operations:

- `Construct` a stack, leaving it empty.
- Push an element: put a new element on to the top of the stack.
- Pop an element: remove the top element from the top of the stack.
- Top an element: retrieve the top element.

Basic operations of Stacks

Extended operations:

- Determine whether the stack is empty or not.
- Determine whether the stack is `full` or not.
- Find the `size` of the stack.
- `Clear` the stack to make it empty.

Basic operations of Stacks: Push

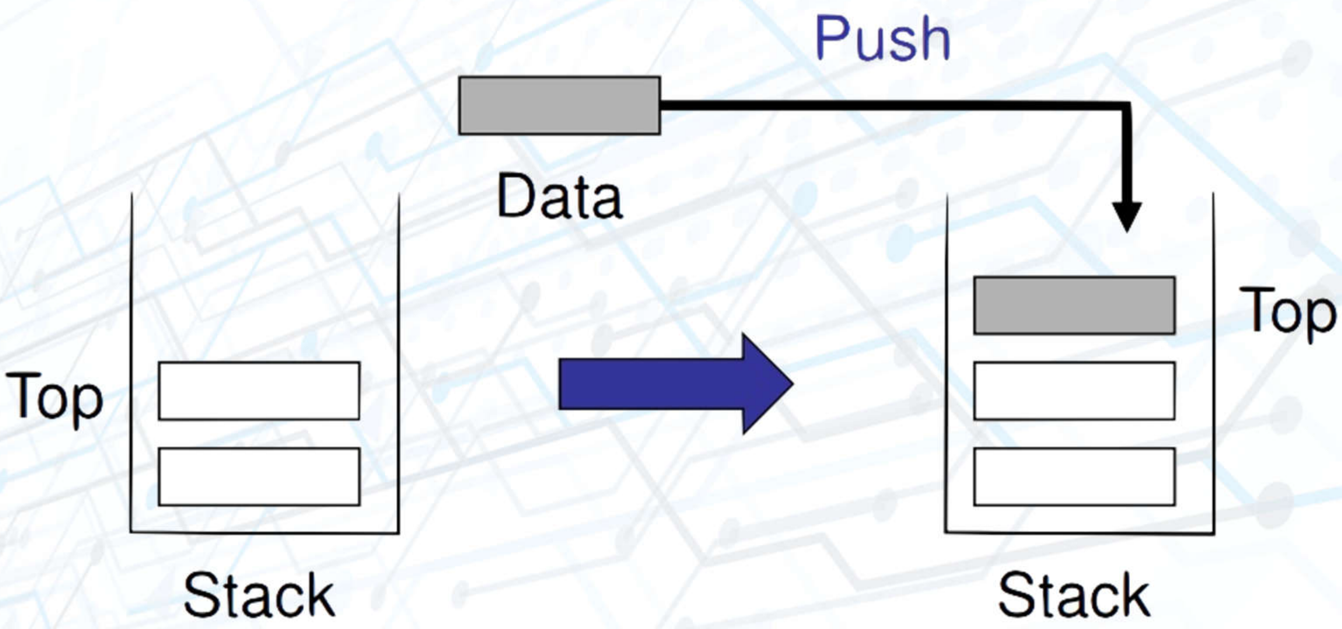


Figure 4: Successful Push operation

Basic operations of Stacks: Push

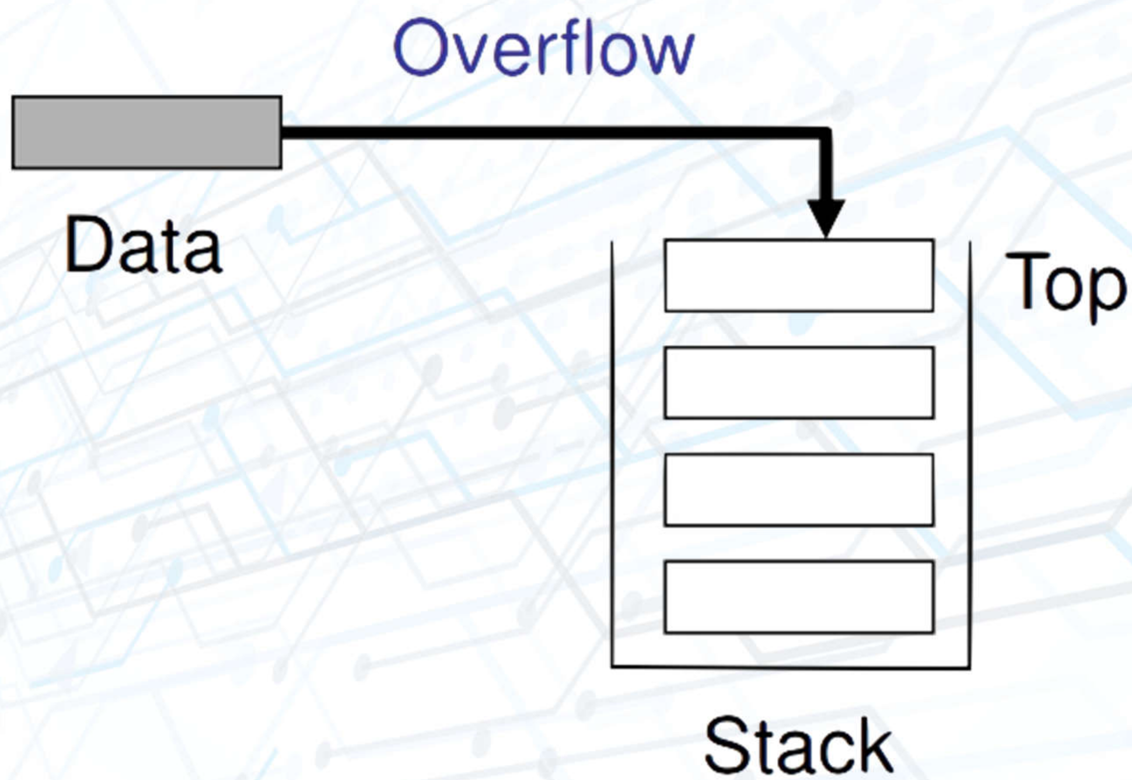


Figure 5: Unsuccessful Push operation. Stack remains unchanged.

