INF1008
Data Structures & Algorithms

Group 10

Contents

Question 5

List of Figures

Question 1

Question 2

Question 3

Question 4

Question 5

Question 1

1.1 Problem Statement

Implement the queue ADT using a Doubly linked list using any programming language. After the implementation, make use of the standard queue operations to implement the stack ADT. Clearly demonstrate the validity of your implementation through enough test cases. Evaluate the time complexity of the push, pop, empty and full operations.

1.2 Requirements/Specification

Users will have access to a container with behaviour akin to a stack, however in the background, the processes are done using a queue and its functions built upon a linked list structure. Users will have access to the standard stack functions - `push`, `pop`, `isEmpty` and `isFull` operations.

1.3 User Guide

An executable is provided, users can run the executable directly and follow the on-screen prompts, more in-depth details are provided in the Testing section.

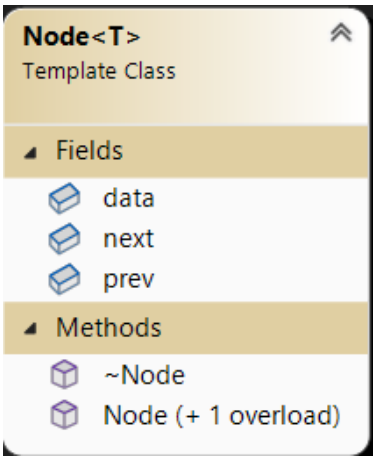
1.4 Structure/Design

The stack as well as the underlying queue containers both have generic types built into the system. Thus, the same code can be re-used to store different types of data, including class objects, should the programmer wish to do that.

There are 3 classes utilised in this program, "Node", "QueueADT" and "StackADT". All 3 classes are template classes using typename `T`.

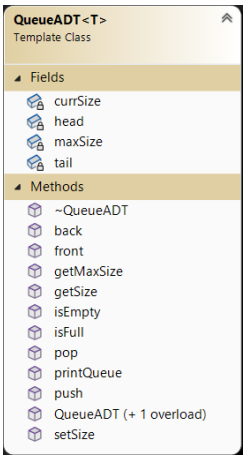
1.4.1 Node

Figure 1.1: Node Class Overview



- Data Members
  1. `T data` – Used to store the inputted data
  2. `Node<T>* next` – Used to store the address of the next node, for use in a linked list
  3. `Node<T>* prev` – Used to store the address of the previous node, for use in a linked list
- Methods
  1. `Node()` – Default constructor
  2. `~Node()` – Default destructor
  3. `Node(T data)` – An overloaded constructor, takes in a variable to initialise the data on construction.

Figure 1.2: Queue Class Overview



1.4.2 QueueADT

- Data Members
  1. `int maxSize` – Used to limit the size of the container
  2. `int currSize` – Denotes the amount of data stored in the container, will be updated as the data is added and removed from the container

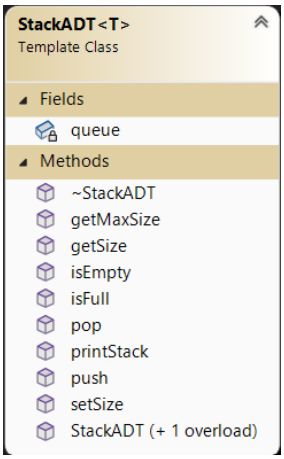
3. `Node<T>* head` – A pointer to the head node of the queue
4. `Node<T>* tail` – A pointer to the tail node of the queue

- Methods

1. `QueueADT()` – Default constructor
2. `~QueueADT()` – Default destructor, will iterate through the linked list and delete all nodes when called
3. `QueueADT(int size)` – An overloaded constructor, takes an int argument to initialise `maxSize`
4. `front()` – Returns a pointer to the head node of the queue
5. `back()` – Returns a pointer to the tail node of the queue
6. `setMaxSize(int size)` – Passes in an integer to change the container's max allotted size
7. `getMaxSize()` – Returns `maxSize`
8. `getSize()` – Returns `currSize`
9. `isEmpty()` – Returns the truth value of `if currSize` equal to `0` and if `head` or `tail` are `NULL` as an added precaution, has a time complexity of $O(1)$ as `currSize` is updated together with the container, with the greater than or equal to comparator being used as an added precaution
10. `isFull()` – Returns the truth value of if `currSize` is greater than or equal to `maxSize`, has a time complexity of $O(1)$ as `currSize` is updated together with the container, with the greater than or equal to comparator being used as an added precaution.
11. `push(T data)` – `data` is passed in, and a `Node` is constructed using its overloaded constructor to be added to the linked list, as well as link the nodes between each other, has a time complexity of $O(1)$, as the pointer to the `tail` is stored, new elements can simply be added directly behind `tail` as no comparisons are required. Updates `currSize`, `head`, and `tail` members accordingly
12. `pop()` – Removes the element at the front of the queue, and returns a pointer to it to have its data extracted or deleted accordingly, has a time complexity of $O(1)$, as a pointer to `head` is stored, thus the front element can be removed directly with no comparisons. Updates `currSize`, `head`, and `tail` members accordingly
13. `printQueue()` – Prints the entire linked list, has a time complexity of $O(n)$ as iteration through the entire list is required

1.4.3 StackADT

Figure 1.3: Stack Class Overview



- Data Members

1. `QueueADT<T>* queue` – A pointer to the queue container used to store data

- Methods
  1. `StackADT()` – Default constructor
  2. `~StackADT()` – Default destructor, invokes the queue destructor, and deletes the pointer to the queue
  3. `StackADT(int size)` – Overloaded constructor, initialises the `QueueADT` member with a `maxSize` of the value passed in
  4. `setMaxSize(int size)` – Invokes the `QueueADT` member's `setMaxSize(int size)`, passing the same value in
  5. `getMaxSize()` – Invokes the `QueueADT` member's `getMaxSize()`
  6. `getSize()` – Invokes the `QueueADT` member's `getSize()`
  7. `isEmpty()` – Invokes the `QueueADT` member's `isEmpty()`, therefore time complexity of $O(1)$
  8. `isFull()` – Invokes the `QueueADT` member's `isFull()`, therefore time complexity of $O(1)$
  9. `push(T data)` – Invokes the `QueueADT` member's `push(T data)`, after pushing the initial data in, all the other members in front of it are popped, and re-pushed into the queue to simulate a stack. This causes the function to have a time complexity of $O(n)$, as every element in the container has to be reorganised
  10. `pop()` – Invokes the `QueueADT` member's `pop()`, therefore time complexity of $O(1)$

1.5 Limitations

The data type specified on creation is final and is unable to be changed unless the stack is completely re-initialised. A consideration was made to utilise a class holding multiple data types - `int`(4 bytes), `float`(4 bytes), `double`(8 bytes), `char`(1 byte), `std::string`(> 24 bytes) - and construct a container with the type of that class. It would allow the container to store any data that has shares the property of being a standard data type. However, upon further deliberation, a class with that many types will cause memory bloat, as an example if the majority of the data entered was integers, for every 4 bytes used, > 37 bytes are reserved but unused by the system.

1.6 Testing

Users will be prompted (option 1 or option 2) to either allow the program to automatically generate test cases, or test the system out themselves. Users can also input a "$" to terminate the program.

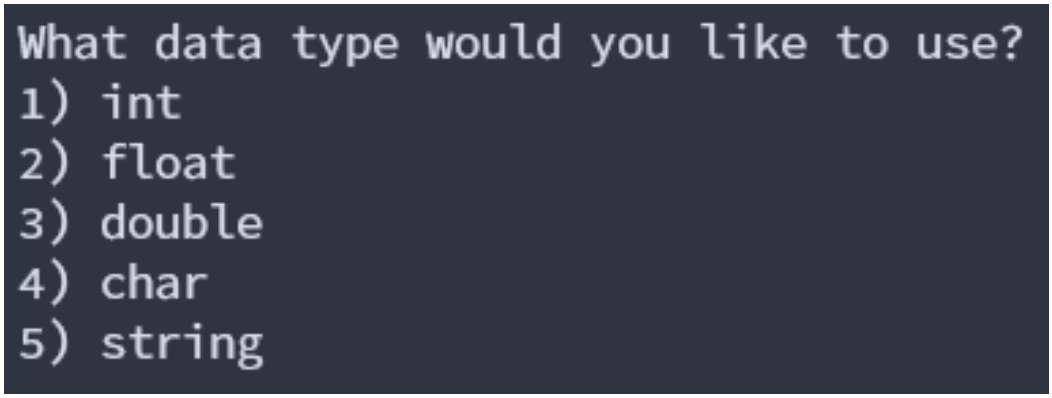
Figure 1.4: Command-line Interface prompt

```
This is a demo of the stack ADT with queue ADT as the base. What would you like to do?
1) Auto generate 10 stacks of random length(1-10), random amount of data(1-10) and data.
2) Manually input test cases.
Enter $ if you wish to stop the process.
```

1.6.1 Option 1 – Automatic Generation

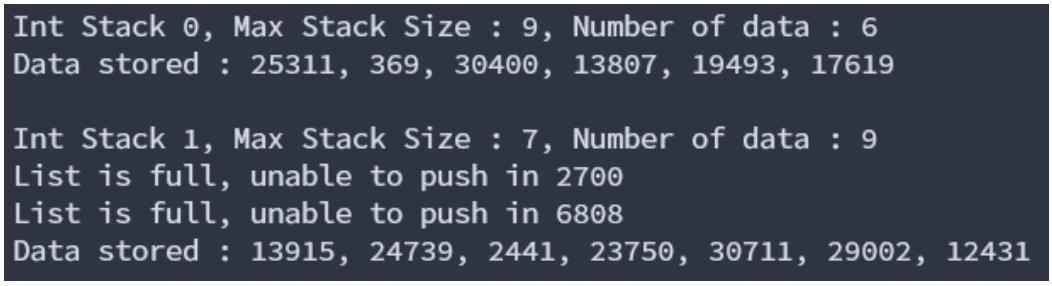
The program will prompt the user for the type of data they wish to store.

