CS-202

Dynamic Data Structures (Pt.4)

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Course Week

Course , Projects , Labs:

Monday	Tuesday	Wednesday	Thursday	Friday		Sunday
			Lab (8 Sections)			
	CLASS		CLASS			
PASS Session	PASS Session	**Project DEADLINE**	NEW Project	PASS Session		PASS Session

Your 8th Project Deadline is this Wednesday 4/17.

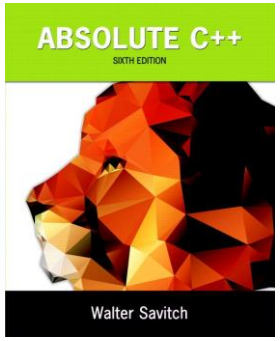
- PASS Sessions held Friday-Sunday-&-Monday-Tuesday, get all the help you need!
- 24-hrs delay after Project Deadline incurs 20% grade penalty.
- Past that, NO Project accepted. Better send what you have in time!

Today's Topics

Dynamic Data Structures

Stack(s)

- Array-based
- List-based
- Traversal
- Insertion
- Deletion
- Search



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Walter Savitch

What is a Stack?

- Data structure
  - that has homogeneous items of elements.
  - Elements are added and removed from the top of the stack
  - The last element to be added is the first to be removed
    LIFO: Last In, First Out

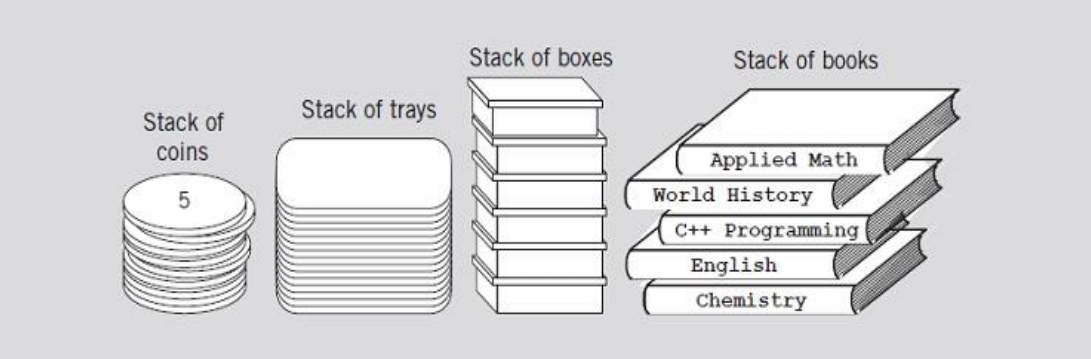
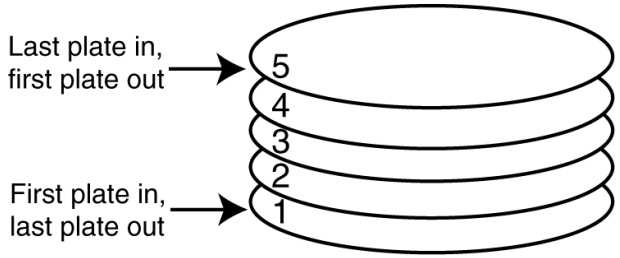
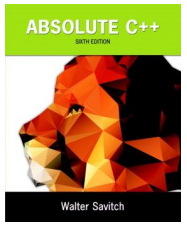


FIGURE 7-1 Various examples of stacks





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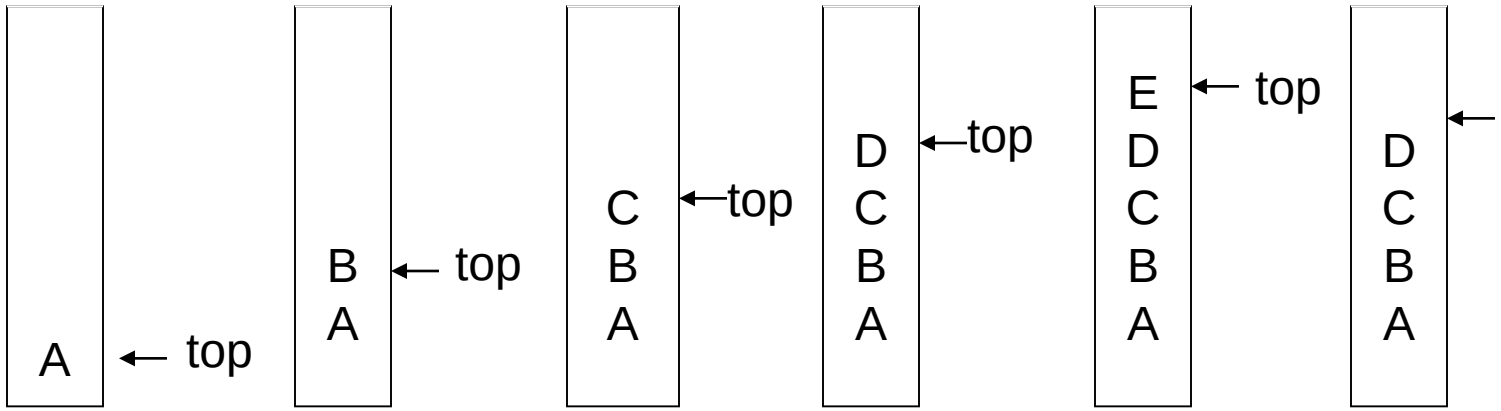
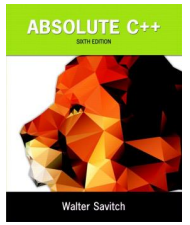
Last In First Out





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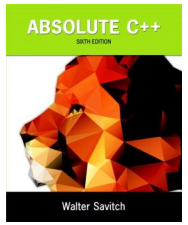
Stacks

- Some operations on a stack
  - `push` operation
    - Add element onto the stack
  - `top` operation
    - Retrieve top element of the stack
  - `pop` operation
    - Remove top element from the stack



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Stacks (cont'd.)

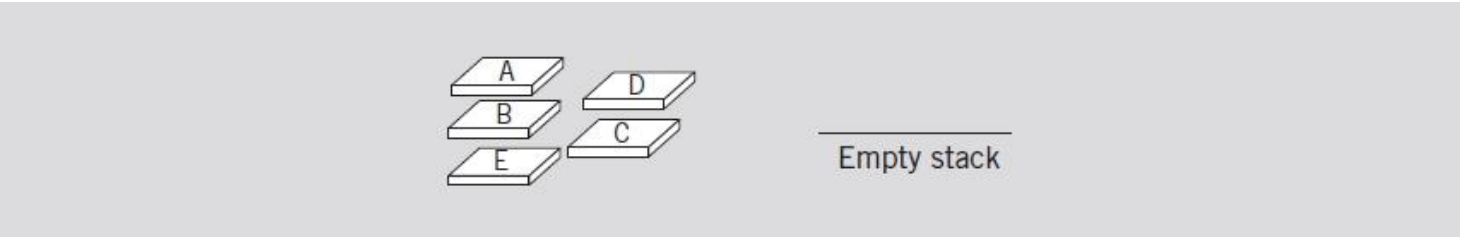


FIGURE 7-2 Empty stack

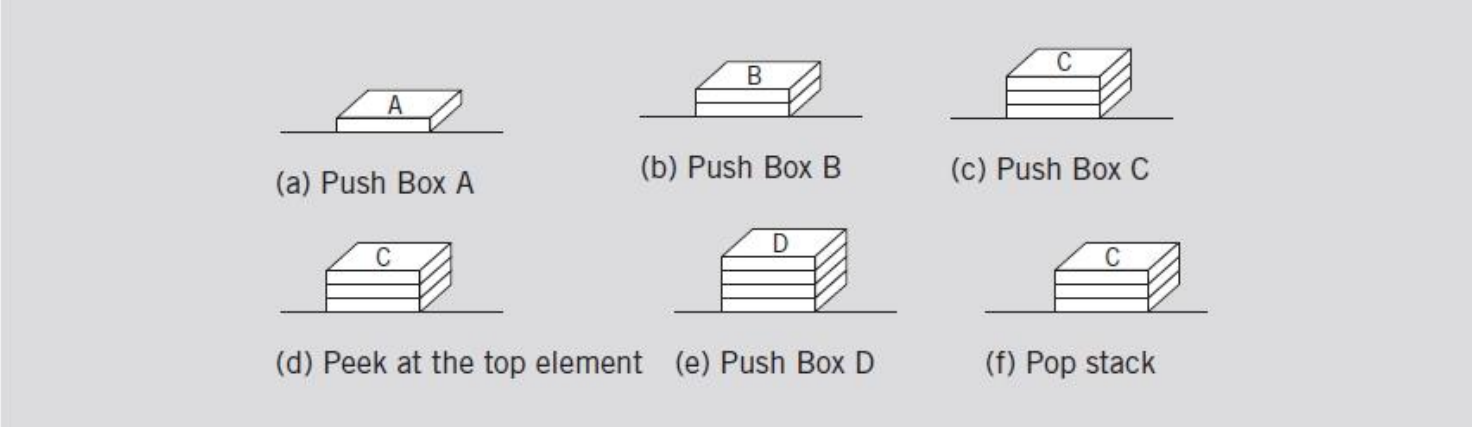
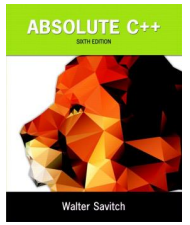
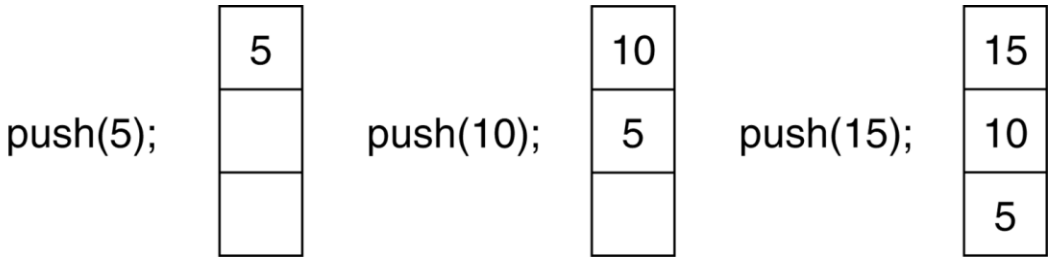