Basic operations of Stacks: Pop

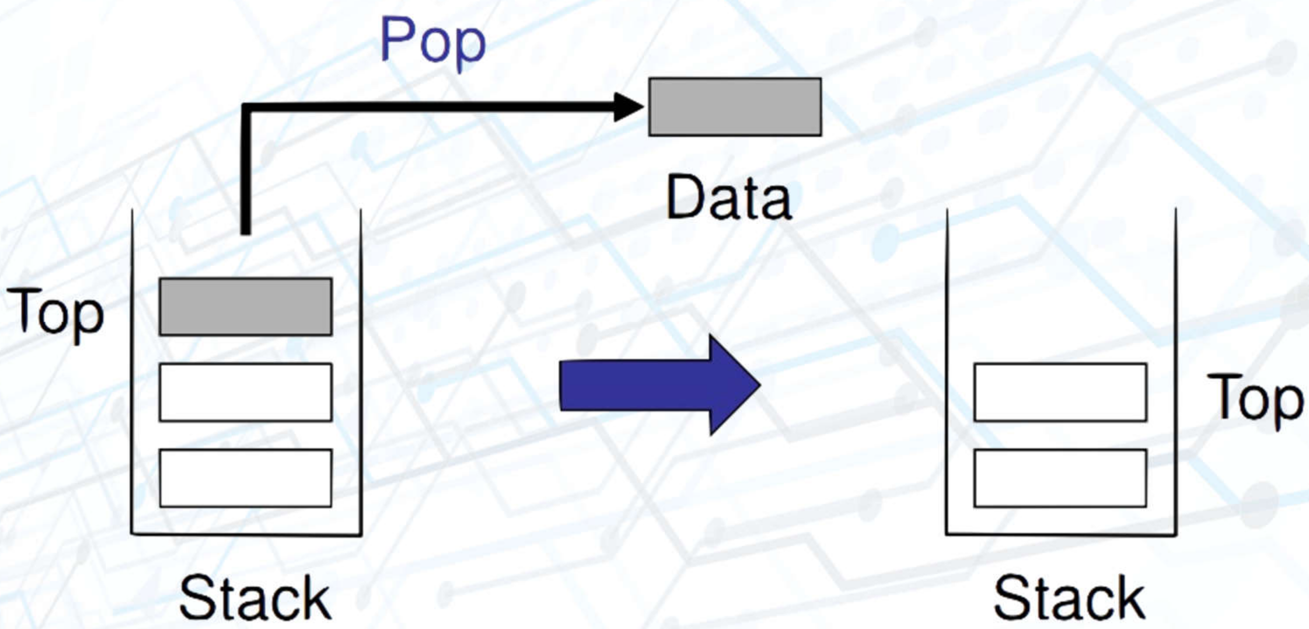


Figure 6: Successful Pop operation

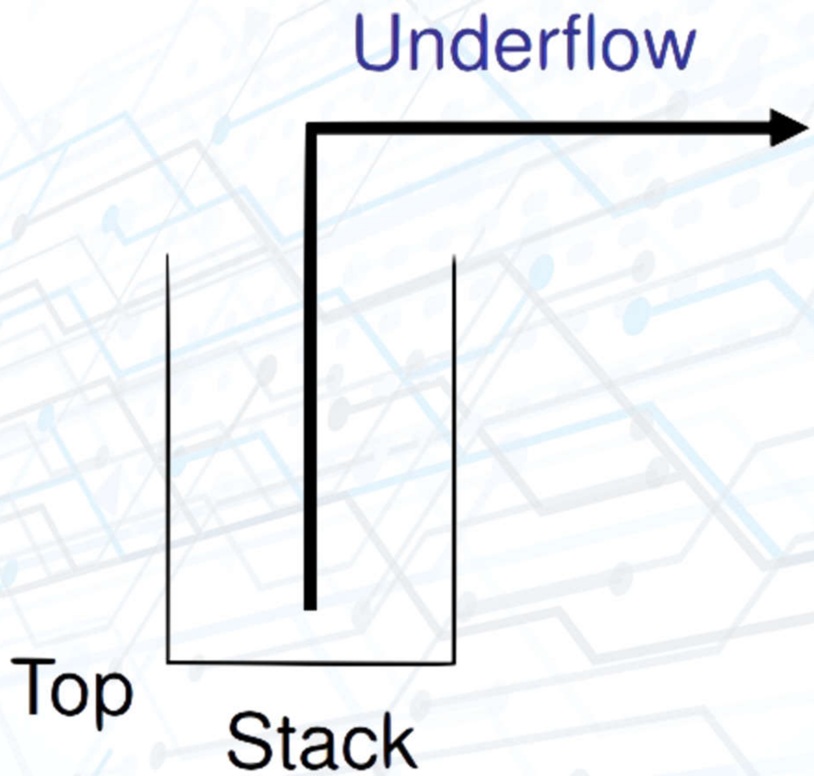


Figure 7: Unsuccessful Pop operation. Stack remains unchanged.

Basic operations of Stacks: Top

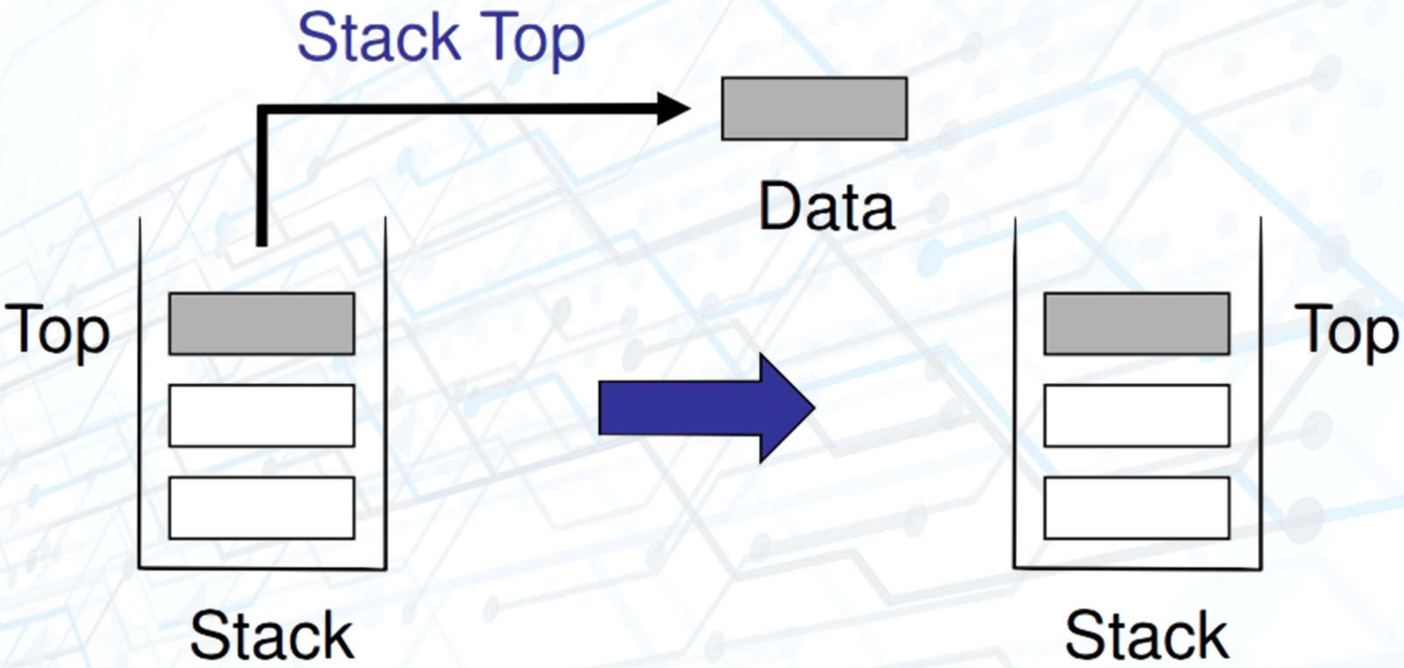


Figure 8: Successful Top operation. Stack remains unchanged.

Basic operations of Stacks: Top

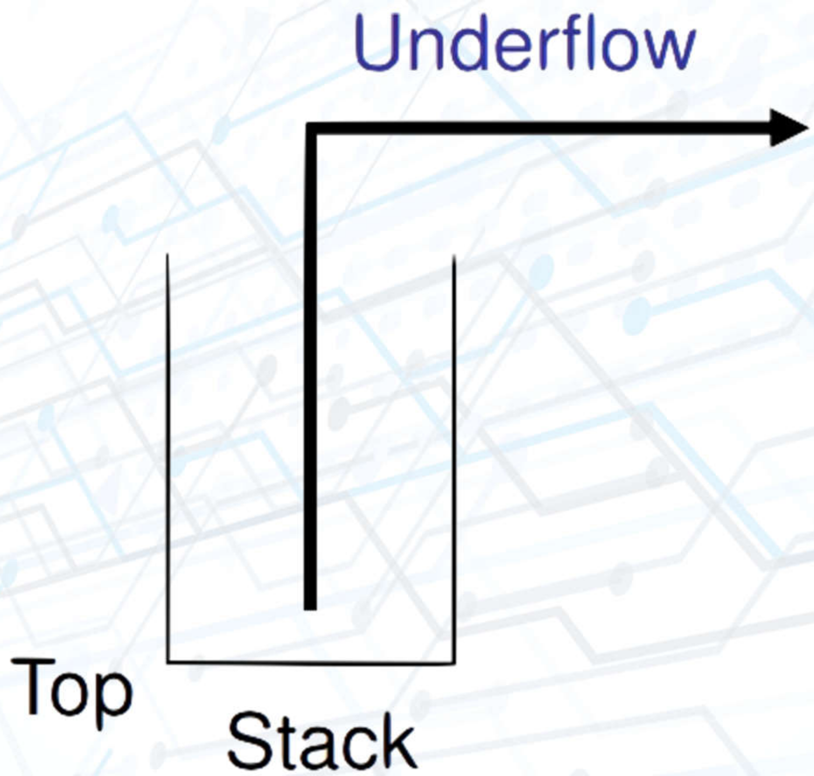
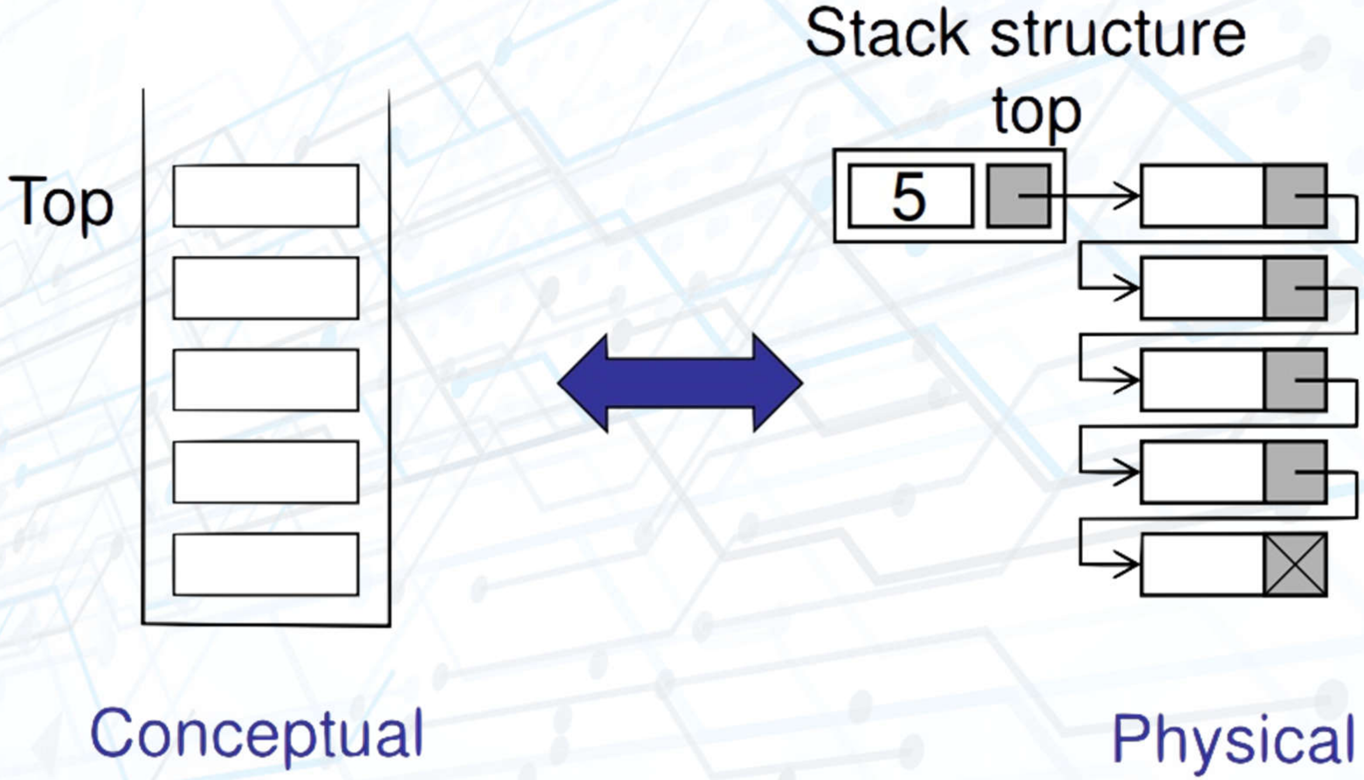


Figure 9: Unsuccessful Top operation. Stack remains unchanged.

