Priority Queue and its Application

Bingcheng HU

516021910219

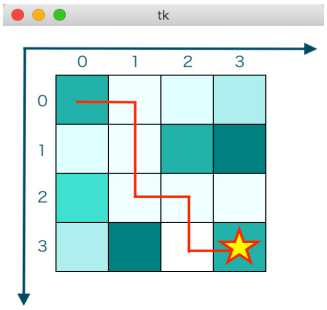
VE281

Motivation

This project will give you experience in implementing priority queues using C++. You will also empirically study the efficiency of different implementations.

Project Overview

In this project, you are given a rectangular grid of cells. Each cell has a number indicating its weight, which is the cost of passing through the cell (In Fig.1, the color of the cell symbolizes its weight). You can assume the weights are positive integers. The input will give you the starting coordinate and the ending coordinate. As figure 1 shows, your task is to use priority queue to find the shortest path from the source cell to the ending cell.



Input

You will read from the standard input. (For the ease of testing, you can write each test case in

a file and then use Linux file redirection function “<” to read from the file.)

The format of the input is as follows:

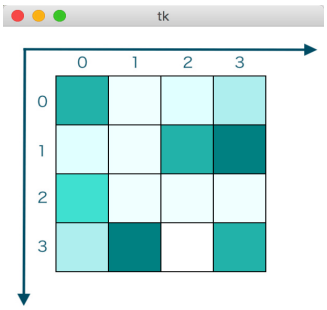
```
<width m>
<height n>
<Start x> <Start y>
<End x> <End y>
<W(0,0)> <W(1,0)> ... <W(m-1,0)>
...
<W(0,n-1)> <W(1,n-1)> ... <W(m-1,n-1)>
```

The first and the second line give the width m and the height n of the grid, respectively. They are positive integers. The third and the fourth line give the starting coordinate and the ending coordinate, respectively. They are non-negative integers within the valid range. The upper left corner has the coordinate (0, 0). The x-coordinate increases from left to right and the y-coordinate increases from top to bottom. The remaining lines give the weights of the cells in the grid. They represent a two dimensional array of n rows and m columns, as shown above. $W(i,j)$ is the weight of the cell at coordinate (i,j) $(0 \leq i \leq m-1, 0 \leq j \leq n-1)$. The weights are all positive integers.

For example, we have an input:

```
4
4
00
33
5123
2156
4111
3605
```

It specifies a grid of width 4 and height 4. We want to find the shortest path form point (0, 0), which has weight 5, to the point (3, 3), which has weight 5. With `draw boxes.py` you can draw the figure below.



Algorithm

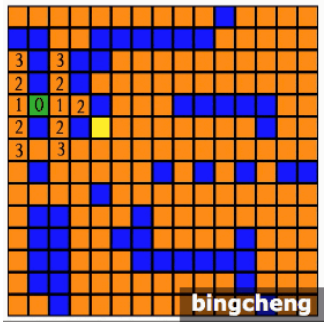
Below is the pseudo-code of the algorithm:

```
Let PQ be a priority queue;
start_point.pathcost = start_point.cellweight;
Mark start_point as reached;
PQ.enqueue(start_point);
while(PQ is not empty) {
    C = PQ.dequeueMin(); // The key is cell's pathcost
    for each neighbor N of C that has not been reached {
```

```
        N.pathcost = C.pathcost + N.cellweight;
        mark cell N as reached;
        mark the predecessor of N as C;
        // I.e., N is reached from C.
        if(end_point == N) {
            trace_back_path(); // Trace and print the path
                               // through predecessor info
            return;
        }
        else PQ.enqueue(N);
    }
}
```

start pin

end pin



Command Line Input

Your program should be named main. It should take the following case-sensitive command-line options:

1. -i, --implementation: a required option. It changes the priority queue implementation at runtime. An argument should immediately follow that option, being BINARY, UNSORTED, or FIBONACCI to indicate the implementation (see Section VII Implementations of Priority Queues).
2. -v, --verbose: an optional flag that indicates the program should print additional outputs (see Section VI Output).

