Ch. 18: ADTs: Stacks and Queues

CS 2308
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Abstract Data Type

- A data type for which:
  - only the properties of the data and the operations to be performed on the data are specific,
  - not concerned with how the data will be represented or how the operations will be implemented.
- In fact, an ADT may be implemented by various specific data types or data structures, in many ways and in many programming languages.
- Examples:
  - ItemInventory (impl'd using array AND linked list)
  - Stacks and Queues

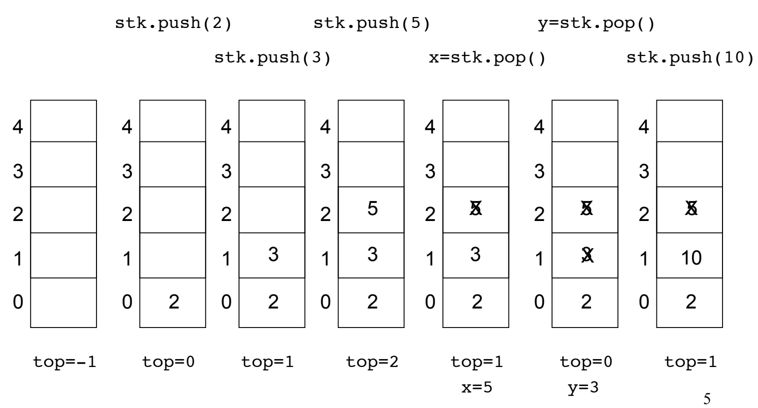
Introduction to the Stack

- Stack: an abstract data type that holds a collection of elements of the same type.
  - The elements are accessed according to LIFO order: last in, first out
  - No random access to other elements
- Examples:
  - plates in a cafeteria
  - bangles . . .

Stack Operations

- Operations:
  - push: add a value onto the top of the stack
    - make sure it's not full first.
  - pop: remove a value from the top of the stack
    - make sure it's not empty first.
  - isFull: true if the stack is currently full, i.e.,has no more space to hold additional elements
  - isEmpty: true if the stack currently contains no elements

Stack illustrated



Stack Application: Postfix notation

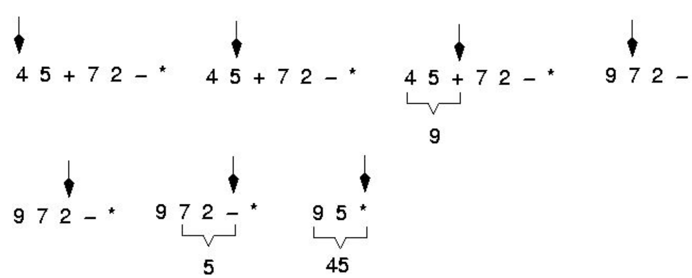
- Postfix notation is another way of writing arithmetic expressions.
- We normally use infix, the operator is between the operands
- In postfix notation, the operator is written after the two operands.

  infix: 2+5 postfix: 2 5 +

- Expressions are evaluated from left to right.
- Precedence rules and parentheses are never needed!!

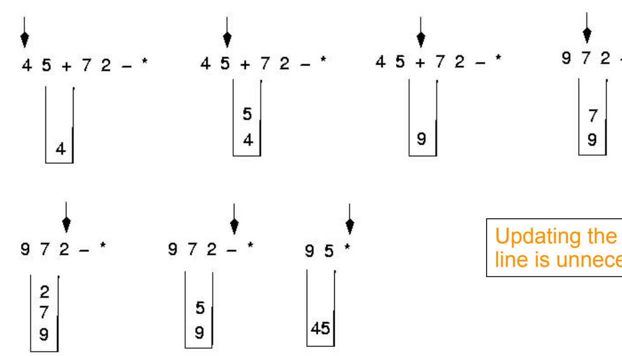
Postfix notation

- evaluation from left to right
- replace evaluated expression with result



Postfix notation: using a stack

- evaluation from left to right: push operands
- for operator: pop two values, perform operation, and push the result



Updating the input line is unnecessary

Evaluate Postfix Expression algorithm

- Using a stack:

```
WHILE more input items exist
   get next item
   IF item is a number
     stack.push(item)
   ELSE (item is an operator)
     num2 = stack.pop()
     num1 = stack.pop()
     Compute result
     stack.push(result)
end WHILE

result = stack.pop()
```


Implementing a Stack Class

- IntStack:
  - contains ints
  - implemented using a dynamically allocated array, but once allocated, the array does not change size
- Alternative implementations of an integer stack:
  - use a regular array of ints
  - use a linked list with nodes that contain ints (see 18.2)
  - std::stack from the C++ library (STL) (see 18.3)

IntStack: A stack class

IntStack.h

```
class IntStack
{
private:
   int *stackArray;   // Pointer to the stack array
   int stackSize;     // The stack size (will not change)
   int top;           // Index to the top of the stack

public:
   // Constructor
   IntStack(int);

   // Destructor
   ~IntStack();

   // Stack operations
   void push(int);
   int pop();
   bool isFull() const;
   bool isEmpty() const;
};
```