FIGURE 7-3 Stack operations

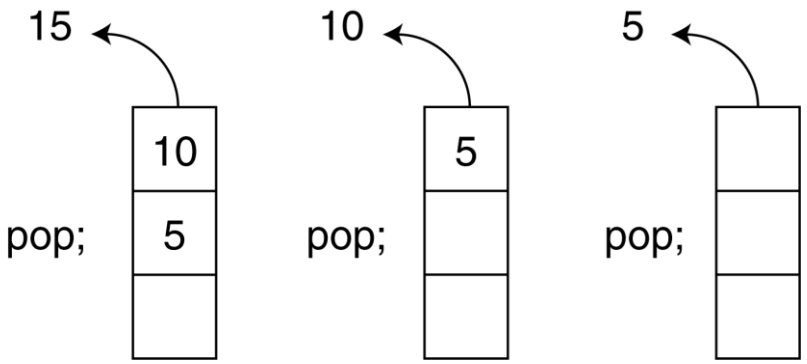


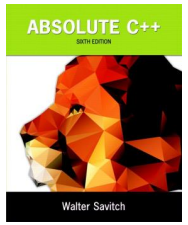
`Push` and `Pop` Example

The state of the stack after each of the `push` operations:



Now, suppose we execute three consecutive `pop` operations on the same stack:





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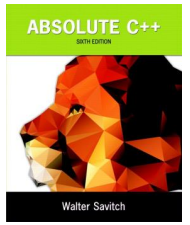
Stacks (cont'd.)

- Stack element removal
  - Occurs only if something is in the stack
- Stack element added only if room available
- `isFullStack` operation
  - Checks for full stack
- `isEmptyStack` operation
  - Checks for empty stack
- `initializeStack` operation
  - Initializes stack to an empty state



Stacks (cont'd.)

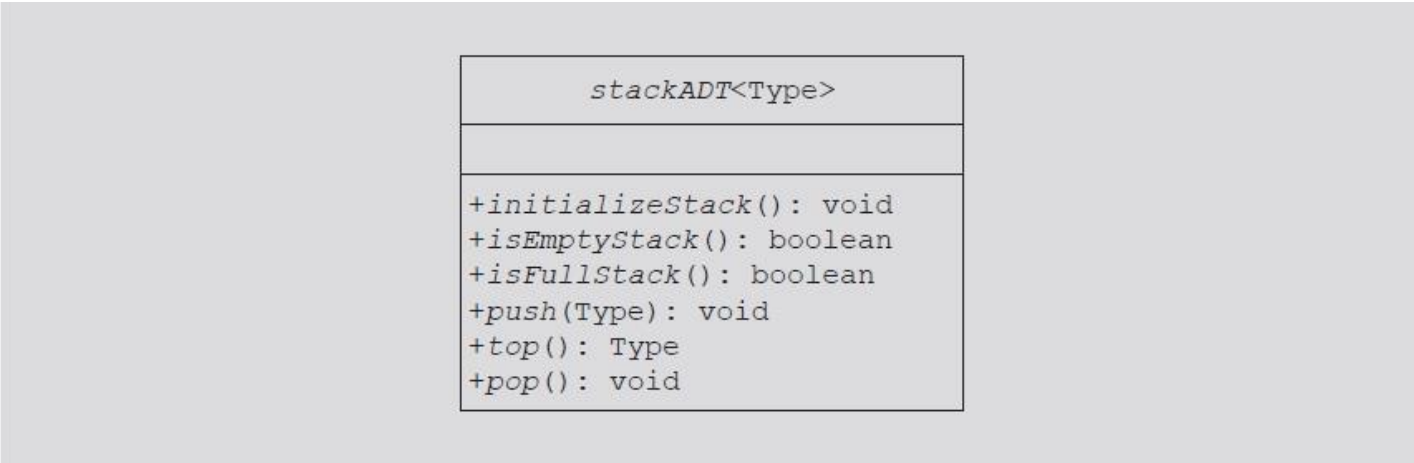
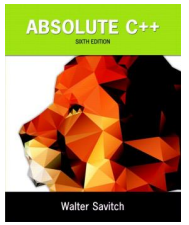


FIGURE 7-4 UML class diagram of the `class stackADT`



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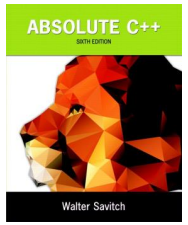
Static and Dynamic Stacks

- Static Stacks
  - Fixed size
  - Can be implemented with an array
- Dynamic Stacks
  - Grow in size as needed
  - Can be implemented with a linked list



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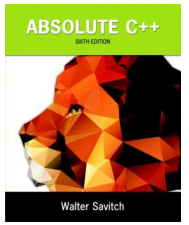
Implementation of Stacks as Arrays



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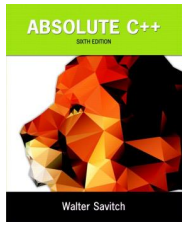
Implementation of Stacks as Arrays

- Advantages
  - best performance
- Disadvantage
  - fixed size
- Basic implementation
  - initially empty array
  - field to record where the next data gets placed into
  - if array is full, push() returns false
    - otherwise adds it into the correct spot
  - if array is empty, pop() returns null
    - otherwise removes the next item in the stack



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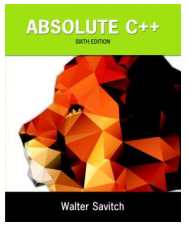
Implementation of Stacks as Arrays

- First stack element
  - Put in first array slot
- Second stack element
  - Put in second array slot, and so on
- Top of stack
  - Index of last element added to stack
- Stack element accessed only through the top
  - Problem: array is a random access data structure
  - Solution: use another variable (`stackTop`)
    - Keeps track of the top position of the array



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Implementation of Stacks as Arrays (cont'd.)

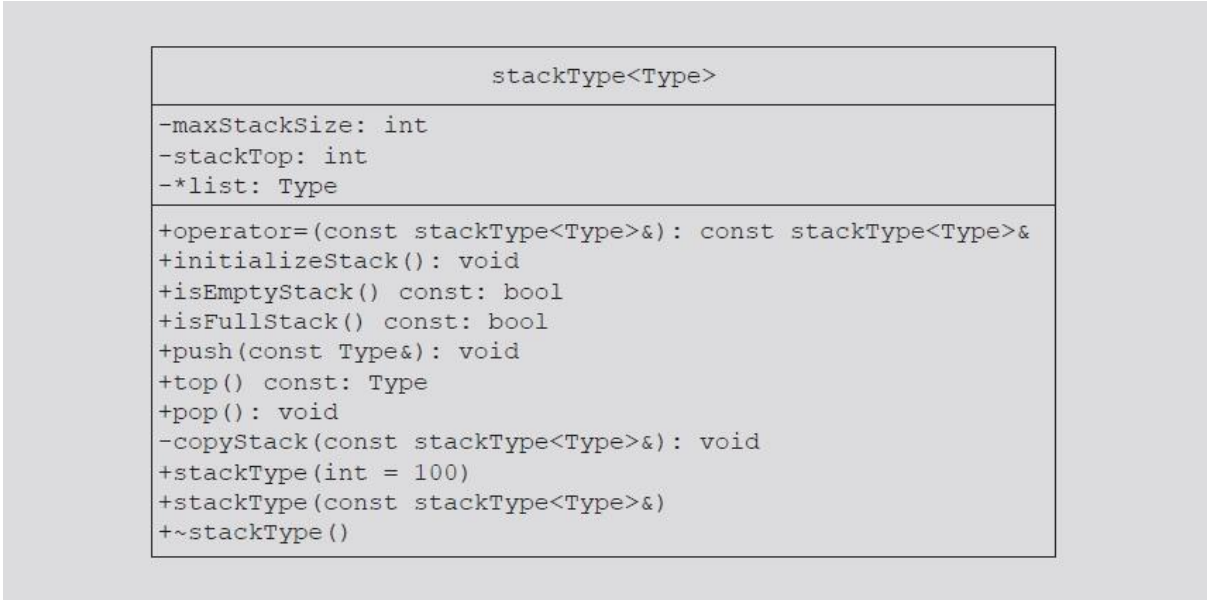
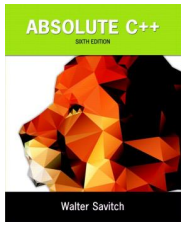


FIGURE 7-5 UML class diagram of the `class stackType`



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Implementation of Stacks as Arrays (cont'd.)