Examples of legal command lines:

- ./main --implementation BINARY < infile.txt
- ./main --verbose -i UNSORTED < infile.txt > outfile.txt
- ./main --verbose -i FIBONACCI

Note that the first two calls read the input stored in the infile.txt. The third call reads from the standard input.

Examples of illegal command lines:

- ./main < infile.txt No implementation is specified. Implementation is a required option.
- ./main --implementation BINARY infile.txt

You are not using input redirection "<" to read from the file infile.txt.

We require you to realize the above requirement using the function **getopt_long**. See its usage and an example at http://www.gnu.org/software/libc/manual/html_node/Getopt.html#Getopt

In testing your program, we will supply correct command-line inputs, but you are encouraged to detect and handle errors in the command-line inputs.

Three Heap Algorithm

1. Unsorted heap

operator	time complexity
enqueue	O(1)
dequeue min	O(N)
get min	O(N)

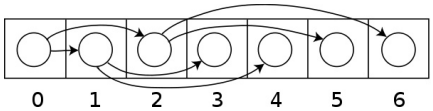
Here we can use `std::min_element` and `std::distance` as here says. Below is an example.

```
#include <algorithm>
#include <iostream>
#include <vector>
int main(){
    std::vector<int> v{3, 1, 4, 1, 5, 9};
    std::vector<int>::iterator result = std::min_element(std::begin(v), std::end(v));
    std::cout << "min element at: " << std::distance(std::begin(v), result);
}
```

2. Binary Heap

operator	time complexity
enqueue	O(logN)
dequeue min	O(logN)
get min	O(1)

A small complete binary tree stored in an array is arranged as below as an array.

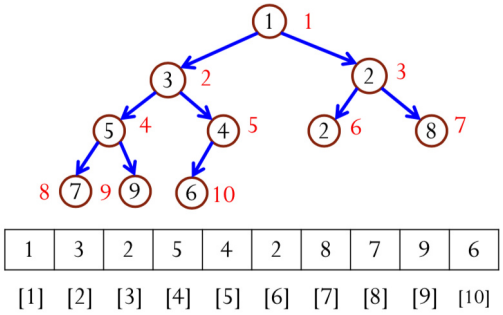


According to the courseware, we know:

1. The first element is stored at index 1.
2. A node at index i ($i \neq 1$) has its parent at index
3. Assume the number of nodes is n. A node at index i ($2i \leq n$) has its left child at $2i$. If $2i > n$, it has no left child.

4. A node at index i ($2i + 1 \leq n$) has its right child at $2i + 1$.

   If $2i + 1 > n$, it has no right child.



To make the first element to be stored at index 1 instead of index 0, we add `data.push_back(TYPE())` at the beginning of the constructor, such that we can make the program much simple and easy to write.

caution!

Persucode of `dequeueMin` is shown as below.

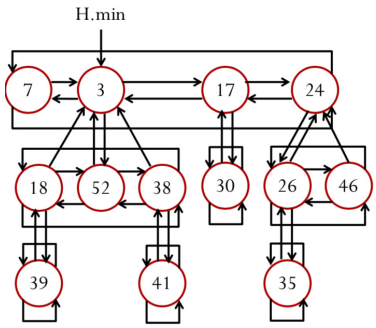
```
Item minHeap::dequeueMin() {
  swap(heap[1], heap[size--]);
  percolateDown(1);
  return heap[size+1];
}
```

Here `size--` means we need to decrease `size` by 1 at function `percolateDown`.

3. Fibonacci Heap

operator	time complexity
enqueue	O(1)
dequeue min	O(logN)
get min	O(1)

A Fibonacci heap is a collection of trees satisfying the minimum-heap property, that is, the key of a child is always greater than or equal to the key of the parent.



According to `Pseudo-code for Fibonacci heap` at appendix, we can find that fot Fibonacci heap we need `n, min, degree, key, child, parent`.

> *n stores the number of elements in the heap*

> *min refers to the minimal element in the heap*

so we can constract this structure as private part.

```
    struct node
    {
        TYPE val;
        typename std::list<fib_node> child;
        int degree=0;
    };
    typename std::list<fib_node> parent;
    typename std::list<fib_node>::iterator min;
    int n=0;
    TYPE empty_fib=TYPE();
```

The Efficiency of Different Implementations

Algorithm

You can check `gen_rand.cpp` and `performance.cpp` at appendix.

