Abstract Data Types II - Stacks & Queues

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Linked Lists

Linear Abstract Data Types:

- Lists
  - Definition: is a collection with a finite number of data objects (same type) and has a finite size.
  - List ADT: Array-based Lists, Linked Lists
  - List Operations
- Stacks
- Queues

Today Objectives

- Introduce the basics of Stacks and Queues: declaration, initialization, and use.
- Learn different functions and operations with Stacks and Queues: add, remove, search, etc.
- Implement examples in C/C++.

Plan

Stacks

Stack of books

Stack of coins

Stacks

General Definition

A **stack** is a pile of objects, typically one that is neatly arranged.

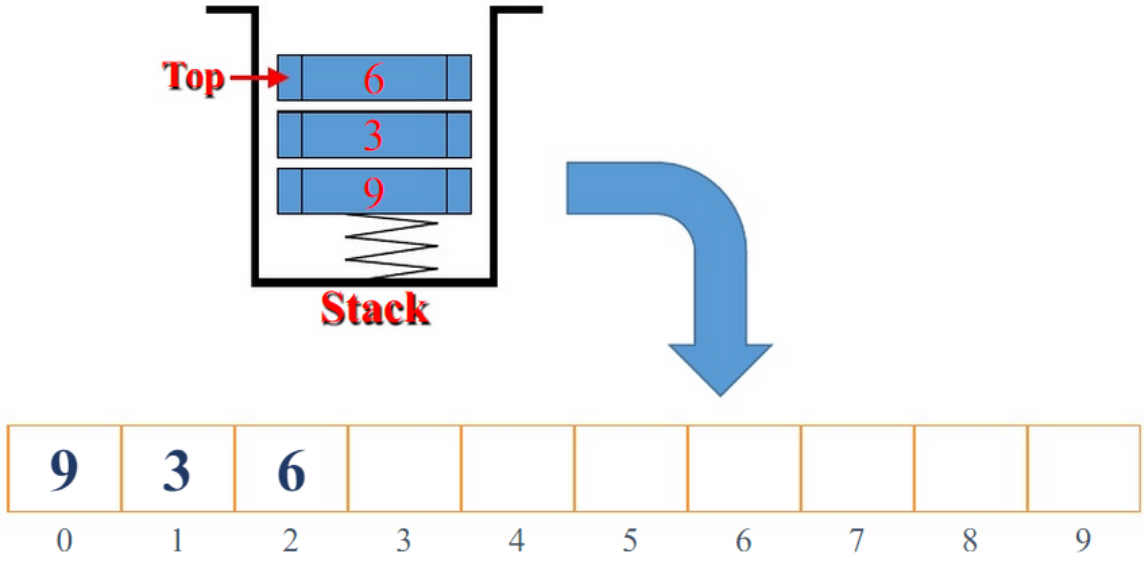
Programming Definition

A **stack** is a container of objects inserted and removed according to the First In Last Out (FILO) principle.

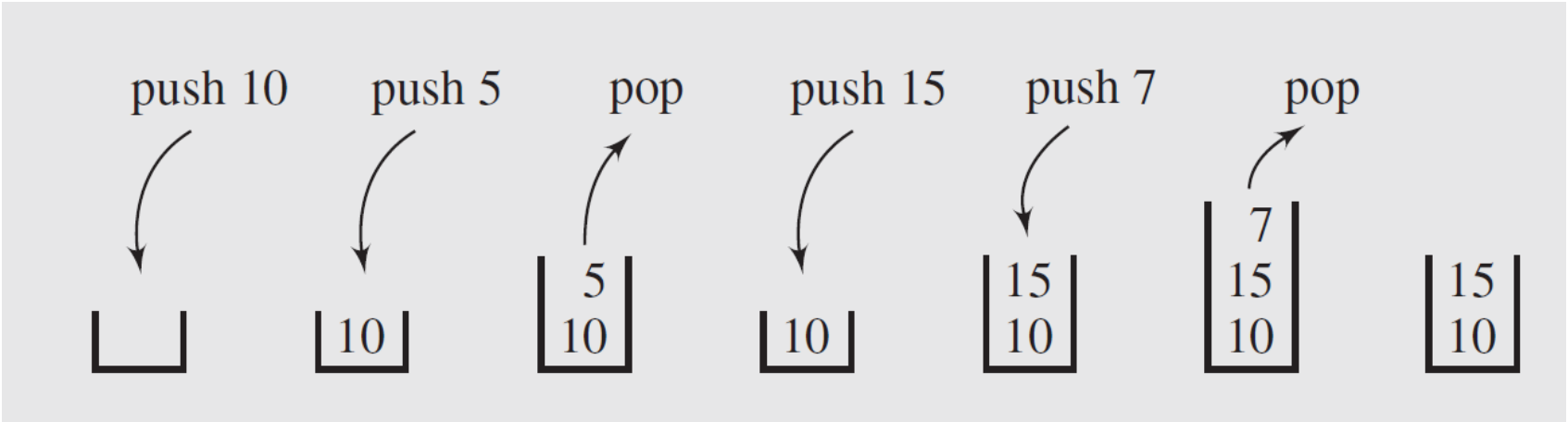
Stacks

ADT Stacks

- A linear data structure is used to store data in a particular order.
- Storing and retrieving data are performed only on the top: **Push** inserts an element; **Pop** removes the last element that was added.
- Access of items in a stack is restricted; it follows **First In Last Out** (**FILO**) order.