Figure 1.5: Option 1 prompt



The program will then generate 10 stacks of random length and random amount of data corresponding to the data type specified by the user.

Figure 1.6: Option 1 testing

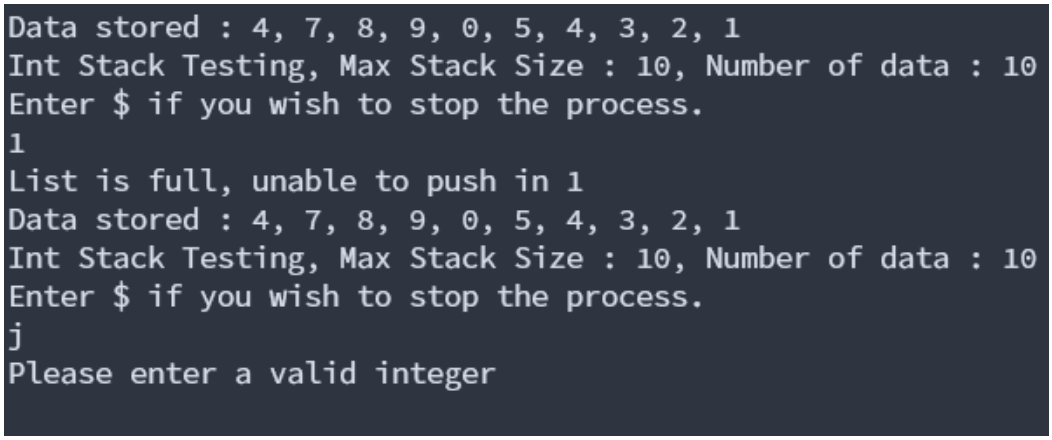


1.6.2 Option 2 – Manual Testing

The program will similarly prompt the user for the type of data they wish to store. Additionally, it will enquire on the size they wish for the container to be.

The user will then be able to enter data fitting to the data type into the stack, any data not fitting the data type will be rejected, discarding it and looping back to where the user can continue inputting data. Similarly, if the user tries to add more data into the stack when it is full, the program will also reject the entry. At any time the user can choose to enter "$" and the process will end, and loop back to the start of the program.

Figure 1.7: Option 2 testing with invalid inputs



1.7 Listings

1.7.1 QueueADT.cpp

```
1
2   #pragma once
3   #include "QueueADT.h"
4
5   template <class T>
6   QueueADT<T>::QueueADT() {
7     maxSize = 0;
8     currSize = 0;
9     head = tail = NULL;
10  }
11
12  template <class T>
13  QueueADT<T>::QueueADT(int size) {
14    maxSize = size;
15    currSize = 0;
16    head = tail = NULL;
17  }
18
19  //delete, could do the same thing as empty?
20  template <class T>
21  QueueADT<T>::~QueueADT() {
22    Node<T>* iter = head;
23    //while iter exists, delete it and move next
24    while (iter) {
25      head = iter;
26      iter = iter->next;
27      delete head;
28      head = NULL;
29    }
30    //safety
31    head = tail = iter = NULL;
32  }
33  template <class T>
34  void QueueADT<T>::setMaxSize(int size) {
35    maxSize = size;
36  }
37
38  template <class T>
39  int QueueADT<T>::getSize() {
40    return currSize;
41  }
42
43  template <class T>
44  int QueueADT<T>::getMaxSize() {
45    return maxSize;
46  }
47
48  //insert element at the end of the Queuee
49  template <class T>
50  void QueueADT<T>::push(T data) {
51
52    // if list is full return out
53    if (isFull()) {
54      std::cout << "Container full, failed to push "<< data << std::endl;
55      return;
56    }
57
58    Node<T>* newNode = new Node<T>(data);
59
60    //check if list is empty, if yes assign head and tail to same node
61    if (isEmpty()) {
62      head = tail = newNode;
63      ++currSize;
64      return;
65    }
```

```
66
67    //getting last object and linking newNode to list
68    Node<T>* iter = tail;
69    iter->next = newNode;
70    newNode->prev = iter;
71    tail = newNode;
72    ++currSize; //add to counter
73  }
74
75  //remove and return 1st element
76  template <class T>
77  Node<T>* QueueADT<T>::pop() {
78    if (isEmpty()) {
79      return NULL;
80    }
81    Node<T>* iter = head;
82    if (head->next != NULL) {
83      head = head->next; //move head pointer back
84    }
85    head->prev = NULL; //break prev link to old head node
86    iter->next = NULL; //break next link from old head node
87    --currSize; //minus counter
88    return iter;
89  }
90
91  //checks if container is empty
92  template <class T>
93  bool QueueADT<T>::isEmpty() {
94    //returns if head and tail are both NULL
95    return ((head == NULL || tail == NULL) && currSize == 0);
96  }
97
98  //returns if the Queuee is full / at capacity
99  template <class T>
100 bool QueueADT<T>::isFull() {
101   return currSize >= maxSize;
102 }
103
104 template <class T>
105 void QueueADT<T>::printQueue() {
106   //if head or tail is not init, something wrong return out
107   if (!head || !tail)
108     return;
109
110   std::cout << "Data stored : ";
111   //printing data in list
112   Node<T>* iter = head;
113   while (iter != NULL) {
114     //printf("%.6f", iter->data); //printf here to acheieve format
115     std::cout << iter->data;
116     //formatting
117     if (iter->next != NULL)
118       std::cout << ", ";
119     iter = iter->next;
120   }
121   std::cout << std::endl;
122 }
123
124 template<class T>
125 Node<T>* QueueADT<T>::front()
126 {
127   //if head exists return head else NULL
128   if (head)
129     return head;
130
131   return NULL;
132 }
133
134 template<class T>
135 Node<T>* QueueADT<T>::back()
136 {
```

```
    //if tail exists return head else NULL
    if (tail)
      return tail;

    return NULL;
  }
```

1.7.2 StackADT.cpp

```

  #pragma once
  #include "StackADT.h"

  template<class T>
  StackADT<T>::StackADT(){
    queue = new QueueADT<T>(0);
  }

  template<class T>
  StackADT<T>::StackADT(int size){
    queue = new QueueADT<T>(size);
  }

  template<class T>
  StackADT<T>::~StackADT(){
    //if queue was init, delete
    if (queue) {
      delete queue;
      queue = NULL;
    }
  }

  template<class T>
  void StackADT<T>::setMaxSize(int size){
    queue->setMaxSize(size);
  }

  template<class T>
  int StackADT<T>::getSize(){
    return queue->getSize();
  }

  template<class T>
  int StackADT<T>::getMaxSize() {
    return queue->getMaxSize();
  }

  template<class T>
  void StackADT<T>::push(T data){
    // if list is full return out
    if (isFull()) {
      std::cout << "List is full, unable to push in " << data << std::endl;
      return;
    }

    //push the new data on,
    queue->push(data);
    //iterate through pop and re-push everything in to
    //push the new data to the top
    if (queue->getSize() > 1) {
      for (int i = 0; i < queue->getSize()-1; ++i) {
        Node<T> * oldNode = queue->pop();
        T oldData = oldNode->data;
        if(oldNode){
          delete oldNode;
          oldNode = NULL;
        }
        queue->push(oldData);
      }
```

```
    }
  }

  template<class T>
  Node<T>* StackADT<T>::pop()
  {
    //get front of queue / top of stack
    //Node<T>* iter = queue->pop();
    return queue->pop();
  }

  template<class T>
  bool StackADT<T>::isEmpty()
  {
    return queue->isEmpty();
  }

  template<class T>
  bool StackADT<T>::isFull()
  {
    return queue->isFull();;
  }

  template<class T>
  void StackADT<T>::printStack()
  {
    queue->printQueue();
  }
```