Note: the code on the website contains a copy constructor

IntStack: functions

IntStack.h

```
//***********************************************
// Constructor                                  *
// This constructor creates an empty stack. The *
// size parameter is the size of the stack.     *
//***********************************************

IntStack::IntStack(int size)
{
   stackArray = new int[size];  // dynamic alloc
   stackSize = size;            // save for reference
   top = -1;                    // empty
}


//***********************************************
// Destructor                                   *
//***********************************************

IntStack::~IntStack()
{
   delete [] stackArray;
}
```

IntStack: push

```
//*************************************************
// Member function push pushes the argument onto  *
// the stack.                                     *
//*************************************************

void IntStack::push(int num)
{
   if (isFull())
   {
      cout << "The stack is full.\n";
   }
   else
   {
      top++;
      stackArray[top] = num;
   }
}
```

This is called stack overflow

IntStack: pop

```
//****************************************************
// Member function pop pops the value at the top    *
// of the stack off, and returns it as the result.  *
//  If the stack is empty, outputs a message and    *
//  returns -1                                      *
//****************************************************

void IntStack::pop(int &num)
{
   int num = -1;
   if (isEmpty())
   {
      cout << "The stack is empty.\n";
   }
   else
   {
      num = stackArray[top];
      top--;
   }
   return num;
}
```

This is called stack underflow

IntStack: test functions

```
//***************************************************
// Member function isFull returns true if the stack *
// is full, or false otherwise.                     *
//***************************************************

bool IntStack::isFull() const
{
   return (top == stackSize - 1);
}

//****************************************************
// Member function isEmpty returns true if the stack *
// is empty, or false otherwise.                     *
//****************************************************

bool IntStack::isEmpty() const
{
   return (top == -1);
}
```


IntStack: driver

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

#include "IntStack.h"


int main() {

   // set up the stack
   IntStack stack(50);
    stack.push(2);
    stack.push(3);
    stack.push(5);
    int x;
    x = stack.pop();
    x = stack.pop();
    stack.push(10);
    cout << x << endl;

}
```

What is output?

What is left on the stack when the driver is done?

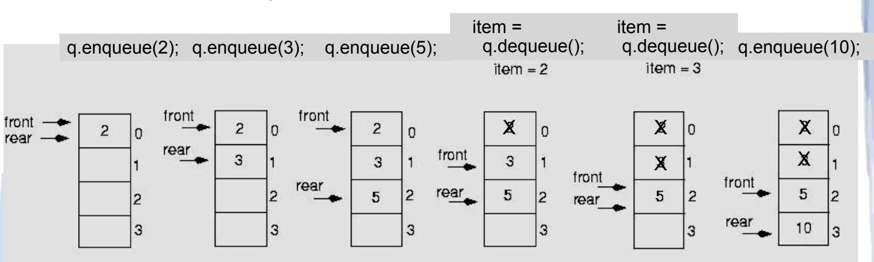
Introduction to the Queue

- Queue: an abstract data type that holds a collection of elements of the same type.
  - The elements are accessed according to FIFO order: first in, first out
  - No random access to other elements
- Examples:
  - people in line at a theatre box office
  - print jobs sent to a (shared) printer

Queue Operations

- Operations:
  - enqueue: add a value onto the rear of the queue (the end of the line)
    - make sure it's not full first.
  - dequeue: remove a value from the front of the queue (the front of the line) "Next!"
    - make sure it's not empty first.
  - isFull: true if the queue is currently full, i.e.,has no more space to hold additional elements
  - isEmpty: true if the queue currently contains no elements

Queue illustrated



Note: front and rear are variables used by the implementation to carry out the operations

```
int item;
q.enqueue(2):
q.enqueue(3);
q.enqueue(5);
item = q.dequeue(); //item is 2
item = q.dequeue(); //item is 3
q.enqueue(10);
```


Queue Applications

- The best example applications of queues involve multiple processes.
- For example, imagine the print queue for a computer lab.
- Any computer can add a new print job to the queue (enqueue).
- The printer performs the dequeue operation and starts printing that job.
- While it is printing, more jobs are added to the Q
- When the printer finishes, it pulls the next job from the Q, continuing until the Q is empty

Implementing a Queue Class

- IntQueue:
  - contains ints
  - implemented using a dynamically allocated array, but once allocated, the queue does not change size
- Alternative implementations of an integer queue:
  - use a regular array of ints
  - use a linked list with nodes that contain ints (see 18.5)
  - std::deque and std::queue from the C++ library (STL) (see 18.6)

Implementing a Queue class

issues using a fixed length array

- The previous illustration assumed we were using an array to implement the queue
- When an item was dequeued, the items were NOT shifted up to fill the slot vacated by dequeued item
  - why not?
- Instead, both front and rear indices move through the array.

Implementing a Queue Class

- When front and rear indices move in the array:
  - problem: rear hits end of array quickly
  - solution: wrap index around to front of array

					7	9	6
					front		rear

q.enqueue(3):

3					7	9	6
rear					front		

q.enqueue(4):

3	4				7	9	6
	rear				front		

Implementing a Queue Class

- To "wrap" the rear index back to the front of the array, you can use this code to increment rear during enqueue:

```
if (rear = queueSize-1)
   rear = 0;
else
   rear = rear+1;
```

- The following code is equivalent, but shorter (assuming 0 <= rear < queueSize):

```
rear = (rear + 1) % queueSize;
```

- Do the same for advancing the front index.

Implementing a Queue Class

- When is it full?

3	4				7	9	6
	rear				front		

```
q.enqueue(5);
q.enqueue(2);
q.enqueue(1);
```

Note: enqueue increments rear

3	4	5	2	1	7	9	6
				rear	front		

- It's full:

(rear+1)%queueSize==front

Implementing a Queue Class

- When is it empty?

```
int x;
for (int i=0; i<queueSize;i++)
    x = q.dequeue();
```

Note: dequeue increments front

after the first one:

3	4	5	2	1		9	6
				rear		front	

one element left:

				1			
				front rear			

no elements left, front passes rear:

				rear	front		

- It's empty:

(rear+1)%queueSize==front

Implementing a Queue Class

- When is it full? (rear+1)%queueSize==front
- When is it empty? (rear+1)%queueSize==front
- How do we define isFull and isEmpty?
  - Use a counter variable, numItems, to keep track of the total number of items in the queue.
- enqueue: numItems++
- dequeue: numItems--
- isEmpty is true when numItems == 0
- isFull is true when numItems == queueSize

Implementing a Queue Class

- In the implementation that follows:
- the queue is a dynamically allocated array, whose size does not change once initialized.
- If the queue is not empty:
  - rear is the index of the last item that was enqueued.
  - front is the index of the next item to be dequeued.
- numItems: how many items are in the queue
- initial values: rear = -1, front = 0, numItems=0;
- queueSize: the size of the array

IntQueue: a queue class

```
class IntQueue
{
private:
   int *queueArray;   // Points to the queue array
   int queueSize;     // The queue size
   int front;         // Subscript of the queue front
   int rear;          // Subscript of the queue rear
   int numItems;      // Number of items in the queue
public:
   // Constructor
   IntQueue(int);

   // Destructor
   ~IntQueue();

   // Queue operations
   void enqueue(int);
   int dequeue();
   bool isEmpty();
   bool isFull();
};
```


IntQueue: functions

```
//*******************************************************
// Creates an empty queue of a specified size.         *
//*******************************************************

IntQueue::IntQueue(int s)
{
   queueArray = new int[s];
   queueSize = s;
   front = 0;
   rear = -1;
   numItems = 0;
}

//*******************************************************
// Destructor                                           *
//*******************************************************

IntQueue::~IntQueue()
{
   delete [] queueArray;
}
```


IntQueue: enqueue

```
//*******************************************************
// Enqueue inserts a value at the rear of the queue.   *
//*******************************************************

void IntQueue::enqueue(int num)
{
   if (isFull())
      cout << "The queue is full.\n";
   else
   {
      // Calculate the new rear position
      rear = (rear + 1) % queueSize;
      // Insert new item
      queueArray[rear] = num;
      // Update item count
      numItems++;
   }
}
```


IntQueue: dequeue

```
//*******************************************************
// Dequeue removes the value at the front of the      *
// queue and copies it into num.                       *
//  If the queue is empty, outputs a message and       *
//  returns -1                                         *
//*******************************************************

int IntQueue::dequeue(int &num)
{
   int num = -1;
   if (isEmpty()) {
      cout << "The queue is empty.\n";
   }
   else {
      // Retrieve the front item
      num = queueArray[front];
      // Move front
      front = (front + 1) % queueSize;
      // Update item count
      numItems--;
   }
   return num;
}
```

IntQueue: test functions

```
//*******************************************************
// isEmpty returns true if the queue is empty,          *
// otherwise false.                                     *
//*******************************************************

bool IntQueue::isEmpty()
{
   return (numItems == 0);
}

//*******************************************************
// isFull returns true if the queue is full, otherwise *
// false.                                               *
//*******************************************************

bool IntQueue::isFull()
{
   return (numItems == queueSize);
}
```


IntQueue: driver

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

#include "IntQueue.h"

int main() {

   // set up the queue
   IntQueue q(50);
    int item;
    q.enqueue(2);
    q.enqueue(3);
    q.enqueue(5);
    item = q.dequeue();
    item = q.dequeue();
    q.enqueue(10);
    cout << item << endl;

}
```

What is output?

What is left on the queue when the driver is done?