2023/2024(2)
EF234201 Data Structure

Lecture #4

Array: Stack & Queue

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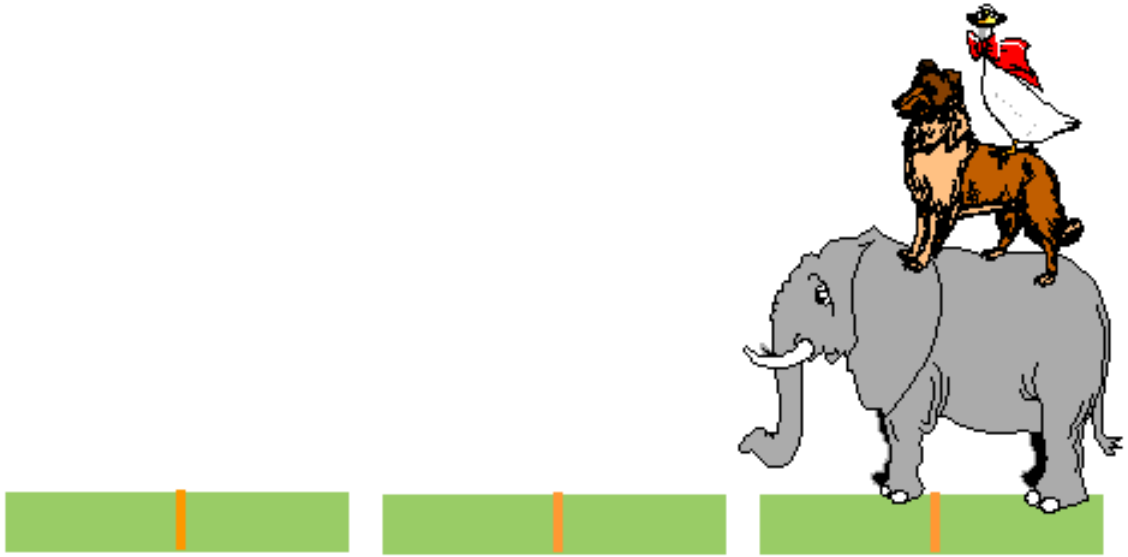
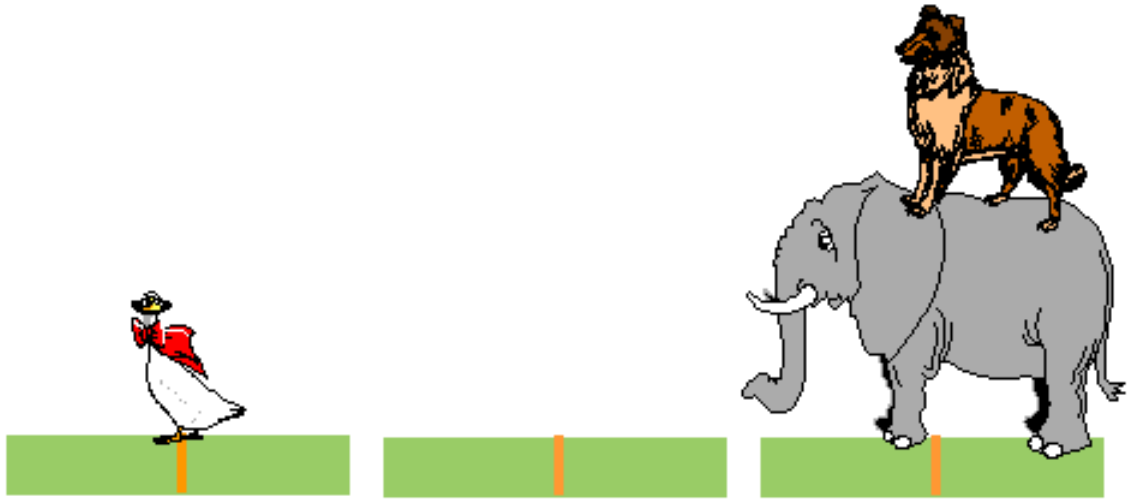
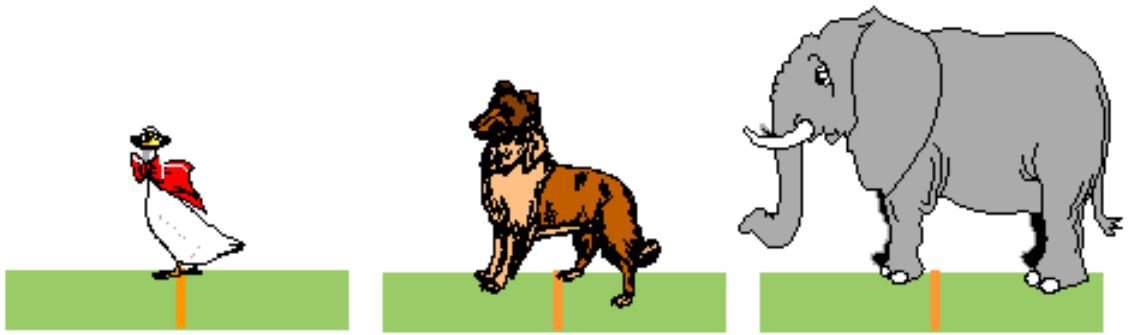
Towers of Hanoi



Towers of Hanoi (continued)



Towers of Hanoi (continued)



Towers of Hanoi (continued)

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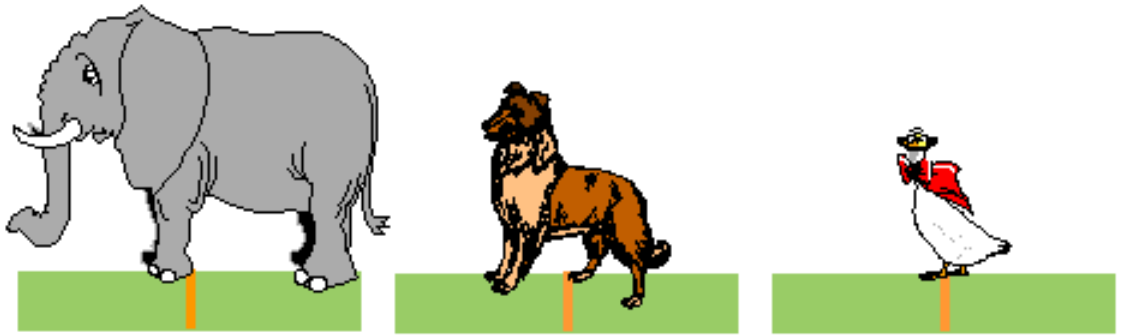
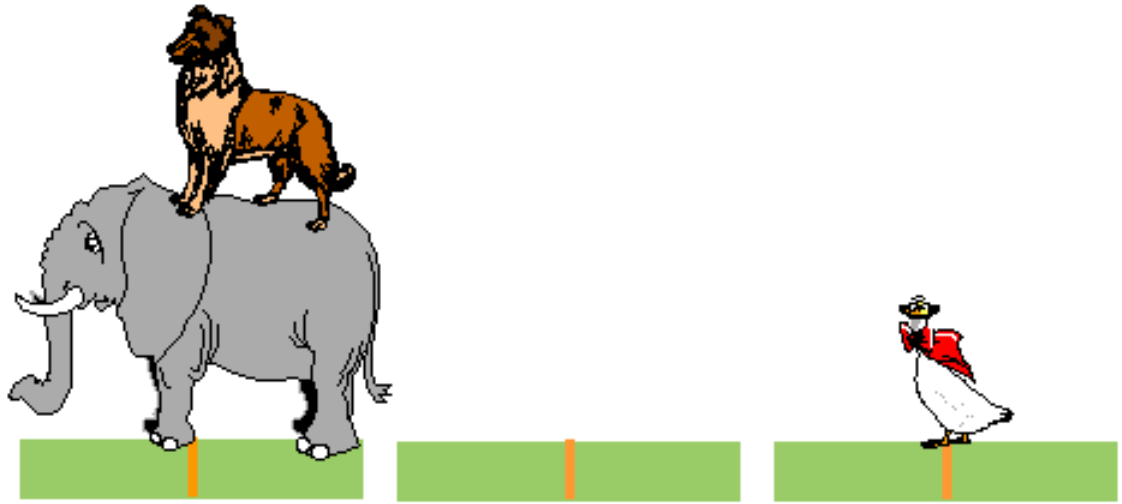
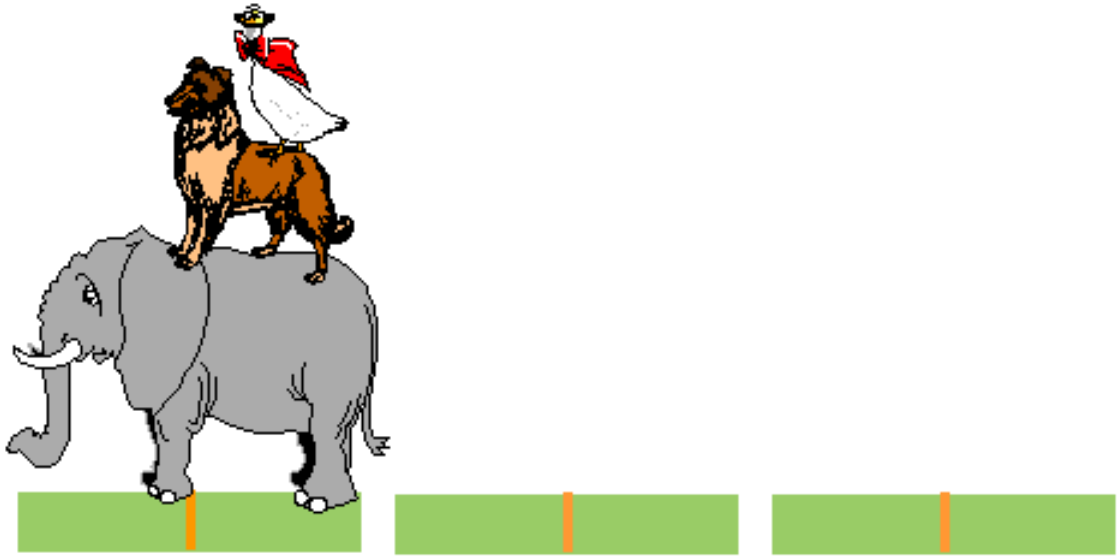


Towers of Hanoi (continued)



Towers of Hanoi (continued)



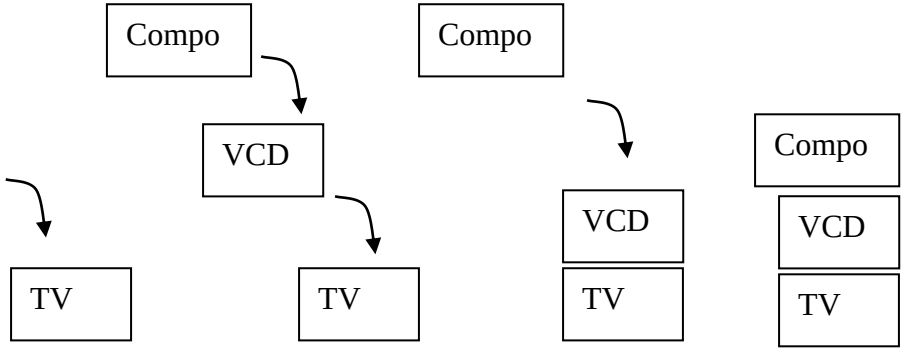
Towers of Hanoi: The Code

```c
#include <stdio.h>

// Function to move a disk from one rod to another
void towerOfHanoi(int n, char from_rod, char to_rod, char aux_rod) {
    if (n == 1) {
        printf("\nMove disk 1 from rod %c to rod %c", from_rod, to_rod);
        return;
    }
    towerOfHanoi(n - 1, from_rod, aux_rod, to_rod);
    printf("\nMove disk %d from rod %c to rod %c", n, from_rod, to_rod);
    towerOfHanoi(n - 1, aux_rod, to_rod, from_rod);
}

int main() {
    int n = 3; // Number of disks
    towerOfHanoi(n, 'A', 'C', 'B'); // A, B, and C are the three rods
    return 0;
}
```