1.7.3 Source.cpp

```

  #include <stdio.h>
  #include <iostream>
  #include "StackADT.h"
  #include "StackADT.cpp"
  #include <string>
  #include <cstdlib>
  #include <ctime>
  #include <iomanip>

  enum TestCase {
    TC_NOTSELECTED,
    TC_AUTOGEN,
    TC_MANUAL,
  };

  enum DataType {
    DT_NOTSELECTED,
    DT_INT,
    DT_FLOAT,
    DT_DOUBLE,
    DT_CHAR,
    DT_STRING
  };

  int main(void) {

    //seeding
    srand(time(0));

    //void* theStack;
    StackADT<int>* intStack = NULL;
    StackADT<float>* floatStack = NULL;
    StackADT<double>* doubleStack = NULL;
    StackADT<char>* charStack = NULL;
    StackADT<std::string>* stringStack = NULL;
    bool mainLoop = true;
    //theStack = charStack;
```

```
39      while (mainLoop) {
40        TestCase testCase = TC_NOTSELECTED;
41        DataType dataType = DT_NOTSELECTED;
42        std::string option = "";
43        int stackSize = 0; //to determine the size of stack to init
44
45        std::cout << "This is a demo of the stack ADT with queue ADT as the base. What would you
      like to do?" << std::endl;
46        std::cout << "1) Auto generate 10 stacks of random length(1-10), random amount of data
      (1-10) and data." << std::endl;
47        std::cout << "2) Manually input test cases." << std::endl;
48        std::cout << "Enter $ if you wish to stop the process." << std::endl;
49
50        //giving user options to showcase algorithm************************************
51        while (testCase == TC_NOTSELECTED) {
52          std::getline(std::cin, option);
53          if (option == "$") {
54            mainLoop = false;
55            break;
56          }
57
58          //just take the 1st char in the string then set the option
59          switch (option[0]) {
60          case '1':
61            testCase = TC_AUTOGEN;
62            break;
63          case '2':
64            testCase = TC_MANUAL;
65            break;
66          default:
67            std::cout << "Please enter a valid option." << std::endl;
68            testCase = TC_NOTSELECTED;//safety
69            break;
70          }
71          option = ""; //clear string, safety
72
73        }
74        if (!mainLoop) {
75          break;
76        }
77
78        //data type option ***************************************************************
79        std::cout << "What data type would you like to use?" << std::endl;
80        std::cout << "1) int" << std::endl;
81        std::cout << "2) float" << std::endl;
82        std::cout << "3) double" << std::endl;
83        std::cout << "4) char" << std::endl;
84        std::cout << "5) string" << std::endl;
85
86        while (dataType == DT_NOTSELECTED) {
87          std::getline(std::cin, option);
88
89          //just take the 1st char in the string then set the option
90          switch (option[0]) {
91          case '1':
92            dataType = DT_INT;
93            break;
94          case '2':
95            dataType = DT_FLOAT;
96            break;
97          case '3':
98            dataType = DT_DOUBLE;
99            break;
100         case '4':
101           dataType = DT_CHAR;
102           break;
103         case '5':
104           dataType = DT_STRING;
105           break;
106         default:
107           std::cout << "Invalid input. Please enter a valid option." << std::endl;
```

```
108           dataType = DT_NOTSELECTED;//safety
109           break;
110         }
111         option = ""; //clear string, safety
112 
113       }
114 
115       //auto generate test case
116       if (testCase == TC_AUTOGEN) {
117 
118         int numtest = 10;
119         for (int i = 0; i < numtest; i++) {
120           int stackSize = rand() % 10;
121           int numberOfData = rand() % 10;
122 
123           switch (dataType) {
124           case DT_INT:
125             intStack = new StackADT<int>(stackSize);
126             std::cout << "Int Stack " + std::to_string(i) + ", Max Stack Size : " + std::
    to_string(stackSize)
127               + ", Number of data : " + std::to_string(numberOfData) << std::endl;
128             for (int j = 0; j < numberOfData; j++) {
129               int data = rand();
130               intStack->push(data);
131             }
132             intStack->printStack();
133             break;
134           case DT_FLOAT:
135             floatStack = new StackADT<float>(stackSize);
136             std::cout << "Float Stack " + std::to_string(i) + ", Max Stack Size : " + std::
    to_string(stackSize)
137               + ", Number of data : " + std::to_string(numberOfData) << std::endl;
138             for (int j = 0; j < numberOfData; j++) {
139               float data = (float)(rand() % RAND_MAX) / RAND_MAX;
140               floatStack->push(data);
141             }
142             floatStack->printStack();
143             break;
144           case DT_DOUBLE:
145             doubleStack = new StackADT<double>(stackSize);
146             std::cout << "Double Stack " + std::to_string(i) + ", Max Stack Size : " + std::
    to_string(stackSize)
147               + ", Number of data : " + std::to_string(numberOfData) << std::endl;
148             for (int j = 0; j < numberOfData; j++) {
149               double data = (double)(rand() % RAND_MAX) / RAND_MAX;
150               doubleStack->push(data);
151             }
152             doubleStack->printStack();
153             break;
154           case DT_CHAR:
155             charStack = new StackADT<char>(stackSize);
156             std::cout << "Char Stack " + std::to_string(i) + ", Max Stack Size : " + std::
    to_string(stackSize)
157               + ", Number of data : " + std::to_string(numberOfData) << std::endl;
158             for (int j = 0; j < numberOfData; j++) {
159               int number = rand() % 2;
160               char data;
161               if (number == 0) { //generate upper case
162                 number = rand() % 26 + 65;
163               }
164               else { //generate lower case
165                 number = rand() % 26 + 97;
166               }
167               data = (char)(number);
168               charStack->push(data);
169             }
170             charStack->printStack();
171             break;
172           case DT_STRING:
173             stringStack = new StackADT<std::string>(stackSize);
174             std::cout << "String Stack " + std::to_string(i) + ", Max Stack Size : " + std::
```

```
    to_string(stackSize)
175             + ", Number of data : " + std::to_string(numberOfData) << std::endl;
176           for (int j = 0; j < numberOfData; j++) {
177             int stringLen = rand() % 10;
178             std::string data = "";
179             //data.append
180             for (int k = 0; k < stringLen; k++) {
181               int number = rand() % 2;
182               char letter;
183               if (number == 0) { //generate upper case
184                 number = rand() % 26 + 65;
185               }
186               else { //generate lower case
187                 number = rand() % 26 + 97;
188               }
189               letter = (char)(number);
190               data += letter;
191             }
192             stringStack->push(data);
193           }
194           stringStack->printStack();
195           break;
196         default:
197           //reset loop?
198           break;
199         }
200         //formatting
201         std::cout << std::endl;
202 
203         if (intStack) {
204           delete intStack;
205           intStack = NULL;
206         }
207         if (charStack) {
208           delete charStack;
209           charStack = NULL;
210         }
211         if (floatStack) {
212           delete floatStack;
213           floatStack = NULL;
214         }
215         if (doubleStack) {
216           delete doubleStack;
217           doubleStack = NULL;
218         }
219         if (stringStack) {
220           delete stringStack;
221           stringStack = NULL;
222         }
223 
224       }
225     }
226     else if (testCase == TC_MANUAL) {
227       std::cout << "Please enter the size you wish the list to be." << std::endl;
228       while (true) {
229         //check if user input was an int, if yes stack size determined
230         if (std::cin >> stackSize) {
231           break;
232         }
233         std::cout << "Invalid input. Please enter an integer." << std::endl;
234         //clear stream safety
235         std::cin.clear();
236         std::cin.ignore(std::numeric_limits<std::streamsize>::max(), '\n');
237       }
238       //user test loop
239       std::string input = "";
240       bool activeLoop = true;
241       bool validInput = false;
242       switch (dataType) {
243       case DT_INT:
244         intStack = new StackADT<int>(stackSize);
```

```
245           //loop that runs to accept user input
246           while (activeLoop) {
247             std::cout << "Int Stack Testing, Max Stack Size : " + std::to_string(stackSize)
248               + ", Number of data : " + std::to_string(intStack->getSize()) << std::endl;
249             std::cout << "Enter $ if you wish to stop the process." << std::endl;
250             int data = 0;
251             //validation, looping till get a valid input
252             validInput = false;
253             while (!validInput) {
254               std::getline(std::cin, input);
255               std::cin.clear();
256               if (input.empty()) //skip empty entries
257                 continue;
258               if (input == "$") { //to break out of the loop
259                 activeLoop = false;
260                 break;
261               }
262               try {
263                 data = std::stoi(input);
264                 validInput = true;
265               }
266               catch (const std::invalid_argument& e) {
267                 std::cout << "Please enter a valid integer" << std::endl;
268                 validInput = false;
269               }
270             }
271             //to skip the pushing if the user wants to exit
272             if (!activeLoop) {
273               break;
274             }
275             intStack->push(data);
276             intStack->printStack();
277           }
278           break;
279         case DT_FLOAT:
280           floatStack = new StackADT<float>(stackSize);
281           //loop that runs to accept user input
282           while (activeLoop) {
283             std::cout << "Float Stack Testing, Max Stack Size : " + std::to_string(stackSize)
284               + ", Number of data : " + std::to_string(floatStack->getSize()) << std::endl;
285             std::cout << "Enter $ if you wish to stop the process." << std::endl;
286             float data = 0;
287             validInput = false;
288             //validation, looping till get a valid input
289             while (!validInput) {
290               std::getline(std::cin, input);
291               std::cin.clear();
292               if (input.empty()) //skip empty entries
293                 continue;
294               if (input == "$") {
295                 activeLoop = false;
296                 break;
297               }
298               try {
299                 data = std::stof(input);
300                 validInput = true;
301               }
302               catch (const std::invalid_argument& e) {
303                 std::cout << "Please enter a valid float" << std::endl;
304                 validInput = false;
305               }
306             }
307             //to skip the pushing if the user wants to exit
308             if (!activeLoop) {
309               break;
310             }
311             floatStack->push(data);
312             floatStack->printStack();
313           }
314           break;
315         case DT_DOUBLE:
```

```
316           doubleStack = new StackADT<double>(stackSize);
317           //loop that runs to accept user input
318           while (activeLoop) {
319             std::cout << "Double Stack Testing, Max Stack Size : " + std::to_string(stackSize)
320               + ", Number of data : " + std::to_string(doubleStack->getSize()) << std::endl;
321             std::cout << "Enter $ if you wish to stop the process." << std::endl;
322             double data = 0;
323             validInput = false;
324             //validation, looping till get a valid input
325             while (!validInput) {
326               std::getline(std::cin, input);
327               std::cin.clear();
328               if (input.empty()) //skip empty entries
329                 continue;
330               if (input == "$") {
331                 activeLoop = false;
332                 break;
333               }
334               try {
335                 data = std::stod(input);
336                 validInput = true;
337               }
338               catch (const std::invalid_argument& e) {
339                 std::cout << "Please enter a valid double" << std::endl;
340                 validInput = false;
341               }
342             }
343             //to skip the pushing if the user wants to exit
344             if (!activeLoop) {
345               break;
346             }
347             doubleStack->push(data);
348             doubleStack->printStack();
349           }
350           break;
351         case DT_CHAR:
352           charStack = new StackADT<char>(stackSize);
353           //loop that runs to accept user input
354           while (activeLoop) {
355             std::cout << "Char Stack Testing, Max Stack Size : " + std::to_string(stackSize)
356               + ", Number of data : " + std::to_string(charStack->getSize()) << std::endl;
357             std::cout << "Enter $ if you wish to stop the process." << std::endl;
358             char data = ' ';
359             validInput = false;
360             //validation, looping till get a valid input
361             while (!validInput) {
362               std::getline(std::cin, input);
363               std::cin.clear();
364               if (input.empty()) //skip empty entries
365                 continue;
366               if (input == "$") {
367                 activeLoop = false;
368                 break;
369               }
370               try {
371                 data = input[0];
372                 validInput = true;
373               }
374               catch (const std::invalid_argument& e) {
375                 std::cout << "Please enter a valid char" << std::endl;
376                 validInput = false;
377               }
378             }
379             //to skip the pushing if the user wants to exit
380             if (!activeLoop) {
381               break;
382             }
383             charStack->push(data);
384             charStack->printStack();
385           }
386           break;
```

```
        case DT_STRING:
          stringStack = new StackADT<std::string>(stackSize);
          //loop that runs to accept user input
          while (activeLoop) {
            std::cout << "String Stack Testing, Max Stack Size : " + std::to_string(stackSize)
              + ", Number of data : " + std::to_string(stringStack->getSize()) << std::endl;
            std::cout << "Enter $ if you wish to stop the process." << std::endl;
            std::getline(std::cin, input);
            std::cin.clear();
            if (input.empty()) //skip empty entries
              continue;
            //to skip the pushing if the user wants to exit
            if (input == "$") {
              activeLoop = false;
              break;
            }

            stringStack->push(input);
            stringStack->printStack();
          }
          break;
        default:
          break;
        }

      }

      if (intStack) {
        delete intStack;
        intStack = NULL;
      }
      if (charStack) {
        delete charStack;
        charStack = NULL;
      }
      if (floatStack) {
        delete floatStack;
        floatStack = NULL;
      }
      if (doubleStack) {
        delete doubleStack;
        doubleStack = NULL;
      }
      if (stringStack) {
        delete stringStack;
        stringStack = NULL;
      }
    }
    if (intStack) {
      delete intStack;
      intStack = NULL;
    }
    if (charStack) {
      delete charStack;
      charStack = NULL;
    }
    if (floatStack) {
      delete floatStack;
      floatStack = NULL;
    }
    if (doubleStack) {
      delete doubleStack;
      doubleStack = NULL;
    }
    if (stringStack) {
      delete stringStack;
      stringStack = NULL;
    }

    return 0;
}
```