Part of tha makefile is shown below. you can run `$make gen` then `$make per` to test it;

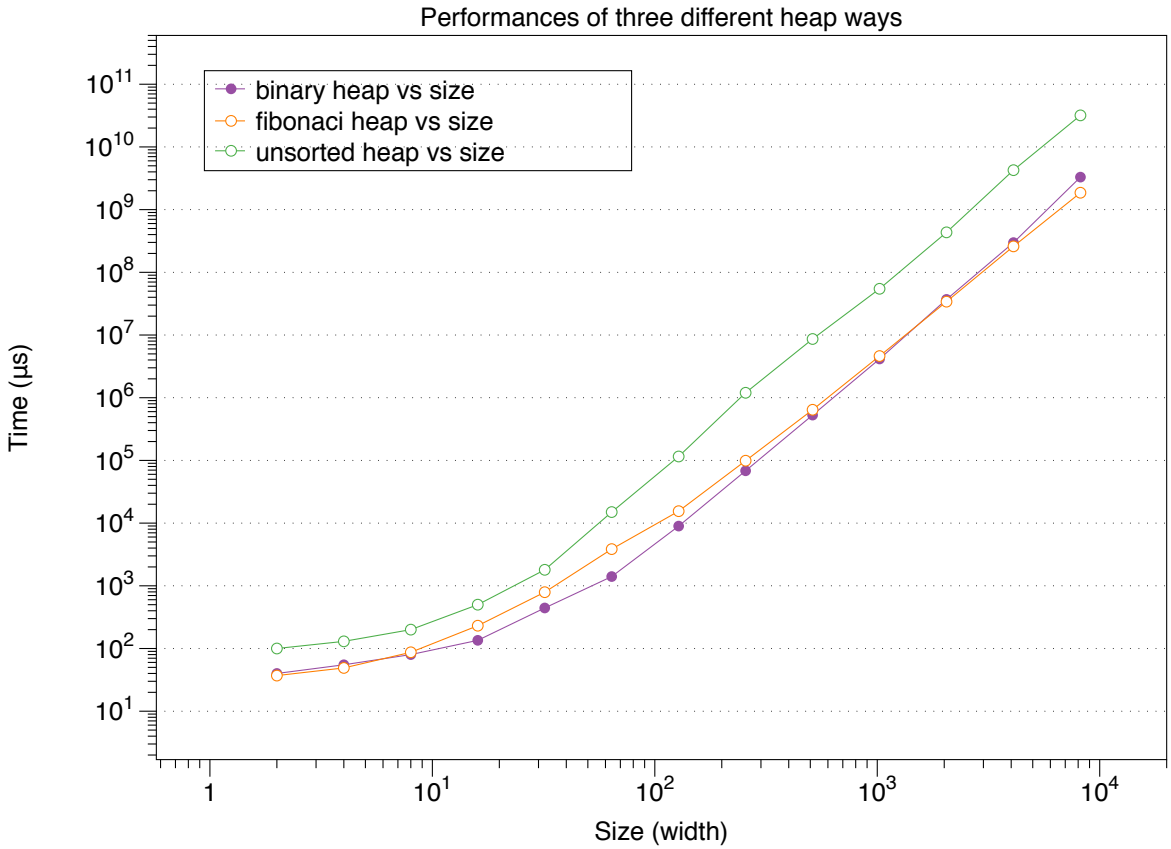
```
gen: gen_rand.cpp
    g++ -std=c++11 -O2 -o gen_rand_matrix gen_rand.cpp
    ./gen_rand_matrix > matrix.in

per: performance.cpp
    g++ -std=c++11 -O3 -o perform performance.cpp
    ./perform < matrix.in > out.csv
```

The out put of `per` is `out.csv` and it's shown below

```
size    binary heap fibonaci heap   unsorted heap
2   40  37  100
4   55  49  130
8   80  87  200
16  135 231 500
32  443 791 1800
64  1405    3849    15000
128 8964    15502   115502
256 68323   98871   1198871
512 528216  642127  8642127
1024    4149496 4618324 54618324
2048    36979493    34048446    434048446
4096    297947134   259392634   4259392634
8192    3297947134  1859392634  31859392634
```

Result Analysis

With these data, we can draw the graph below with DataGraph, and you can check this software at appendix.