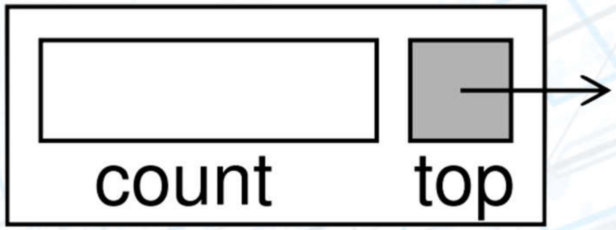
Implementation of Stacks

Linked-list implementation



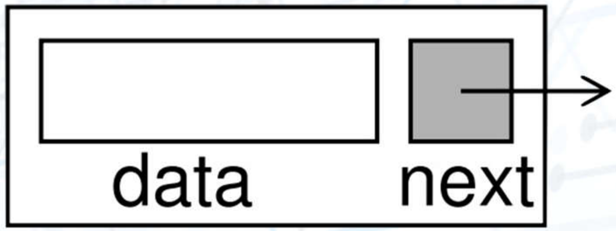
Linked-list implementation

Stack structure




```
stack
   count <integer>
   top <node pointer>
end stack
```

Stack node structure




```
node
   data <dataType>
   next <node pointer>
end node
```

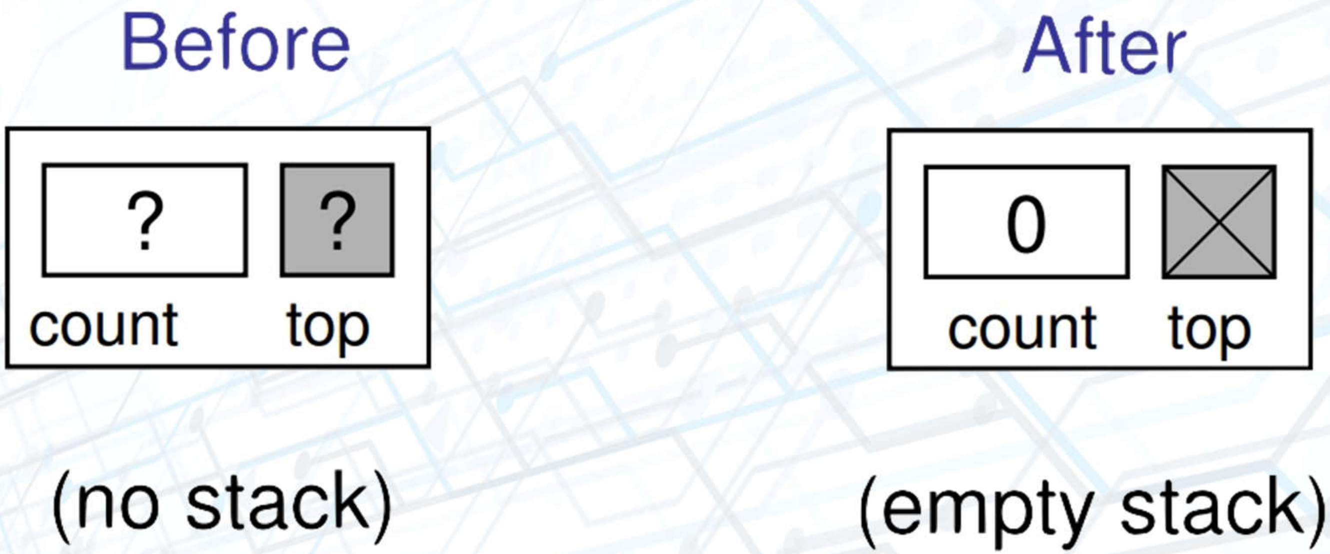
Linked-list implementation in C++

```
template <class ItemType>
struct Node {
  ItemType data;
  Node<ItemType> *next;
};
```

Linked-list implementation in C++

```
template <class List_ItemType>
class Stack {
  public: Stack();
    ~Stack();
    void Push(List_ItemType dataIn);
    int Pop(List_ItemType &dataOut);
    int GetStackTop(List_ItemType &dataOut);
    void Clear();
    int IsEmpty();
    int GetSize();
    Stack<List_ItemType>* Clone();
    void Print2Console();
  private:
    Node<List_ItemType>* top;
    int count;
};
```

Create an empty Linked Stack



Create an empty Linked Stack

Algorithm createStack(ref stack <metadata>)

Initializes the metadata of a stack

Pre: `stack` is a metadata structure of a stack

Post: metadata initialized

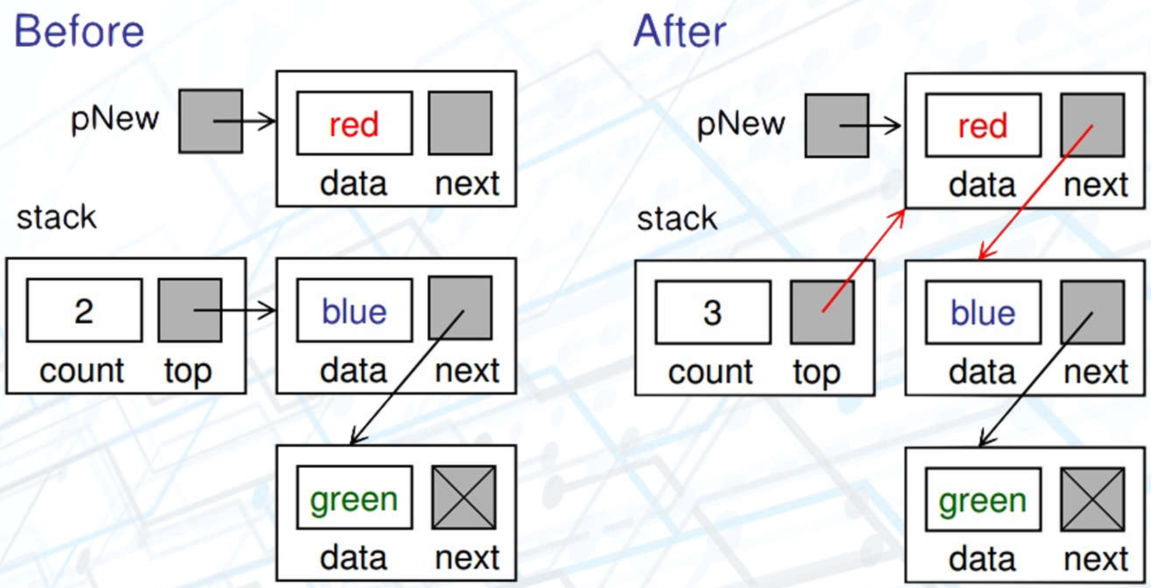
```
stack.count = 0
stack.top = null
return
```

End createStack

Create an empty Linked Stack

```
template <class List_ItemType>
Stack<List_ItemType>::Stack(){
  this->top = NULL;
  this->count = 0;
}

template <class List_ItemType>
Stack<List_ItemType>::~Stack(){
  this->Clear();
}
```

Push data into a Linked Stack



1. Allocate memory for the new node and set up data.
2. Update pointers:
   - Point the new node to the top node (before adding the new node).
   - Point top to the new node.
3. Update count

Push data into a Linked Stack

Algorithm pushStack(ref stack <metadata>, val data <dataType>)

Inserts (pushes) one item into the stack

Pre: `stack` is a metadata structure to a valid stack

`data` contains value to be pushed into the stack

Post: data have been pushed in stack

Return `true` if successful; `false` if memory overflow

Push data into a Linked Stack

```
if stack full then
    success = false
else
    allocate (pNew)
    pNew -> data = data
    pNew -> next = stack.top
    stack.top = pNew
    stack.count = stack.count + 1
    success = true
end
return success
End pushStack
```