Question 2

2.1 Problem Statement

Write a program that reads in a sequence of characters, and determines whether its parentheses, braces, and curly braces are "balanced." Your program should read one line of input containing what is supposed to be a properly formed expression in algebra and tells whether it is in fact legal. The expression could have several sets of grouping symbols of various kinds, (), [], and {}. Your program needs to make sure that these grouping symbols match up properly. Analyse the efficiency of your implementation and provide a detailed discussion of its time and space complexity.

2.2 Requirements/Specification

Given any algebraic statement, (e.g. $-b \pm \left[\sqrt{\{b^2\} - (4)(a)(c)}\right] /2(a)$), determine if the braces are balanced; That is, if the number of opening braces match the number of closing braces, and that the first closing brace matches with the last opening brace. The algorithm expects a properly formed expression in algebra as a string and outputs either `True` or `False`.

2.3 User Guide

To run the program, simply type `python main.py` in a terminal window. The program then prompts the user for an algebraic statement. If the statement is balanced, the program returns `True` and vice versa. No external libraries other than the standard `Python 3` libraries are required.

2.4 Structure/Design

The algorithm works by pushing opening brackets to a stack by looping through all bracket characters in the original statement. When encountering a closing bracket, it pops the last element of the stack and compares if they are complementary. If at any point the check fails, the algorithm returns `False` and ends the loop prematurely. At the end of the loop, the algorithm checks that the stack is empty. If it is, it returns `True` and `False` otherwise.

Algorithm 1: Bracket balance checker

Input: str statement

```
1  Function is_balanced(statement: str) is
2      statement ← all brackets from statement;
3      bracket_pairings ← {opening_bracket : closing_bracket};
4      if len(statement)  mod 2 ≠ 0 then
5          return False;
6      end
7      stack = [];
8      foreach character in statement do
9          if character is an opening bracket then
10             stack.push(character);
11         end
12         else if bracket_pairing[stack.pop()] ≠ character then
13             return False;
14         end
15     end
16     return len(stack) == 0;
17 end
```

As the algorithm iterates through the input string only once, the time complexity is $O(n)$ for a given input string of length n. The opening brackets are iteratively pushed to and popped from a stack, so the space complexity is $O(n)$ as well.

Note:-

The time complexity of **Regular Expressions** and **Stack Operations** for insertion and deletion are known to be $O(n)$ and $O(1)$ respectively, so the time and space complexity of the algorithm remains at $O(n)$.