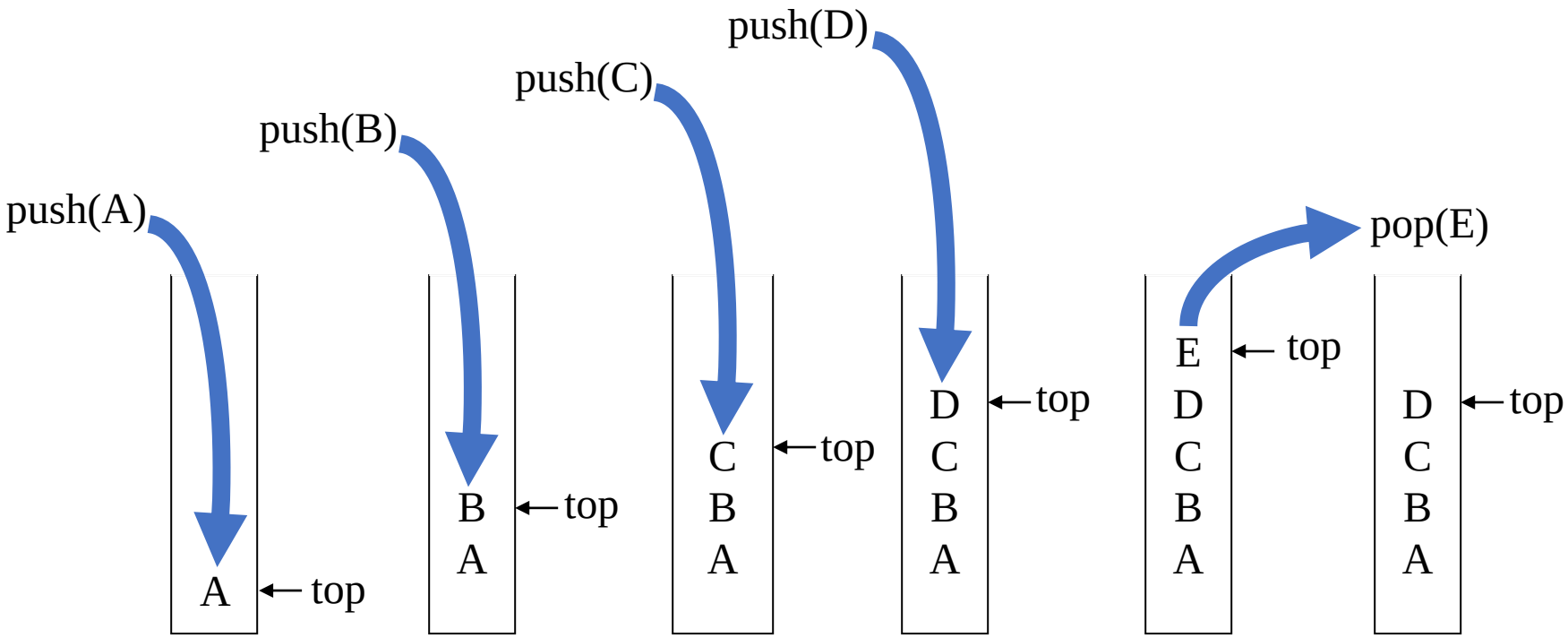
```
Move disk 1 from rod A to rod C
Move disk 2 from rod A to rod B
Move disk 1 from rod C to rod B
Move disk 3 from rod A to rod C
Move disk 1 from rod B to rod A
Move disk 2 from rod B to rod C
Move disk 1 from rod A to rod C
```

Stack: The Definition

- A data collection arrangement where data can be added and deleted is always done at the end of the data, which is called the top of the stack (TOS)
- Stack is LIFO (Last In First Out)
  - The last object to enter the stack will be the first to leave the stack



Last In First Out

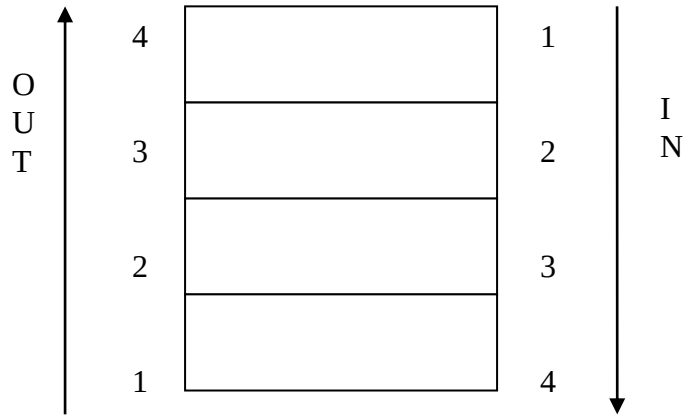


Stack: The Application

- Real life
  - Pile of books (stack of books)
  - Plate trays (stacks of plates)
- More applications related to computer science
  - Program execution stack (read more from your text)
  - Evaluating expressions

Stack: The Operation

- Push: used to add items to the stack at the top of the stack
- Pop: used to take items on the stack at the top of the stack
- Clear: used to clear the stack
- IsEmpty: function used to check whether the stack is empty
- IsFull: function used to check whether the stack is full



Stack with Array of Structs

- Define a Stack using a struct
- Define the MAX_STACK constant to store the maximum contents of the stack
- The Stack struct element is an array of data and the top indicates the top data position
- Create a stacked variable as an implementation of the Stack struct
- Declare the operations/functions above and implement them

Stack: The Program

- Example of MAX_STACK declaration

```
#define MAX_STACK 10
```

- Example of STACK declaration with struct and data array

```
typedef struct myStruct {
   int top;
   int data[10];
} STACK;
```

- Declare/create variables from structs

```
STACK stack;
```

Stack: The Program (continued)

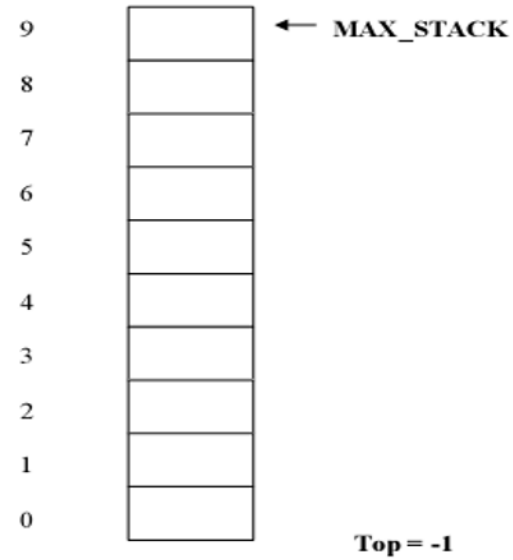
```c
#include <stdio.h>
#include <stdlib.h>
#define MAX_STACK 10

typedef struct myStruct {
    int top;
    int data[10];
} STACK;
STACK stack;

void init() {
    stack.top = -1;
}

int isFull() {
    return (stack.top == MAX_STACK - 1) ? 1 : 0;
}

int isEmpty() {
    return (stack.top == -1) ? 1 : 0;
}

void push(int data) {
    stack.data[++stack.top] = data;
}

void pop() {
    printf("Popped data: %d\n", stack.data[stack.top]);
    stack.top--;
}

void printStack() {
    for (int i = stack.top; i >= 0; i--) {
        printf("Stack data index #%d: %d\n", i, stack.data[i]);
    }
}

void addData() {
    int data;
    while (!isFull()) {
        printf("Add the data: ");
        scanf("%d", &data);
        push(data);
    }
}

void getData() {
    while (!isEmpty()) {
        pop();
    }
}

void main() {
    printf("Initialise the stack.\nSet the top of stack with -1.\nIndex starts from 0.\nSo, it means it's empty stack.\n");
    init();
    printf("\nAdd the stack with 10 numbers.\n");
    addData();
    printf("\nShow the content of the stack.\n");
    printStack();
    printf("\nGet the data from the stack. There're 10 numbers.\n");
    getData();
}
```

```
Initialise the stack.
Set the top of stack with -1.
Index starts from 0.
So, it means it's empty stack.

Add the stack with 10 numbers.
Add the data: 1
Add the data: 2
Add the data: 3
Add the data: 4
Add the data: 5
Add the data: 6
Add the data: 7
Add the data: 8
Add the data: 9
Add the data: 10

Show the content of the stack.
Stack data index #9: 10
Stack data index #8: 9
Stack data index #7: 8
Stack data index #6: 7
Stack data index #5: 6
Stack data index #4: 5
Stack data index #3: 4
Stack data index #2: 3
Stack data index #1: 2
Stack data index #0: 1

Get the data from the stack. There're 10 numbers.
Popped data: 10
Popped data: 9
Popped data: 8
Popped data: 7
Popped data: 6
Popped data: 5
Popped data: 4
Popped data: 3
Popped data: 2
Popped data: 1
```

Stack: The Program (continued)

- Initialization: `init()`
  - Initially fill the top with -1, because arrays in C language start from 0, which means that the data stack is EMPTY!
  - Top is a marker variable in the Stack that indicates the top element of the current Stack data. **Top of Stack** will always move until it reaches the MAX_STACK which causes the stack to be FULL

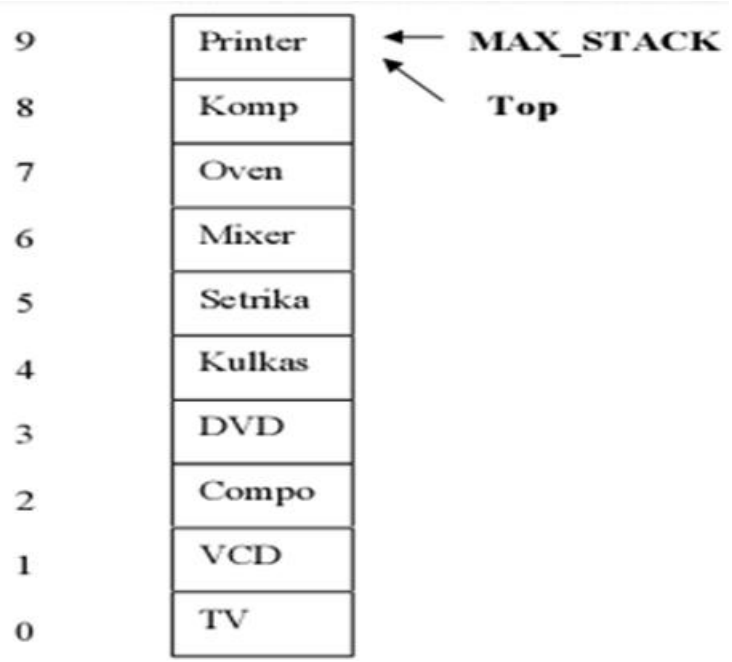
```
11  void init() {
12      stack.top = -1;
13  }
```



Stack: The Program (continued)

- `isFull()`
  - To check whether the stack is full?
  - By checking the **Top of Stack**
    - If it is the same as MAX_STACK-1 then it is full
    - If not (it's still smaller than MAX_STACK-1) then it is not full

```
15  int isFull() {
16      return (stack.top == MAX_STACK - 1) ? 1 : 0;
17  }
```



Stack: The Program (continued)

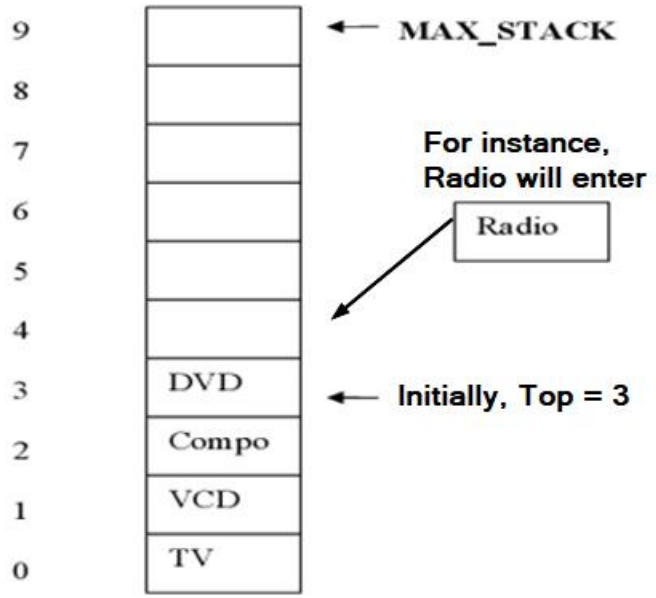
- `isEmpty()`
  - To check whether the Stack data is still empty
  - By checking the **Top of Stack**, if it is still -1 then it means the Stack data is still empty!

