COMP 2012H Honors Object-Oriented Programming and Data Structures

Topic 15: Stack & Queue

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Data Structures

- Computer science is the study of how to process information (data) efficiently using computers.
- A data structure helps store, organize, and manipulate data in a particular way so that they can be processed efficiently by computers.
- Different applications require different data structures.
- Examples: array, linked list, stack, queue, (binary) tree, etc.
- An abstract data type (ADT) is the mathematical model of a data structure that is independent of its implementation. It may be used to analyze the efficiency of algorithms.

Stack and Queue

Stack and queue let you insert and remove items at the ends only, not in the middle.

Part I

Stack

Stack: How it Works

Consider a pile of cookies.

- more cookies: new cookies are added on top, one at a time.
- fewer cookies: cookies are consumed one at a time, starting at the top.

As an ADT, insertions and removals of items on a stack are based on the *last-in first-out (LIFO)* policy.

It supports:

- Data: an ordered list of data/items.
- Operations (major ones):

top : get the value of the top item
push : add a new item to the top
pop : remove an item from the top

Stack of int Data — stack.h

```
#include <iostream>     /* File: int-stack.h */
#include <cstdlib>
using namespace std;
const int BUFFER_SIZE = 5;

class int_stack
{
  private:
    int data[BUFFER_SIZE];  // Use an array to store data
    int top_index;          // Starts from 0; -1 when empty

  public:
    // CONSTRUCTOR member functions
    int_stack();            // Default constructor

    // ACCESSOR member functions: const => won't modify data members
    bool empty() const;     // Check if the stack is empty
    bool full() const;      // Check if the stack is full
    int size() const;       // Give the number of data currently stored
    int top() const;        // Retrieve the value of the top item

    // MUTATOR member functions
    void push(int);         // Add a new item to the top of the stack
    void pop();             // Remove the top item from the stack
};
```

Stack of int Data — Test Program

```
#include "int-stack.h" /* File: int-stack-test.cpp */

void print_stack_info(const int_stack& s)
{
    cout << "No. of data currently on the stack = " << s.size() << "\t";
    if (!s.empty())
        cout << "Top item = " << s.top();
    cout << endl << "Empty: " << boolalpha << s.empty()
         << "\t\t" << "Full: " << boolalpha << s.full() << endl << endl;
}

int main()
{
    int_stack a; print_stack_info(a);
    a.push(4);   print_stack_info(a);
    a.push(15);  print_stack_info(a);
    a.push(26);  print_stack_info(a);
    a.push(37);  print_stack_info(a);
    a.pop();     print_stack_info(a);
    a.push(48);  print_stack_info(a);
    a.push(59);  print_stack_info(a);

    return 0;
} /* compile: g++ -L. -o int-stack-test int-stack-test.cpp -lintstack */
```

Example: Decimal to Binary Conversion — Illustration

- e.g., $26_{(10)} = 11010_{(2)}$
- Algorithm to convert $N_{(10)} = M_{(2)}$:

Step 1 : divide N by 2 successively

Step 2 : each time push the remainder onto a stack

Step 3 : print the answer by popping the stack successively

2	26		
2	13	...	0
2	6	...	1
2	3	...	0
2	1	...	1
	0	...	1

Example: Decimal to Binary Conversion

```
#include "int-stack/int-stack.h" /* File: decimal2binary.cpp */

int main()  // Convert +ve decimal number to binary number using an stack
{
    int_stack a;
    int x, number;

    while (cin >> number)
    {   // Conversion: decimal to binary
        for (x = number; x > 0; x /= 2)
            a.push(x % 2);

        // Print a binary that is stored on a stack
        cout << number << "(base 10) = ";
        while (!a.empty())
        {
            cout << a.top();
            a.pop();
        }
        cout << "(base 2)" << endl;
    }

    return 0;
} // Compile: g++ -o decimal2binary -Lint-stack decimal2binary.cpp -lintstack
```