Stacks



Push and pop operations follow FILO order.

Stacks

Stack Application

- Expression evaluation: calculate arithmetic expression.
- Backtracking: This is a process when you need to access the most recent data element in a series of elements
  - Find your way through a maze.
  - Find a path from one point in a graph (roadmap) to another point.
  - Play a game with moves to be made (checkers, chess, sudoku).
- Undo/Redo-mechanism of text editors (Back/Forward Navigation of web-browsers).
- Call stack in recursive functions.
- Data structures for Machine Learning algorithms.

Stacks

Stack Application

Arithmetic Expression:

- infix - operation between operands

  (3+5)*10

- prefix - operation before operands

  * + 3 5 10

- postfix - operation after operands

  3 5 + 10 *

Stacks

Stack Application

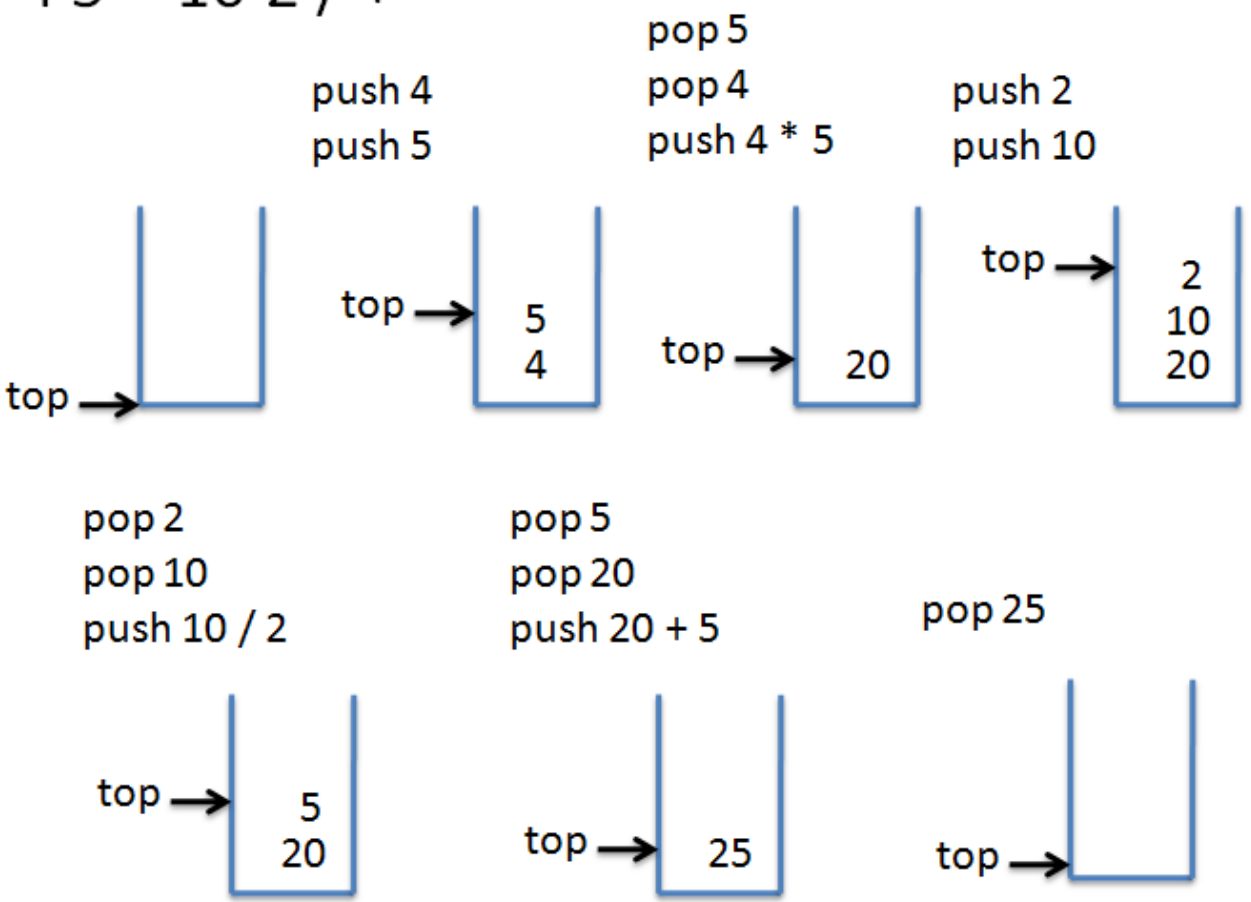
Arithmetic Expression: evaluating postfix

- repeat
  - find the first operation preceded by two operands
  - evaluate and replace
- Example:

$$\begin{aligned} & 4\ 5\ *\ 10\ 2\ /\ + \\ = & \ 20\ \ 10\ 2\ /\ + \\ = & \ \ 20\ 5\ + \\ = & \ 25 \end{aligned}$$

Stacks

4 5 * 10 2 / +



Stacks

Stacks implementation may offer the possible operations:

- init(): create an empty stack.
- isEmpty(): check if the stack is empty.
- push(): add a new item at the top of a stack.
- pop(): remove the top item of a stack.
- top(): retrieve the top item of a stack.