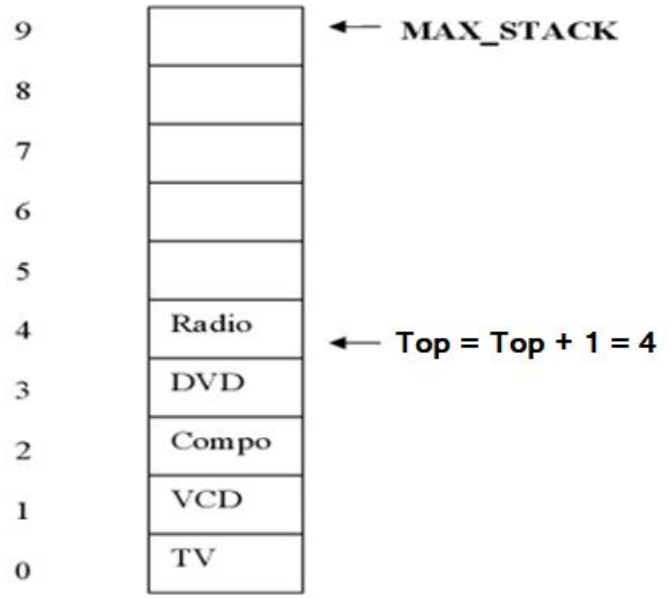
```
19  int isEmpty() {
20      return (stack.top == -1) ? 1 : 0;
21  }
```

Stack: The Program (continued)

- `push()`
  - To insert elements into Stack data. The input data is **always** the top element of the Stack (which is pointed by ToS, **Top of Stack**)
  - If the **data is not yet full**,
    - Add one (increment) value to the **Top of Stack** first every time there is an addition to the Stack data array.
    - Fill the new data into the stack based on the **Top of Stack** index that was previously incremented.
  - If not, output “Full”

Stack: The Program (continued)



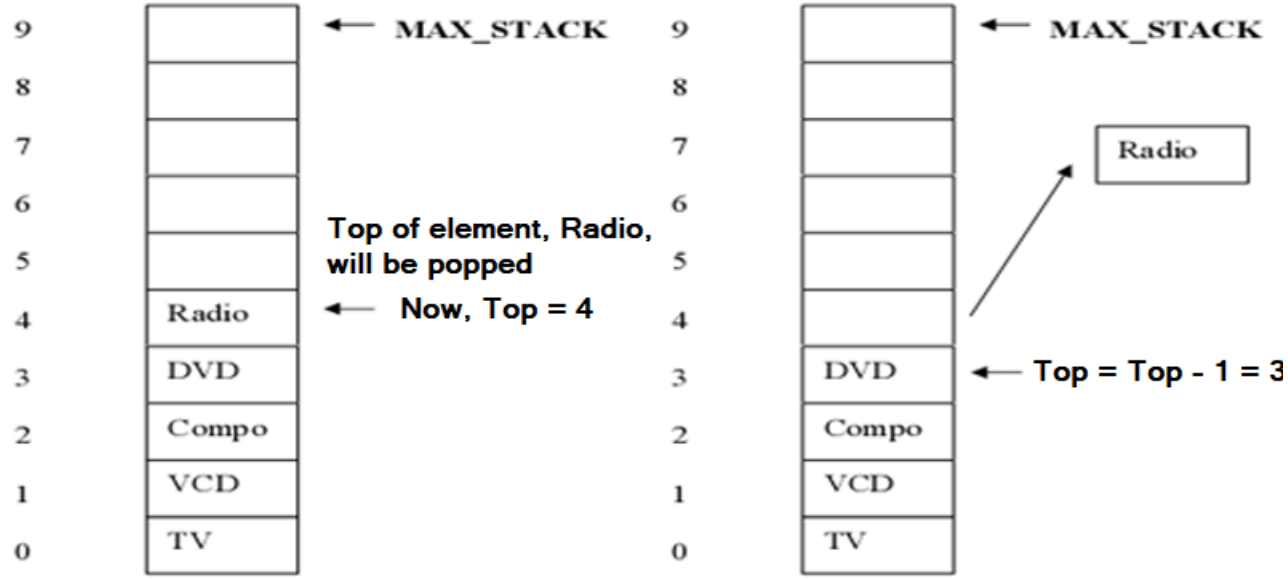



```
23  void push(int data) {
24      stack.data[++stack.top] = data;
25  }
```

Stack: The Program (continued)

- `pop()`
  - To retrieve Stack data at the top (data which is pointed by ToS, **Top of Stack**)
  - First, display the value of the top element of the stack by accessing its index according to the **Top of Stack**, then decrease the value of the **Top of Stack** so that the number of stack elements is reduced

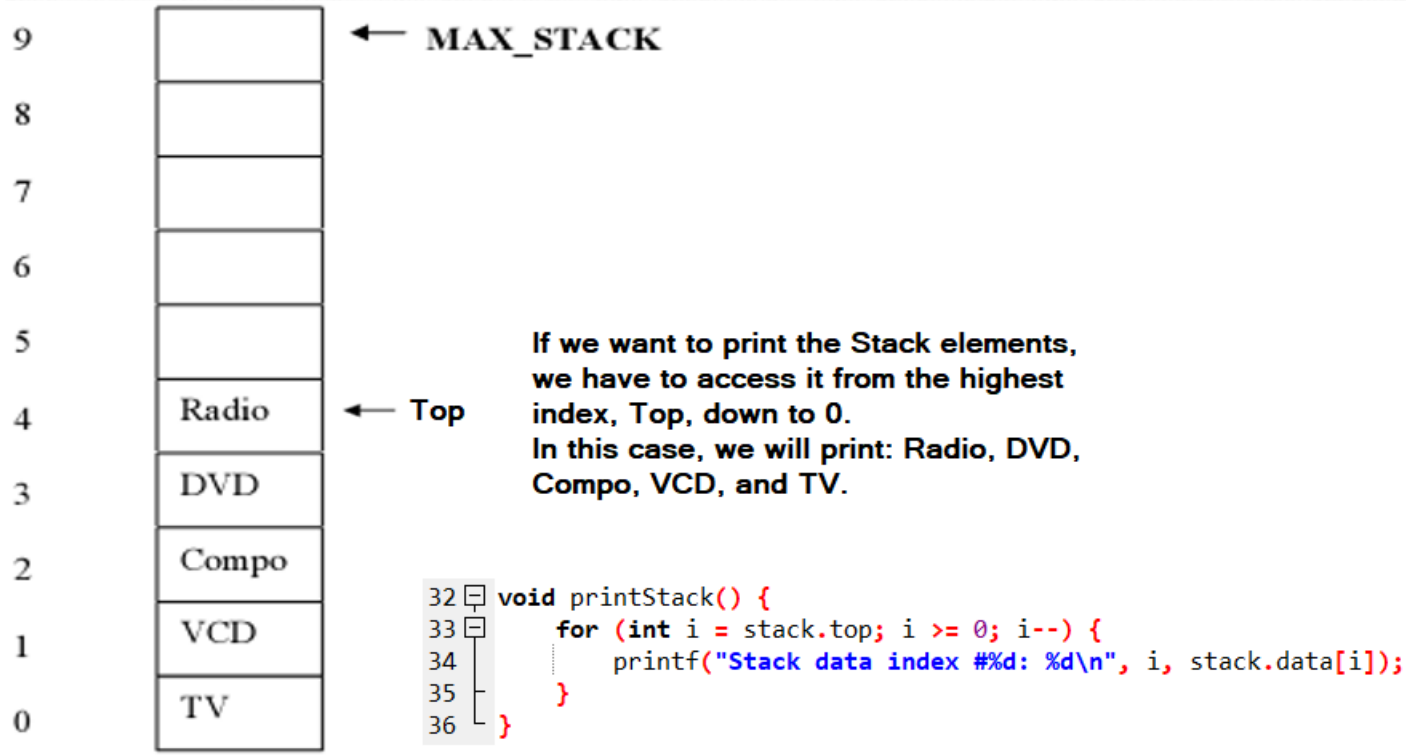
```
27  void pop() {
28      printf("Popped data: %d\n", stack.data[stack.top]);
29      stack.top--;
30  }
```



Stack: The Program (continued)

- `printStack()`
  - To display all of Stack data elements
  - By looping all the array values in reverse, because we have to access from the highest array index first and then to the smaller index!

Stack: The Program (continued)



If we want to print the Stack elements, we have to access it from the highest index, Top, down to 0.
In this case, we will print: Radio, DVD, Compo, VCD, and TV.

```
32  void printStack() {
33      for (int i = stack.top; i >= 0; i--) {
34          printf("Stack data index #%d: %d\n", i, stack.data[i]);
35      }
36  }
```

Stack: The Program (continued)

- `peek()`
  - Used to see/pick the ToS, **Top of Stack**

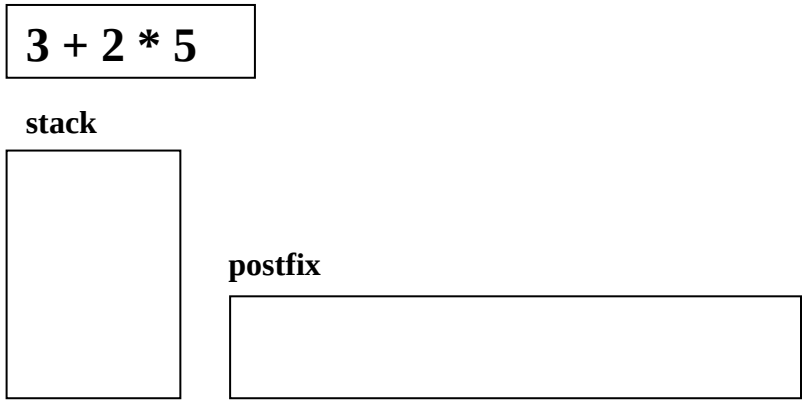
```
53  void main() {
54      printf("Initialise the stack.\nSet the top of stack with -1.\nIndex starts from 0.\nSo, it means it's empty stack.\n");
55      init();
56      printf("\nAdd the stack with 10 numbers.\n");
57      addData();
58      printf("\nShow the content of the stack.\n");
59      printStack();
60      printf("\nToS, the Top of Stack: %d\n", peek());
61      printf("\nGet the data from the stack. There're 10 numbers.\n");
62      getData();
63  }
64
65  int peek() {
66      return stack.data[stack.top];
67  }
```

```
Show the content of the stack.
Stack data index #9: 10
Stack data index #8: 9
Stack data index #7: 8
Stack data index #6: 7
Stack data index #5: 6
Stack data index #4: 5
Stack data index #3: 4
Stack data index #2: 3
Stack data index #1: 2
Stack data index #0: 1

ToS, the Top of Stack: 10

Get the data from the stack. There're 10 numbers.
Popped data: 10
```