Combining the output and figure above, we can conclude the following points.

1. For each priority queue, the run time increases as the size of the grid increases.
2. binary_heap, fib_heap have the similar running speed and the result satisfy the theory that they have the time complexity of O(log n) in enqueing, finding minimum and dequeing minimum.
3. Unsorted_heap is slower than those three queues, because it have the time complexity of O(n) in finding minimum and dequeing minimum.
4. when the table size is very small, binary heap is faster than fib heap, while when size is beteew 10×10 and $10^3 \times 10^3$, fib heap is faster. But when size od gride is latger than 10^3, binary heap is faster again.

Appendix

Example of Parsing Long Options with `getopt_long`

1. `getopt_long`

```
c = getopt_long (argc, argv, "vti:", long_options, &option_index);
```

`vti:` means `-v` is single option while `-i` cannot show up alone, it should be like `-i FLAG_AFTER`, and in this program if we run some commands in the terminal:

```
1 $make op
```

```
g++ -std=c++11 -O3 -o getop_test getop_test.cpp
$make test
./getop_test --implementation BINARY
option -i with value `BINARY'
verbose flag is disabled
./getop_test -i BINARY
option -i with value `BINARY'
verbose flag is disabled
./getop_test --verbose -i UNSORTED
option -i with value `UNSORTED'
verbose flag is set
./getop_test --v -i UNSORTED
option -i with value `UNSORTED'
verbose flag is set
./getop_test --verbose -i FIBONACCI
option -i with value `FIBONACCI'
verbose flag is set
./getop_test -test -i FIBONACCI
option -t
getop_test: invalid option -- e
getop_test: invalid option -- s
option -t
option -i with value `FIBONACCI'
verbose flag is disabled
```

2. get_long_opt_test.cpp

```
#include <iostream>
#include <getopt.h>

using namespace std;

/* Flag set by ‘--verbose’. */
static int verbose_flag;

int main (int argc, char **argv)
{
  int c;
  string argument;
  while (1)
    {
      static struct option long_options[] =
        {
          /* These options set a flag. */
          {"verbose", no_argument,       &verbose_flag, 1},
          {"brief",   no_argument,       &verbose_flag, 0},
          /* These options don’t set a flag.
             We distinguish them by their indices. */
          {"test",              no_argument,       0, 't'},
          {"implementation",    required_argument,       0, 'i'},
```

```
        {0, 0, 0, 0}
      };
    /* getopt_long stores the option index here. */
    int option_index = 0;

    c = getopt_long (argc, argv, "vti:",
                     long_options, &option_index);

    /* Detect the end of the options. */
    if (c == -1)
      break;

    switch (c)
      {
      case 0:
        /* If this option set a flag, do nothing else now. */
        if (long_options[option_index].flag != 0)
          break;
        printf ("option %s", long_options[option_index].name);
        if (optarg)
          printf (" with arg %s", optarg);
        printf ("\n");
        break;

      case 't':
        printf ("option -t\n");
        break;

      case 'i':
        printf ("option -i with value `%s'\n", optarg);
        argument = optarg;
        break;

      case '?':
        /* getopt_long already printed an error message. */
        break;

      default:
        abort ();
      }
  }

/* Instead of reporting ‘--verbose’
   and ‘--brief’ as they are encountered,
   we report the final status resulting from them. */
if (verbose_flag)
  puts ("verbose flag is set");
else puts("verbose flag is disabled");

```

```
  /* Print any remaining command line arguments (not options). */
  if (optind < argc)
    {
      printf ("non-option ARGV-elements: ");
      while (optind < argc)
        printf ("%s ", argv[optind++]);
      putchar ('\n');
    }

  exit (0);
}
```