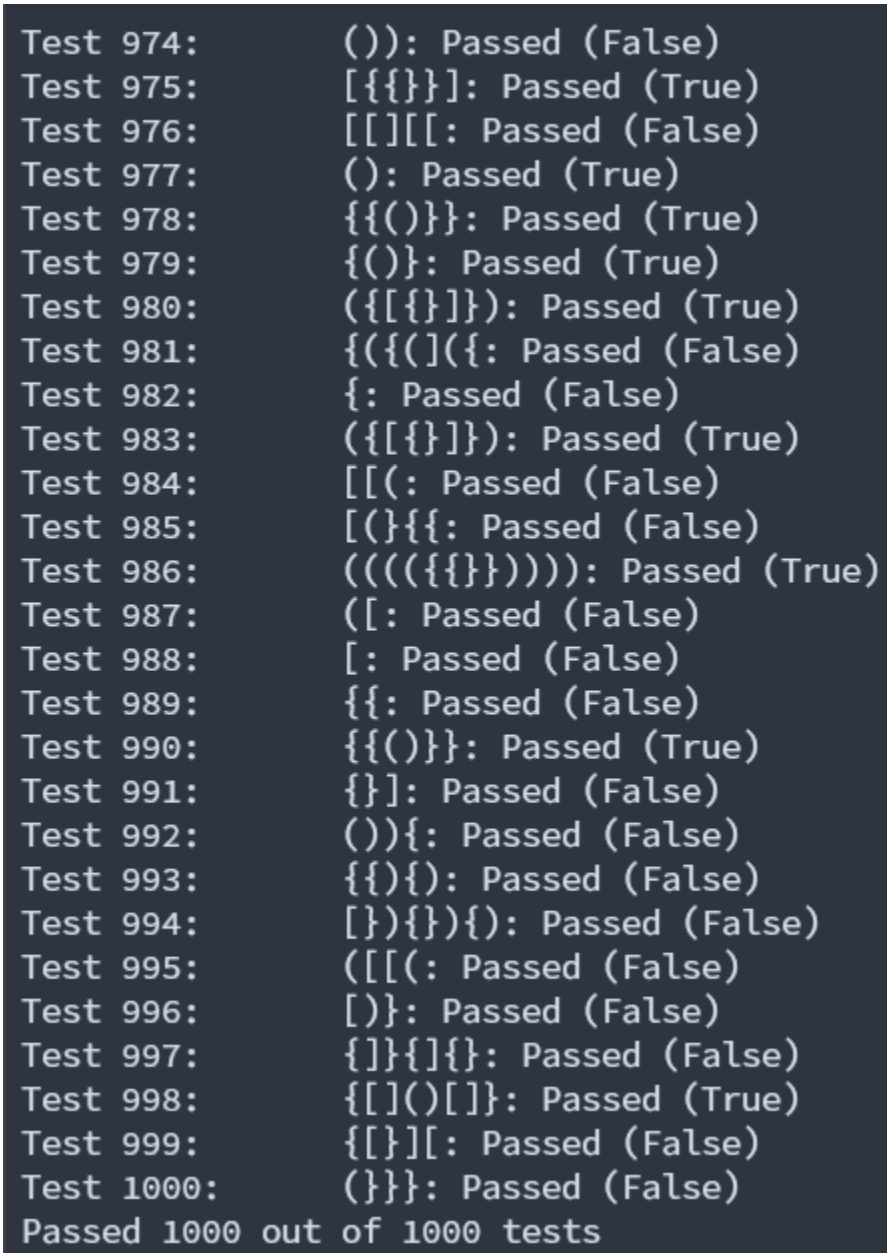
2.5 Limitations

While the algorithm determines perfectly if the brackets within any given algebraic statement are balanced, it does not check if the statement itself is a properly formed algebraic statement. Furthermore, it does not check that brackets on two sides of a given equality are balanced, as it only checks for bracket placement relative to other brackets in the entire input string (i.e. ([0]{=}2) will be evaluated as balanced).

2.6 Testing

Testing is handled by the `tests.py` file, which generates t input strings of up to length l, of which $n/2$ inputs are valid, and the other half are invalid. To generate valid inputs, the generator randomly selects an opening bracket or a closing bracket that matches the last opening bracket until reaching the halfway point of the string length, at which point it iteratively closes all the remaining open brackets. An example output of running the tests is shown in Figure 2.1.

Figure 2.1: Test output



2.6.1 Invalid Inputs

Invalid inputs are a superset of valid inputs, thus the selection of brackets to insert at any given point is expanded to include all invalid closing brackets as well. The generator then selects a random index i to insert random brackets until the max length is reached. Then, the generator checks if the number of opening brackets match the number of closing brackets for each type of bracket. If they match, a random index is selected again to either insert or remove a bracket. This ensures that we also deal with the case that the length of the input string is odd. The generator then provides the input string and whether the string is valid to a checker function, which compares the output of the developed algorithm with the validity of the input string. To run the tests, a user may run `python test.py --tests \{number of tests\} --length \{max length of input strings\}`. The output will show how many tests the algorithm passes, and what the generated input strings were for each test.

2.7 Listings

2.7.1 Algorithm

```python
import re

def main(statement:str):
  return is_balanced(statement)

def is_balanced(statement:str) -> bool:
  bracket_pairing = {
    "{": "}",
    "[": "]",
    "(": ")"
  }
  # fast check
  statement = re.sub(r"[A-Za-z0-9\*\-\+\^\/\=]", "", statement)
  if len(statement) % 2 != 0: return False
  brackets = [bracket for bracket in bracket_pairing.keys()]\
    + [bracket for bracket in bracket_pairing.values()]
  stack = [ ]
  for char in statement:
    if char in brackets:
      if char in bracket_pairing.keys():
        stack.append(char)
      else:
        try:
          if bracket_pairing[stack.pop()] != char:
            return False
        except IndexError:
          return False
  return len(stack) == 0

if __name__ == "__main__":
  res = main(input("Enter an algebraic statement: "))
  print(res)
```

2.7.2 Testing

```python
import argparse
import random
from main import is_balanced

def test_is_balanced(iters: int, max_length:int=10):
  """Tests the is_balanced function over a given number of iterations.

  Args:
    iters (int): number of iterations
  """
  results = []
  for i in range(iters):
    statement, proper = statement_generator(random.randint(1, max_length))
    print(f"Test {i+1}:\t{statement}:", end=" ")
    res = is_balanced(statement)
    if res == proper:
      print(f"Passed ({res})")
    else:
      print(f"Failed: {res} (should be {proper})")
    results.append(res == proper)
  print(f"Passed {results.count(True)} out of {iters} tests")

def statement_generator(length: int):
  """Generates a random algebraic statement of a given length.

  Args:
    length (int): length of the statement

```

```
    Returns:
      str: random algebraic statement
    """
    length //= 2
    bracket_pairing = {
      "{": "}",
      "[": "]",
      "(": ")"
    }
    brackets = [bracket for bracket in bracket_pairing.keys()]\
      + [bracket for bracket in bracket_pairing.values()]
    ret = ""
    state = random.choice([True, False])
    ret += random.choice([bracket for bracket in bracket_pairing.keys()])
    stack = [ret[0]]
    for _ in range(length):
      if state:
        candidates = [b for b in bracket_pairing.keys()]
        if ret[-1] in bracket_pairing.keys():
          candidates += [bracket_pairing[ret[-1]]]
        ret += random.choice(candidates)
        if ret[-1] in bracket_pairing.values():
          stack.pop()
        else:
          stack.append(ret[-1])
      else:
        ret += random.choice(brackets)
    for _ in range(len(stack)):
      if state:
        ret += bracket_pairing[stack.pop()]
      else:
        ret += random.choice(brackets)
    if not state:
      n_additions = random.randint(0, length)
      insertion_index = random.randint(0, len(ret))
      additions = [random.choice(brackets) for _ in range(n_additions)]
      ret = ret[:insertion_index-1] + "".join(additions) + ret[insertion_index+1:len(ret)+1-
    n_additions]
      # count the number of bracket pairs
      bracket_counts = {(k, v): 0 for k, v in bracket_pairing.items()}
      for char in ret:
        for k, v in bracket_pairing.items():
          if char == k:
            bracket_counts[(k, v)] += 1
          elif char == v:
            bracket_counts[(k, v)] -= 1
      # if the statement is potentially balanced, either remove or add a random character.
      if all([count == 0 for count in bracket_counts.values()]):
        # remove a random character
        if len(ret) > 2:
          loc = random.randint(1, len(ret)-1)
          ret = ret[:loc] + ret[loc+1:]
        else:
          ret += random.choice(brackets)
    return (ret, state)

  def main(tests: int=1000, max_length:int=10):
    test_is_balanced(tests, max_length)

  if __name__ == "__main__":
    parser = argparse.ArgumentParser()
    parser.add_argument("-t", "--tests", type=int, default=1000, help="number of tests to run")
    parser.add_argument("-l", "--length", type=int, default=10, help="maximum length of the
    statement")
    args = parser.parse_args()
    main(args.tests, args.length)
```

Question 3

3.1 Problem Statement

Write an array-based implementation of the array list ADT that achieves $O(1)$ time for insertion and removals at the front and at the end of the array list. Your implementation should also provide for an $O(1)$ time `get(i)` method. Assume that overflow does not occur. Explain and justify why your implementation has achieved the stated time complexity requirements.

3.2 Requirements/Specification

The program creates an array list with functions to insert and remove items at the front and back of the array as well as a function `get(i)` to get the element in the array at index `i`.

The function `insertItem(int input, int position)` inserts an item into the array. The argument input will be the item and the argument position will decide where the item will be inserted into the array. If the position is 0, the item will be inserted at the front of the array. If the position is 1, the item will be inserted at the end of the array. For example, `insertItem(15, 1)` will insert the item `15` at the end of the array.

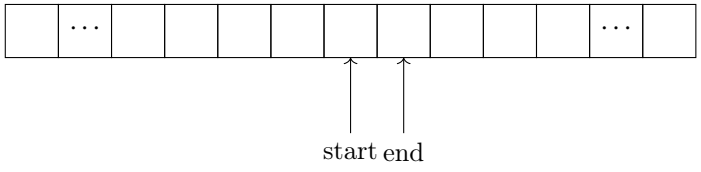
The function `removeItem(int position)` removes an item from the array. The argument position will decide whether the item will be removed from the start or from the end of the array. If the position is 0, the item at the start of the array will be removed. If the position is 1, the item at the end of the array will be removed. For example, `removeItem(0)` will remove the item at the start of the array.