Other operations can be possibly defined:

- size(): return the size of a stack.
- isFull(): check if the stack is full.
- display(): display the content of a stack.
- etc.

Stacks

Stack Data Structure

There are several solutions to the stack implementation using different declarations.

- Static array-based stack: arrays can be simply used to manipulate collections of items.
- Dynamic array-based stack: **malloc()** is capable of representing a stack.
- Linked stack: A very flexible mechanism for dynamic memory management is provided by pointers.

Static Array-Based Stacks

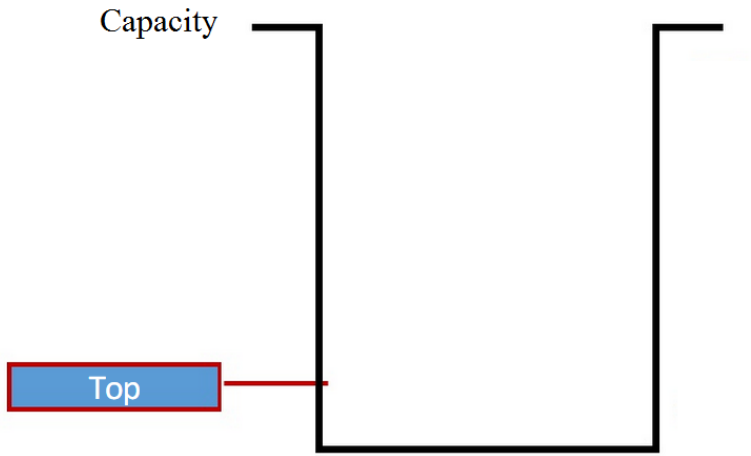
The idea is to store a stack in a fixed-size static array for simple implementation.

```
1 struct _Stack {
2     <DataType> data[CAPACITY];
3     int top;
4 };
5 typedef struct _Stack Stack;
```

Static Array-Based Stacks

- init(): this function allows for creating an empty stack.

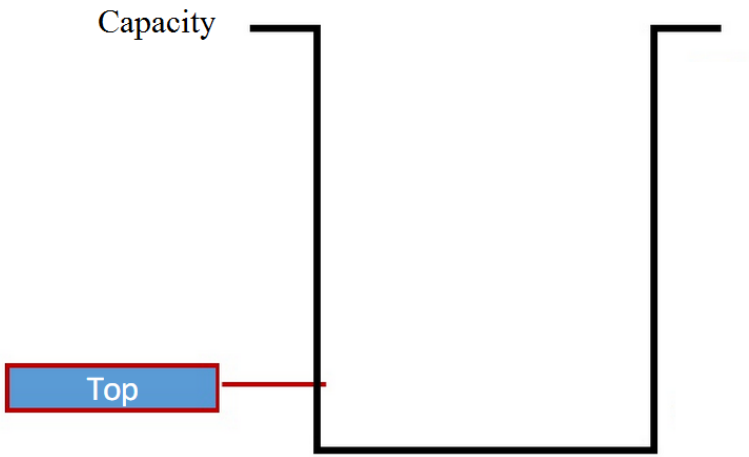
```
1 void init(Stack *st) {
2     // st must get malloc() in main()
3     st->top = -1;
4 }
```



Static Array-Based Stacks

- init(): this alternative function allows for creating an empty stack.

```
1 Stack * init(Stack *st) {
2     st = (Stack*)malloc(sizeof(Stack));
3     st->top = -1;
4     return st;
5 }
```



Static Array-Based Stacks

- isEmpty(): this action allows checking if a stack is empty.

```
1 int isEmpty(Stack st){
2   return (st.top<0);
3 }
```

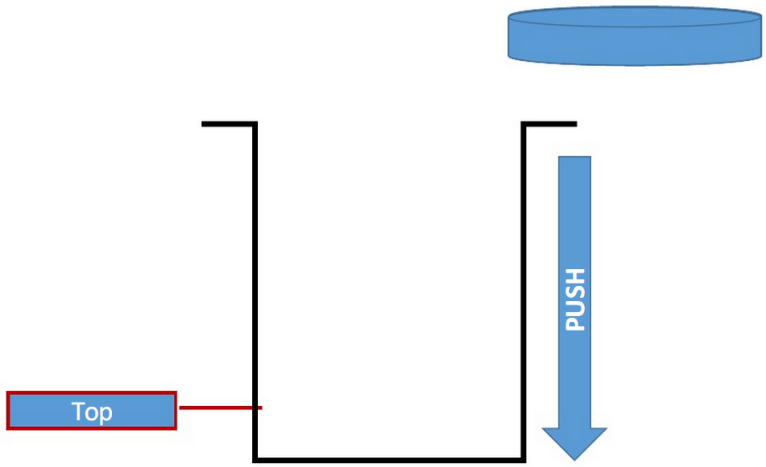
- size(): this function returns the stack size.

```
1 int size(Stack st){
2   return st.top+1;
3 }
```

Static Array-Based Stacks

- push(): this function allows to add a new item into a stack.