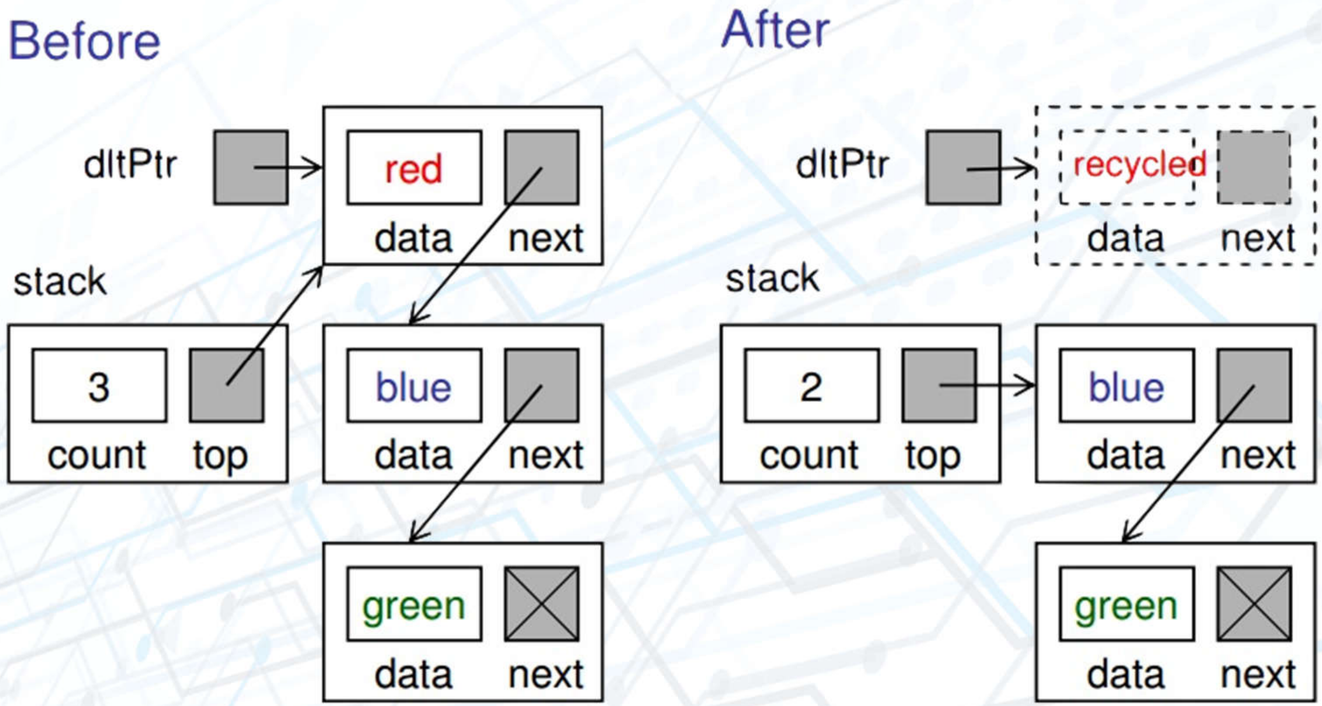
Push data into a Linked Stack

```
template <class List_ItemType>
void Stack<List_ItemType>::Push
                (List_ItemType value){
  Node<List_ItemType>* pNew =
                new Node<List_ItemType>();
  pNew->data = value;
  pNew->next = this->top;
  this->top = pNew;
  this->count++;
}
```

Push data into a Linked Stack

- Push is successful when allocation memory for the new node is successful.
- There is no difference between push data into a stack having elements and push data into an empty stack (`top` having NULL value is assigned to pNew->next: that's corresponding to a list having only one element).

Pop Linked Stack



1. `dltPtr` holds the element on the top of the stack.
2. `top` points to the next element.
3. Recycle `dltPtr`. Decrease `count` by 1.

Pop Linked Stack

Algorithm popStack(ref stack <metadata>, ref dataOut <dataType>)

Pops the item on the top of the stack and returns it to caller

Pre: `stack` is a metadata structure to a valid stack

`dataOut` is to receive the popped data

Post: data have been returned to caller

Return `true` if successful; `false` if stack is empty

Pop Linked Stack

```
if stack empty then
    success = false
else
    dltPtr = stack.top
    dataOut = stack.top -> data
    stack.top = stack.top -> next
    stack.count = stack.count - 1
    recycle(dltPtr)
    success = true
end
return success
End popStack
```

Pop Linked Stack

```
template <class List_ItemType>
int Stack<List_ItemType>::Pop(List_ItemType &dataOut){
  if (this->GetSize() == 0)
    return 0;
  Node<List_ItemType>* dltPtr = this->top; dataOut = dltPtr->data;
  this->top = dltPtr->next;
  this->count--;
  delete dltPtr;
  return 1;
}
```

Pop Linked Stack

- Pop is successful when the stack is not empty.
- There is no difference between pop an element from a stack having elements and pop the only-one element in the stack (`dltPtr->next` having NULL value is assigned to top: that's corresponding to an empty stack).

Stack Top

Algorithm stackTop(ref stack <metadata>, ref dataOut <dataType>)

Retrieves the data from the top of the stack without changing the stack

Pre: `stack` is a metadata structure to a valid stack

`dataOut` is to receive top stack data

Post: data have been returned to caller

Return `true` if successful; `false` if stack is empty

Stack Top

```
if stack empty then
    success = false
else
    dataOut = stack.top -> data
    success = true
end
return success
End stackTop
```

Stack Top

```
template <class List_ItemType>
int Stack<List_ItemType>::GetStackTop
                    (List_ItemType &dataOut){

  if (this->GetSize() == 0)
    return 0;

  dataOut = this->top->data;

  return 1;
}
```

Destroy Stack

Algorithm destroyStack(ref stack <metadata>)

Releases all nodes back to memory

Pre: `stack` is a metadata structure to a valid stack

Post: stack empty and all nodes recycled

Destroy Stack

```
if stack not empty then
    while stack.top not null do
        temp = stack.top
        stack.top = stack.top -> next
        recycle(temp)
    end
end
stack.count = 0
return
End destroyStack
```

Destroy Stack

```
template <class List_ItemType>
void Stack<List_ItemType>::Clear() {
  Node<List_ItemType>* temp;
  while (this->top != NULL){
    temp = this->top;
    this->top = this->top->next;
    delete temp;
  }
  this->count = 0;
}
```

isEmpty Linked Stack

Algorithm isEmpty(ref stack <metadata>)

Determines if the stack is empty

Pre: `stack` is a metadata structure to a valid stack

Post: return stack status

Return `true` if the stack is empty, `false` otherwise

if *count* = *0* **then**

  Return `true`

else

  Return `false`

end

End isEmpty

isEmpty Linked Stack

```
template <class List_ItemType>
int Stack<List_ItemType>::IsEmpty() {
  return (count == 0);
}

template <class List_ItemType>
int Stack<List_ItemType>::GetSize() {
  return count;
}
```

isFull Linked Stack

```
template <class List_ItemType>
int Stack<List_ItemType>::IsFull() {
  Node<List_ItemType>* pNew = new Node<List_ItemType>();

  if (pNew != NULL) {
    delete pNew;
    return 0;
  }
  else {
    return 1;
  }
}
```

Print Stack

```
template <class List_ItemType>
void Stack<List_ItemType>::Print2Console() {
  Node<List_ItemType>* p;
  p = this->top;
  while (p != NULL){
    cout << p->data << "+";
    p = p->next;
  }
  cout << endl;
}
```

Using Stack

```
int main(int argc, char* argv[]){
  Stack<int> *myStack = new Stack<int>();
  int val;
  myStack->Push(7);
  myStack->Push(9);
  myStack->Push(10);
  myStack->Push(8);
  myStack->Print2Console();
  myStack->Pop(val);
  myStack->Print2Console();
  delete myStack;
  return 0;
}
```

Array-based stack implementation

Implementation of array-based stack is very simple. It uses `top` variable to point to the topmost stack's element in the array.

1. Initialy `top = -1`;
2. `push` operation increases `top` by one and writes pushed element to `storage[top]`;
3. `pop` operation checks that `top` is not equal to -1 and decreases `top` variable by 1;
4. `getTop` operation checks that `top` is not equal to -1 and returns `storage[top]`;
5. `isEmpty` returns boolean if `top == -1`.

Array-based stack implementation

```
#include <string>
using namespace std;

class ArrayStack {
private:
  int top;
  int capacity;
  int *storage;
public:
  ArrayStack(int capacity) {
    storage = new int[capacity];
    this->capacity = capacity;
    top = -1;
  }
  // ...
```

Array-based stack implementation

```
~ArrayStack() {
  delete[] storage;
}

void push(int value) {
  if (top == capacity - 1)
    throw string("Stack+is+overflow");
  top++;
  storage[top] = value;
}
void pop(int &dataOut) {
  if (top == -1)
    throw string("Stack+is+empty");
  dataOut = storage[top];
  top--;
}

// ...
```

Array-based stack implementation

```
int getTop() {
  if (top == -1)
    throw string("Stack+is+empty");
  return storage[top];
}

bool isEmpty() {
  return (top == -1);
}

bool isFull() {
  return (top == capacity-1);
}
```

Array-based stack implementation

```
  int getSize() {
    return top + 1;
  }

  void print2Console() {
    if (top > -1) {
        for (int i = top; i >= 0; i--) {
            cout << storage[i] << "+";
        }
        cout << endl;
    }
  }

};
```

Using array-based stack

```
int main(int argc, char* argv[]){
  ArrayStack *myStack = new ArrayStack(10);
  int val;
  myStack->push(7);
  myStack->push(9);
  myStack->push(10);
  myStack->push(8);
  myStack->print2Console();
  myStack->pop(val);
  myStack->print2Console(); delete
  myStack;
  return 0;
}
```

Applications of Stack

Applications of Stack

- Reversing data items
  - Reverse a list
  - Convert Decimal to Binary
- Parsing
  - Brackets Parse
- Postponement of processing data items
  - Infix to Postfix Transformation
  - Evaluate a Postfix Expression
- Backtracking
  - Goal Seeking Problem
  - Knight's Tour
  - Exiting a Maze
  - Eight Queens Problem

Basic operations of Queues

Queue

Definition

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

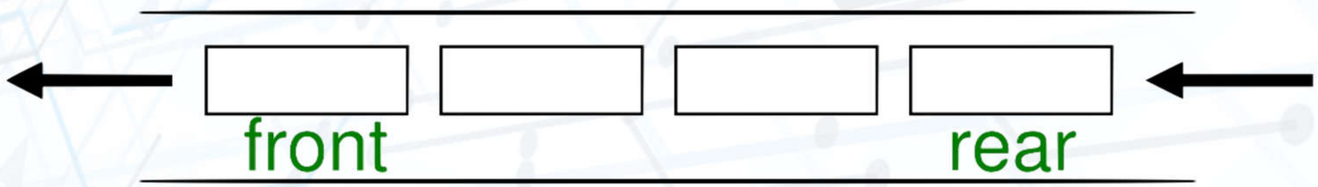
Queue is a First In - First Out (FIFO) data structure.