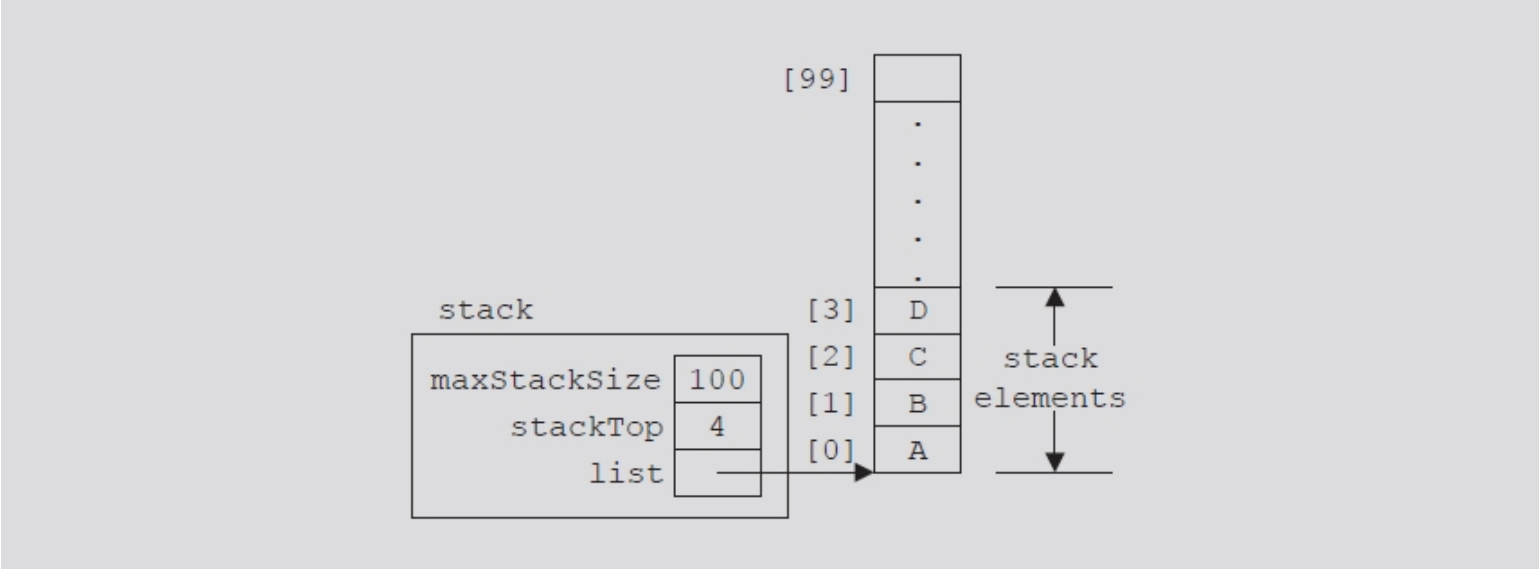
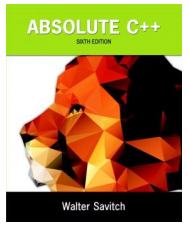


FIGURE 7-6 Example of a stack



Initialize Stack

- Value of `stackTop` if stack empty
  - Set `stackTop` to zero to initialize the stack
- Definition of function `initializeStack`

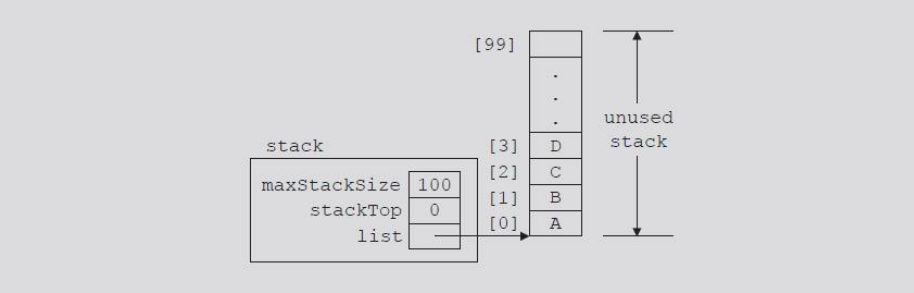
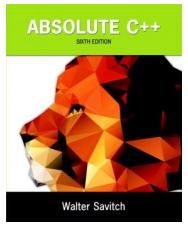


FIGURE 7-7 Empty stack

```
template <class Type>
void stackType<Type>::initializeStack()
{
    stackTop = 0;
}//end initializeStack
```



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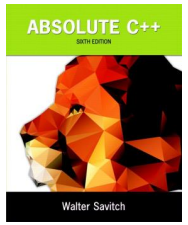
Empty Stack

- Value of `stackTop` indicates if stack empty
  - If `stackTop` = zero: stack empty
  - Otherwise: stack not empty
- Definition of function `isEmptyStack`

```
template <class Type>
bool stackType<Type>::isEmptyStack() const
{
    return(stackTop == 0);
}//end isEmptyStack
```



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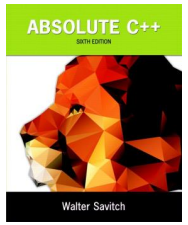
Full Stack

- Stack full
  - If `stackTop` is equal to `maxStackSize`
- Definition of function `isFullStack`

```
template <class Type>
bool stackType<Type>::isFullStack() const
{
    return(stackTop == maxStackSize);
} //end isFullStack
```



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Push

- Two-step process
  - Store `newItem` in array component indicated by `stackTop`
  - Increment `stackTop`

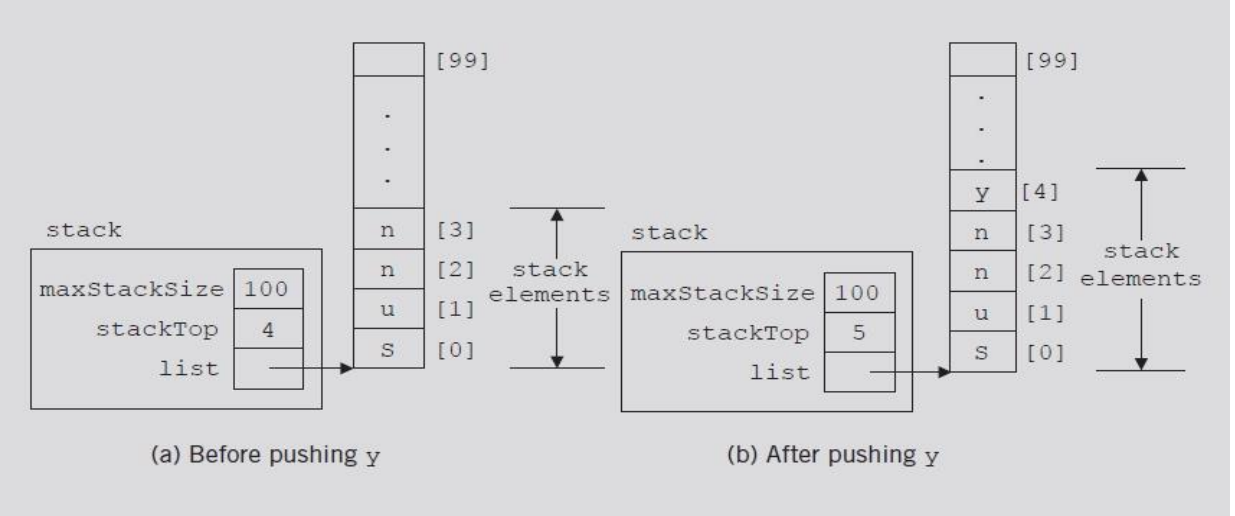
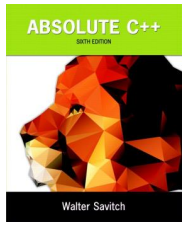


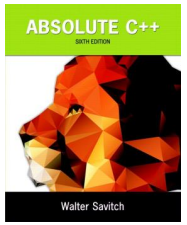
FIGURE 7-8 Stack before and after the `push` operation



Push (cont'd.)

- Definition of `push` operation

```
template <class Type>
void stackType<Type>::push(const Type& newItem)
{
    if (!isFullStack())
    {
        list[stackTop] = newItem;  //add newItem at the top
        stackTop++; //increment stackTop
    }
    else
        cout << "Cannot add to a full stack." << endl;
}//end push
```



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Pop

- Remove (pop) element from stack
  - Decrement `stackTop` by one

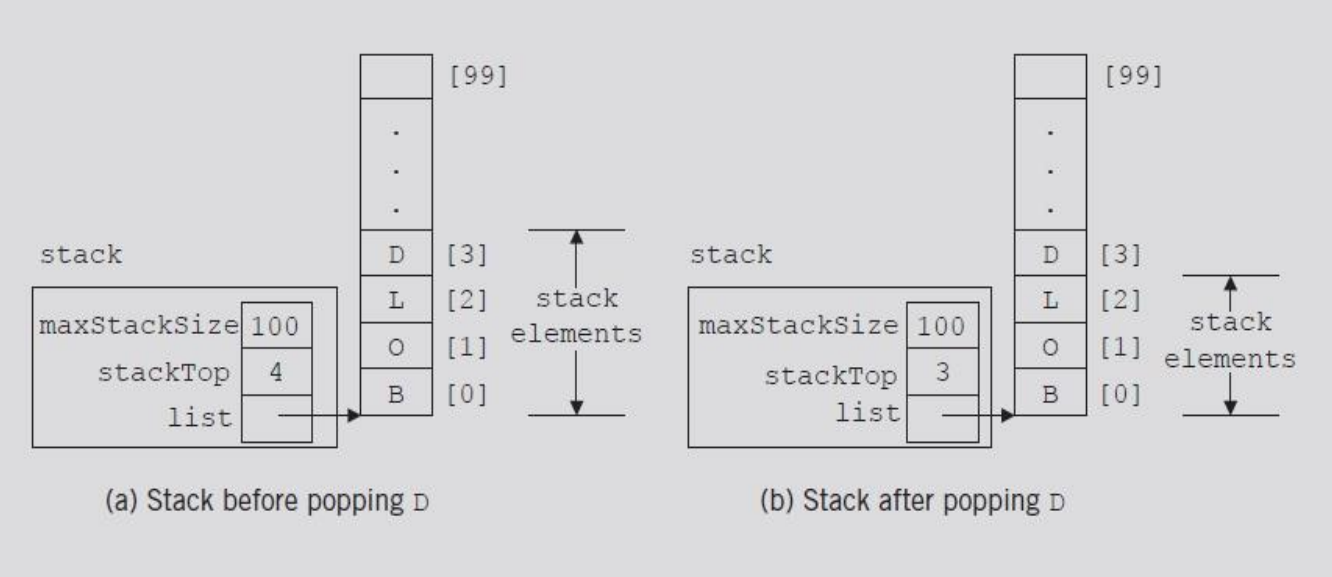
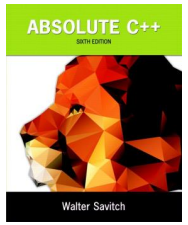


FIGURE 7-9 Stack before and after the `pop` operation



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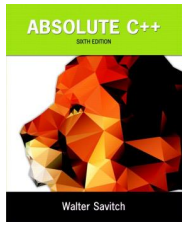
Pop (cont'd.)