3.3 User Guide

3.4 Structure/Design

The program starts by creating an array with a large size (e.g. `int arr[100];`) and variables start (e.g. `int start = 50;`) and end (e.g. `int end = 51;`) to represent the starting and ending index of the array respectively. The array will be initialised somewhere in the middle of the array with the start index and end index next to each other. The array is between the start and end index of the array which will then expand or contract from there depending on where the items are inserted or removed (at the front or at the back of the array).

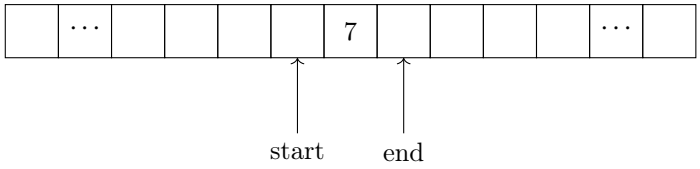
Figure 3.1: Initialising the array



To add an item at the start of the array, the start position of the array will first take in the value of the item, then the start index will shift left (i.e. `start--;`). Similarly, to add an item at the end of the array, the end position of the array will take in the value of the item, then the end index will shift right (i.e. `end++;`). Since the

function does not need to iterate through the array to insert the items, the time complexity for inserting items is $O(1)$.

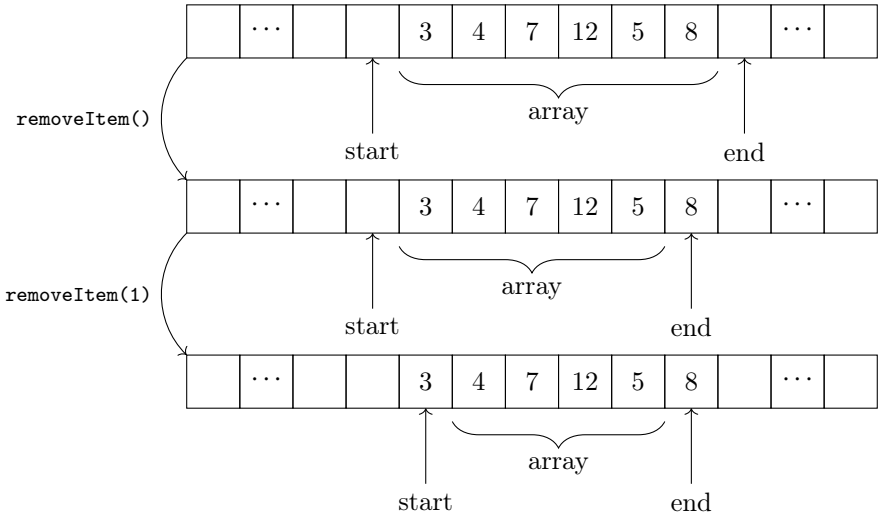
Figure 3.2: Insertion



Even though the problem statement assumes that overflow does not occur, safety measures were put in place to prevent overflowing. If the start index is at the start of the array (i.e. `start == 0`) or the end index is at the end of the array (i.e. `end == 99`), trying to add another item into the array will print "Overflow!"

To remove an item from the start of the array, the start index will simply shift right (i.e. `start++;`), and to remove an item from the end of the array, the end index will simply shift left (i.e. `end--;`). Since the function only shifts the start or end index when removing items and does not iterate through the array, the time complexity for removing items is $O(1)$.

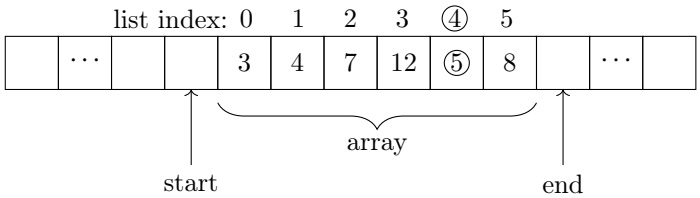
Figure 3.3: Removal of nodes



The array is deemed empty when the start and end index are next to each other. When a function is called to remove another item while the array is empty, it will print "List is empty!".

To get the item at index `i` of the array, the function starts counting at the start of the array (i.e. `arr[start + 1]`) and returns the item at index `i` of the array (i.e. `arr[start + 1 + i]`). Since this function returns the item at the stated index and does not require iteration through the array, the time complexity for this function is $O(1)$.

Figure 3.4: List access example (accessing index 4)



3.5 Limitations

The limitation of this array list ADT is that it has a maximum size depending on the value used during initialization and has a finite number of items that can be added into the array. The function only stops the list from overflowing, but it does not have a solution to overflowing (e.g. increasing the size of the array).

3.6 Testing

Testing is handled by the `main()` function in the program. Initially, the array is empty.

First, the program tests the `insertItem()` function by adding elements to the start and end of the array. Adding an item to an invalid position will output ``‘‘Invalid Input!’’``.

Figure 3.5: insertItem() testing

```
Initial list: []
After adding 10 items to the start of the list: [19,18,17,16,15,14,13,12,11,10]
After adding 10 items to the end of the list: [19,18,17,16,15,14,13,12,11,10,0,2,4,6,8,10,12,14,16,18]
After adding the item '13' to the start of the list: [13,19,18,17,16,15,14,13,12,11,10,0,2,4,6,8,10,12,14,16,18]
After adding the item '14' to the start of the list: [13,19,18,17,16,15,14,13,12,11,10,0,2,4,6,8,10,12,14,16,18,14]
Adding the item '15' to an invalid position:
Invalid Input!
Current list: [13,19,18,17,16,15,14,13,12,11,10,0,2,4,6,8,10,12,14,16,18,14]
```

Next, the program tests the `removeItem()` function by removing an item at the start and at the end of the array. Removing an item at an invalid location will output ``‘‘Invalid Input!’’``.

Figure 3.6: removeItem() testing

```
After removing item at the start of the list: [19,18,17,16,15,14,13,12,11,10,0,2,4,6,8,10,12,14,16,18,14]
After removing item at the end of the list: [19,18,17,16,15,14,13,12,11,10,0,2,4,6,8,10,12,14,16,18]
Removing item at an invalid position:
Invalid Input!
Current list: [19,18,17,16,15,14,13,12,11,10,0,2,4,6,8,10,12,14,16,18]
```

Thirdly, the program tests the `get()` function at index `5`. Using an out of range index will output ``‘‘Index Out Of Range!’’``.

Figure 3.7: get() testing

```
Item at index 5: 14
Getting an item with an index that is out of range (index 20):
Index out of range!
Item at index 20: 0
```

Subsequently, the program will attempt to overflow the array at the start and end. The program will then output “Overflow!” when items cannot be added to that respective position any more.

Figure 3.8: Overflow testing

```
Attempting to overflow at the start of the list:
Overflow!
Overflow!
Current list: [1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,19,18,17,16,15,14,13,12,1
1,10,0,2,4,6,8,10,12,14,16,18]
Attempting to overflow at the end of the list:
Overflow!
Overflow!
Current list: [1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,19,18,17,16,15,14,13,12,1
1,10,0,2,4,6,8,10,12,14,16,18,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0]
```

Lastly, the program will remove every item in the array to empty the array. Then, it will attempt to remove an item from the empty array, which will output ``‘‘List is empty!’’``. This concludes the testing.

Figure 3.9: Empty array removeItem() testing

```
After removing every items in the list: []
Removing an item from an empty list:
List is empty!
Current list: []
```