FIFO: The first item stored in the queue is the first item that can be taken out.

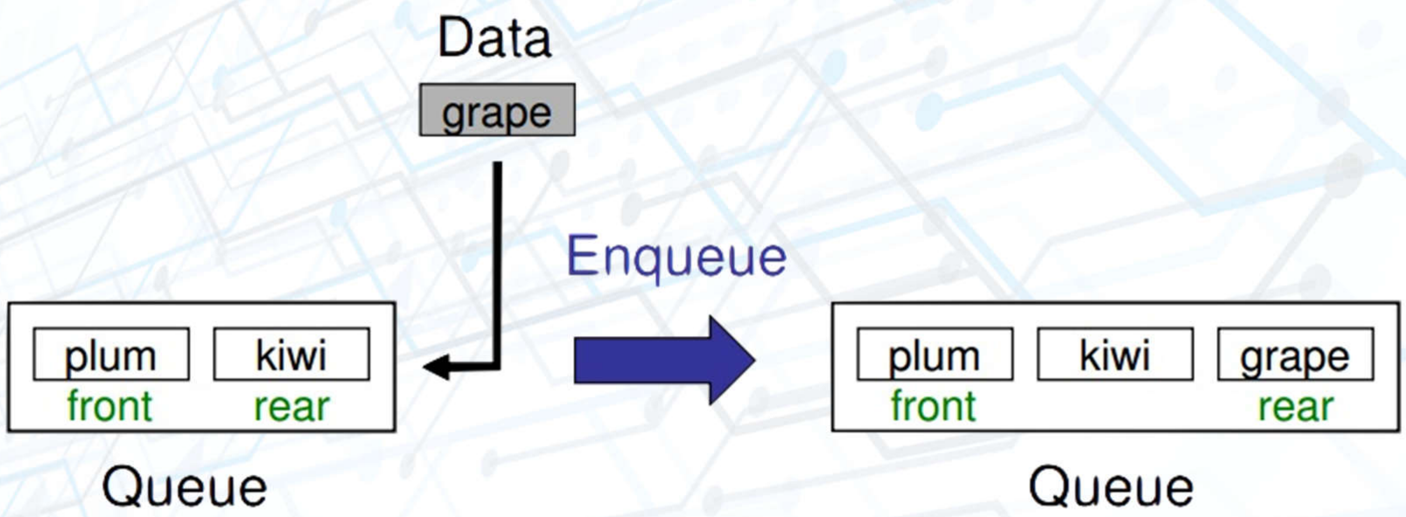
Basic operations of Queues

Basic operations:

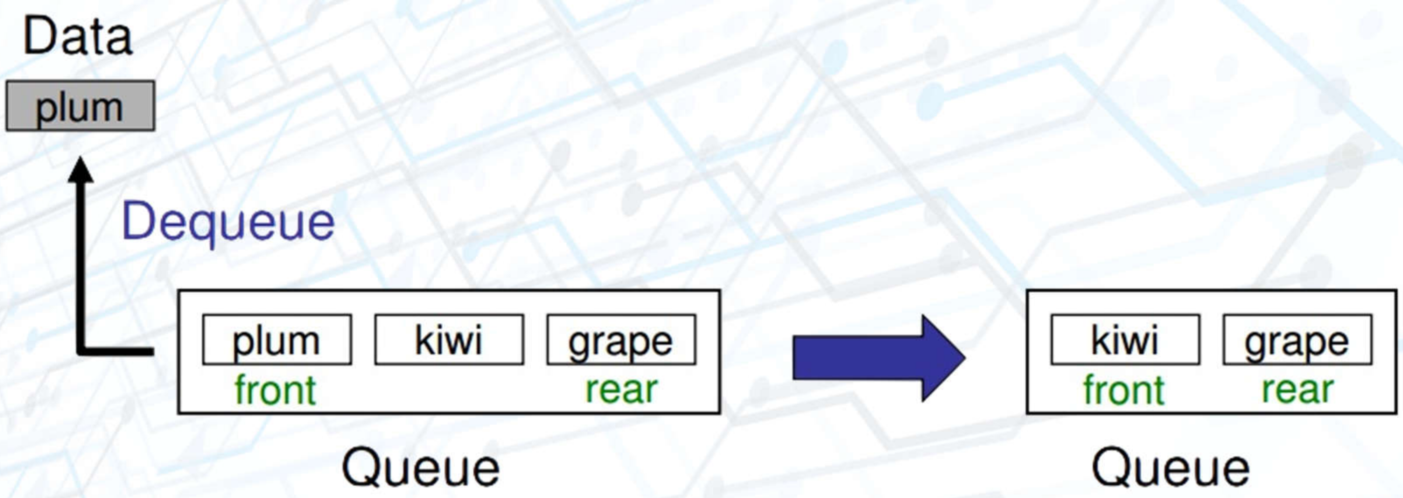
- Construct a queue, leaving it empty.
- Enqueue: put a new element in to the rear of the queue.
- Dequeue: remove the first element from the front of the queue.
- Queue Front: retrieve the front element.
- Queue Rear: retrieve the rear element.