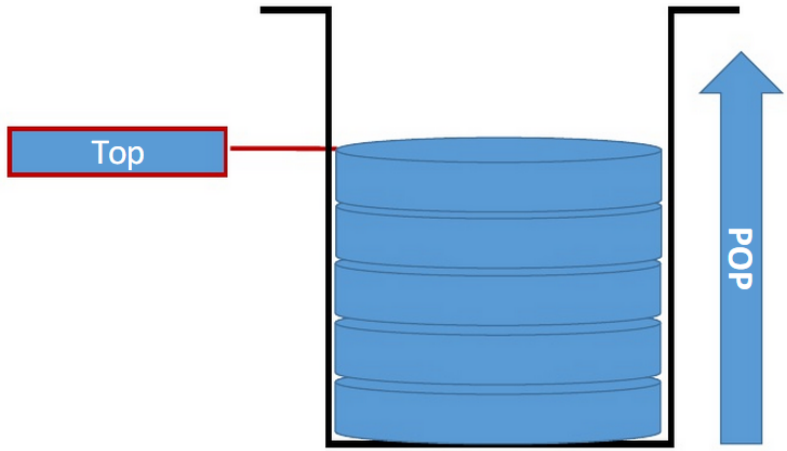
```
1  void push(Stack *s, int val){
2   if (isFull(*s))
3       printf(''Stack is full!'');
4   else{
5       s->top ++;
6       s->data[s->top] = val;
7   }
8  }
```



Static Array-Based Stacks

- pop(): this function allows to remove the top item from a stack,

```
1  void pop(Stack *s){
2   if (isEmpty(*s))
3       printf(``Stack empty!'');
4   else{
5       s->top --;
6   }
7  }
```



Dynamic Array-Based Stacks

The idea is to perform the stack implementation with a dynamic array.

```
1 struct _Stack {
2     int top;
3     int capacity
4     int *data;
5 };
6 typedef  struct _Stack Stack;
```

Dynamic Array-Based Stacks

- init(): this function allows to create an empty stack.

```
1  void init (Stack *s, int N) {
2     // s gets malloc() in the main() function
3     s->top = 0;
4     s->capacity = N;
5     s->array = (int *)malloc(s->capacity);
6  }
```

Array-Based Stacks

Array-based stack implementation:

Pros

- Simple to understand and implement.
- Stack is asserted at the top without changing other elements.

Cons

- Stack size has to be manipulated.

Stack Implementation with Linked Lists

Definition

In this implementation, each item is placed together with the link to the next item, resulting in a simple component called a node:

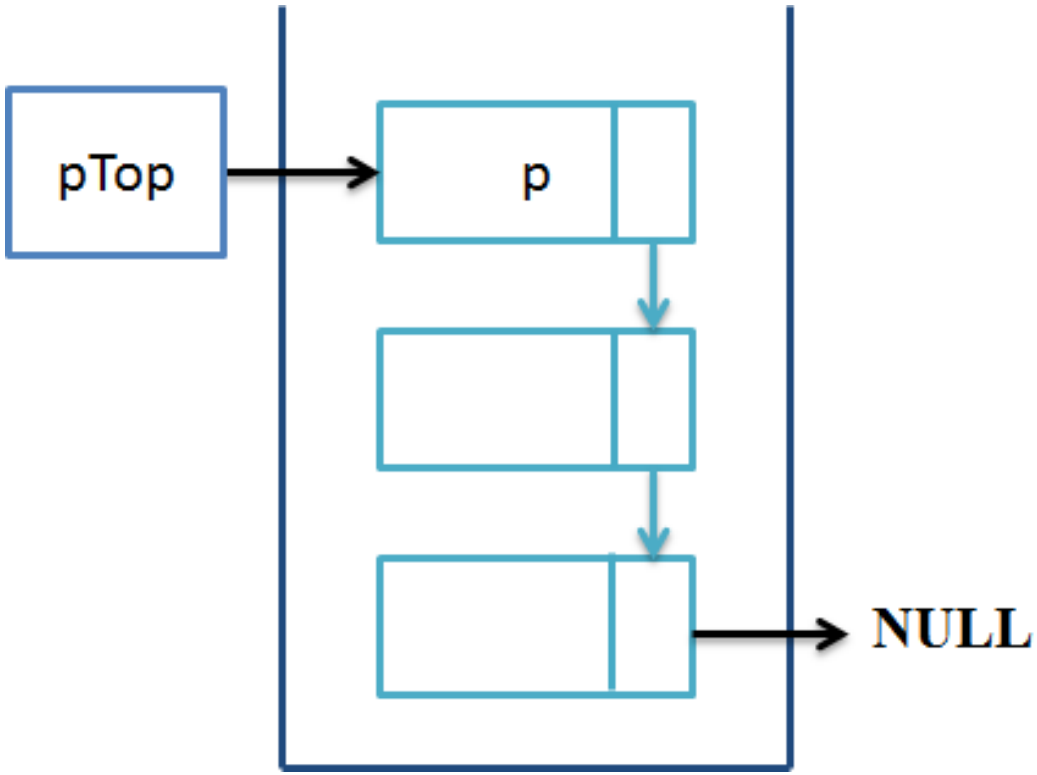
- A data part stores an element value of the stack.
- A next part contains a link (or pointer) that indicates the node's location containing the next element.