3. Makefile

```
op: getop_test.cpp
    g++ -std=c++11 -O3 -o getop_test getop_test.cpp

test:
    ./getop_test --implementation BINARY
    ./getop_test -i BINARY
    ./getop_test --verbose -i UNSORTED
    ./getop_test --v -i UNSORTED
    ./getop_test --verbose -i FIBONACCI
    ./getop_test -test -i BINARY
```

draw boxes.py

```
#!/usr/bin/env python
# -*- coding: utf-8 -*-

from tkinter import *
def drawboard(board,colors,startx=50,starty=50,cellwidth=50):
    width=2*startx+len(board)*cellwidth
    height=2*starty+len(board)*cellwidth
    canvas.config(width=width,height=height)
    for j  in range(len(board)):
        for i in range(len(board)):

            index=board[j][i]
            color=colors[6-index]
            cellx=startx+i*50
            celly=starty+j*50
            canvas.create_rectangle(cellx,celly,cellx+cellwidth,celly+cellwidth,
                fill=color,outline="black")
    canvas.update()
root=Tk()
canvas=Canvas(root,bg="white")
canvas.pack()
board=[ [5,1,2,3],
        [2,1,5,6],
```

```
        [4,1,1,1],
        [3,6,0,5]]
colors=['teal','lightseagreen','turquoise','paleturquoise','lightcyan','azure','white']
drawboard(board,colors)
root.mainloop()
```

priority_queue.h

```
#ifndef PRIORITY_QUEUE_H
#define PRIORITY_QUEUE_H

#include <functional>
#include <vector>

// OVERVIEW: A simple interface that implements a generic heap.
//           Runtime specifications assume constant time comparison and
//           copying. TYPE is the type of the elements stored in the priority
//           queue. COMP is a functor, which returns the comparison result of
//           two elements of the type TYPE. See test_heap.cpp for more details
//           on functor.
template<typename TYPE, typename COMP = std::less<TYPE> >
class priority_queue {
public:
  typedef unsigned size_type;

  virtual ~priority_queue() {}

  // EFFECTS: Add a new element to the heap.
  // MODIFIES: this
  // RUNTIME: O(n) - some implementations *must* have tighter bounds (see
  //          specialized headers).
  virtual void enqueue(const TYPE &val) = 0;

  // EFFECTS: Remove and return the smallest element from the heap.
  // REQUIRES: The heap is not empty.
  //           Note: We will not run tests on your code that would require it
  //           to dequeue an element when the heap is empty.
  // MODIFIES: this
  // RUNTIME: O(n) - some implementations *must* have tighter bounds (see
  //          specialized headers).
  virtual TYPE dequeue_min() = 0;

  // EFFECTS: Return the smallest element of the heap.
  // REQUIRES: The heap is not empty.
  // RUNTIME: O(n) - some implementations *must* have tighter bounds (see
  //          specialized headers).
  virtual const TYPE &get_min() const = 0;

  // EFFECTS: Get the number of elements in the heap.
```

```
  // RUNTIME: O(1)
  virtual size_type size() const = 0;

  // EFFECTS: Return true if the heap is empty.
  // RUNTIME: O(1)
  virtual bool empty() const = 0;

};

#endif //PRIORITY_QUEUE_H