Case Study: Scientific Calculator

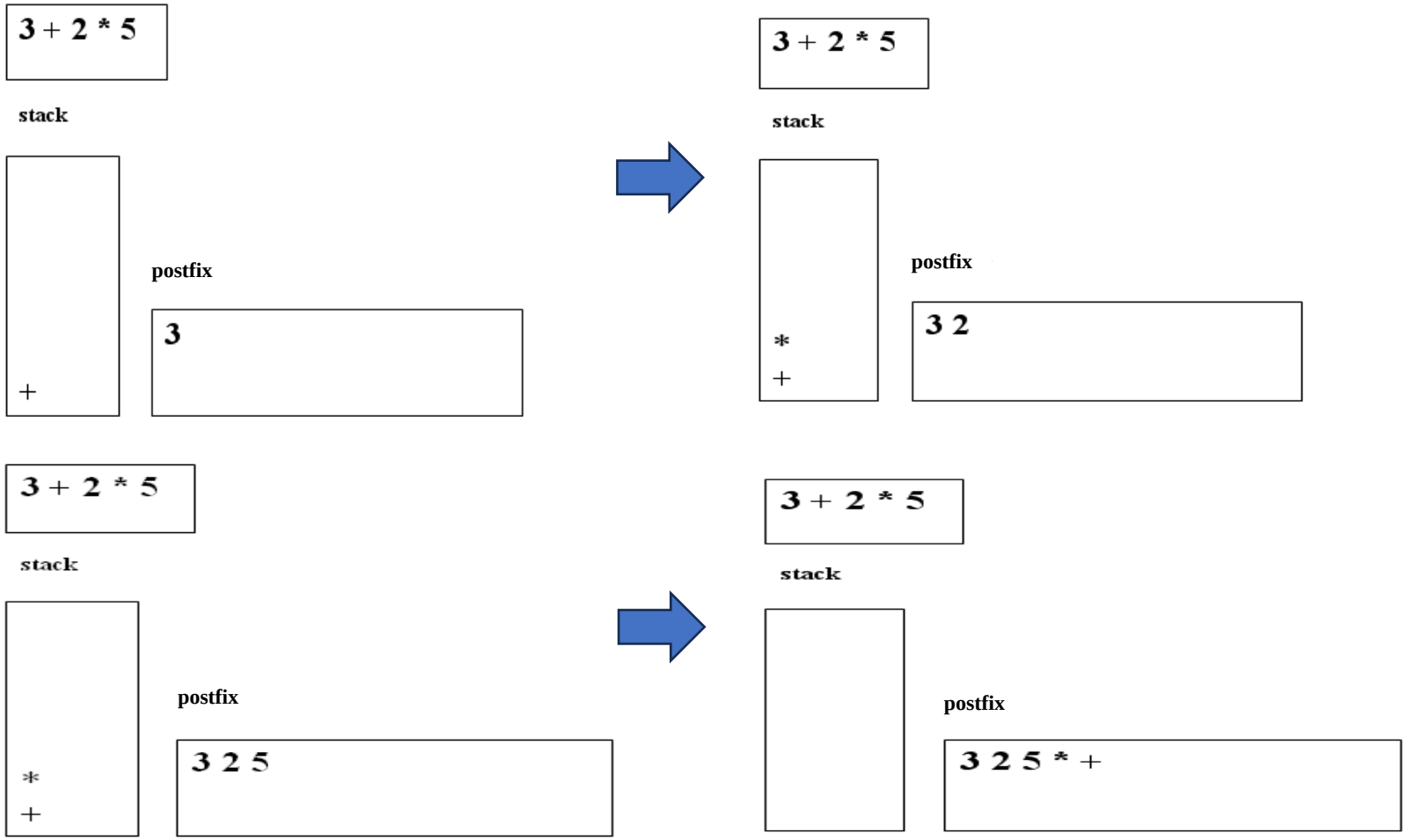
- Suppose the operation is: `3 + 2 * 5`
- The above operation is called **infix** notation
- The **infix** notation must first be changed to **postfix** notation
- `3 + 2 * 5` → postfix notation is `3 2 5 * +`

Case Study: Scientific Calculator (continued)



- Read the input from the front to the back
- If it is an **operand**, then enter it into **postfix**
- If it is an **operator**, then:
  - If the **stack** is still empty, push to the stack
  - If the degree of the problem operator > the degree of the ToS (**Top of Stack**) operator
    - Push the input operator to the stack
  - As long as the problem operator degree <= ToS operator degree
    - Pop the ToS and insert it into the postfix
    - After everything is done, push the input operator to the stack
- If you have read all the input, pop all the contents of the stack and push them to postfix in the correct order

Case Study: Scientific Calculator (continued)



Another example

- a+b*c-d
  - Stack (empty) and Postfix (empty)
- Scan a
  - Postfix: a
- Scan +
  - Stack: +
- Scan b
  - Postfix: ab
- Scan *, because ToS (+) < *, then add to Stack
  - Stack: +*

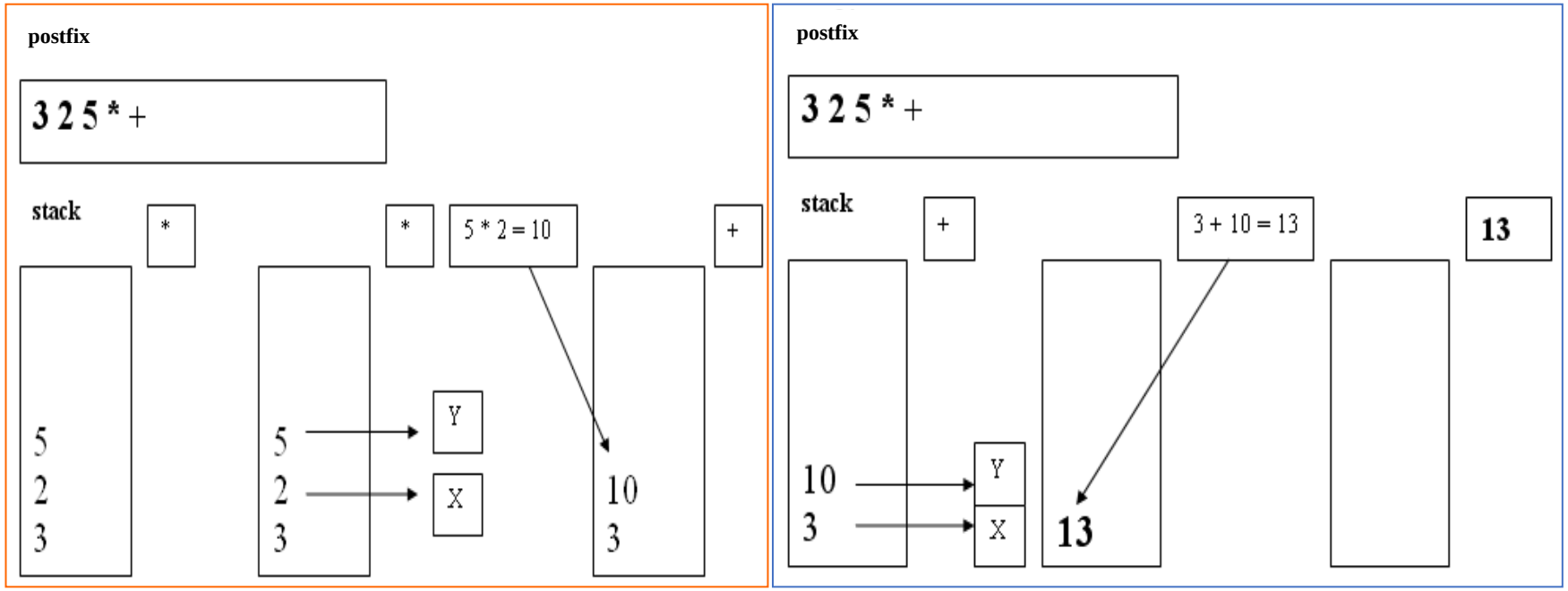
Another example (continued)

- Scans c
  - Postfix: abc
- Scan –, because * > -, then pop Stack, and add to Postfix
  - Stack: +
  - Postfix: abc*
  - Because + >= -, then pop Stack, and add to Postfix, because Stack is empty, then push – to stack
  - Stacks: -
  - Postfix: abc*+
- Scan d
  - Postfix: abc*+d
- Since it’s running out, pop the ToS stack into Postfix
  - Postfix: abc*+d-

Postfix Evaluator

- Scan the Postfix string from the left to the right
- Prepare an empty stack
- If the input is an operand, add it to the stack. If it is an operator, then there will be at least 2 operands on the stack
  - Pop the stack twice, the first pop is stored in y, and the second pop is stored in x. Then evaluate x <operator> y. Save the result and push it onto the stack again.
- Repeat until all inputs have been scanned
- If everything is done, the last element on the stack is the result.
- If there is more than one element, it means an error occurs!

Example: 325*+


postfix
3 2 5 * +
stack
*
*
5 * 2 = 10
+
5
2
3
5
2
3
Y
X
10
3
postfix
3 2 5 * +
stack
+
3 + 10 = 13
13
10
3
Y
X
13

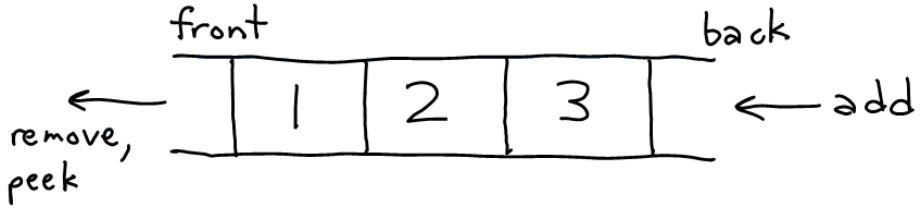
Queue

- What's the difference between Stack and Queue?
  - Stack – a container that allows push and pop
  - Queue – a container that allows enqueue and dequeue

Queue: The Definition & Operation

- Queue: A list with the restriction that insertions are done at one end and deletions are done at the other
  - First-In, First-Out (FIFO)
  - Elements are stored in order of insertion but don't have indexes.
  - Client can only add to the end of the queue, and can only examine/remove the front of the queue.

- Basic queue operations:
  - Add (enqueue): Add an element to the back.
  - Remove (dequeue): Remove the front element.
  - Peek: Examine the elements at the front.



Queue: The Applications

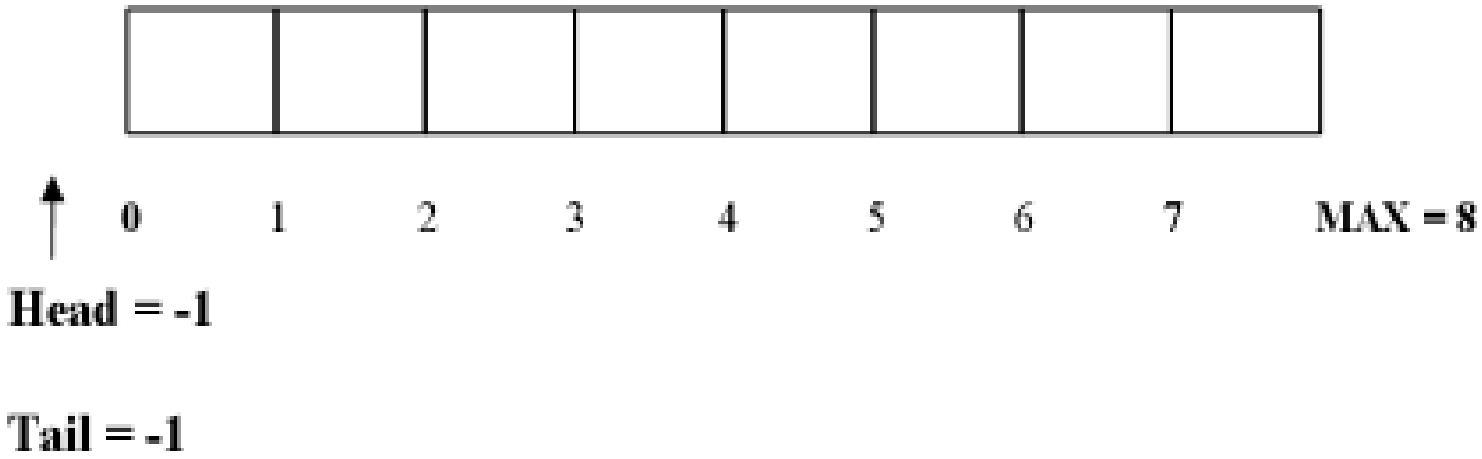
- Real-life examples
  - Waiting in line
  - Waiting on hold for tech support
- Applications related to Computer Science
  - Threads
  - Job scheduling (e.g. Round-Robin algorithm for CPU allocation)