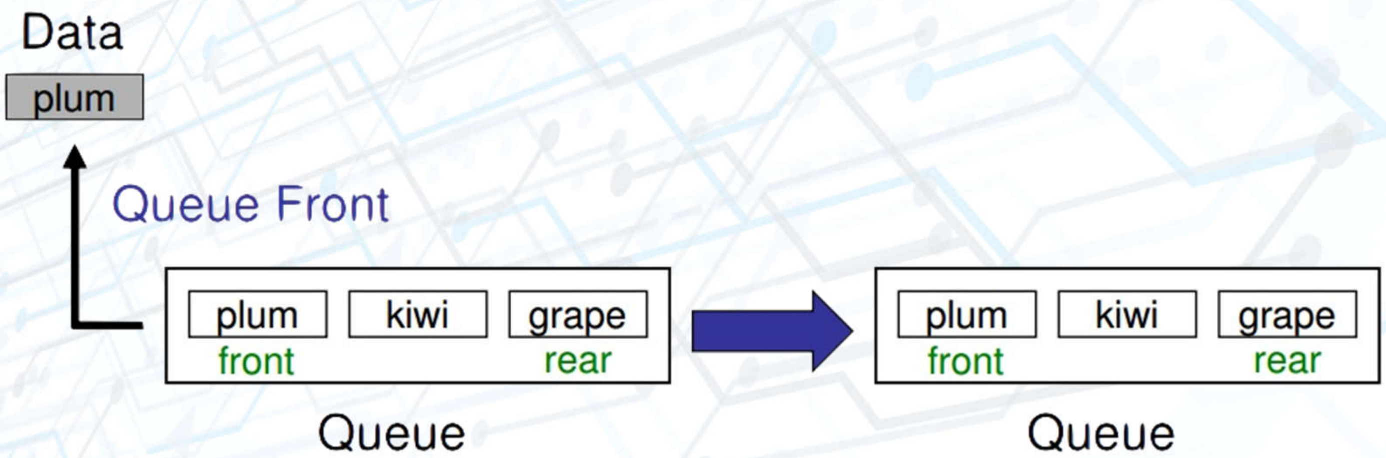
Basic operations of Queues: Enqueue



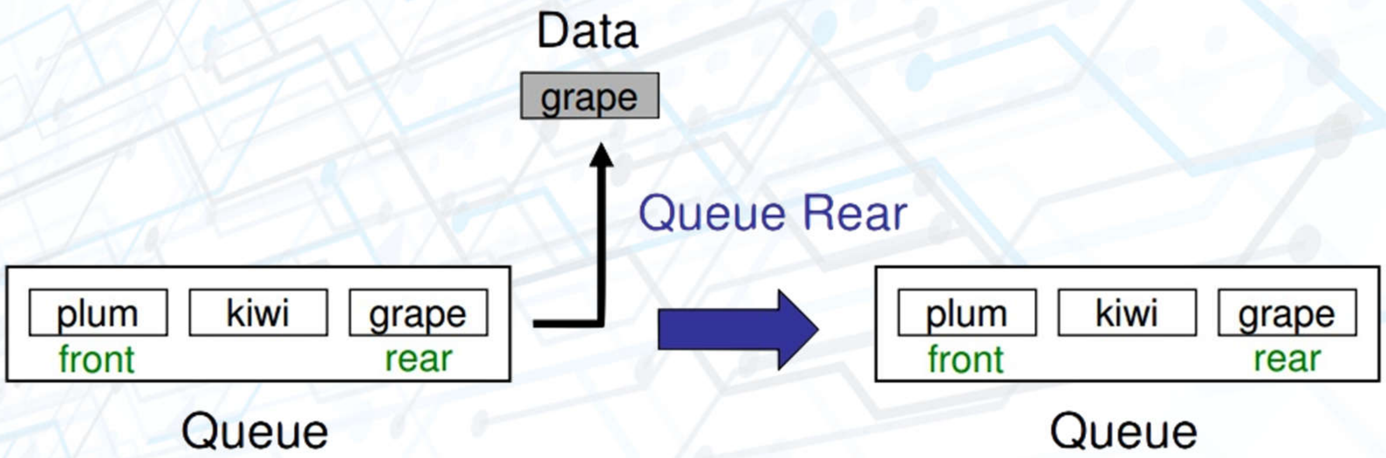
Basic operations of Queues: Dequeue



Basic operations of Queues: Queue Front

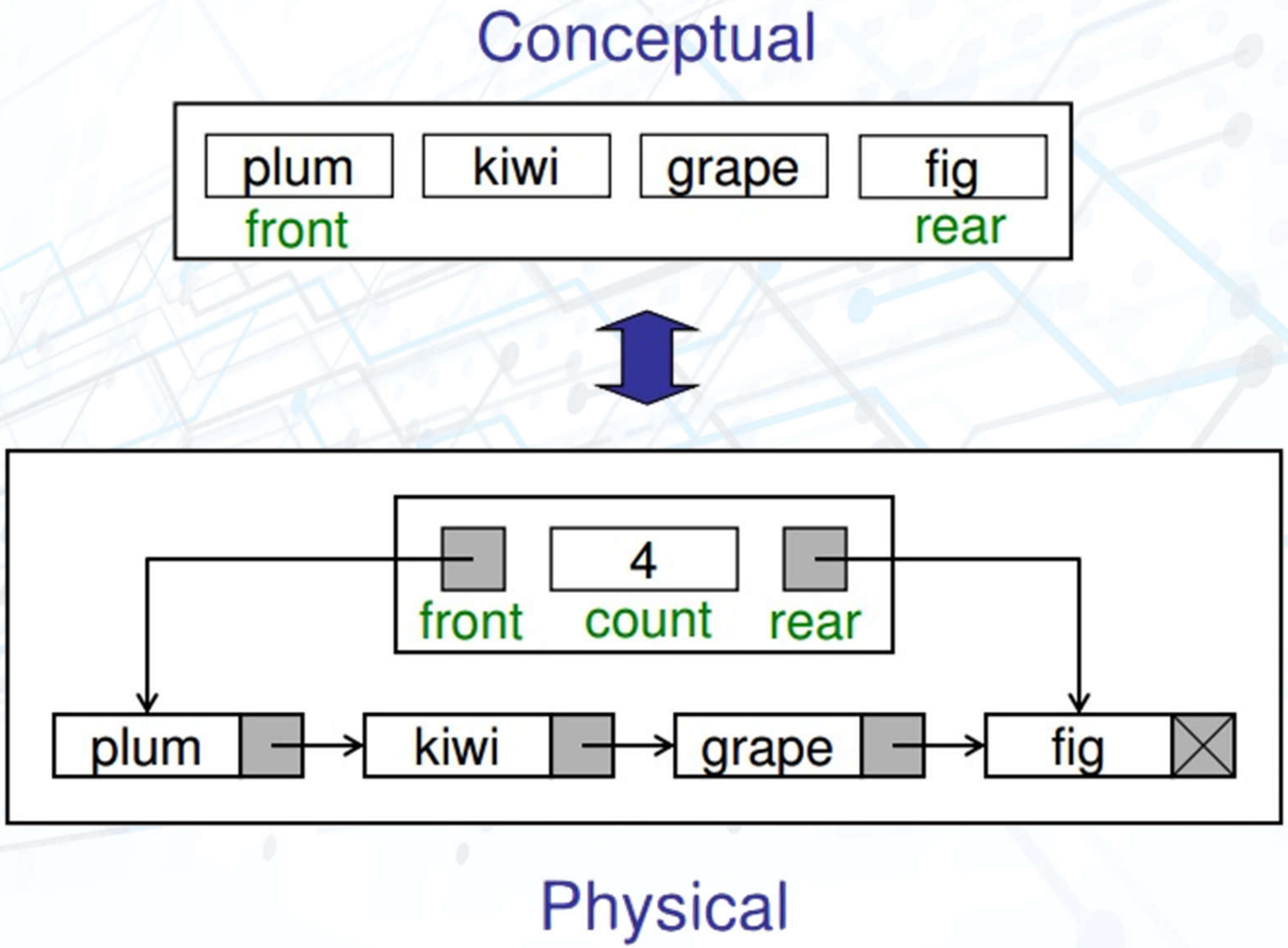


Basic operations of Queues: Queue Rear



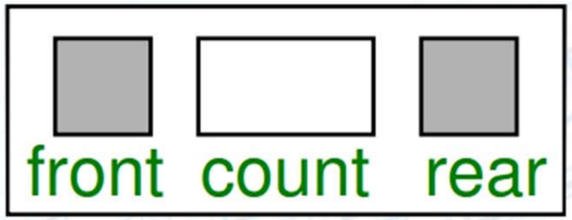
Implementation of Queue

Linked-list implementation



Linked-list implementation

Queue structure




```
queue
   count <integer>
   front <node pointer>
   rear <node pointer>
endqueue
```

Queue node structure


```
node
   data <dataType>
   next <node pointer>
end node
```

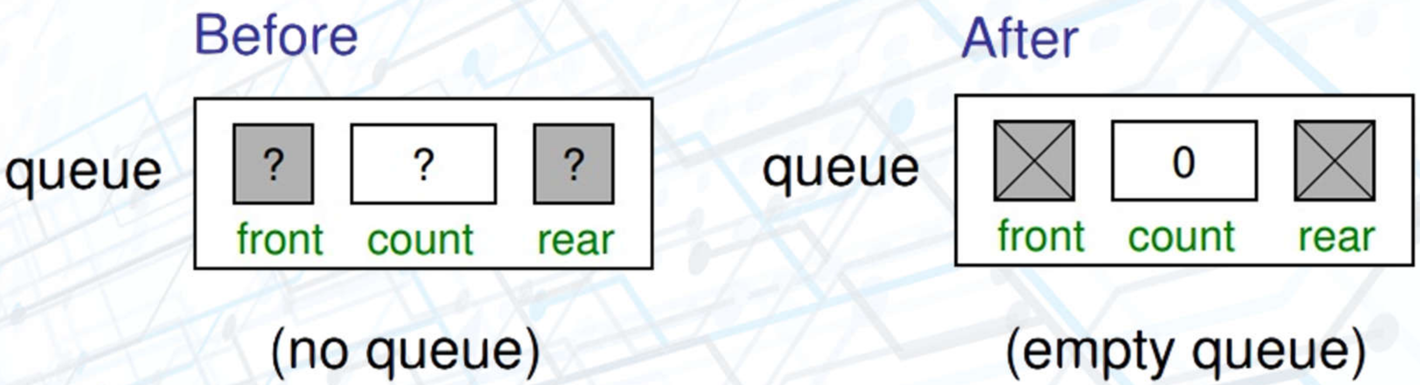
Linked-list implementation in C++

```
template <class ItemType>
struct Node {
  ItemType data;
  Node<ItemType> *next;
};


template <class List_ItemType>
class Queue {
  public: Queue();
    ~Queue();
```

Linked-list implementation in C++

```
    void Enqueue(List_ItemType dataIn);
    int Dequeue(List_ItemType &dataOut);
    int GetQueueFront(List_ItemType &dataOut);
    int GetQueueRear(List_ItemType &dataOut);
    void Clear();
    int IsEmpty();
    int GetSize();
    void Print2Console();

  private:
    Node<List_ItemType> *front, *rear;
    int count;
};
```

Create Queue



Create Queue

Algorithm createQueue(ref queue <metadata>)

Initializes the metadata of a queue

Pre: queue is a metadata structure of a queue

Post: metadata initialized

queue.count= 0

queue.front = null

queue.rear = null return

End createQueue

Create Queue

```
template <class List_ItemType>
Queue<List_ItemType>::Queue(){
  this->count = 0;
  this->front = NULL; this->rear =
  NULL;
}

template <class List_ItemType>
Queue<List_ItemType>::~Queue(){
  this->Clear();
}
```