- Definition of `pop` operation
- Underflow
  - Removing an item from an empty stack
    - Check within `pop` operation (see below)
    - Check before calling function `pop`

```
template <class Type>
void stackType<Type>::pop()
{
    if (!isEmptyStack())
        stackTop--;     //decrement stackTop
    else
        cout << "Cannot remove from an empty stack." << endl;
}//end pop
```



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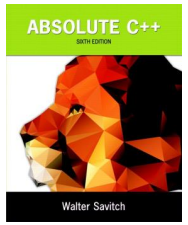
Copy Stack

- Definition of function `copyStack`

```
template <class Type>
void stackType<Type>::copyStack(const stackType<Type>& otherStack)
{
    delete [] list;
    maxStackSize = otherStack.maxStackSize;
    stackTop = otherStack.stackTop;
    list = new Type[maxStackSize];

        //copy otherStack into this stack
    for (int j = 0; j < stackTop; j++)
        list[j] = otherStack.list[j];
} //end copyStack
```



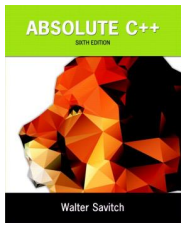
Constructor and Destructor

```
template <class Type>
stackType<Type>::stackType(int stackSize)
{
    if (stackSize <= 0)
    {
        cout << "Size of the array to hold the stack must "
             << "be positive." << endl;
        cout << "Creating an array of size 100." << endl;

        maxStackSize = 100;
    }
    else
        maxStackSize = stackSize;    //set the stack size to
                                     //the value specified by
                                     //the parameter stackSize

    stackTop = 0;                    //set stackTop to 0
    list = new Type[maxStackSize];   //create the array to
                                     //hold the stack elements
}//end constructor

template <class Type>
stackType<Type>::~stackType() //destructor
{
    delete [] list; //deallocate the memory occupied
                    //by the array
}//end destructor
```



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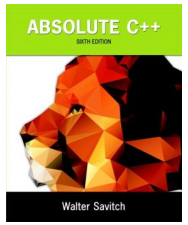
Copy Constructor

- Definition of the copy constructor

```
template <class Type>
stackType<Type>::stackType(const stackType<Type>& otherStack)
{
    list = NULL;

    copyStack(otherStack);
}//end copy constructor
```



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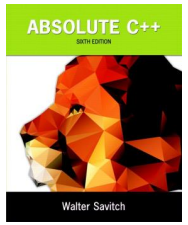
Overloading the Assignment Operator (=)

- Classes with pointer member variables
  - Assignment operator must be explicitly overloaded
- Function definition to overload assignment

```
template <class Type>
const stackType<Type>& stackType<Type>::operator=
                          (const stackType<Type>& otherStack)
{
    if (this != &otherStack) //avoid self-copy
        copyStack(otherStack);

    return *this;
} //end operator=
```



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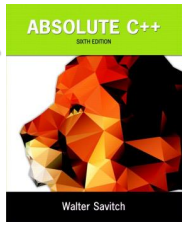
Stack Header File

- `myStack.h`
  - Header file name containing `class stackType` definition

```
//Header file: myStack.h

#ifndef H_StackType
#define H_StackType

#include <iostream>
#include <cassert>

#include "stackADT.h"

using namespace std;

//Place the definition of the class template stackType, as given
//previously in this chapter, here.

//Place the definitions of the member functions as discussed here.
#endif
```



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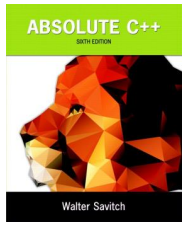
Implementation of Stacks as Linked List



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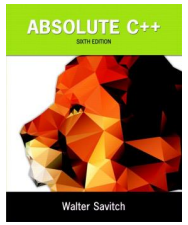
Linked Implementation of Stacks

- Disadvantage of array (linear) stack representation
  - Fixed number of elements can be pushed onto stack
- Solution
  - Use pointer variables to dynamically allocate, deallocate memory
  - Use linked list to dynamically organize data
- Value of `stackTop`: linear representation
  - Indicates number of elements in the stack
    - Gives index of the array
  - Value of `stackTop` – 1
    - Points to top item in the stack



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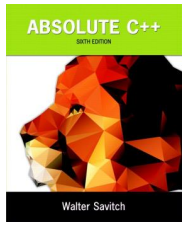
Implementing a Stack: Linked List

- Advantages:
  - always constant time to push or pop an element
  - can grow to an infinite size
- Disadvantages
  - the common case is the slowest of all the implementations
  - can grow to an infinite size
- Basic implementation
  - list is initially empty
  - *push()* method adds a new item to the head of the list
  - *pop()* method removes the head of the list



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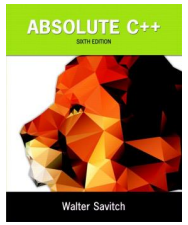
Linked Implementation of Stacks (cont'd.)

- Value of `stackTop`: linked representation
  - Locates top element in the stack
    - Gives address (memory location) of the top element of the stack



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Linked Implementation of Stacks (cont'd.)

- Example 7-2
  - Stack: object of type `linkedStackType`

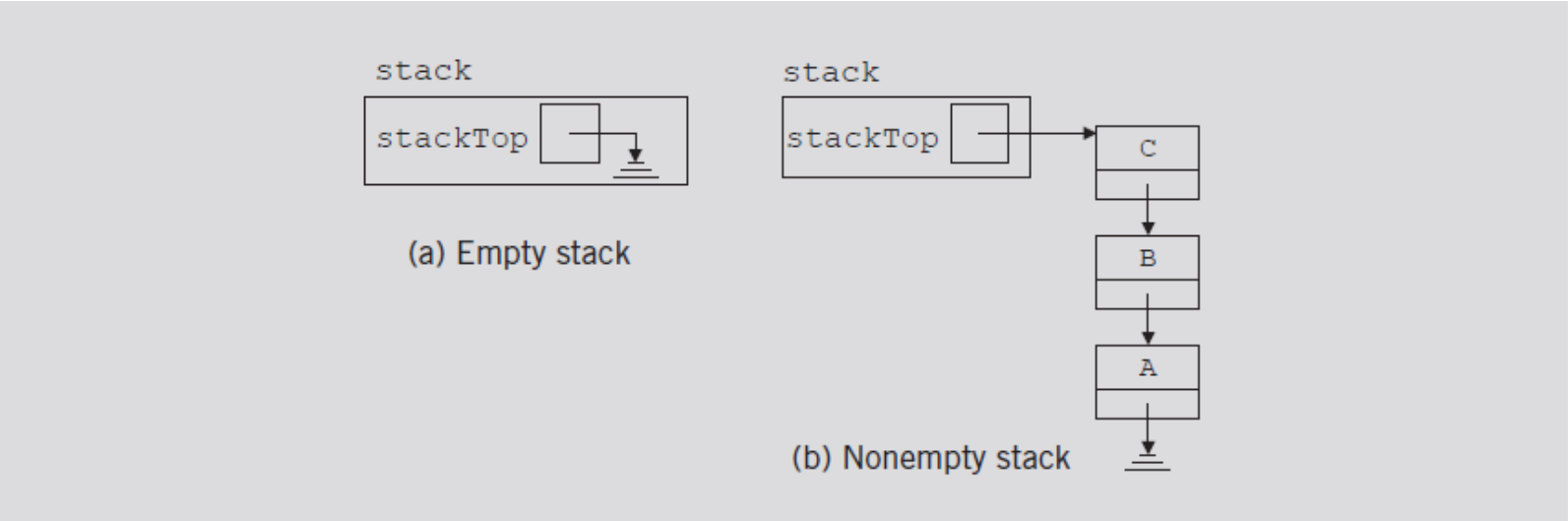
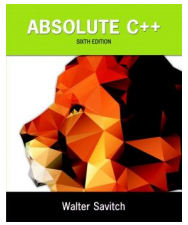


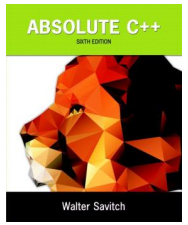
FIGURE 7-10 Empty and nonempty linked stacks



Default Constructor

- When stack object declared
  - Initializes stack to an empty state
  - Sets `stackTop` to `NULL`
- Definition of the default constructor

```
template  <class Type>
linkedStackType<Type>::linkedStackType()
{
    stackTop = NULL;
}
```



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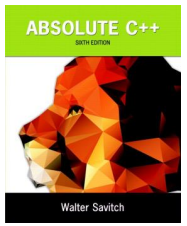
Empty Stack and Full Stack

- Stack empty if `stackTop` is `NULL`
- Stack never full
  - Element memory allocated/deallocated dynamically
  - F
    e
    \

```
template <class Type>
bool linkedStackType<Type>::isEmptyStack() const
{
    return(stackTop == NULL);
} //end isEmptyStack

template <class Type>
bool linkedStackType<Type>::isFullStack() const
{
    return false;
} //end isFullStack
```



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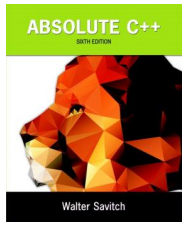
Initialize Stack