Stack Implementation with Linked Lists

Implementing a stack as a linked list:

```
1  struct _Node{
2      int data;
3      struct _Node *next;
4  };
5  typedef struct _Node Node;
6  struct _Stack{
7      int size;
8      Node  *pTop;
9  };
10 typedef struct _Stack Stack;
```

Stacks



Stacks Implementation with Linked Lists

Several basic operations are re-written to adapt to the new use of stack implementation.

```
1  void init(Stack *s){
2      // s gets malloc() in the main() function
3      s->size = 0;
4      s->pTop = NULL;
5  }
6  int isEmpty(Stack st){
7     return (st.size);
8  }
```

Stack Implementation with Linked Lists

Push operation is adapted to the new declaration:

```
1  int push(int newData, Stack *st){
2      Node *p;
3      p=(Node *)malloc(sizeof(Node));
4      if (p == NULL)
5        return 0;
6      p->data = newData;
7      //insert at the beginning of the list
8      p->next = st->pTop->next;
9      st->pTop = p;
10     st->size++;
11     return 1;
12 }
```

Stack Implementation with Linked Lists

Pop operation is adapted to the new declaration:

```
1  int pop(stack *st){
2      Node *p;
3      if (isEmpty(*st))
4          return 0; // fail to pop
5      p = st->pTop;
6      st->pTop = st->pTop->next;
7      st->size--;
8      free(p);
9      return 1;
10 }
```

Complexity

Comparisons of complexity for different stack implementations

	push()	pop()	top()
Array-based Stacks	O(1)	O(1)	O(1)
Stacks with Linked List	O(1)	O(1)	O(1)

Stack Implementation with Linked Lists

Pros

- Stack implementation with linked lists is flexible to the size and memory.

Cons

- If the top element is not used in the implementation, we have to traverse all the elements in the stack to find the top.

Queues

Queues

General Definition

A **queue** is a line or sequence of people or vehicles awaiting their turn to be attended to or to proceed.

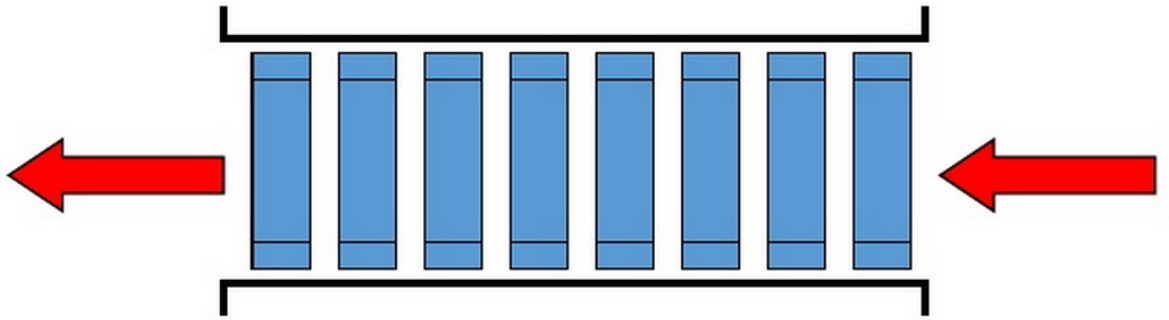
Programming Definition

A **queue** is a container of objects (a linear collection) that are inserted and removed according to the first-in-first-out (FIFO) principle.

Queues

ADT Queues

- A special data structure of lists used to store data in a particular order.
- Basic operations are done in both ends: insert at one end (back/rear) and remove at the other end (front/head).
- Access of items in a Queue is restricted; it follows the First In First Out (FIFO) order.



Queues

Queue Application

Typical uses of queues are in simulations and operating systems.

- Operating systems often maintain a queue of processes ready to execute or to wait for a particular event to occur.
- Anything that involves "waiting in line": printing on the computer, seating customers at a restaurant, etc.

Queues

Queues are an abstract data structure, and its implementation may offer the possible operations:

- init(): initialize an empty queue.
- isEmpty(): check if the queue is empty.
- enqueue(): add a new item at the back of the queue.
- dequeue(): remove the front item of the queue.