Stack of int Data — Constructors, Assessors

```
#include "int-stack.h"  /* File: int-stack1.cpp */

          /***** Default CONSTRUCTOR member function *****/
int_stack::int_stack() { top_index = -1; } // Create an empty stack

          /***** ACCESSOR member functions *****/
// Check if the int_stack is empty
bool int_stack::empty() const { return (top_index == -1); }

// Check if the int_stack is full
bool int_stack::full() const { return (top_index == BUFFER_SIZE-1); }

// Give the number of data currently stored
int int_stack::size() const { return top_index + 1; }

// Retrieve the value of the top item
int int_stack::top() const
{
    if (!empty())
        return data[top_index];

    cerr << "Warning: Stack is empty; can't retrieve any data!" << endl;
    exit(-1);
}
```

Stack of int Data — Mutators

```
#include "int-stack.h"  /* File: int-stack2.cpp */

        /***** MUTATOR member functions *****/
void int_stack::push(int x) // Add a new item to the top of the stack
{
    if (!full())
        data[++top_index] = x;
    else
    {
        cerr << "Error: Stack is full; can't add (" << x << ")!" << endl;
        exit(-1);
    }
}

void int_stack::pop()       // Remove the top item from the stack
{
    if (!empty())
        --top_index;
    else
    {
        cerr << "Error: Stack is empty; can't remove any data!" << endl;
        exit(-1);
    }
}
```

Part II

Queue

Queue: How it Works

Consider the case when people line up for tickets.

- more people: new customers join the back of a queue, one at a time.
- fewer people: the customer at the front buys a ticket and leaves the queue.

As an ADT, insertions and removals of items on a queue are based on a *first-in first-out (FIFO)* policy.

It supports:

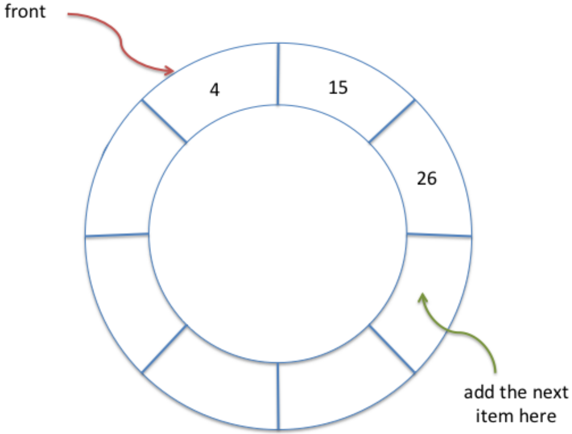
- Data: an ordered list of data/items.
- Operations (major ones):

front : get the value of the front item

enqueue : add a new item to the back

dequeue : remove an item from the front

Circular Queue of int Data — Illustration



Circular Queue of int Data — queue.h

```
#include <iostream>      /* File: int-queue.h */
#include <cstdlib>
using namespace std;
const int BUFFER_SIZE = 5;

class int_queue // Circular queue
{
  private:
    int data[BUFFER_SIZE]; // Use an array to store data
    int num_items;         // Number of items on the queue
    int first;             // Index of the first item; start from 0

  public:
    // CONSTRUCTOR member functions
    int_queue();           // Default constructor

    // ACCESSOR member functions: const => won't modify data members
    bool empty() const;    // Check if the queue is empty
    bool full() const;     // Check if the queue is full
    int size() const;      // Give the number of data currently stored
    int front() const;     // Retrieve the value of the front item
    // MUTATOR member functions
    void enqueue(int);     // Add a new item to the back of the queue
    void dequeue();        // Remove the front item from the queue
};
```