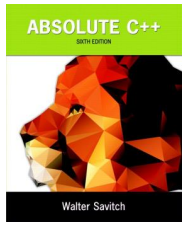
- Reinitializes stack to an empty state
- Because stack might contain elements and you are using a linked implementation of a stack
  - Must deallocate memory occupied by the stack elements, set `stackTop` to `NULL`
- Definition of the `initializeStack` function



Initialize Stack (cont'd.)

```
template <class Type>
void linkedStackType<Type>:: initializeStack()
{
    nodeType<Type> *temp; //pointer to delete the node

    while (stackTop != NULL)   //while there are elements in
                               //the stack
    {
        temp = stackTop;     //set temp to point to the
                             //current node
        stackTop = stackTop->link;  //advance stackTop to the
                                    //next node
        delete temp;     //deallocate memory occupied by temp
    }
} //end initializeStack
```



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Push

- `newElement` added at the beginning of the linked list pointed to by `stackTop`
- Value of pointer `stackTop` updated

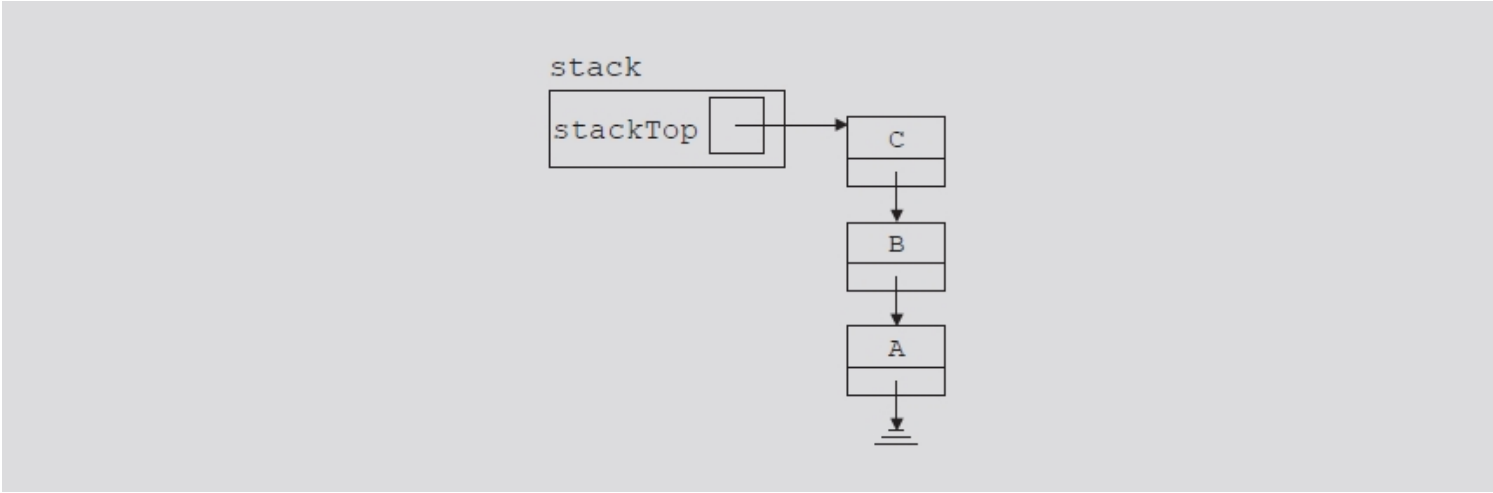
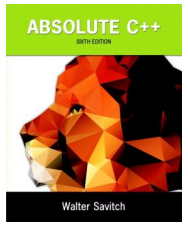


FIGURE 7-11 Stack before the `push` operation



Push (cont'd.)

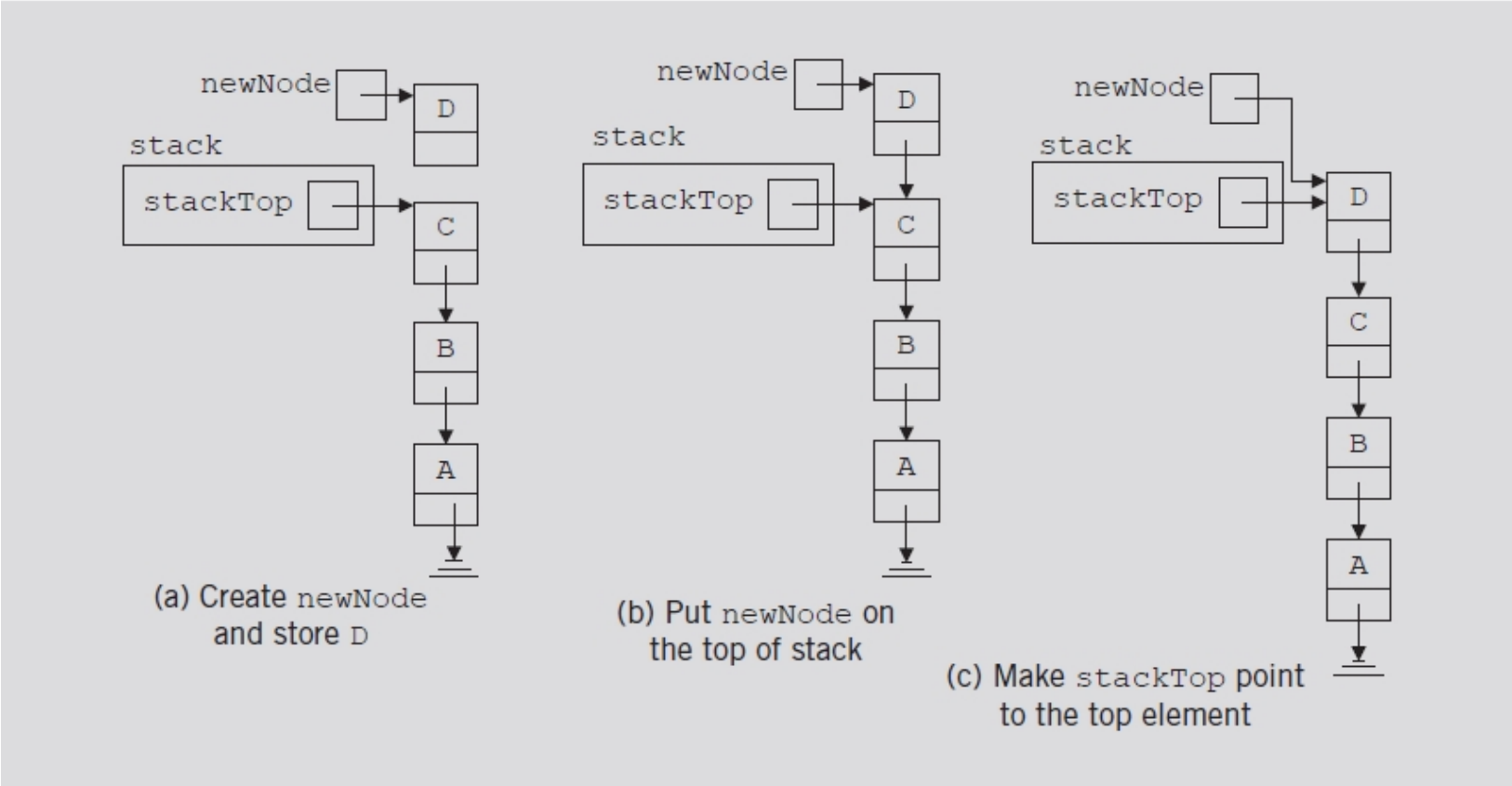
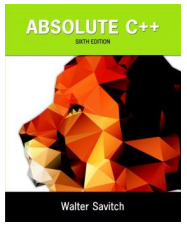


FIGURE 7-12 `Push` operation



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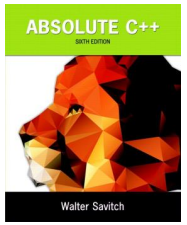
Push (cont'd.)

- Definition of the `push` function

```
template <class Type>
void linkedStackType<Type>::push(const Type& newElement)
{
    nodeType<Type> *newNode;  //pointer to create the new node

    newNode = new nodeType<Type>; //create the node

    newNode->info = newElement; //store newElement in the node
    newNode->link = stackTop; //insert newNode before stackTop
    stackTop = newNode;       //set stackTop to point to the
                              //top node
} //end push
```



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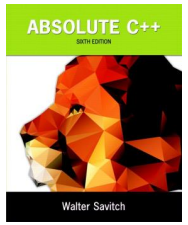
Return the Top Element

- Returns information of the node to which `stackTop` pointing
- Definition of the `top` function

```
template <class Type>
Type linkedStackType<Type>::top() const
{
    assert(stackTop != NULL); //if stack is empty,
                              //terminate the program
    return stackTop->info;    //return the top element
}//end top
```