Other operations can be possibly defined:

- length(): return the size of a queue.
- front(): retrieve the front item of the queue.
- isFull(): check if the queue is full.
- display(): display the content of a queue.

Queues

ADT Queues

There are several solutions to queue implementation using different declarations.

- Static array-based queue: arrays can be simply used to manipulate collections of items.
- Dynamic array-based queue: **malloc()** is capable of representing a queue.
- Linked queue: A very flexible mechanism for dynamic memory management is provided by pointers.

Static Array-Based Queues

The idea is to store a queue in a fixed-size static array for simple implementation.

```
1 struct _Queue {
2     int data[CAPACITY];
3     int front, back;
4     // front is optional
5 };
6 typedef struct _Queue Queue;
```

Static Array-Based Queues

- init(): this function allows to create an empty queue.

```
1  void init(Queue *q){
2      // q gets malloc() in the main() function
3      q->front = 0;
4      q->back = 0;
5  }
```

- isEmpty(): this operation verifies that a queue is empty.

```
1  int isEmpty(Queue *q){
2      return (q->back ==0);
3  }
```

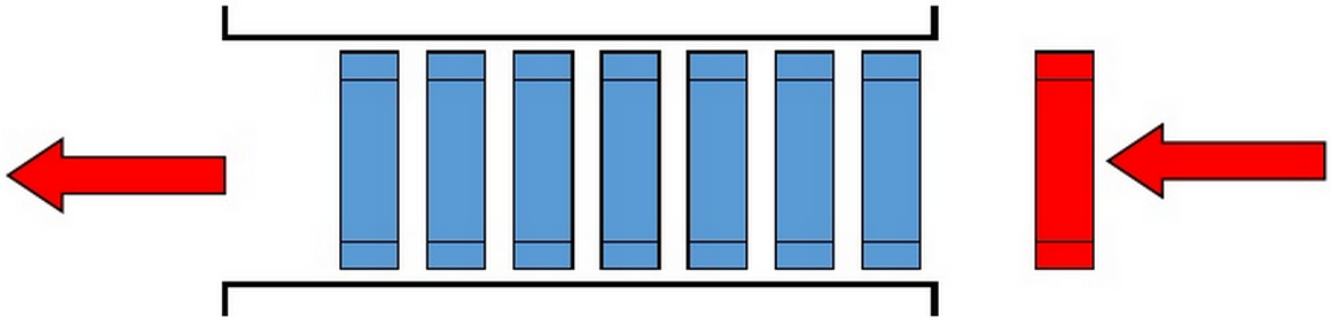
Static Array-Based Queues

- length(): this operation returns the queue size.

```
1  int length(Queue *q){
2      int l = q->back-q->front;
3      return l;
4  }
```

Static Array-Based Queues

Due to the FIFO order, new items are inserted at the back of the queue. The function enqueue() allows to add a new item into a queue.



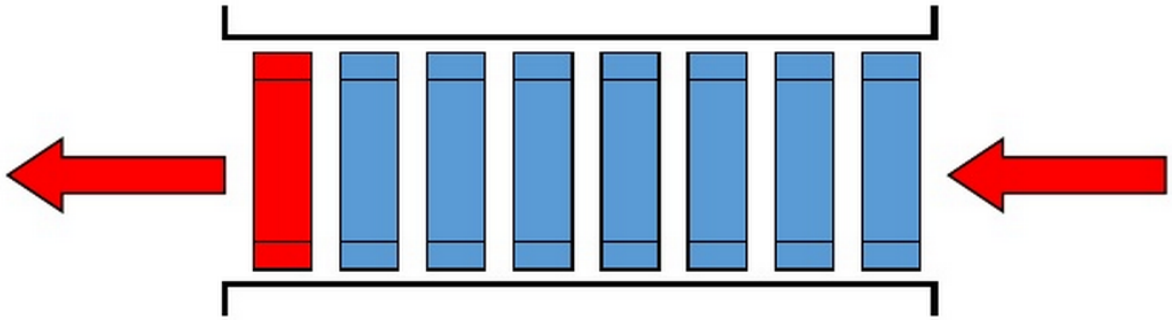
Static Array-Based Queues

There are three cases to be proceeded for enqueue(): the queue is full, empty, and has at least one item.

```
1  int enqueue(Queue *q, <DataType> newData){
2      if (length(q) == CAPACITY){
3          printf("Queue is full!");
4          return 0;
5      }
6      if (isEmpty(q)){
7          q->val[0] = newData;
8      } else {
9              int idx = q->back;
10             q->val[idx] = newData;
11     }
12     q->back++;
13     return 1;
14 }
```

Static Array-Based Queues

Due to the FIFO order, if we want to remove items from a queue, this action will proceed at the front of the queue. The function dequeue() asserts the deletion.