```

fib_heap.h

```
//
//  fib_heap.h
//  VE281 2018 Autumn
//  project3
//  Bingcheng HU
//
#ifndef FIB_HEAP_H
#define FIB_HEAP_H

#include <algorithm>
#include <cmath>
#include <list>
#include "priority_queue.h"

// OVERVIEW: A specialized version of the 'heap' ADT implemented as a
//           Fibonacci heap.
template<typename TYPE, typename COMP = std::less<TYPE> >
class fib_heap: public priority_queue<TYPE, COMP> {
public:
    typedef unsigned size_type;

    // EFFECTS: Construct an empty heap with an optional comparison functor.
    //          See test_heap.cpp for more details on functor.
    // MODIFIES: this
    // RUNTIME: O(1)
    fib_heap(COMP comp = COMP());

    // EFFECTS: Add a new element to the heap.
    // MODIFIES: this
    // RUNTIME: O(1)
    virtual void enqueue(const TYPE &val);

    // EFFECTS: Remove and return the smallest element from the heap.
```

```
34      // REQUIRES: The heap is not empty.
35      // MODIFIES: this
36      // RUNTIME: Amortized O(log(n))
37      virtual TYPE dequeue_min();
38
39      // EFFECTS: Return the smallest element of the heap.
40      // REQUIRES: The heap is not empty.
41      // RUNTIME: O(1)
42      virtual const TYPE &get_min() const;
43
44      // EFFECTS: Get the number of elements in the heap.
45      // RUNTIME: O(1)
46      virtual size_type size() const;
47
48      // EFFECTS: Return true if the heap is empty.
49      // RUNTIME: O(1)
50      virtual bool empty() const;
51
52  private:
53      // Note: compare is a functor object
54      COMP compare;
55
56  private:
57      // Add any additional member functions or data you require here.
58      // You may want to define a strcut/class to represent nodes in the heap and a
59      // pointer to the min node in the heap.
60      struct Node{
61          TYPE key;
62          unsigned int degree;
63          Node *child;
64          Node *parent;
65          Node *left;
66          Node *right;
67          Node(TYPE t_value=TYPE()):
68          key(t_value),parent(NULL),child(NULL),
69          left(this),right(this),degree(0){}
70      };
71      unsigned int Node_count;
72      Node *min;
73      std::vector<Node*> root;
74      TYPE empty_fib=TYPE();
75      virtual void Insert2left(Node *origin_node, Node *new_node);
76      virtual void Fibonacci_Heap_Link(Node *y,Node *x);
77      virtual void Consolidate();
78
79  };
80
81  // Add the definitions of the member functions here. Please refer to
82  // binary_heap.h for the syntax.
```

```
83
84  template<typename TYPE, typename COMP>
85  void fib_heap<TYPE, COMP> ::Insert2left(Node *origin_node, Node *new_node) {
86      if(origin_node!=NULL){
87          new_node->left->right=new_node->right;
88          new_node->right->left=new_node->left;
89          origin_node->right->left=new_node;
90          new_node->right=origin_node->right;
91          origin_node->right=new_node;
92          new_node->left=origin_node;
93          new_node->parent=origin_node->parent;
94          if(origin_node->parent!=NULL) origin_node->parent->degree+=1;
95      }
96  }
97
98
99  template<typename TYPE, typename COMP>
100 void fib_heap<TYPE, COMP> ::Fibonacci_Heap_Link(Node *y,Node *x){
101     unsigned int id;
102     for(int i=0;i<root.size();i++){
103         if(root[i]==y) id=i;
104     }
105     Node *N=root[id];
106     root[id]=root[root.size()-1];
107     root.pop_back();
108     if(x->child==NULL){
109         x->degree+=1;
110         x->child=N;
111         N->parent=x;
112         N->left->right=N->right;
113         N->right->left=N->left;
114         N->left=N;
115         N->right=N;
116     }
117     else Insert2left(x->child,y);
118 }
119
120 template<typename TYPE, typename COMP>
121 void fib_heap<TYPE, COMP> ::Consolidate() {
122     int root_size = Node_count;
123     std::vector<Node*> A(root_size,NULL);
124     for(int i=0; i<root.size(); ++i){
125         Node *x=root[i];
126         unsigned int d=x->degree;
127         while(A[d]!=NULL){
128             Node *y=A[d];
129             if(compare(y->key,x->key)){
130                 Node *N=x;
131                 x=y;
```

```
                y=N;
            }
            Fibonacci_Heap_Link(y,x);
            A[d]=NULL;
            d++;
        }
        A[d]=x;
    }
    this->min=NULL;
    for(int j=0;j<root.size();j++){
        Node *t=root[j];
        if(this->min==NULL) this->min=root[j];
        else if(compare( t->key,this->min->key))
            this->min=root[j];
    }
}

template<typename TYPE, typename COMP>
fib_heap<TYPE, COMP> ::fib_heap(COMP comp) {
    this->Node_count=0;
    compare = comp;
    this->min=NULL;
}

template<typename TYPE, typename COMP>
void fib_heap<TYPE, COMP> :: enqueue(const TYPE &val) {
    Node *N=new Node(val);
    N->degree=0;
    N->child=NULL;
    N->parent=NULL;
    if(this->min==NULL){
        root.push_back(N);
        this->min=N;
        N->right=N;
        N->left=N;
    }
    else{
        root.push_back(N);
        Insert2left(min,N);
        if(compare(N->key,this->min->key)) this->min=N;
    }
    this->Node_count+=1;
};


template<typename TYPE, typename COMP>
TYPE fib_heap<TYPE, COMP> :: dequeue_min(){
    TYPE key_out = min->key;
    Node *mid_node=this->min;
```

```
181     if(mid_node!=NULL){
182         if(mid_node->child!=NULL){
183             Node *new_mid=mid_node->child;
184             do{
185                 root.push_back(new_mid);
186                 new_mid->parent=NULL;
187                 new_mid=new_mid->right;
188             }while(new_mid!=mid_node->child);
189             new_mid->left->right=mid_node->right;
190             mid_node->right->left=new_mid->left;
191             new_mid->left=mid_node->left;
192             mid_node->left->right=new_mid;
193         }
194         // delete mid_node;
195         unsigned int id;
196         for(int i=0;i<root.size();i++){
197             if(root[i]==mid_node) id=i;
198         }
199 
200 
201         root.erase(root.begin()+id);
202         // delete mid_node;
203         this->Node_count-=1;
204         if(this->Node_count==0)this->min=NULL;
205         else Consolidate();
206     }
207     return key_out;
208 };
209 
210 template<typename TYPE, typename COMP>
211 const TYPE &fib_heap<TYPE, COMP> :: get_min() const{
212     if(this->empty())
213     {
214         return empty_fib;
215     }
216     return min->key;
217 };
218 
219 template<typename TYPE, typename COMP>
220 unsigned fib_heap<TYPE, COMP> :: size() const {
221     return Node_count;
222 }
223 
224 template<typename TYPE, typename COMP>
225 bool fib_heap<TYPE, COMP> :: empty() const {
226     return this->size()==0;
227 }
228 
229 #endif //FIB_HEAP_H
```