Queue: In Computer Science

- Operating systems:
  - Queue of print jobs to send to the printer
  - Queue of programs/processes to be run
  - Queue of network data packets to send
- Programming:
  - Modelling a line of customers or clients
  - Storing a queue of computations to be performed in order
- Real-world examples:
  - People on an escalator or waiting in a line
  - Cars at a gas station (or on an assembly line)

Queue: Linear Array

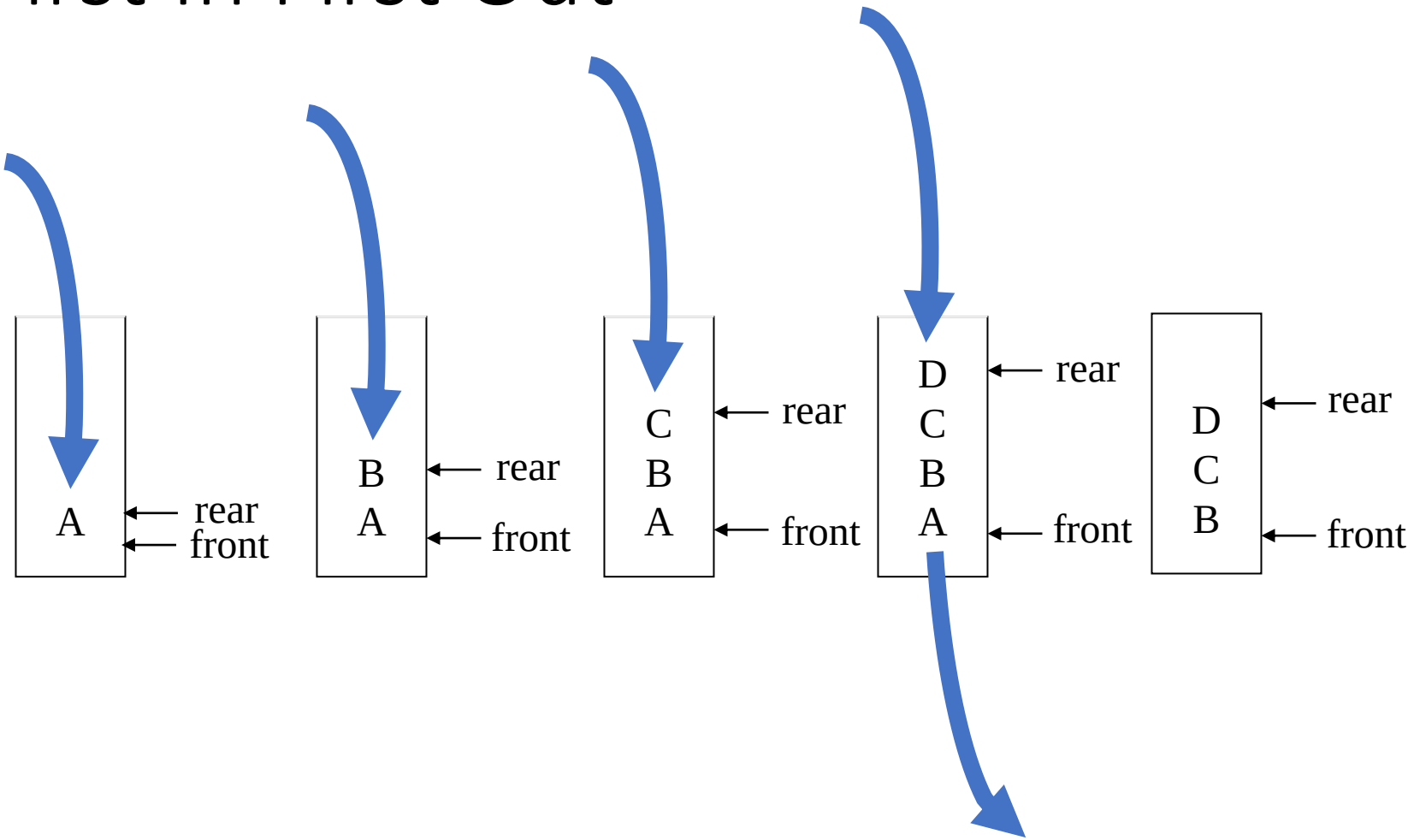
- There is one entrance at one end and one exit at the other end
- So it requires 2 variables: Head and Tail



Queue: Using Array

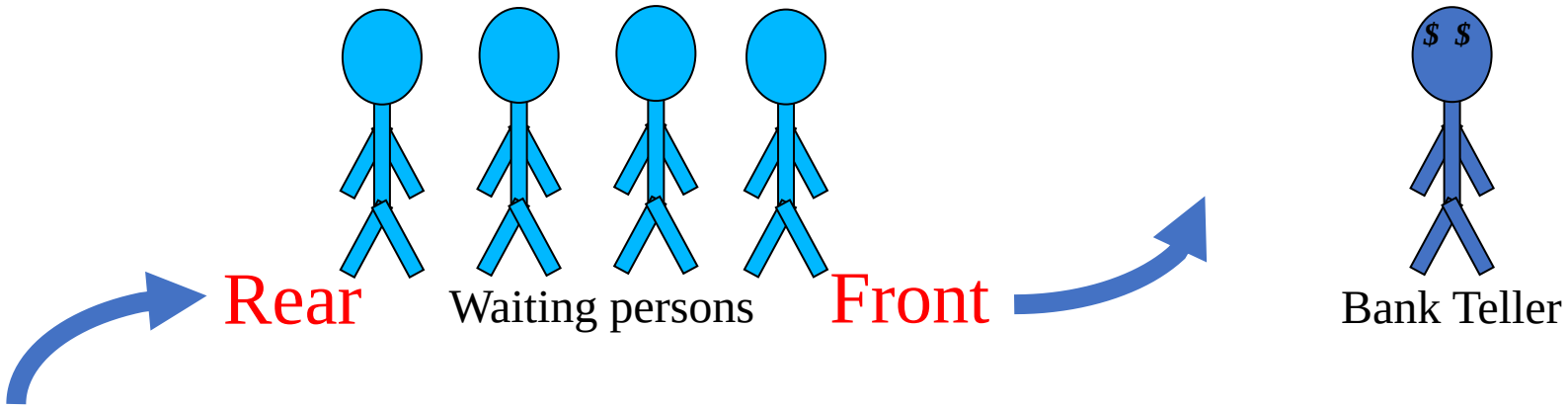
- FIFO (First In First Out)
- The element that enters the queue **first** will be the **first to exit**
- DEQUEUE is removing one element from a Queue
- Queues can be created using: Linear Array and Circular Array

FIFO: First In First Out



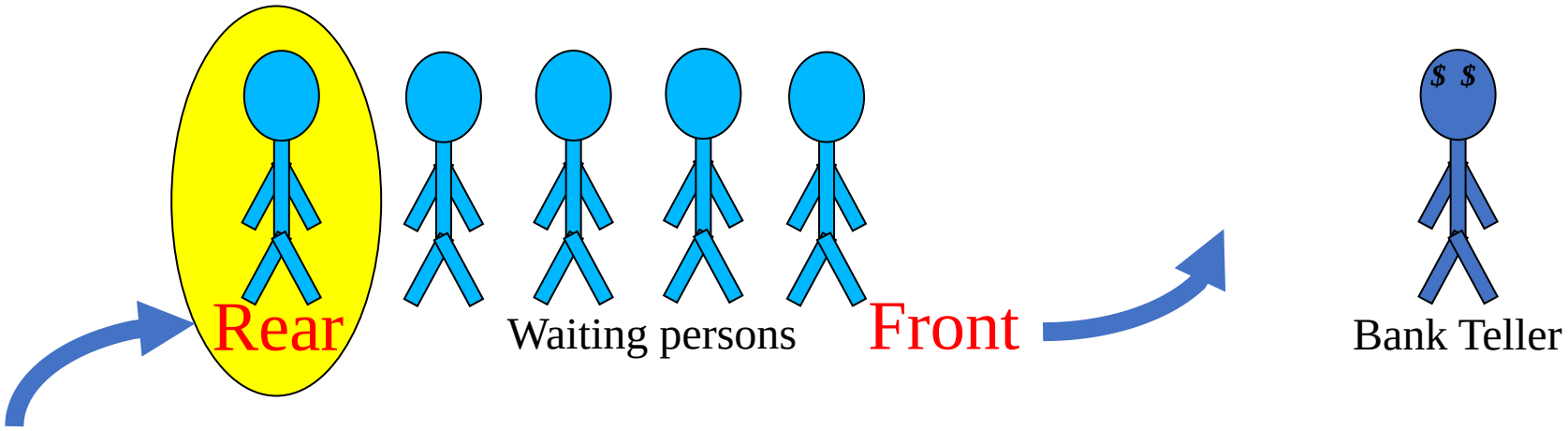
Queue: The Operations

- A queue is like a line of persons waiting for some bank's services by a bank teller
- The queue has a **front** and a **rear**



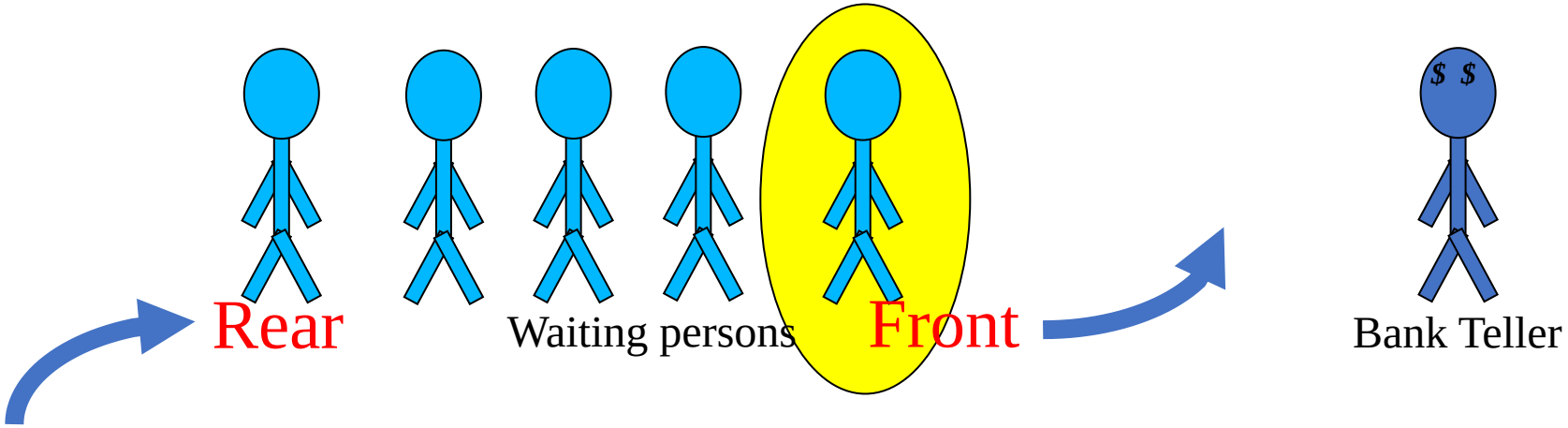
Queue: The Operations (continued)

- An incoming person must enter the queue at the rear
- It's usually called an **enqueue** operation