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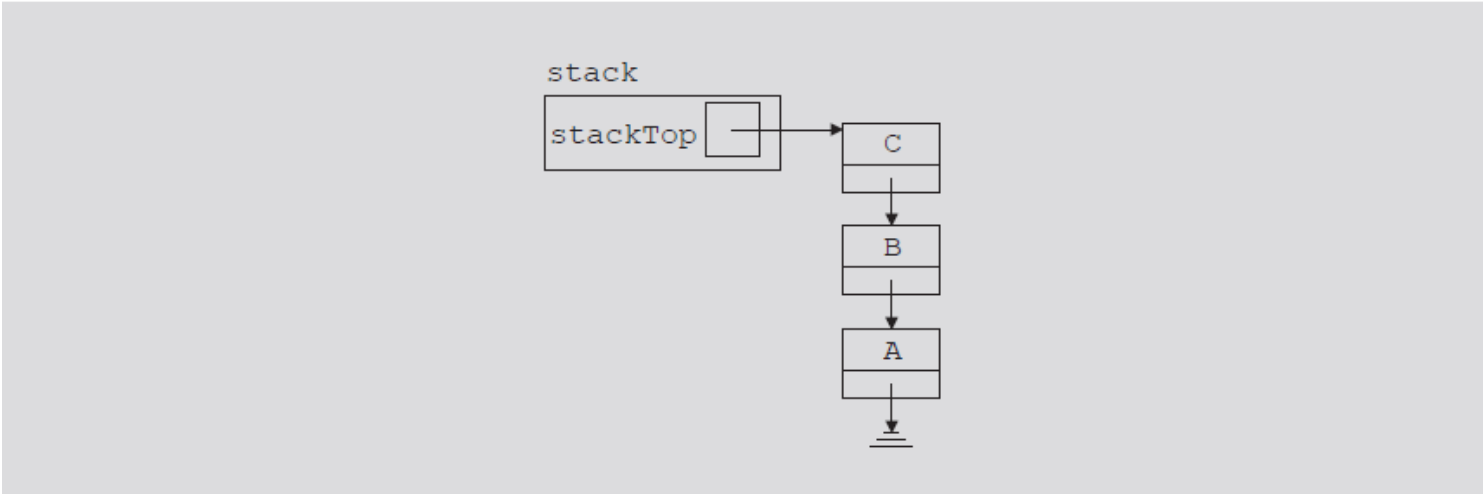
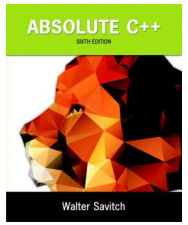
Pop

- Removes top element of the stack
  - Node pointed to by `stackTop` removed
  - Value of pointer `stackTop` updated





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Pop (cont'd.)

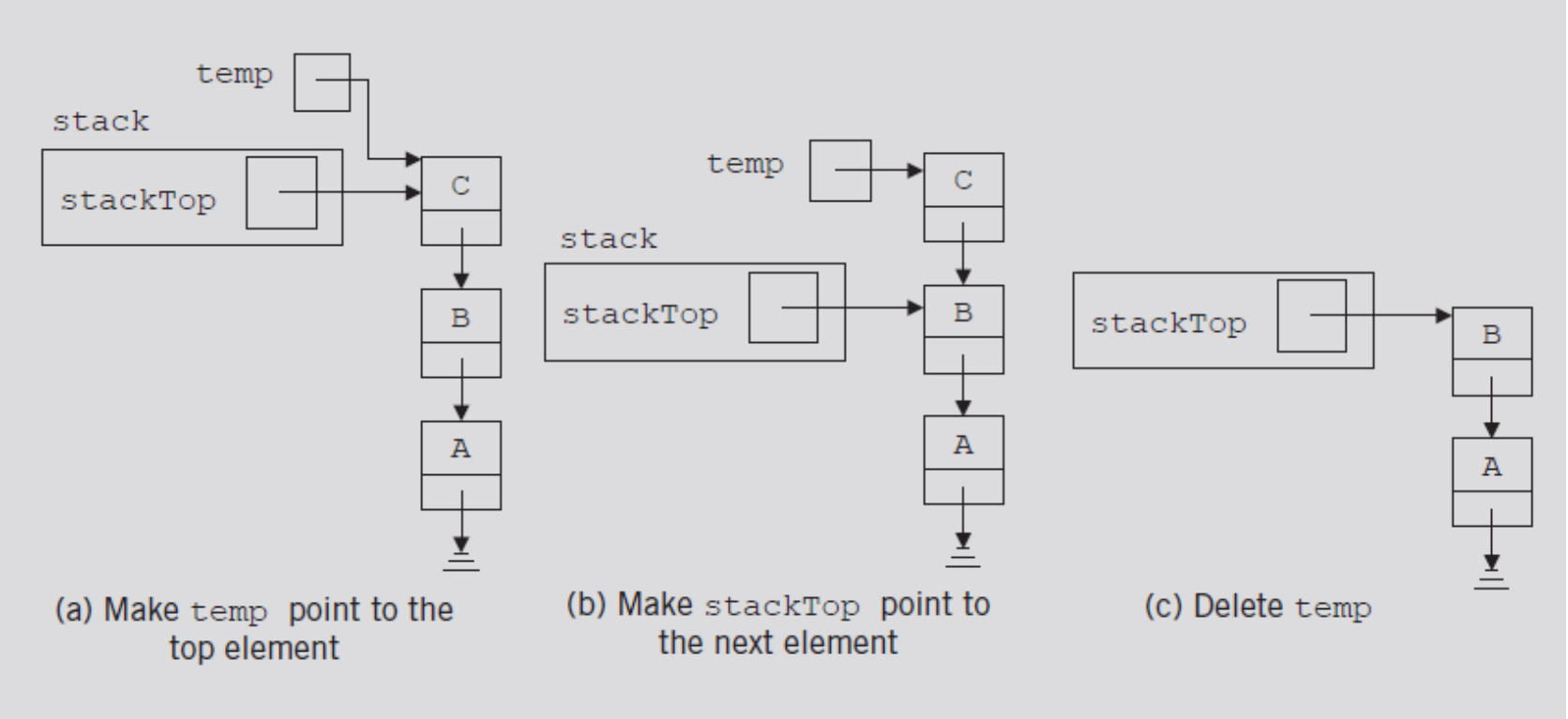
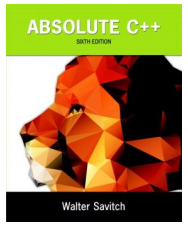


FIGURE 7-14 `Pop` operation



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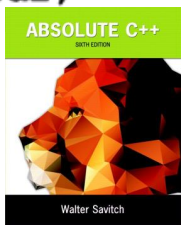
Pop (cont'd.)

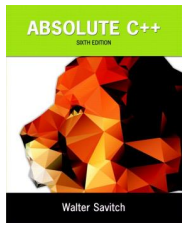
- Definition of the `pop` function

```
template <class Type>
void linkedStackType<Type>::pop()
{
    nodeType<Type> *temp;    //pointer to deallocate memory

    if (stackTop != NULL)
    {
        temp = stackTop;  //set temp to point to the top node

        stackTop = stackTop->link;  //advance stackTop to the
                                    //next node
        delete temp;    //delete the top node
    }
    else
        cout << "Cannot remove from an empty stack." << endl;
}//end pop
```



Copy Stack

- Makes an identical copy of a stack
- Definition similar to the definition of copyList for linked lists
- Definition of the `copyStack` function



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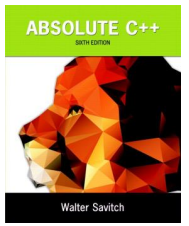
```
template  <class Type>
void linkedStackType<Type>::copyStack
                     (const linkedStackType<Type>& otherStack)
{
    nodeType<Type> *newNode, *current, *last;

    if (stackTop != NULL) //if stack is nonempty, make it empty
        initializeStack();

    if (otherStack.stackTop == NULL)
        stackTop = NULL;
    else
    {
        current = otherStack.stackTop;  //set current to point
                                        //to the stack to be copied

            //copy the stackTop element of the stack
        stackTop = new nodeType<Type>;  //create the node

        stackTop->info = current->info; //copy the info
        stackTop->link = NULL;  //set the link field to NULL
        last = stackTop;        //set last to point to the node
        current = current->link; //set current to point to the
                                 //next node
            //copy the remaining stack
        while (current != NULL)
        {
            newNode = new nodeType<Type>;

            newNode->info = current->info;
            newNode->link = NULL;
            last->link = newNode;
            last = newNode;
            current = current->link;
        }//end while
    }//end else
} //end copyStack
```



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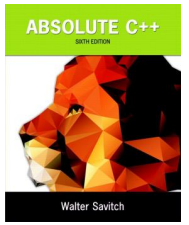
Constructors and Destructors

- Definition of the functions to implement the copy constructor and the destructor

```
    //copy constructor
template <class Type>
linkedStackType<Type>::linkedStackType(
                       const linkedStackType<Type>& otherStack)
{
    stackTop = NULL;
    copyStack(otherStack);
}//end copy constructor

    //destructor
template  <class Type>
linkedStackType<Type>::~linkedStackType()
{
    initializeStack();
}//end destructor
```

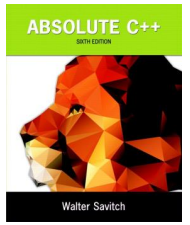


Overloading the Assignment Operator (=)

- Definition of the functions to overload the assignment operator

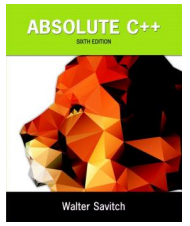
```
template <class Type>
const linkedStackType<Type>& linkedStackType<Type>::operator=
                        (const linkedStackType<Type>& otherStack)
{
    if (this != &otherStack) //avoid self-copy
        copyStack(otherStack);

    return *this;
}//end operator=
```



Stack Applications

- Stacks are a very common data structure
  - compilers
    - parsing data between delimiters (brackets)
  - operating systems
    - program stack
  - virtual machines
    - manipulating numbers
      - pop 2 numbers off stack, do work (such as add)
      - push result back on stack and repeat
  - artificial intelligence
    - finding a path



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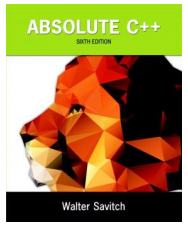
Application of Stacks: Postfix Expressions Calculator

- Arithmetic notations
  - Infix notation: operator between operands
  - Prefix (Polish) notation: operator precedes operands
  - Reverse Polish notation: operator follows operands
- Stack use in compilers
  - Translate infix expressions into some form of postfix notation
  - Translate postfix expression into machine code



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Application of Stacks: Postfix Expressions Calculator (cont'd.)