unsorted_heap.h

```
//
//  unsorted_heap.h
//  VE281 2018 Autumn
//  project3
//  Bingcheng HU
//
#ifndef UNSORTED_HEAP_H
#define UNSORTED_HEAP_H

#include <algorithm>
#include "priority_queue.h"

// OVERVIEW: A specialized version of the 'heap' ADT that is implemented with
//           an underlying unordered array-based container. Every time a min
//           is required, a linear search is performed.
template<typename TYPE, typename COMP = std::less<TYPE> >
class unsorted_heap: public priority_queue<TYPE, COMP> {
public:
  typedef unsigned size_type;

  // EFFECTS: Construct an empty heap with an optional comparison functor.
  //          See test_heap.cpp for more details on functor.
  // MODIFIES: this
  // RUNTIME: O(1)
  unsorted_heap(COMP comp = COMP());

  // EFFECTS: Add a new element to the heap.
  // MODIFIES: this
  // RUNTIME: O(1)
  virtual void enqueue(const TYPE &val);

  // EFFECTS: Remove and return the smallest element from the heap.
  // REQUIRES: The heap is not empty.
  // MODIFIES: this
  // RUNTIME: O(n)
  virtual TYPE dequeue_min();

  // EFFECTS: Return the smallest element of the heap.
  // REQUIRES: The heap is not empty.
  // RUNTIME: O(n)
  virtual const TYPE &get_min() const;

  // EFFECTS: Get the number of elements in the heap.
  // RUNTIME: O(1)
  virtual size_type size() const;
```

```
46
47    // EFFECTS: Return true if the heap is empty.
48    // RUNTIME: O(1)
49    virtual bool empty() const;
50
51  private:
52    // Note: This vector *must* be used in your heap implementation.
53    std::vector<TYPE> data;
54    // Note: compare is a functor object
55    COMP compare;
56  private:
57    // Add any additional member functions or data you require here.
58    TYPE is_empty = TYPE();
59  };
60
61  template<typename TYPE, typename COMP>
62  unsorted_heap<TYPE, COMP> :: unsorted_heap(COMP comp) {
63      compare = comp;
64      // Fill in the remaining lines if you need.
65  }
66
67  template<typename TYPE, typename COMP>
68  void unsorted_heap<TYPE, COMP> :: enqueue(const TYPE &val) {
69      // Fill in the body.
70      data.push_back(val);
71  }
72
73  template<typename TYPE, typename COMP>
74  TYPE unsorted_heap<TYPE, COMP> :: dequeue_min() {
75      // Fill in the body.
76      if (empty()) return is_empty;
77      auto min = std::min_element(data.begin(), data.end(), compare);
78      int dis = std::distance(data.begin(), min);
79      std::swap(data[dis], data.back());
80      TYPE dequeue_min = std::move(data.back());
81      data.pop_back();
82      return dequeue_min;
83  }
84
85  template<typename TYPE, typename COMP>
86  const TYPE &unsorted_heap<TYPE, COMP> :: get_min() const {
87      // Fill in the body.
88      if (empty()) return is_empty;
89      auto min = std::min_element(data.begin(), data.end(), compare);
90      return *min;
91  }
92
93  template<typename TYPE, typename COMP>
94  bool unsorted_heap<TYPE, COMP> :: empty() const {
```

```
    // Fill in the body.
    return data.empty();
}

template<typename TYPE, typename COMP>
unsigned unsorted_heap<TYPE, COMP> :: size() const {
    // Fill in the body.
    return data.size();
}

#endif //UNSORTED_HEAP_H