Enqueue: Insert into an empty queue

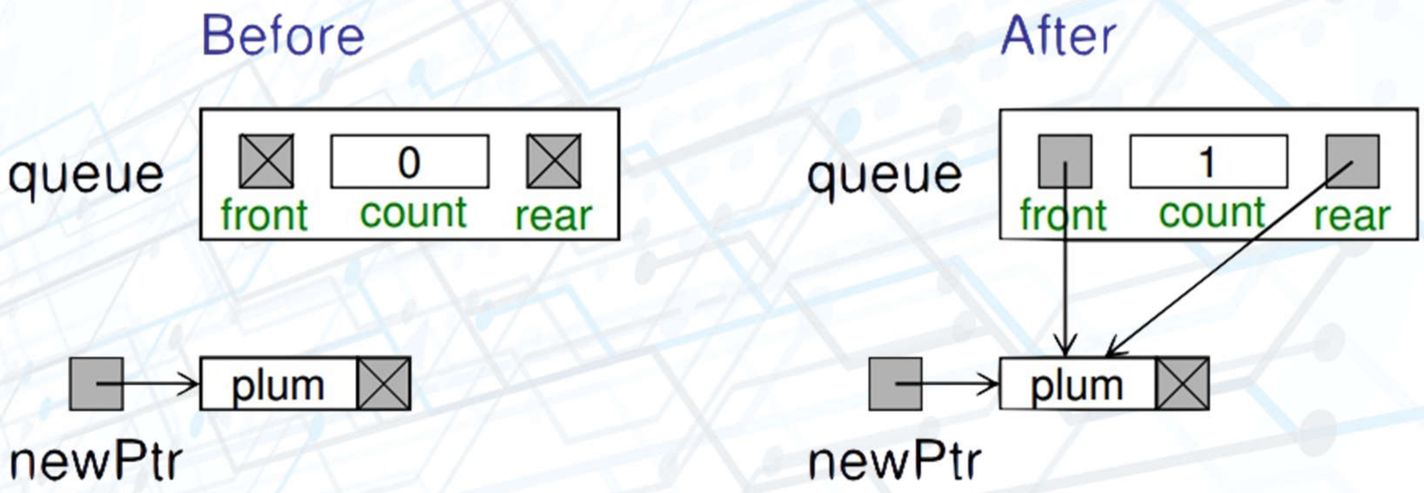


Figure 7: Insert into an empty queue

Enqueue: Insert into a queue with data

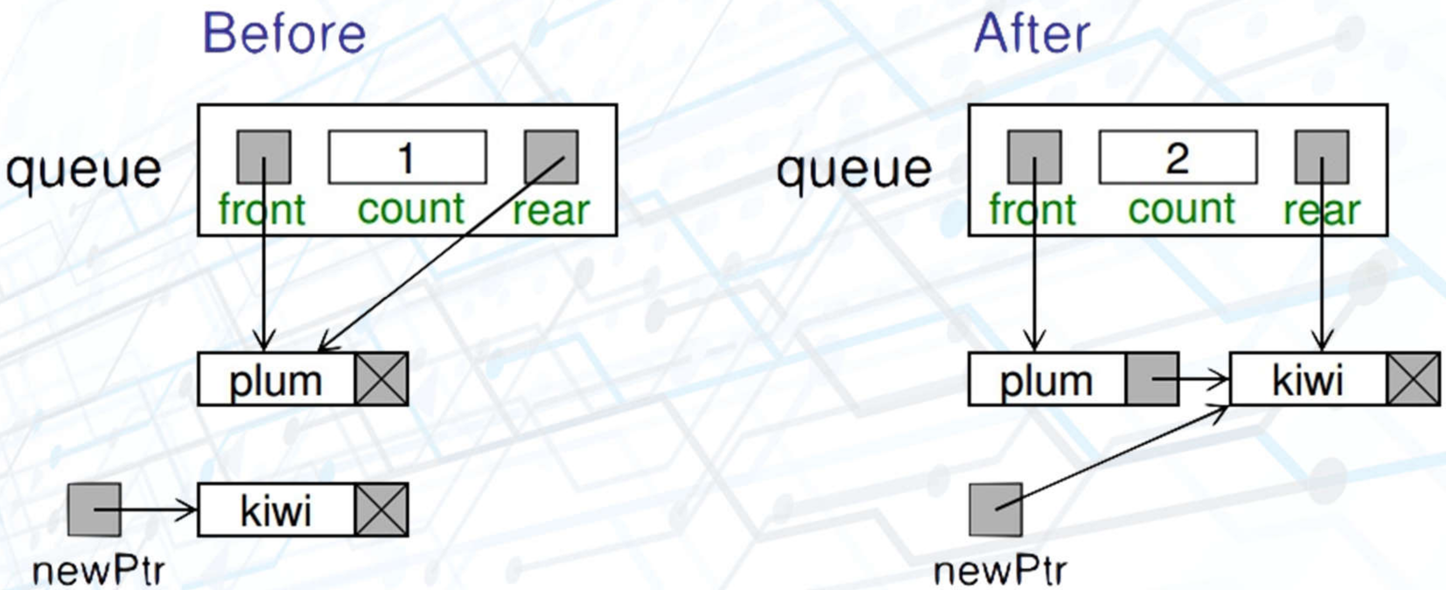


Figure 8: Insert into a queue with data

Enqueue

Algorithm enqueue(ref queue <metadata>, val data <dataType>)
Inserts one item at the rear of the queue

Pre: queue is a metadata structure of a valid queue
`data` contains data to be inserted into queue

Post: `data` have been inserted in queue
Return `true` if successful, `false` if memory overflow

Enqueue

```
if queue full then
|   return false
end
allocate (newPtr)
newPtr -> data = data
newPtr -> next = null
if queue.count = 0 then
|   queue.front = newPtr // Insert into an empty queue
else
|   queue.rear -> next = newPtr // Insert into a queue with data
end
queue.rear = newPtr
queue.count = queue.count + 1
return true
End enqueue
```

Enqueue

```
template <class List_ItemType>
void Queue<List_ItemType>::Enqueue(List_ItemType value){
  Node<List_ItemType>* newPtr = new Node<List_ItemType>();
  newPtr->data = value;
  newPtr->next = NULL;
  if (this->count == 0)
    this->front = newPtr;
  else
    this->rear->next = newPtr;
    this->rear = newPtr;
    this->count++;
}
```

Dequeue: Delete data in a queue with only one item

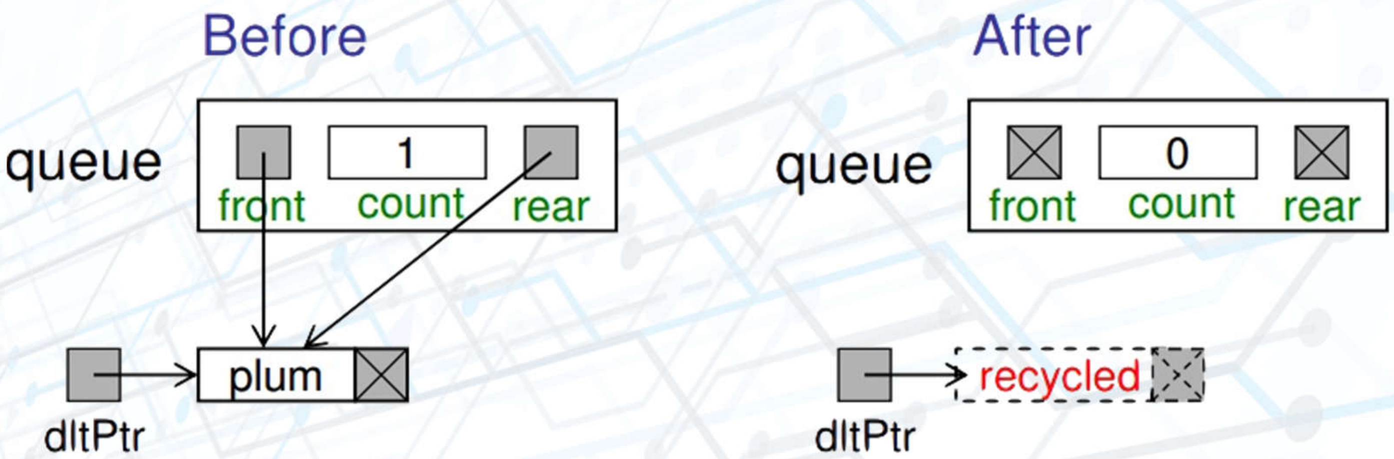


Figure 12: Delete data in a queue with only one item

Dequeue: Delete data in a queue with more than one item

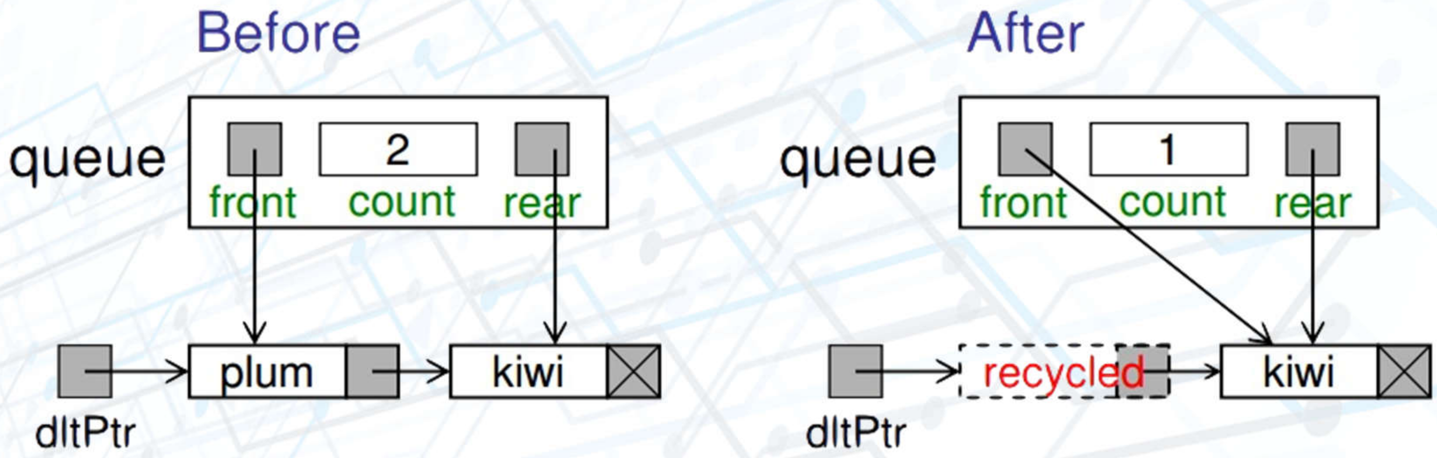


Figure 13: Delete data in a queue with more than one item

Dequeue

Algorithm dequeue(ref queue <metadata>, ref dataOut <dataType>)
Deletes one item at the front of the queue and returns its data to caller

Pre: queue is a metadata structure of a valid queue
`dataOut` is to receive dequeued data

Post: front data have been returned to caller
Return `true` if successful, `false` if memory overflow