- Postfix expression: 6 3 + 2 * =

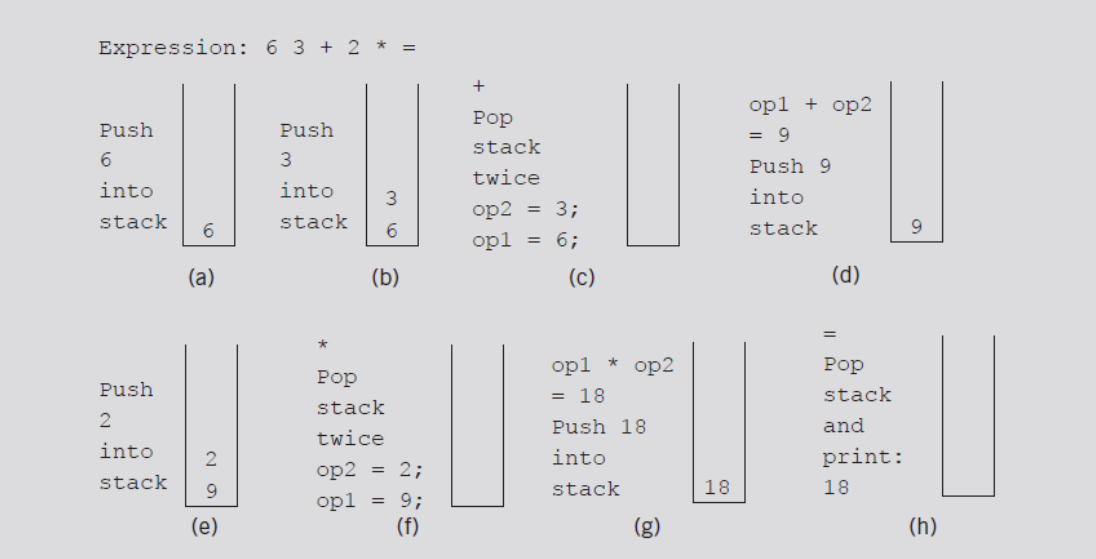
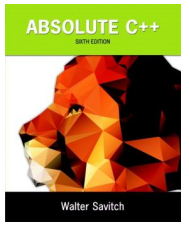


FIGURE 7-15 Evaluating the postfix expression: 6 3 + 2 * =



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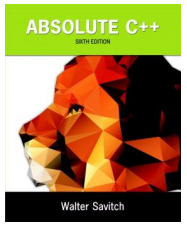
Application of Stacks: Postfix Expressions Calculator (cont'd.)

- Main algorithm pseudocode
  - Broken into four functions for simplicity
    - Function `evaluateExpression`
    - Function `evaluateOpr`
    - Function `discardExp`
    - Function `printResult`

```
Read the first character
while not the end of input data
{
    a. initialize the stack
    b. process the expression
    c. output result
    d. get the next expression
}
```



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Algorithm to Print a Linked List Backward

- Stack
  - Print a linked list backward
- Use linked implementation of stack

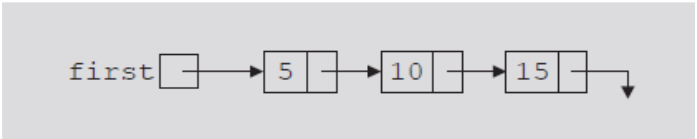
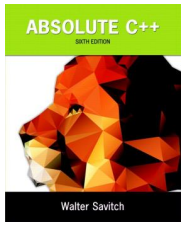


FIGURE 7-16 Linked list

```
current = first;                    //Line 1

while (current != NULL)             //Line 2
{                                   //Line 3
    stack.push(current);            //Line 4
    current = current->link;        //Line 5
}                                   //Line 6
```



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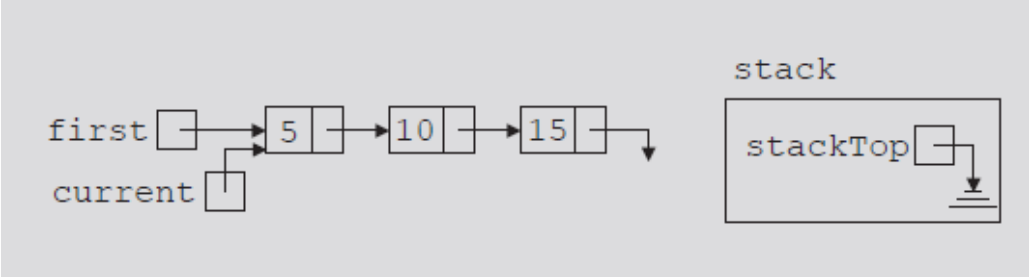


FIGURE 7-17 List after the statement `current = first;` executes

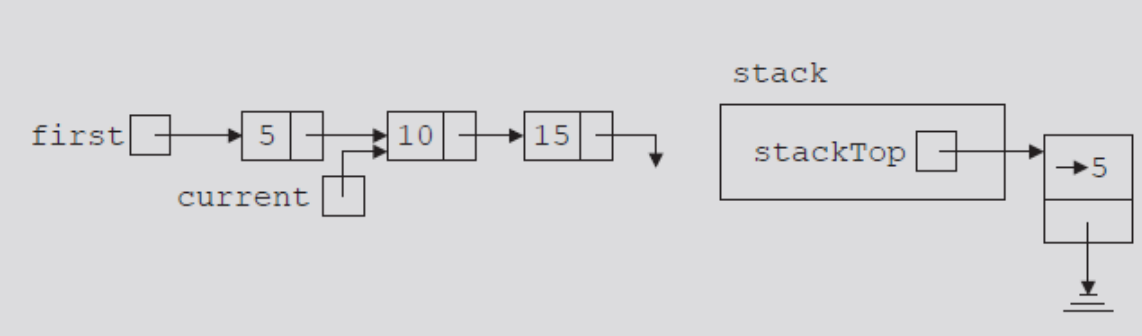
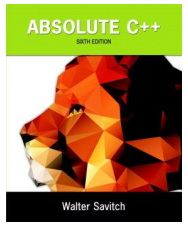


FIGURE 7-18 List and stack after the statements `stack.push(current);` and `current = current->link;` execute



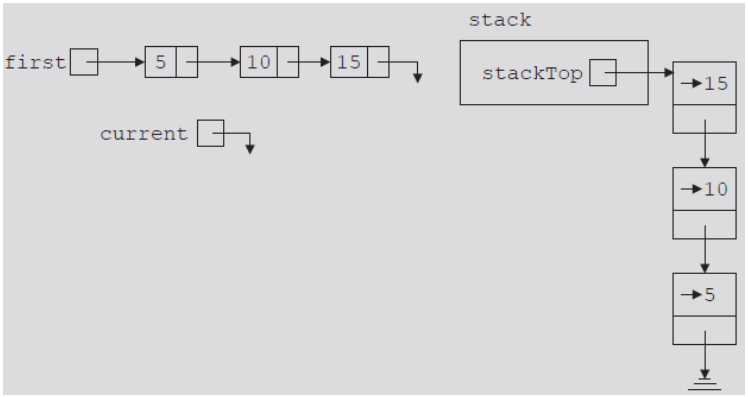


FIGURE 7-19 List and stack after the `while` statement executes

```
while (!stack.isEmptyStack())          //Line 7
{                                      //Line 8
    current = stack.top();             //Line 9
    stack.pop();                       //Line 10
    cout << current->info << " ";      //Line 11
}                                      //Line 12
```

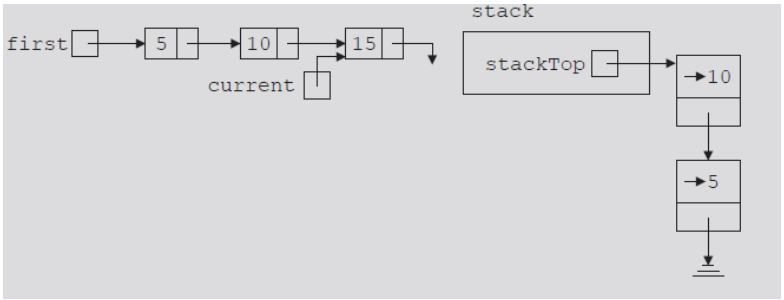
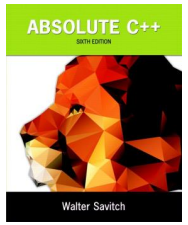


FIGURE 7-20 List and stack after the statements `current = stack.top(); and stack.pop();` execute



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Checking for Balanced Braces

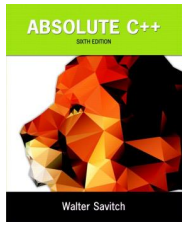
- Example of curly braces in C++ language
  - Balanced

```
abc{defg{ijk}{l{mn}}op}qr
```

  - Not balanced

```
abc{def}}{ghij{kl}m
```

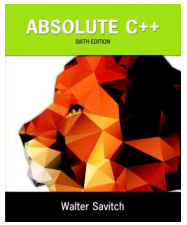
- Requirements for balanced braces
  - For each **}**, must match an already encountered **{**
  - At end of string, must have matched each **{**



Checking for Balanced Braces

- Initial draft of a solution.

```
for (each character in the string)
{
    if (the character is a '{')
        aStack.push('{')
    else if (the character is a '}')
        aStack.pop()
}
```

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Checking for Balanced Braces

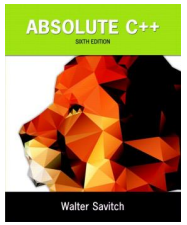
- Detailed pseudocode solution.

```
// Checks the string aString to verify that braces match.
// Returns true if aString contains matching braces, false otherwise.
checkBraces(aString: string): boolean
{
   aStack = a new empty stack
   balancedSoFar = true
   i = 0                          // Tracks character position in string

   while (balancedSoFar and i < length of aString)
   {
      ch = character at position i in aString
      i++

      // Push an open brace
      if (ch is a '{')
         aStack.push('{')

      // Close brace
      else if (ch is a '}')
      {
```