3.7 Listings

```c
#include <stdio.h>

int arr[100];
int start = 50;
int end = 51;

int insertItem(int input, int position) {   // position: 0 for inserting at the front; 1 for inserting at the end
  if (position == 0) {
    if (start == 0) {
      printf("Overflow!\n");
    }
    else {
      arr[start] = input;
      start--;
    }
  }
  else if (position == 1) {
    if (end == 99) {
      printf("Overflow!\n");
    }
    else {
      arr[end] = input;
      end++;
    }
  }
  else {
    printf("Invalid Input!\n");
  }
}

int removeItem(int position) {              // position: 0 for removing at the front; 1 for removing at the end
  if (end - start == 1) {
    printf("List is empty!\n");
    return 0;
  }
  if (position == 0) {
    start++;
  }
  else if (position == 1) {
    end--;
  }
  else {
    printf("Invalid Input!\n");
  }
}

int get(int i) {                            // get(i) returns the item in the list at index i
  if (i >= 0 && i < end - start - 1) {
    return arr[start + 1 + i];

  }
  else {
    printf("Index out of range!\n");
    return NULL;
  }
}

int printList() {
  printf("[");
  for (int i = 0; i < end - start - 2; i++) {
    printf("%d,", arr[start + 1 + i]);
  }
  if (end - start == 1) {
    printf("]\n");
  }
  else {
```

```
67      printf("%d]\n", arr[end - 1]);
68    }
69  }
70
71  int main() {
72    // initial list
73    printf("Initial list: ");
74    printList();
75
76    // inserting 10 items to the start of the list
77    for (int i = 0; i < 10; i++) {
78      insertItem(i + 10, 0);
79    }
80    printf("After adding 10 items to the start of the list: ");
81    printList();
82
83    // inserting 10 items to the end of the list
84    for (int i = 0; i < 10; i++) {
85      insertItem(i * 2, 1);
86    }
87    printf("After adding 10 items to the end of the list: ");
88    printList();
89
90    // inserting the item '13' at the start of the list
91    insertItem(13, 0);
92    printf("After adding the item '13' to the start of the list: ");
93    printList();
94
95    // inserting the item '14' at the end of the list
96    insertItem(14, 1);
97    printf("After adding the item '14' to the start of the list: ");
98    printList();
99
100   // inserting the item '15' at an invalid position
101   printf("Adding the item '15' to an invalid position:\n");
102   insertItem(15, 2);
103   printf("Current list: ");
104   printList();
105
106   // removing the item at the start of the list
107   removeItem(0);
108   printf("After removing item at the start of the list: ");
109   printList();
110
111   // removing the item at the end of the list
112   removeItem(1);
113   printf("After removing item at the end of the list: ");
114   printList();
115
116   // removing the item at an invalid position
117   printf("Removing item at an invalid position:\n");
118   removeItem(2);
119   printf("Current list: ");
120   printList();
121
122   // get the item at index 5 of the list
123   printf("Item at index 5: %d\n", get(5));
124
125   // get the item at index 20 of the list
126   printf("Getting an item with an index that is out of range (index 20):\n");
127   printf("Item at index 20: %d\n", get(20));
128
129   // attempting to overflow at the start of the list
130   printf("Attempting to overflow at the start of the list:\n");
131   for (int i = 0; i < 42; i++) {
132     insertItem(1, 0);
133   }
134   printf("Current list: ");
135   printList();
136
137   // attempting to overflow at the end of the list
```

```
    printf("Attempting to overflow at the end of the list:\n");
    for (int i = 0; i < 40; i++) {
      insertItem(0, 1);
    }
    printf("Current list: ");
    printList();

    // removing all the items in the list
    for (int i = 0; i < 98; i++) {
      removeItem(1);
    }
    printf("After removing every items in the list: ");
    printList();

    // attempting to remove an item from an empty list
    printf("Removing an item from an empty list:\n");
    removeItem(1);
    printf("Current list: ");
    printList();
}
```

Question 4

4.1 Problem Statement

Write a recursive algorithm to check that a sentence is a palindrome (ignoring blanks, lower case and upper case differences, and punctuation marks, so that "Madam, I'm Adam" is accepted as a palindrome). Analyse the efficiency of your implementation and provided a detailed discussion of its time complexity.

Example 4.1.1

Please enter a sentence: Madam, I'm Adam Check if "Madam, I'm Adam" is a palindrome: True

4.2 Requirements/Specification

This program is supposed to compare the characters in the sentence. First and last, Second and second last etc. If it matches, it is a palindrome. Some assumptions/conditions would be ignoring blanks, lower case, upper case differences, and punctuation marks. Some assumptions/conditions would be ignoring blanks, lower case, upper case differences, and punctuation marks. Empty strings will be considered as a palindrome too.

4.3 User Guide

1. Click on the "Run" button in the IDE to run the program with python. Alternatively, running `python <filename>.py` will run the program.
2. Input a sentence when prompted in the command line interface.
3. The resulting output will show whether the input sentence was a palindrome.

4.4 Structure/Design

The design of the system is that it will remove all punctuations and black spaces in the string then change all uppercase characters to lowercase characters before passing through the `palindrome` function. After the system has recorded the new string, a function for `palindrome` and `isPalindrome` will run to check the string and determine whether it is a palindrome.

For the `palindrome` function, if there is only one character it will return `true`. If the first and last characters do not match, it will return `false`. For more than 2 characters, it will check the middle substring whether the characters match.

For the `isPalindrome` function, if it is an empty string, it will be considered a palindrome and return `true`.

The operation of removing punctuations and blanks, and converting the string to lowercase is $O(n)$, n being the length of the string. As it iterates through the function `palindrome`, it checks if the first and last characters match, hence the time complexity of this function is $O(n)$. The function `isPalindrome` checks if the string is empty, hence the time complexity of the entire algorithm is $O(n)$.

4.5 Limitations

The algorithm assumes an ASCII input, thus input strings with extended UTF-8 encoding may result in erroneous output.

4.6 Testing

From the `main.py` file, users are able to manually input a string they would like to check and if the string is a palindrome, it will return True. However, when the user inputs invalid inputs such as string that is not a palindrome, it will return False.

Figure 4.1: Valid and invalid inputs

```
❯ python main.py
Enter a string: A Man, A Plan, A Canal, Panama
True
```

```
❯ python main.py
Enter a string: 123
False
```

From the `test.py` file, the input strings are generated randomly with 50% being palindromes. The user can set the arguments `-i` and `-l` to set the number of tests and max generated string length (ASCII letters only) respectively. ASCII symbols are generated in between ASCII letters in order to test the filtering capabilities of the algorithm. An example output of running the testing script is shown in Figure 4.2.

Figure 4.2: Running the testing script

```
❯ python test.py -i 10 -v

Test 1: $a#D.o'T/x*i$N>Y'Y(N:i!x!T+o]D+a: Passed (True)
Test 2: [Y.a'i:z@z"i.a"Y: Passed (True)
Test 3: ]J%M'M]z)u:r/r]u^z,M{M!J: Passed (True)
Test 4: ]p@F}P)E(m&V+q+U;D+i?D~y=k`r: Passed (False)
Test 5: "B_D/x#G#s}t/X$a#a#X:t,s~G*x#D*B: Passed (True)
Test 6: "x(N.j.U"v~b-n[M<j.B@s>i]W: Passed (False)
Test 7: #j@r@P$p%m}r_Q/Q@r`m(p(P{r*j: Passed (True)
Test 8: ;M#P+s:D|O[H)O;p>f^O:d:j.j)d(O/f,p(O^H<O!D<s+P"M: Passed (True)
Test 9: "h#d!S&m-G<l[Q=O>s$Y_V|V>Y*s>O;Q%l@G.m;S,d@h: Passed (True)
Test 10:        #z(d: Passed (False)
Passed 10 out of 10 tests
```

4.7 Listings

4.7.1 Algorithm

```
1  def main():
2    # user input for string
3    input_str = input("Enter a string: ")
4    # Output
5    if isPalindrome(input_str):
6      print("True")
7    else:
8      print("False")
9
10 def palindrome(str2, s, e):
11   # If there is only one character
12   if (s == e):
13     return True
14
15   # If first and last characters do not match
16   if (str2[s] != str2[e]):
```

```
    return False

  # for > 2 characters, checking for middle substring
  if (s < e + 1):
    return palindrome(str2, s + 1, e - 1)
  return True

# for empty string, it will be considered as palindrome too
def isPalindrome(input_str):

  # remove all punctuations and blank spaces
  str2 = ''.join(i for i in input_str if i.isalnum())
  # lower uppercase characters
  str2 = str2.lower()
  n = len(str2)

  if n == 0:
    return True
  return palindrome(str2, 0, n - 1)
if __name__ == "__main__":
  main()
```

4.7.2 Testing

```
import argparse
import random
import string

from main import isPalindrome

def string_generator(length: int, is_palindrome: bool):
  half_length = length // 2
  odd = length % 2
  letter = string.ascii_letters
  generated_string = ''.join(random.choice(letter) for i in range(length))
  if is_palindrome:
    half = generated_string[:half_length + odd][::-1]
    generated_string = generated_string[:half_length + odd] + half
  elif generated_string[0].lower() == generated_string[-1].lower():
    generated_string += random.choice([i for i in letter if i.lower() != generated_string[0].
  lower()])
  elif len(generated_string) == 1:
    generated_string += random.choice([i for i in letter if i.lower() != generated_string[0].
  lower()])
  symbols = string.punctuation
  generated_string = ''.join(random.choice(symbols) + i for i in generated_string)
  return generated_string

def test_is_palindrome(iters: int, max_length: int=10, verbose: bool=False, hackerman: bool=
  False):
  """Tests the isPalindrome function over a given number of iterations.

  Args:
    iters (int): number of iterations
  """
  results = []
  if hackerman:
    end = '\x1b[2K\r'
  else:
    end = "\n"
  i = 0
  while True:
    test_state = random.choice([True, False])
    generated_string = string_generator(random.randint(1, max_length), test_state)
    res = isPalindrome(generated_string)
    p = ""
    if verbose or res != test_state:
      print(f"{end}Test {i+1}:\t{generated_string}:", end=" ")
    if res == test_state:
```

```
        p = f"Passed ({res})" if verbose else ""
      else:
        p = f"Failed: {res} (should be {test_state})"
      if len(p):
        print(f"{p:<50}", end="")
      results.append(res == test_state)
      i += 1
      if i == iters:
        break
    print(f"{end}Passed {results.count(True)} out of {iters} tests")

if __name__ == "__main__":
    parser = argparse.ArgumentParser(description="Test the isPalindrome function")
    parser.add_argument("-i", "--iters", type=int, default=100000, help="number of iterations")
    parser.add_argument("-l", "--length", type=int, default=25, help="maximum length of the
    string")
    parser.add_argument("-v", "--verbose", action="store_true", help="verbose mode")
    parser.add_argument("-H", "--hackerman", action="store_true", help="hackerman mode")
    args = parser.parse_args()
    test_is_palindrome(args.iters, args.length, args.verbose, args.hackerman)
```

Question 5

5.1 Problem Statement

(a) Explain the meaning of stability in a sorting algorithm.