Circular Queue of int Data — Test Program

```
#include "int-queue.h" /* File: int-queue-test.cpp */

void print_queue_info(const int_queue& a) {
    cout << "No. of data currently on the queue = " << a.size() << "\t";
    if (!a.empty()) cout << "Front item = " << a.front();
    cout << endl << "Empty: " << boolalpha << a.empty();
    cout << "\t\t" << "Full: " << boolalpha << a.full() << endl << endl;
}

int main() {
    int_queue a;   print_queue_info(a);
    a.enqueue(4);  print_queue_info(a);
    a.enqueue(15); print_queue_info(a);
    a.enqueue(26); print_queue_info(a);
    a.enqueue(37); print_queue_info(a);
    a.dequeue();   print_queue_info(a);
    a.enqueue(48); print_queue_info(a);
    a.enqueue(59); print_queue_info(a);
    a.dequeue();   print_queue_info(a);
    a.dequeue();   print_queue_info(a);
    a.dequeue();   print_queue_info(a);
    a.dequeue();   print_queue_info(a);
    a.dequeue();   print_queue_info(a);
    return 0;
} /* compile: g++ -L. -o int-queue-test int-queue-test.cpp -lintqueue */
```

Circular Queue of int Data — Constructors, Assessors

```
#include "int-queue.h"  /* File: int-queue1.cpp */

          /***** Default CONSTRUCTOR member function *****/
// Create an empty queue
int_queue::int_queue() { first = 0; num_items = 0; }

          /***** ACCESSOR member functions *****/
// Check if the int_queue is empty
bool int_queue::empty() const { return (num_items == 0); }

// Check if the int_queue is full
bool int_queue::full() const { return (num_items == BUFFER_SIZE); }

// Give the number of data currently stored
int int_queue::size() const { return num_items; }

// Retrieve the value of the front item
int int_queue::front() const
{
    if (!empty())
        return data[first];

    cerr << "Warning: Queue is empty; can't retrieve any data!" << endl;
    exit(-1);
}
```

Circular Queue of int Data — Mutators

```
#include "int-queue.h" /* File: int-queue2.cpp */

void int_queue::enqueue(int x)  // Add a new item to the back of the queue
{
    if (!full())
    {
        data[(first+num_items) % BUFFER_SIZE] = x;
        ++num_items;
    } else {
        cerr << "Error: Queue is full; can't add (" << x << ")!" << endl;
        exit(-1);
    }
}

void int_queue::dequeue()       // Remove the front item from the queue
{
    if (!empty())
    {
        first = (first+1) % BUFFER_SIZE;
        --num_items;
    } else {
        cerr << "Error: Queue is empty; can't remove any data!" << endl;
        exit(-1);
    }
}
```

Further Reading

Simplified STL Stack

- typedef is a keyword used to introduce a synonym for an existing type expression:

typedef < a type expression > <type-synonym>

```
template <typename T, typename Sequence = deque<T> >
class Stack
{
  protected:
    Sequence c; // Underlying container

  public:
    typedef typename Sequence::value_type      value_type;
    typedef typename Sequence::reference       reference;
    typedef typename Sequence::const_reference const_reference;
    typedef typename Sequence::size_type       size_type;

    // (Default) Constructor
    explicit stack(const Sequence& _c = Sequence()) : c(_c) {}
```

Simplified STL Stack ..

```
  // Return true if the stack is empty
  bool empty() const { return c.empty(); }

  // Return the number of elements in the stack
  size_type size() const { return c.size(); }

  // Return a R/W reference to the data at the first element
  reference top() { return c.back(); }

  // Read-only version of top()
  const_reference top() const { return c.back(); }

  // Create an element at the top of the stack and assign x to it
  void push(const value_type& x) { c.push_back(x); }

  // Shrink the stack by one. Note that no data is returned.
  void pop() { c.pop_back(); }
};
```

Stack Application: Balanced Parentheses — Illustration

- e.g., [()][()()]() is balanced but [(]) is not.
- Algorithm to check balanced parentheses:

Step 1 : Scan the given character expression from left to right.

Step 2 : If a left paranthesis is read, push it onto a stack.

Step 3 : If a right paranthesis is read, check if its matching left parenthesis is on the top of the stack.