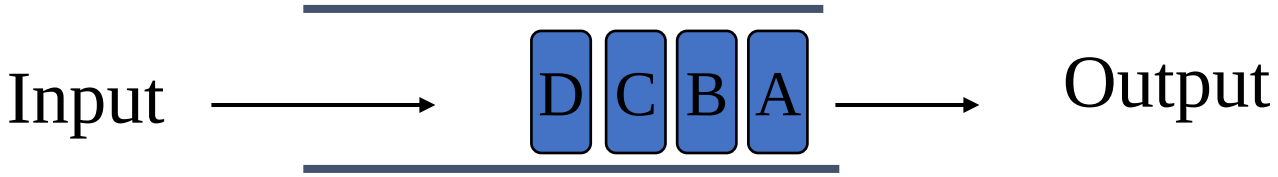
Queue: The Operations (continued)

- When an item is taken from the queue, it always comes from the front
- It's usually called a **dequeue** operation



Queue: The Examples

- Queue: First In First Out (FIFO)



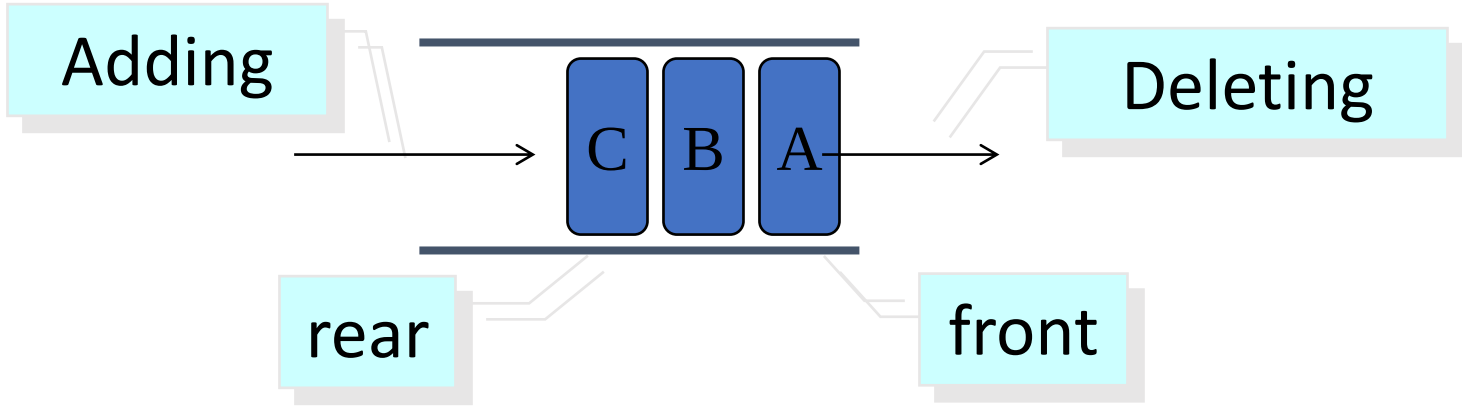
- Toll Stations
  - Car comes, pays, leaves
- Check-out at Big Y market
  - Customer comes, checks out and leaves
- More examples: Printer, Office Hours, …

Queue: More Examples

- In our daily life
  - Airport Security Check
  - Cinema Ticket Office
  - Banks, ATMs
  - Anything else?

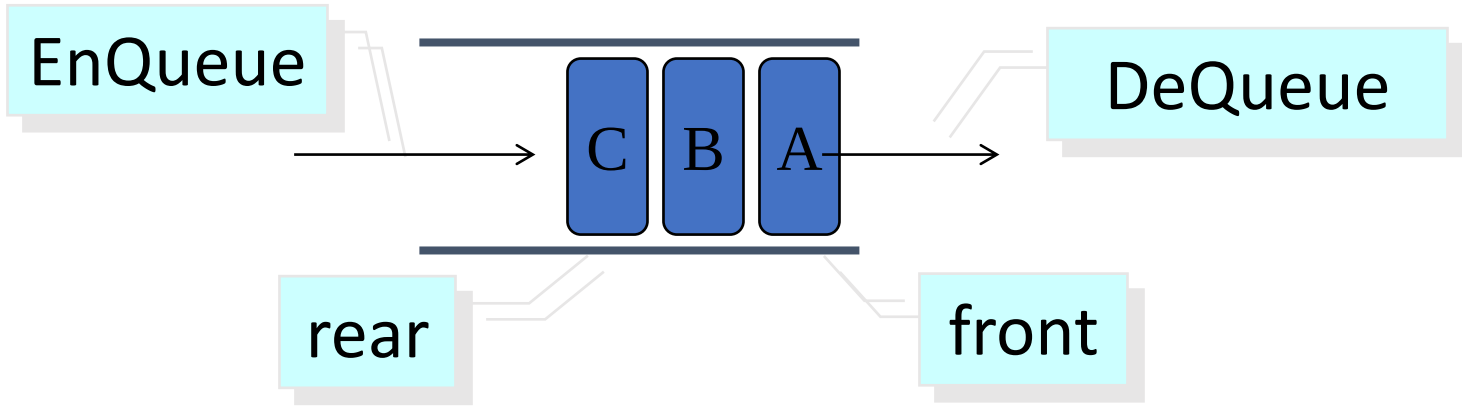
Queue: What is All About?

- Queue is an Abstract Data Type (ADT)
- Adding an entry at the **rear**
- Deleting an entry at the **front**



Queue: Abstract Data Type (ADT)

- Queues
- Operating on both ends
- Operations: EnQueue(**in**), DeQueue(**out**)



Queue: The Mechanism

- Queue is FIFO (First-In First-Out)
- A queue is open at **two ends**
  - You can only add entry (**EnQueue**) at the **rear**, and delete entry (**DeQueue**) at the **front**.
- Note:
  - You cannot **add/extract** entries in the **middle** of the queue!

Queue: Other Applications

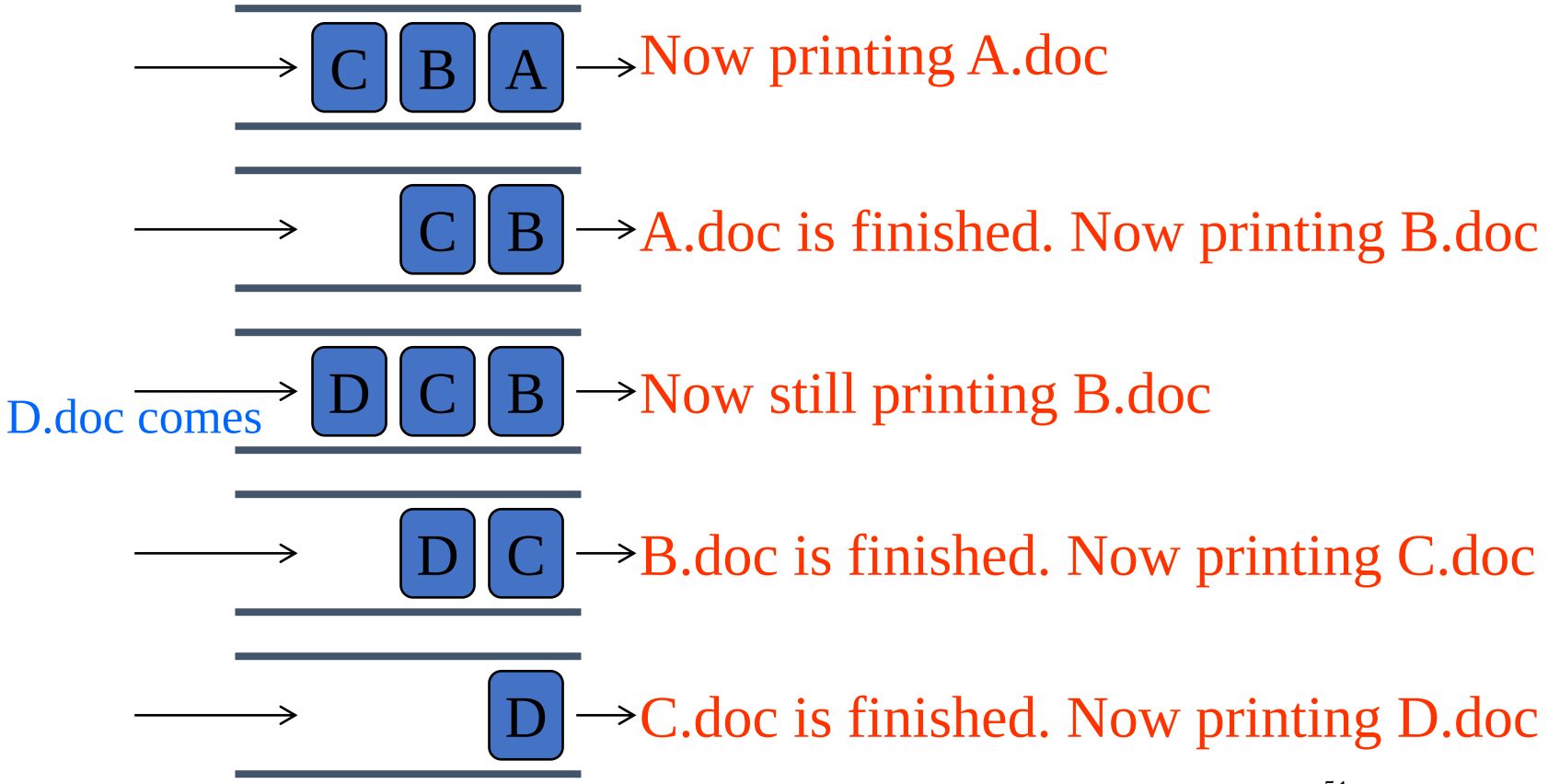
- Printing Job Management
- Packet Forwarding in Routers
- Message queue in Windows
- I/O buffers

Printing Job Management

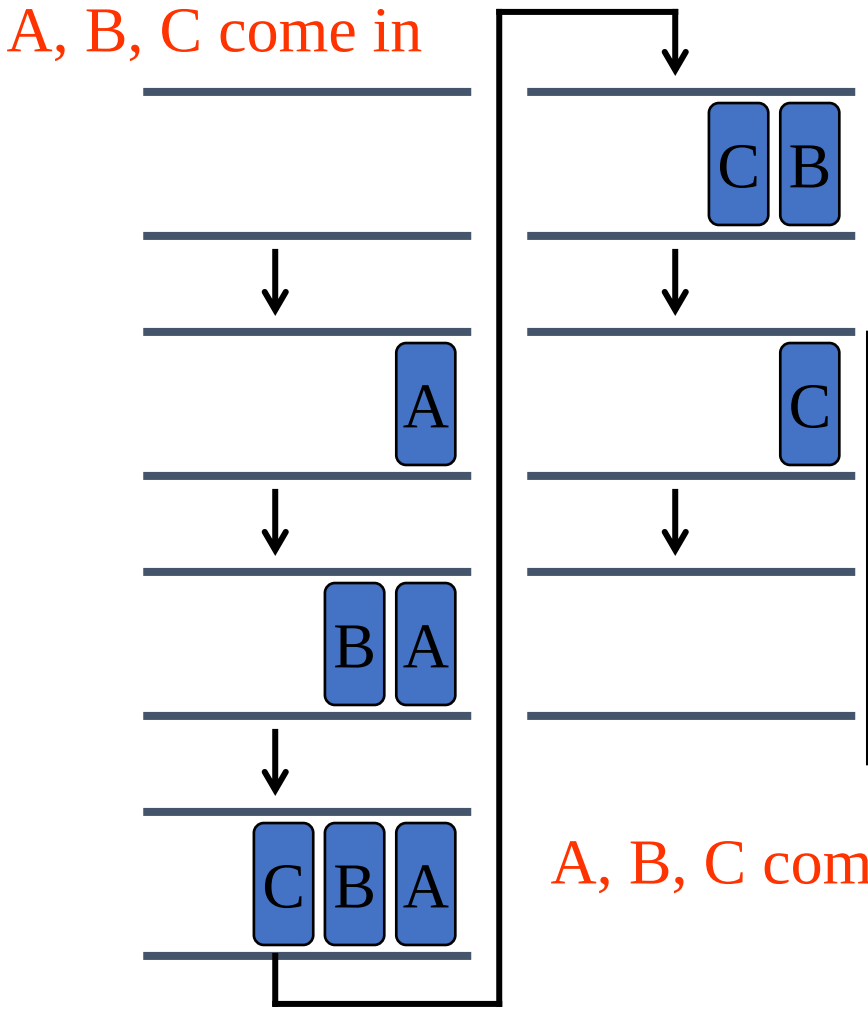
- Many users send their printing jobs to a public printer
- The printer will put them into a queue according to the arrival time and print the jobs one by one
- These printing documents are A.doc, B.doc, C.doc and D.doc