Static Array-Based Queues

Two possible cases for dequeue() must be manipulated: when the queue is empty or not empty.

```
1  int dequeue(Queue *q){
2      if (isEmpty(q))
3          return 0;
4      else {
5          if (length(q) > 1){
6              for (int i = 1; i <length(q);i++)
7                  q->val[i-1] = q->val[i];
8          }
9          q->back = q->back-1;
10     }
11     return 1;
12 }
```

Dynamic Array-Based Queues

A dynamic array-based Queue improves the static array-based implementation.

```
1 struct _Queue{
2         int front,back;
3         int capacity;
4         int *val;
5         };
6 typedef struct _Queue Queue;
```

Dynamic Array-Based Queues

- init(): this function allows to create an empty queue.

```
1  void init(Queue *q, int N){
2      // q gets malloc() in the main() function
3      q->back = 0;
4      q->front = 0;
5      q->capacity = N;
6      q->val = (int *)malloc(q->capacity);
7  }
```

Array-Based Queues

Array-based queue implementation:

Pros

- Simple to understand and implement.
- Enqueue is asserted at the back without shifting elements.

Cons

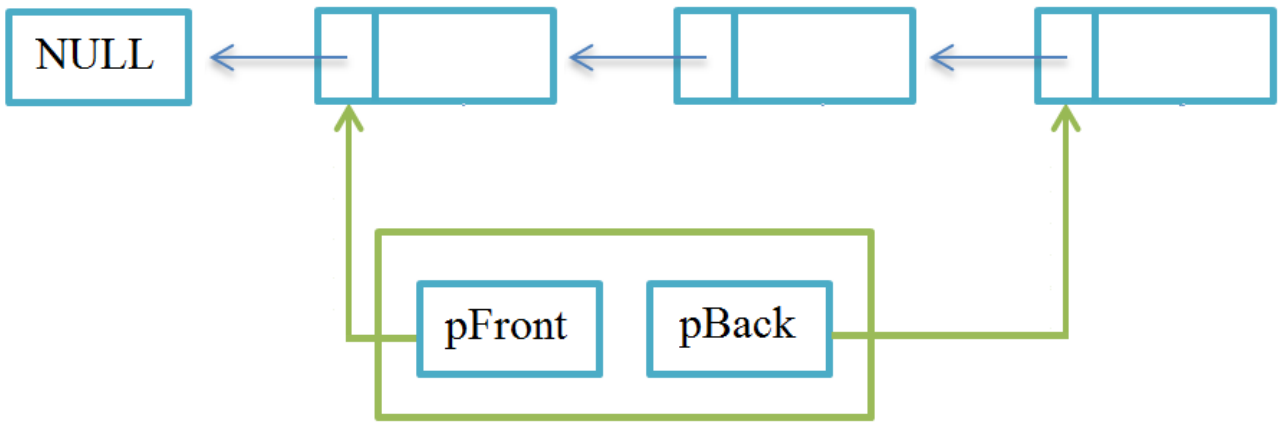
- Only the first element is accessible.
- All the elements have to be shifted (O(n) time for a queue with n elements) after a dequeue.

Queue Implementation with Linked Lists

Definition

In this implementation, each item is placed together with the link to the next item, resulting in a simple component called a node:

- A data part stores an element value of the queue.
- A next part contains a link (or pointer) that indicates the node's location containing the next element.
- The front element points to NULL.



Queue Implementation with Linked Lists

Queue implementation using a linked list

```
1  typedef struct _Node {
2      int data;
3      struct _Node *next;
4  } Node;
5  typedef struct _Queue {
6          Node *pFront, *pBack;
7          int size;
8  }Queue;
```

Queue Implementation with Linked Lists

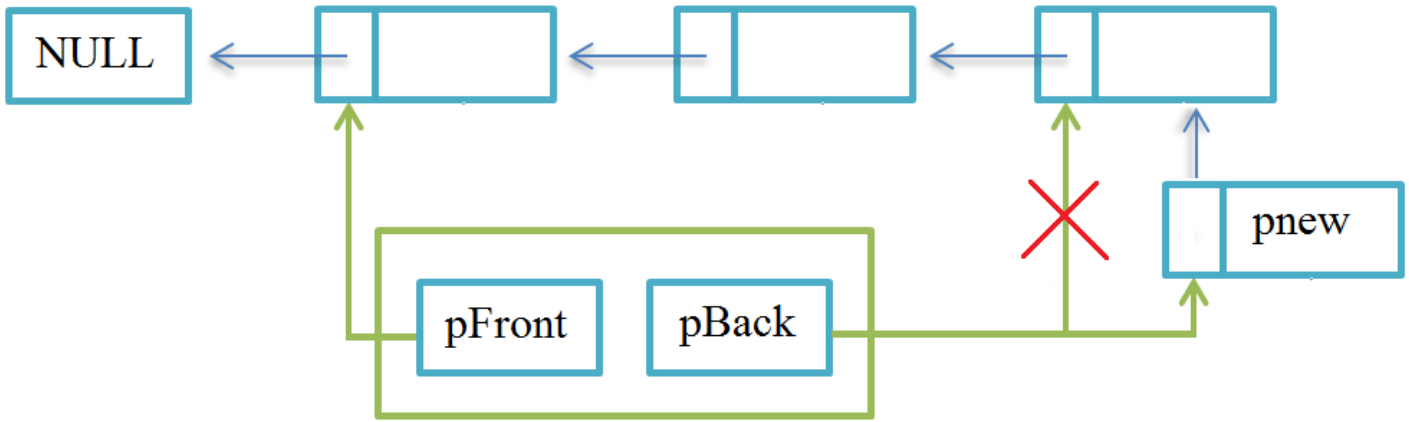
Several basic operations are re-written to adapt to the new use of queue implementation.

```
1  void init(Queue *q){
2      // q gets malloc() in the main() function
3      q->size = 0;
4      q->pFront = q->pBack = NULL;
5  }
6  int isEmpty(Queue q){
7     return (q->qFront == NULL);
8  }
```