Step 4 : If Step 3 is true, pop the stack and continue.

Step 5 : If Step 3 is false, return false and stop.

Step 6 : If the end of the expression is reached, check if the stack is empty.

Step 7 : If Step 6 is true, return true otherwise false.

Stack Application: Balanced Parentheses I

```
#include <iostream>    /* File: balanced-paren.cpp */
#include <stack>
using namespace std;

const char L_PAREN    = '('; const char R_PAREN    = ')';
const char L_BRACE    = '{'; const char R_BRACE    = '}';
const char L_BRACKET  = '['; const char R_BRACKET  = ']';
bool balanced_paren(const char* expr);

int main()  // To check if a string has balanced parantheses
{
    char expr[1024];
    cout << "Input an expression containing parentheses: ";
    cin >> expr;
    cout << boolalpha << balanced_paren(expr) << endl;
    return 0;
}

bool check_char_stack(stack<char>& a, char c)
{
    if (a.empty()) return false;
    if (a.top() != c) return false;
    a.pop(); return true;
}
```

Stack Application: Balanced Parentheses II

```
bool balanced_paren(const char* expr)
{
    stack<char> a;
    for (const char* s = expr; *s != '\0'; ++s)
        switch (*s)
        {
            case L_PAREN: case L_BRACE: case L_BRACKET:
                a.push(*s); break;

            case R_PAREN:
                if (!check_char_stack(a, L_PAREN)) return false;
                break;
            case R_BRACE:
                if (!check_char_stack(a, L_BRACE)) return false;
                break;
            case R_BRACKET:
                if (!check_char_stack(a, L_BRACKET)) return false;
                break;

            default: break;
        }

    return a.empty();
}
```

Simplified STL Queue

```
template<typename T, typename Sequence = deque<T> >
class queue
{
  protected:
    Sequence c; // Underlying container

  public:
    typedef typename Sequence::value_type      value_type;
    typedef typename Sequence::reference       reference;
    typedef typename Sequence::const_reference const_reference;
    typedef typename Sequence::size_type       size_type;

    // (Default) Constructor
    explicit queue(const Sequence& _c = Sequence()) : c(_c) { }

    // Return true if the queue is empty
    bool empty() const { return c.empty(); }

    // Return the number of elements in the queue
    size_type size() const { return c.size(); }

    // Return a R/W reference to the data at the first element of the queue
    reference front() { return c.front(); }
```

Simplified STL Queue ..

```
  // Read-only version of front()
  const_reference front() const { return c.front(); }

  // Return a R/W reference to the data at the last element of the queue
  reference back() { return c.back(); }

  // Read-only version of back()
  const_reference back() const { return c.back(); }

  // Create an element at the end of the queue and assigns x to it
  // i.e., enqueue
  void push(const value_type& x) { c.push_back(x); }

  // It shrinks the queue by one. Note that no data is returned.
  // i.e., dequeue
  void pop() { c.pop_front(); }
};
```

Example: Queue of int Data

```
#include <iostream>    /* File: int-queue-test.cpp */
#include <queue>
using namespace std;

void print_queue_info(const queue<int>& a) {
    cout << "\nNo. of data currently on the queue = " << a.size() << endl;
    if (!a.empty()) {
        cout << "First: " << a.front() << "\nLast: " << a.back() << endl; }
}

int main()
{
    queue<int> a; print_queue_info(a);
    a.push(4);    print_queue_info(a);
    a.push(15);   print_queue_info(a);
    a.push(26);   print_queue_info(a);
    a.push(37);   print_queue_info(a);
    a.pop();      print_queue_info(a);
    a.push(48);   print_queue_info(a);
    a.push(59);   print_queue_info(a);
    a.pop();      print_queue_info(a);
    a.pop();      print_queue_info(a);
    a.pop();      print_queue_info(a);
    a.pop();      print_queue_info(a);
    a.pop();      print_queue_info(a); return 0;
}
```

That's all!

Any questions?