Printing Queue

- A.doc, B.doc, and C.doc arrive at the printer



Printing Queue: FIFO

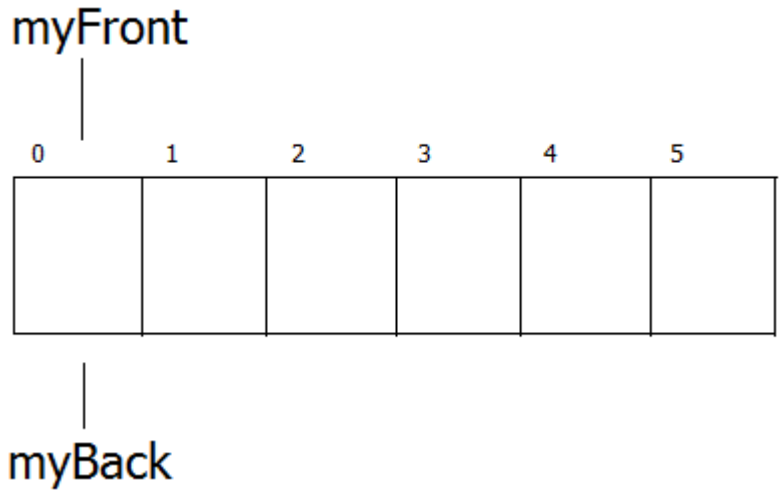


The first one **enqueued** is the first one **dequeued** (FIFO)

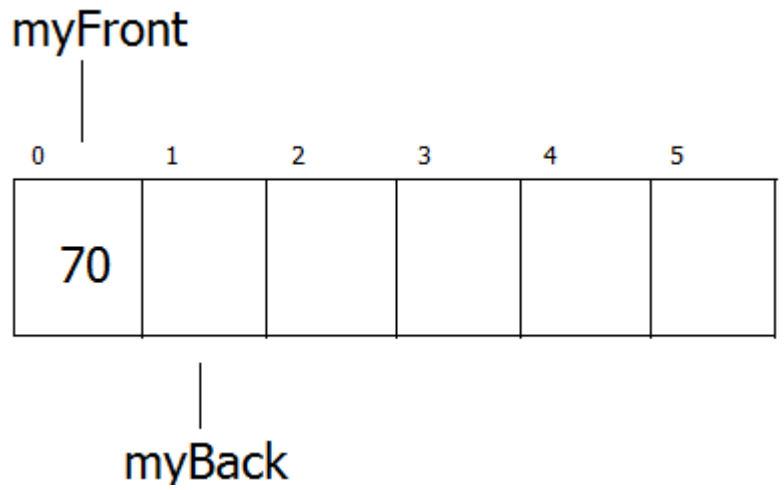
When we enqueue entries in the queue and then dequeue them one by one, we will get the **items** in the **same order**

Queue: The Operation Example

- Empty Queue

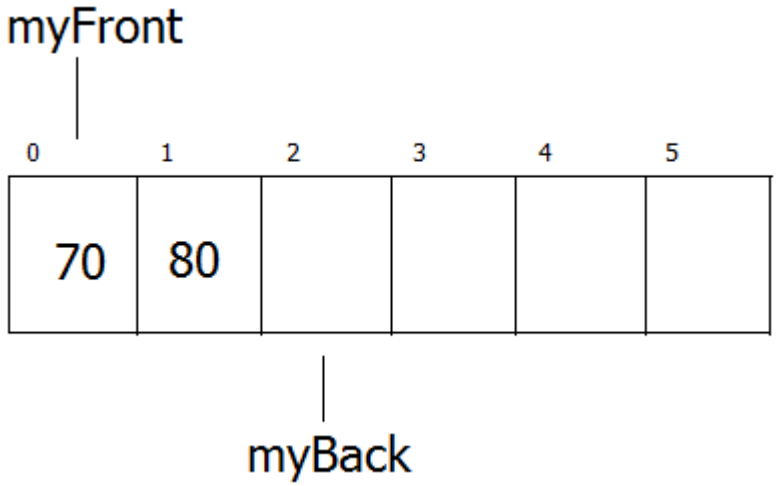


- Enqueue(70)

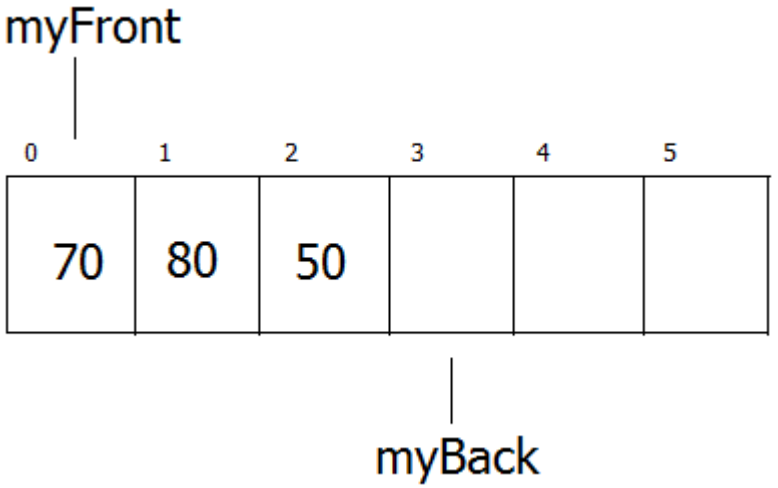


Queue: The Operation Example (continued)

- Enqueue(80)

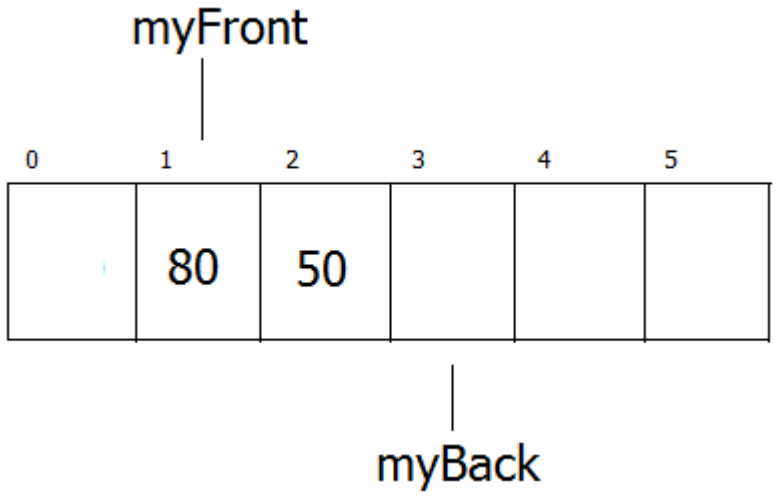


- Enqueue(50)

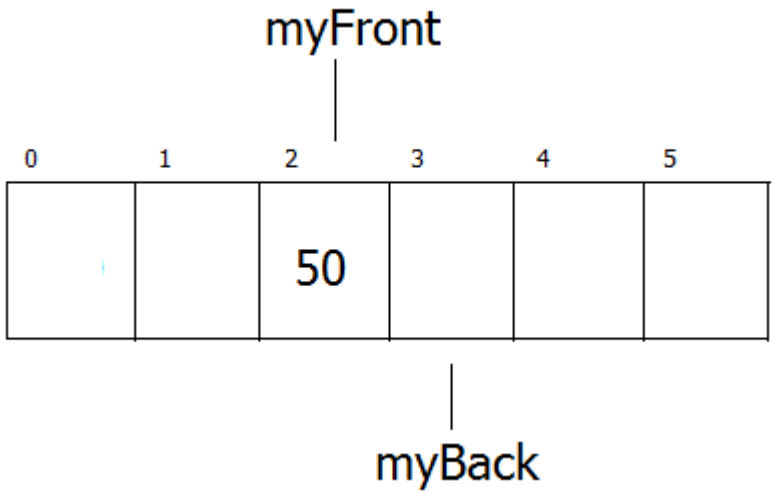


Queue: The Operation Example (continued)

- Dequeue()

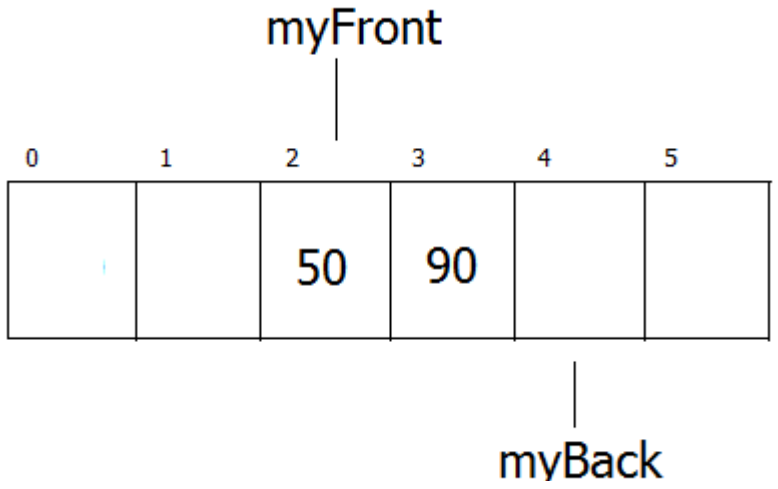


- Dequeue()

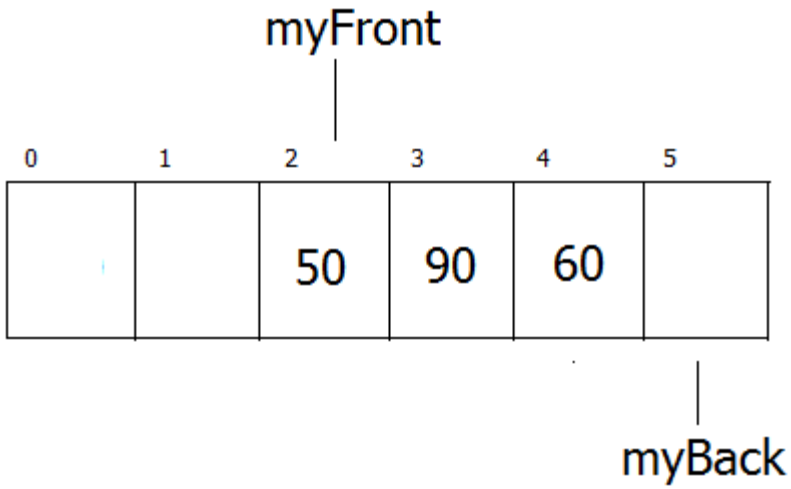


Queue: The Operation Example (continued)

- Enqueue(90)



- Enqueue(60)