Queue Implementation with Linked Lists

Enqueue operation:

- New items are enqueued at the back of the queue.
- The back node points to new items.



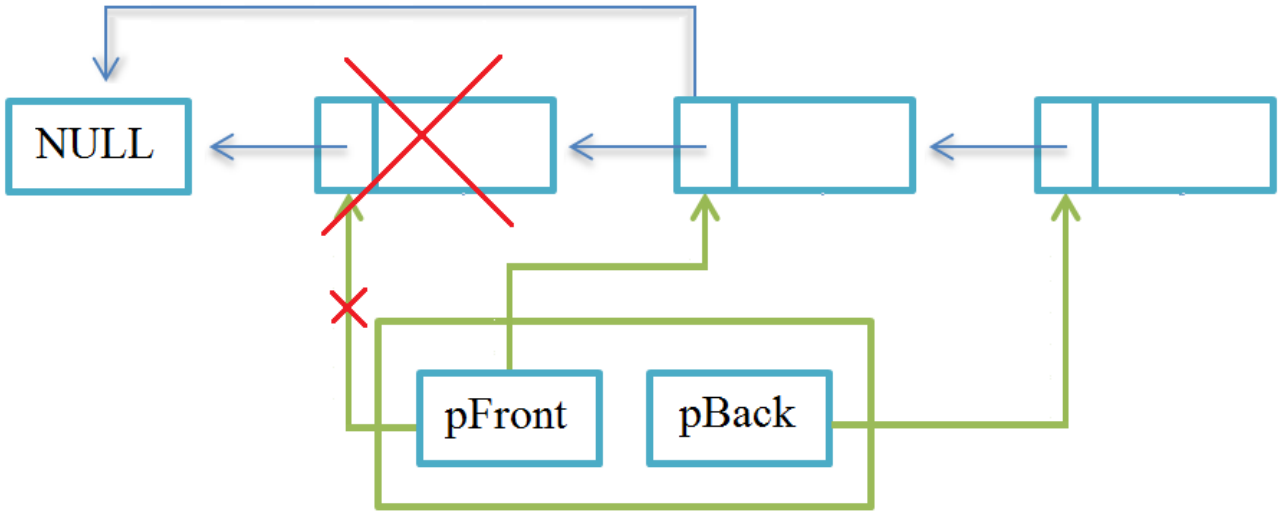
Queue Implementation with Linked Lists

```
1  void enqueue (Queue *q, <DataType> val){
2    Node *p = (Node *)malloc(sizeof(Node));
3    p->name = val;
4    p->next = NULL;
5    if ( q->pFront == NULL)
6       q->pFront = q->pBack = p;
7    else{
8       p->next = q->pBack;
9       q->pBack = p;
10   }
11   q->size++;
12 }
```

Queue Implementation with Linked Lists

Dequeue operation:

- The list should have at least one element.
- The front node points to the node that points to the first one.
- The pointer of this node points to NULL.



Queue Implementation with Linked Lists

```
1  void dequeue(Queue *q){
2  if (isEmpty(*q))
3          return 0;
4      else {
5          if (q->size == 1){
6              q->pFront = q->pBack = NULL;
7              q->size --;
8          }
9          else{
10             Node *p = q->pBack;
11             while (p->next !=q->pFront)
12                     p = p->next;
13             q->pFront = p;
14             q->pFront->next = NULL;
15             q->size --;
16         }
17     }
18     return 1;
19 }
```

Complexity

Comparisons of complexity for different queue implementations

	enqueue()	dequeue()	front()
Array-based Queues	O(1)	O(n)	O(1)
Queues wLL (with pFront, pBack)	O(1)	O(n)	O(1)
Queues wLL (without pFront)	O(1)	O(n)	O(n)
Queues wDLL (with pFront, pBack)	O(1)	O(1)	O(1)

LL - Singly Linked List; DLL - Doubly Linked List

Queue Implementation with Linked Lists

Pros

- Flexible to the size and memory.
- Enqueue can be done without shifting elements.

Cons

- Have to traverse all the way to find the second element for the dequeue