(b) Explain a situation why stability in sorting is desired.

(c) State which algorithms are stable. Prove it with an implementation of a stable and an unstable sorting algorithm. Discuss in detail your justification.

i. Selection sort

ii. Insertion sort

iii. Quick sort

Solution:

(a) Stability refers to whether a sorting algorithm respects the relative positions of elements with equal values during the sort. An unstable sorting algorithm would not preserve the order of elements with equal values.

(b) One situation could be where there is a line of people queueing who need to be ordered by age. If there are two people standing in line whoa re the same age, a stable sort will ensure that the order of the person who arrived first will stay the same.

(c) All three algorithms can have stable and unstable implementations.

■

5.2 Requirements/Specification

The program implements python code for selection, insertion and quick sort algorithms. In order to clearly demonstrate the stability of each algorithm, the program will accept an unsorted list of 2-element tuples, where the first element is a unique identifier for the tuple and the second element is the value that is compared against other values for the sorting algorithms. Some example inputs are: `[("a", 3), ("b", 3)]`, `[["a", 3], ["b", 3]]`, and `[[123, 3], [456, 3]]`.

5.3 User Guide

The program can be run from the command line with `python <filename>.py`. Since the assignment requires a proof by implementation, the input data has been pre-defined in the script. If a user would like to input their own data, they may do so by changing the following variables accordingly.

- `data_selection` – for selection sort
- `data_insertion` – for insertion sort
- `data_quick` – for quick sort

5.4 Structure/Design

The code for all 3 sorting algorithms are contained in functions, so for a user to see the sorting processes, they would have to call each sorting algorithm's respective functions. All 3 sorts will print the elements in the array during each iteration of the sort.

5.5 Limitations

As the program uses tuples to demonstrate the stability of the algorithms, the program will not take in any other formats like simple lists as input. For instance, `[26, 54, 56, 32]` and `["a", "b", "c"]` are not valid inputs.

5.6 Testing

The stability of the algorithm may be demonstrated by showing the unsorted input array and how it is iteratively sorted until the algorithm outputs the sorted array. For the arrays used to test the algorithms, two elements are declared with equal value, with the first of the pair having a 'first' identifier, and the second having a 'second' identifier. This will allow users to track the relative positions of these two elements of equal value. The output of the python script is shown in Figure 5.1.

Figure 5.1: Outputs of stable and unstable variants of the sorting algorithms

```
> python .\question_5.py
=====Stable Selection Sort=====
[('', 4), ('', 5), ('first', 3), ('second', 3)]
[('first', 3), ('', 5), ('', 4), ('second', 3)]
[('first', 3), ('second', 3), ('', 4), ('', 5)]
[('first', 3), ('second', 3), ('', 4), ('', 5)]
[('first', 3), ('second', 3), ('', 4), ('', 5)]
=====Unstable Selection Sort=====
[('', 4), ('', 5), ('first', 3), ('second', 3)]
[('second', 3), ('', 5), ('first', 3), ('', 4)]
[('second', 3), ('first', 3), ('', 5), ('', 4)]
[('second', 3), ('first', 3), ('', 4), ('', 5)]
[('second', 3), ('first', 3), ('', 4), ('', 5)]
=====Stable Insertion Sort=====
[('', 4), ('', 5), ('first', 3), ('second', 3)]
[('', 4), ('', 5), ('first', 3), ('second', 3)]
[('first', 3), ('', 4), ('', 5), ('second', 3)]
[('first', 3), ('second', 3), ('', 4), ('', 5)]
[('first', 3), ('second', 3), ('', 4), ('', 5)]
=====Unstable Insertion Sort=====
[('', 4), ('', 5), ('first', 3), ('second', 3)]
[('', 4), ('', 5), ('first', 3), ('second', 3)]
[('first', 3), ('', 4), ('', 5), ('second', 3)]
[('second', 3), ('first', 3), ('', 4), ('', 5)]
[('second', 3), ('first', 3), ('', 4), ('', 5)]
=====Stable Quick Sort=====
[('first', 3), ('', 5), ('', 4), ('second', 3)]
[('first', 3), ('', 5), ('', 4), ('second', 3)]
[('first', 3), ('second', 3), ('', 4), ('', 5)]
[('first', 3), ('second', 3), ('', 4), ('', 5)]
=====Unstable Quick Sort=====
[('first', 3), ('', 5), ('', 4), ('second', 3)]
[('second', 3), ('first', 3), ('', 4), ('', 5)]
[('second', 3), ('first', 3), ('', 4), ('', 5)]
```

5.7 Listings

```
#Function for selection sort (Stable)
def selectionSort(array, size, stable=True):
  for ind in range(size):
    min_index = ind

    if stable:
      for j in range(ind + 1, size):
        # select the minimum element in every iteration
        if array[j][1] < array[min_index][1]:
          min_index = j
    else:
      for j in range(size - 1, ind, -1):
        if array[j][1] < array[min_index][1]:
          min_index = j
    # swapping the elements to sort the array
    (array[ind], array[min_index]) = (array[min_index], array[ind])
    print(array)

# Function to do insertion sort (Stable)
def insertionSort(arr, stable=True):
  # Traverse through 1 to len(arr)
  for i in range(1, len(arr)):

    key = arr[i]
    # Move elements of arr[0..i-1], that are
    # greater than key, to one position ahead
    # of their current position
    j = i-1
    if stable:
      while j >= 0 and key[1] < arr[j][1]:
        arr[j + 1] = arr[j]
        j -= 1
      arr[j + 1] = key
    else:
      while j >= 0 and key[1] <= arr[j][1]:
        arr[j + 1] = arr[j]
        j -= 1
      arr[j + 1] = key
    print(arr)
  return arr

# Python program for implementation of Quicksort Sort (Stable)
# Function to find the partition position
def partition(array, low, high, stable=True):

  # choose the rightmost element as pivot
  if stable:
    pivot = array[high][1]
  else:
    pivot = array[low][1]

  # pointer for greater element
  i = low - 1

  # traverse through all elements
  # compare each element with pivot
  for j in range(low, high):
    if (stable and array[j][1] <= pivot) or (not stable and array[j][1] < pivot):
      # If element smaller than pivot is found
      # swap it with the greater element pointed by i
      i += 1
      # Swapping element at i with element at j
      (array[i], array[j]) = (array[j], array[i])
      print(array)
  # Swap the pivot element with the greater element specified by i
  (array[i + 1], array[high]) = (array[high], array[i + 1])
  # Return the position from where partition is done
  return i + 1
```

```
69
70  # function to perform quicksort
71  def quickSort(array, low, high, stable=True):
72    if low < high:
73
74      # Find pivot element such that
75      # element smaller than pivot are on the left
76      # element greater than pivot are on the right
77      pi = partition(array, low, high, stable)
78
79      # Recursive call on the left of pivot
80      quickSort(array, low, pi - 1)
81
82      # Recursive call on the right of pivot
83      quickSort(array, pi + 1, high)
84
85  data_selection = [("", 4), ("", 5), ("first", 3), ("second", 3)]
86  #print("Unsorted Array: ", data_selection)
87  print("=====Stable Selection Sort=====")
88  print(data_selection)
89  size = len(data_selection)
90  selectionSort(data_selection, size)
91
92  data_selection = [("", 4), ("", 5), ("first", 3), ("second", 3)]
93  print("=====Unstable Selection Sort=====")
94  size = len(data_selection)
95  print(data_selection)
96  selectionSort(data_selection, size, False)
97
98  print("=====Stable Insertion Sort=====")
99  data_insertion = [("", 4), ("", 5), ("first", 3), ("second", 3)]
100 print(data_insertion)
101 print(insertionSort(data_insertion))
102
103 print("=====Unstable Insertion Sort=====")
104 data_insertion = [("", 4), ("", 5), ("first", 3), ("second", 3)]
105 print(data_insertion)
106 print(insertionSort(data_insertion, False))
107
108 print("=====Stable Quick Sort=====")
109 data_quick = [("first", 3), ("", 5), ("", 4), ("second", 3)]
110 print(data_quick)
111 quickSort(data_quick, 0, len(data_quick) - 1)
112 print(data_quick)
113
114 print("=====Unstable Quick Sort=====")
115 data_quick = [("first", 3), ("", 5), ("", 4), ("second", 3)]
116 print(data_quick)
117 quickSort(data_quick, 0, len(data_quick) - 1, False)
118 print(data_quick)
```