Queue: The Code

```c
#include <stdio.h>
#include <stdlib.h>
#define MAX 10

typedef struct myQueue {
    int head;
    int tail;
    int data[10];
} QUEUE;
QUEUE queue;

void create() {
    queue.head = queue.tail = -1;
}

int isFull() {
    return (queue.tail == MAX - 1) ? 1 : 0;
}

int isEmpty() {
    return (queue.tail == -1) ? 1 : 0;
}

void enQueue(int data) {
    if (isFull()) {
        printf("Queue is full\n");
    }
    if (isEmpty()) {
        queue.head = 0;
    }
    queue.data[++queue.tail] = data;
}

int deQueue() {
    int tmp;
    if (!isEmpty()) {
        tmp = queue.data[queue.head];
        for (int i = queue.head; i <= queue.tail - 1; i++) {
            queue.data[i] = queue.data[i + 1];
        }
        return tmp;
    }
}

void printQueue() {
    if (!isEmpty()) {
        for (int i = queue.head; i < queue.tail; i++) {
            printf("Queue data #%d is %d\n", i, queue.data[i]);
        }
    }
}

void clearQueue() {
    queue.head = queue.tail = -1;
    printf("Clearing the queue\n");
}

void fillData() {
    int data;
    while (!isFull()) {
        printf("Enter the data: ");
        scanf("%d", &data);
        enQueue(data);
    }
}

void main() {
    create();
    fillData();
    printf("DeQueue %d\n", deQueue());
    printQueue();
}
```

```
Enter the data: 1
Enter the data: 2
Enter the data: 3
Enter the data: 4
Enter the data: 5
Enter the data: 6
Enter the data: 7
Enter the data: 8
Enter the data: 9
Enter the data: 10
DeQueue 1
Queue data #0 is 2
Queue data #1 is 3
Queue data #2 is 4
Queue data #3 is 5
Queue data #4 is 6
Queue data #5 is 7
Queue data #6 is 8
Queue data #7 is 9
Queue data #8 is 10
```

Queue: The Code Explanation

`create()`

- To create and initialize the **queue**
- By making **head** and **tail** = -1

```
 4
 5  typedef struct myQueue {
 6      int head;
 7      int tail;
 8      int data[10];
 9  } QUEUE;
10  QUEUE queue;
11
12  void create() {
13      queue.head = queue.tail = -1;
14  }
15
```

Queue: The Code Explanation (continued)

- The first **queue** condition

head = -1

tail = -1

```
11
12  void create() {
13      queue.head = queue.tail = -1;
14  }
15
```

MAX = 8

Queue: The Code Explanation (continued)

`isEmpty()`

- To check whether the **queue** is **empty** or not
- By checking the **tail** value, if **tail** = -1 then it is **empty**
- We do not check the **head**, because **head** is an indicator for the head of the queue (the **first** element in the queue) which will not change
- Movement in the **queue** occurs by adding queue elements **backwards**, i.e., by using the **tail** value

Queue: The Code Explanation (continued)

- The **queue** is empty, because the **tail** = -1

head = -1

tail = -1

```
19
20  int isEmpty() {
21      return (queue.tail == -1) ? 1 : 0;
22  }
23
```

MAX = 8

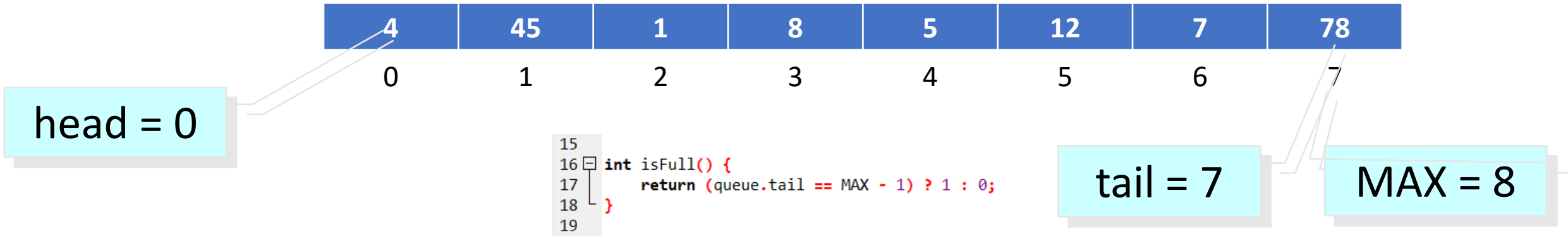
Queue: The Code Explanation (continued)

`isFull()`

- To check whether the **queue** is **full** or not
- By checking the value of **tail**, if **tail** >= MAX-1 (because MAX-1 is the limit of array elements in C) it means it is **full**

Queue: The Code Explanation (continued)

- The **queue** is **full**, because the **tail** = MAX-1




```
15
16  int isFull() {
17      return (queue.tail == MAX - 1) ? 1 : 0;
18  }
19
```

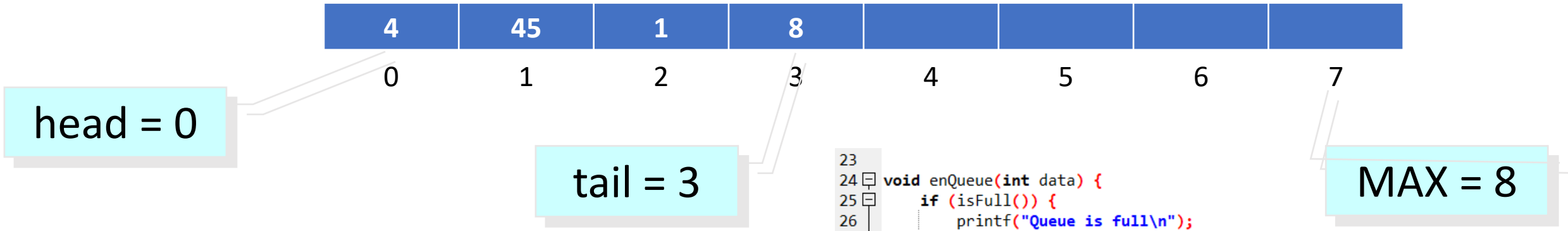
Queue: The Code Explanation (continued)

`enQueue()`

- To **add** an element to the **queue**, the added element is always added to the **last** element
- Adding elements always moves the **tail** variable by incrementing the tail **counter** first

Queue: The Code Explanation (continued)

- The **queue** after `enQueue(8)` has executed




```
23
24  void enQueue(int data) {
25      if (isFull()) {
26          printf("Queue is full\n");
27      }
28      if (isEmpty()) {
29          queue.head = 0;
30      }
31      queue.data[++queue.tail] = data;
32  }
33
```

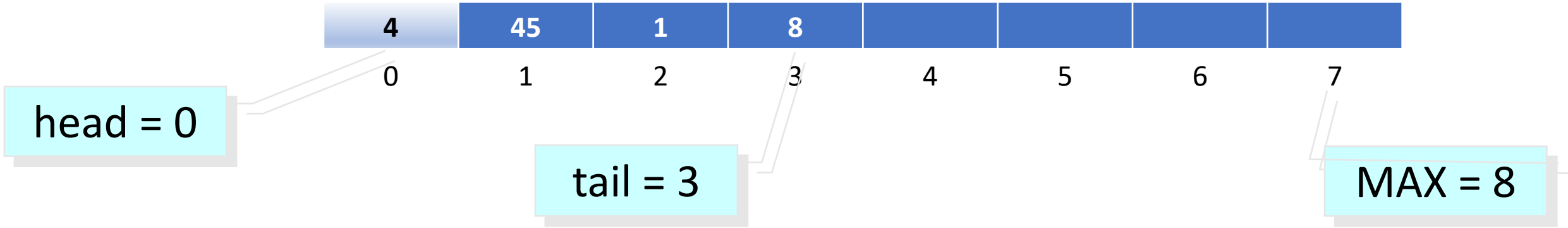
Queue: The Code Explanation (continued)

`deQueue()`

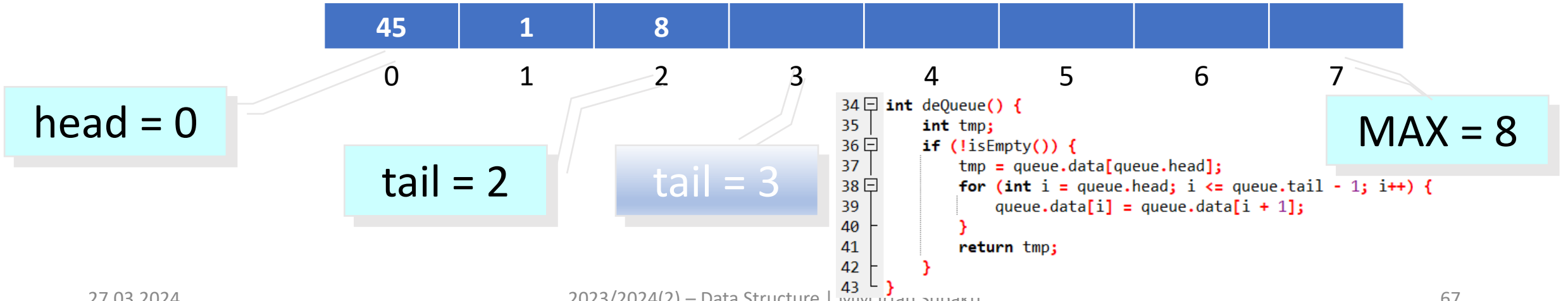
- Used to **delete** the leading/**first** element (**head**) from the **queue**
- By shifting all queue elements forward and reducing the **tail** with 1
- Shifting is done by using **looping**

Queue: The Code Explanation (continued)

- The **queue** after `deQueue()` has executed



- Then, all of element are shifted to the left (move **forward**)




```
34  int deQueue() {
35      int tmp;
36      if (!isEmpty()) {
37          tmp = queue.data[queue.head];
38          for (int i = queue.head; i <= queue.tail - 1; i++) {
39              queue.data[i] = queue.data[i + 1];
40          }
41          return tmp;
42      }
43  }
```

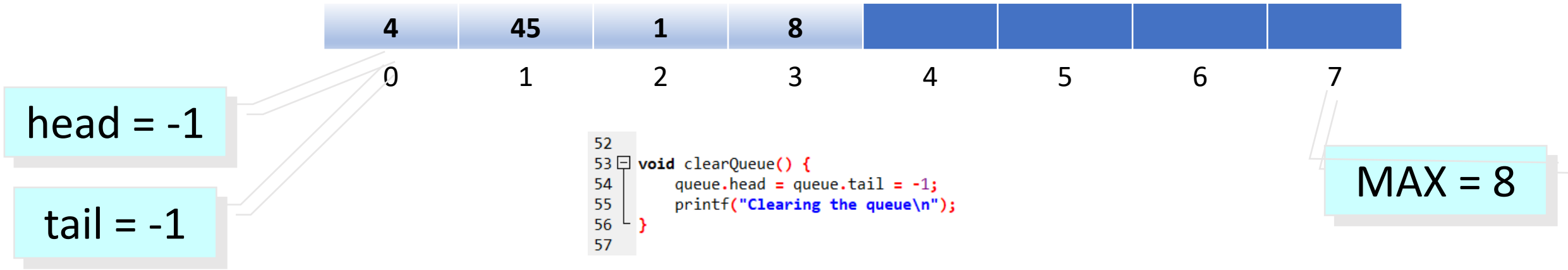
Queue: The Code Explanation (continued)

`clearQueue()`

- To delete the **queue** elements by making **tail** and **head** = -1
- Deleting the queue **elements** does not delete the array, but only sets the **access index** to **-1** so that the queue **elements** are no longer readable

Queue: The Code Explanation (continued)

- The **queue** after `clearQueue()` has executed




```
52
53  void clearQueue() {
54      queue.head = queue.tail = -1;
55      printf("Clearing the queue\n");
56  }
57
```

Queue: The Code Explanation (continued)

`printQueue()`

- To display the queue **element values**
- Using looping from the **head** to the **tail**

```
44
45  void printQueue() {
46      if (!isEmpty()) {
47          for (int i = queue.head; i < queue.tail; i++) {
48              printf("Queue data #%d is %d\n", i, queue.data[i]);
49          }
50      }
51  }
52
```

Exercise

- Add a function to **search** for an **element** in the **queue** & **stack**
- Add a function to **edit an element** in the **queue** & **stack**
- Find the **total**, **average**, **greatest** and **smallest** values of the queue **elements** in a separate function

NEXT: Introduction to **pointers** and **functions by reference**