Modified Slides from:

Absolute C++ 6th Edition

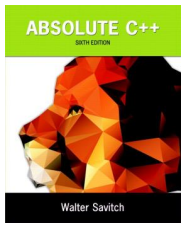
Walter Savitch

Checking for Balanced Braces

- Detailed pseudocode solution.

```
        // Close brace
        else if (ch is a '}')
        {
            if (!aStack.isEmpty())
                aStack.pop()    // Pop a matching open brace
            else                // No matching open brace
                balancedSoFar = false
        }
        // Ignore all characters other than braces
    }

    if (balancedSoFar and aStack.isEmpty())
        aString has balanced braces
    else
        aString does not have balanced braces
}
```

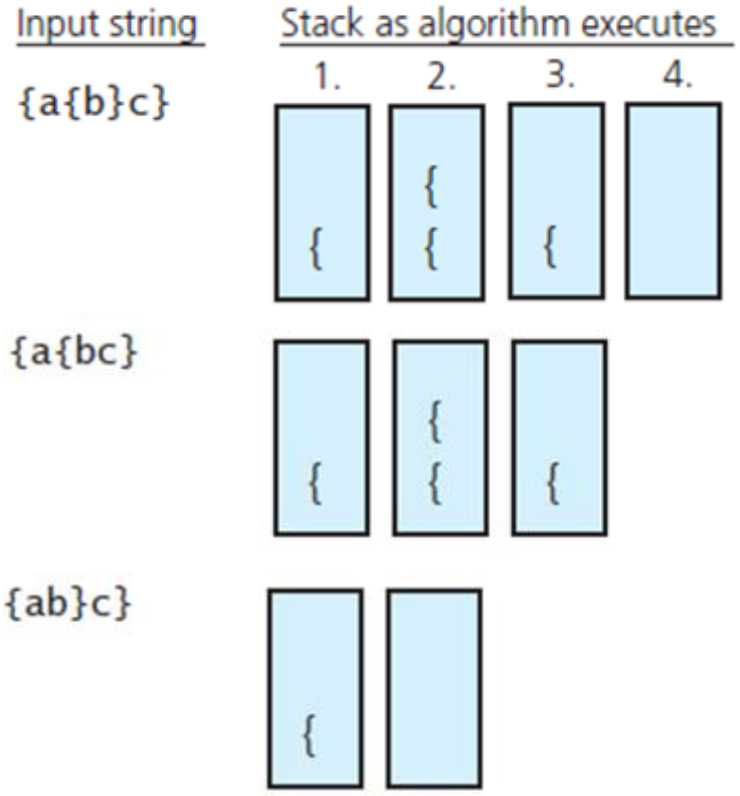
Modified Slides from:

Absolute C++ 6th Edition

Walter Savitch

Checking for Balanced Braces

- Traces of algorithm that checks for balanced braces



1. push {
2. push {
3. pop
4. pop

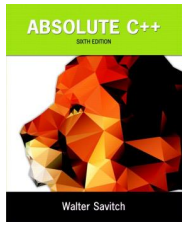
stack empty -> balanced

1. push {
2. push {
3. pop

Stack not empty $\Longrightarrow$ not balanced

1. push {
2. pop

Stack empty when "}" encountered $\Longrightarrow$ not balanced



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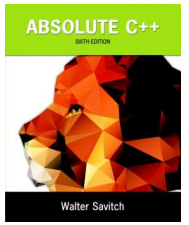
Summary

- Stack
  - Last In First Out (LIFO) data structure
  - Implemented as array or linked list
  - Arrays: limited number of elements
  - Linked lists: allow dynamic element addition



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Application(s)

Queue Applications

A "Palindrome"

- A string of characters that reads the same from left to right as its does from right to left.

  "Nipson anomemata me monan opsin"

  "ΝΙΨΟΝ ΑΝΟΜΗΜΑΤΑ ΜΗ ΜΟΝΑΝ ΟΨΙΝ"

Church of St. Mary of Blachernae

To recognize a palindrome, a Queue can be used in conjunction with a Stack.

- A Stack reverses the order of occurrences.
- A Queue preserves the order of occurrences.

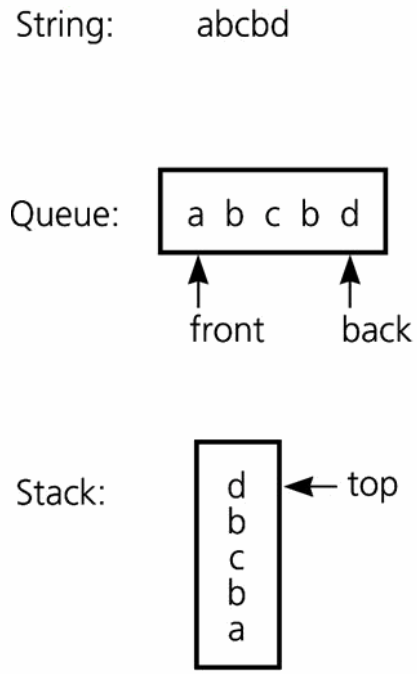
Queue Applications

Recognizing a "Palindrome" – example:

- A non-recursive recognition algorithm for palindromes.

As we traverse the character string from left to right:

- Insert each character into both a queue and a stack.
- Compare the characters at the front of the queue and the top of the stack.



Summary

Position-oriented ADTs

Position-oriented ADTs include:

- The List
- The Stack
- The Queue

Stacks and Queues

- Only the end positions/entries can be accessed.

Lists

- All positions/entries can be accessed.

Summary

Position-oriented ADTs

Operations of stacks and queues can be paired off as:

- **`createStack`** and **`createQueue`**.
- Stack **`empty`** and Queue **`empty`**.
- **`push`** and **`enqueue`**.
- **`pop`** and **`dequeue`**.
- Stack **`top`** and Queue **`front`**.

ADT List operations generalize Stack and Queue operations:

- **`size`** .
- **`insert`** .
- **`remove`** .
- **`retrieve`** .

Preliminary Discussion

Data Structures – a *Cheatsheet*

Literally just scratched the surface:

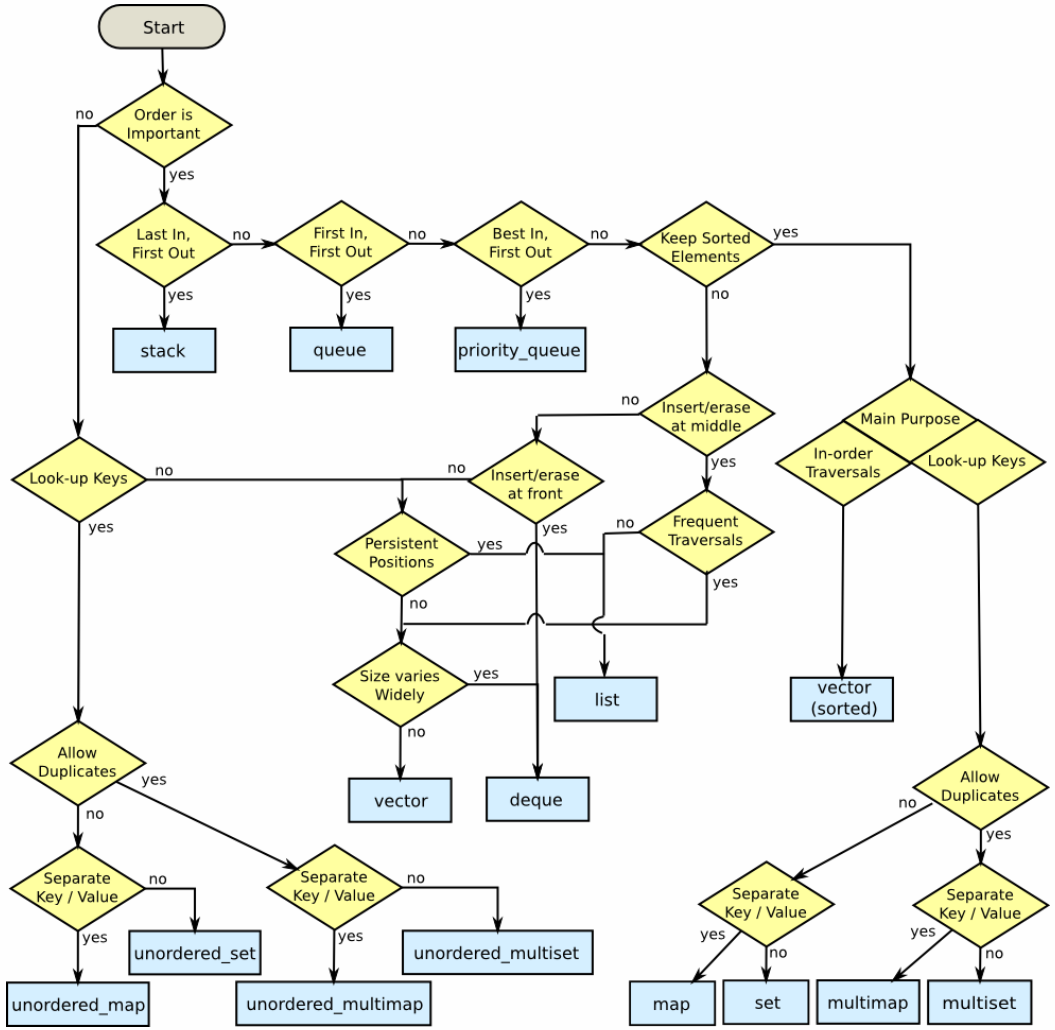
- Array
- Stack
- Queue

  Not even Priority Queue yet …
- List

  Usually Doubly-Linked List

  But a Forward-List also exists

Many more …



CS-202

Time for Questions !