Dequeue

```
if queue empty then
    return false
end
dataOut = queue.front -> data
dltPtr = queue.front
if queue.count = 1 then
    // Delete data in a queue with only one item
    queue.rear = NULL
end
queue.front = queue.front -> next
queue.count = queue.count - 1
recycle (dltPtr)
return true
End dequeue
```

Dequeue

```
template <class List_ItemType>
int Queue<List_ItemType>::Dequeue(List_ItemType &dataOut){
  if (count == 0)
    return 0;
  dataOut = front->data;
  Node<List_ItemType>* dltPtr= this->front;
  if (count == 1)
    this->rear = NULL;
  this->front = this->front->next;
  this->count--;
  delete dltPtr;
  return 1;
}
```

Queue Front

```
template <class List_ItemType>
int Queue<List_ItemType>::GetQueueFront(List_ItemType &dataOut){
  if (count == 0)
    return 0;
  dataOut = this->front->data;
  return 1;
}
```

Queue Rear

```
template <class List_ItemType>
int Queue<List_ItemType>::GetQueueRear(List_ItemType &dataOut){
  if (count == 0)
    return 0;
  dataOut = this->rear->data;
  return 1;
}
```

Destroy Queue

Algorithm destroyQueue(ref queue <metadata>)
Deletes all data from a queue

Pre: queue is a metadata structure of a valid queue

Post: queue empty and all nodes recycled

Return nothing

Destroy Queue

```
if queue not empty then
    while queue.front not null do
        temp = queue.front
        queue.front = queue.front->next
        recycle(temp)
    end
end
queue.front = NULL
queue.rear = NULL
queue.count = 0
return
End destroyQueue
```

Destroy Queue

```
template <class List_ItemType>
void Queue<List_ItemType>::Clear() {
  Node<List_ItemType>* temp;
  while (this->front != NULL){
    temp = this->front;
    this->front= this->front->next;
    delete temp;
  }
  this->front = NULL;
  this->rear = NULL;
  this->count = 0;
}
```

Queue Empty

```
template <class List_ItemType>
int Queue<List_ItemType>::IsEmpty() {
  return (this->count == 0);
}

template <class List_ItemType>
int Queue<List_ItemType>::GetSize() {
  return this->count;
}
```

Print Queue

```
template <class List_ItemType>
void Queue<List_ItemType>::Print2Console(){
  Node<List_ItemType>* p;
  p = this->front;
  cout << "Front:+";
  while (p != NULL){
    cout << p->data << "+";
    p = p->next;
  }
  cout << endl;
}
```

Using Queue

```
int main(int argc, char* argv[]){
  Queue<int> *myQueue = new Queue<int>();
  int val;
  myQueue->Enqueue(7);
  myQueue->Enqueue(9);
  myQueue->Enqueue(10);
  myQueue->Enqueue(8);
  myQueue->Print2Console();
  myQueue->Dequeue(val);
  myQueue->Print2Console();
  delete myQueue;
  return 1;
}
```

Array-based queue implementation

```
#include <string>
using namespace std;
class ArrayQueue {
private:
  int capacity;
  int front;
  int rear;
  int *storage;

 public:
  ArrayQueue(int capacity) {
    storage = new int[capacity];
    this->capacity = capacity;
    front = -1;
    rear = -1;
  }
```

Array-based queue implementation

```
~ArrayQueue() {
  delete[] storage;
}

void enQueue(int value) {
  if(isFull()) throw string("Queue+is+full");
  if (front == -1) front = 0;
  rear++;
  storage[rear % capacity] = value;
}

void deQueue(int &valueOut) {
  if (isEmpty())
    throw string("Queue+is+empty");
    valueOut = storage[front % capacity];
    front++;
}
```

Array-based queue implementation

```
int getFront() {
     if (isEmpty())
          throw string("Queue+is+empty");
     return storage[front % capacity];
}

int getRear() {
    if (isEmpty())
          throw string("Queue+is+empty");
    return storage[rear % capacity];
}
```

Array-based queue implementation

```
    bool isEmpty() {
      return (front > rear || front == -1);
    }

    bool isFull() {
      return (rear - front + 1 ==  capacity);
    }

    int getSize() {
      return rear - front + 1;
    }

};
```

Using Array-based queue

```
int main(int argc, char* argv[]){
  ArrayQueue *myQueue = new ArrayQueue(10);
  int val;
  myQueue->enQueue(7);
  myQueue->enQueue(9);
  myQueue->enQueue(10);
  myQueue->enQueue(8);
  myQueue->deQueue(val);
  delete myQueue;
  return 1;
}
```

Applications of Queue

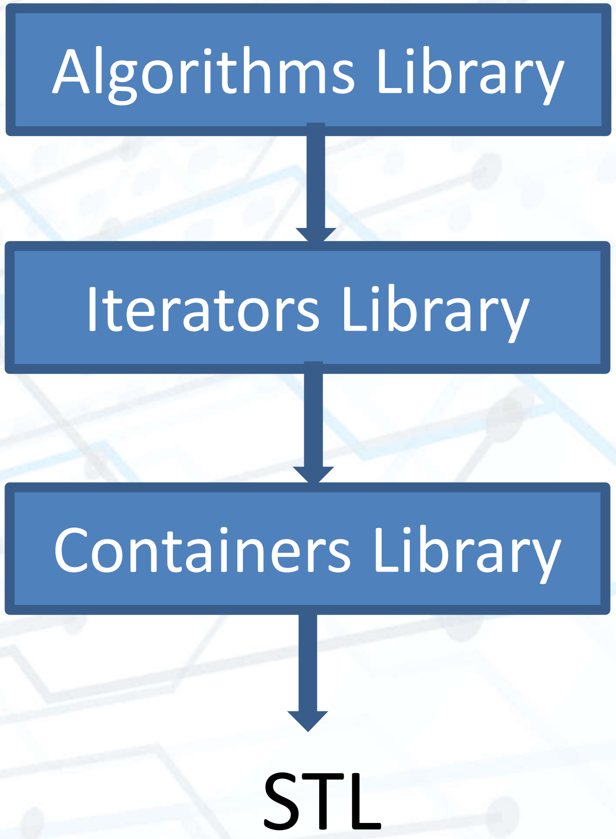
Applications of Queue

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

Standard Template Library (STL)

Component of STL

- Containers
- Iterators
- Algorithms



Container

Containers are used to manage objects of a given type.

Some common containers:

- **vector** : replicates arrays
- **queue** : replicates queues
- **stack** : replicates stack
- **priority_queue** : replicates heaps
- **list** : replicates linked list
- **set** : replicates trees
- **map** : associative arrays

Vector

- C++ Standard Library class template **vector**, which represents a more robust type of array featuring many additional capabilities.
- Vectors are sequence containers representing arrays that can change in size.

SYNTAX for creating a vector is: vector< object_type > vector_name;

Advantages of Vectors

- The size of a vector does not have to be a fixed constant, and it can also grow or shrink during execution
- A vector always knows its own size, so passing one to a function does not require to separately pass this information.
- Elements can be accessed by position in a vector just as they are in an array, but you can also insert and remove elements anywhere in a vector.
- Vectors can be returned from a function easily.

Example

```
#include <vector>

int main()
{
    std::vector<int> my_vector;
}
```

```
#include <vector>

int main()
{
    std::vector<string> v {"Pankaj" ,"The"
                           ,"Java" ,"Coder"};
}
```

Note: Initially the vector is blank, as it has no data, but as you add data, it grows

Member functions of Vector

- push_back() :is used for inserting an element at the end of the vector.
- insert(itr, element) method inserts the element in vector before the position pointed by iterator itr.
- pop_back() is used to remove the last element from the vector. It reduces the size of the vector by one.
- erase(itr_pos) removes the element pointed by the iterator **itr_pos**.
- resize(size_type n, value_type val) method resizes the vector to **n** elements.
- If we have two vectors v1 and v2 and we want to swap the elements inside them, you just need to call v1.swap(v2)
- vector_name.front() retuns the element at the front of the vector (i.e. leftmost element). While vector_name.back() returns the element at the back of the vector (i.e. rightmost element).
- …

Iterators

- Iterators are used to point to the containers in STL, because of iterators it is possible for an algorithm to manipulate different types of data structures/Containers.
- Algorithms in STL don't work on containers, instead they work on iterators, they manipulate the data pointed by the iterators.

Iterators

Syntax for defining an iterator is :

container_type <parameter_list>::iterator iterator_name;

Example:

```
int main(){
    vector<int> v(10);
    /* creates an vector v : 0,0,0,0,0,0,0,0,0,0  */
    vector<int>::iterator i;
    for(i = v.begin(); i! = v.end(); i++)
            cout << *i <<"  ";

    return 0;
}
```

Operations on Iterators

- advance(iterator i ,int distance):increment the iterator **i** by the value of the distance. If the value of distance is negative, then iterator will be decremented.
- distance(iterator first, iterator last): return the number of elements or we can say distance between the first and the last iterator.
- next(iterator i ,int n) return the **nth** iterator to **i**, i.e iterator pointing to the nth element from the element pointed by i.
- prev(iterator i, int n) return the **nth** predecessor to **i**, i.e iterator pointing to the nth predecessor element from the element pointed by i.
- begin() returns an iterator to the start of the given container.
- end() returns an iterator to the end of the given container.

Algorithms

STL provide different types of algorithms that can be implemented upon any of the container with the help of iterators. Thus now we don't have to define complex algorithm instead we just use the built in functions provided by the algorithm library in STL.

Types of Algorithms in Algorithm Library

1. Sorting Algorithms
2. Search algorithms
3. Non modifying algorithms
4. Modifying algorithms
5. Numeric algorithms
6. Minimum and Maximum operations.