```

main.cpp

```
//
//  main.cpp
//  VE281 2018 Autumn
//  project3
//  Bingcheng HU
//
#include <iostream>
#include <getopt.h>
#include "priority_queue.h"
#include "binary_heap.h"
#include "fib_heap.h"
#include "unsorted_heap.h"

using namespace std;
// static int verbose;

class point {
public:
    int x;
    int y;
    int cellweight=0;
    int cost=0;
    bool reached=false;
    point *predecessor=NULL;
    friend bool operator==(const point &p1,const point &p2)
    {
        return
(p1.x==p2.x&&p1.y==p2.y&&p1.cellweight==p2.cellweight&&p1.cost==p2.cost&&p1.reached==p2.
reached&&p1.predecessor==p2.predecessor);
    }
    friend ostream &operator<<(ostream &out, const point &p) {
        out << "(" << p.x << ", " << p.y << ")";
        return out;
    }
```

```
//     During a dequeueMin() operation, if multiple cells have the same smallest path
// cost, choose the cell with the smallest x-coordinate. Furthermore, if there are
multiple
// cells with the same x-coordinate, choose the cell with the smallest y-coordinate.
    struct compare_t
    {
        bool operator()(const point &a, const point &b) const {
            if (a.cost != b.cost) return a.cost < b.cost;
            if (a.x != b.x) return a.x < b.x;
            return a.y < b.y;
        }
    };
};

void trace_back_path(point *p){
    if(p!=NULL){
        trace_back_path(p->predecessor);
        cout<<*p<<endl;
    }
    return;
}

int main(int argc,char* argv[])
{
    std::ios::sync_with_stdio(false);
    std::cin.tie(0);
//----------------- Get Operation----------------
    string mode;
    int verbose = 0;
    while(true)
    {
        static struct option long_options[]=
        {
            {"verbose", no_argument,       0, 'v'},
            // {"v", no_argument,       &verbose, 1},
            // {"brief",   no_argument,       &verbose, 0},
          /* These options don't set a flag.
             We distinguish them by their indices. */
            // {"test",              no_argument,       0, 't'},
            {"implementation",    required_argument,       0, 'i'},
            {0, 0, 0, 0}
        };
        int option_index = 0;
        int c=getopt_long(argc,argv,"vi:",long_options,&option_index);
              if (c == -1)
        break;

      switch (c)
        {
```

```
        case 0:
          /* If this option set a flag, do nothing else now. */
          if (long_options[option_index].flag != 0)
            break;
          // printf ("option %s", long_options[option_index].name);
          if (optarg)
            // printf (" with arg %s", optarg);
          // printf ("\n");
          break;

        case 'v':
          // printf ("option -t\n");
          verbose = 1;
          break;

        case 'i':
          // printf ("option -i with value `%s'\n", optarg);
          mode = optarg;
          break;

        case '?':
          /* getopt_long already printed an error message. */
          break;

        default:
          abort ();
        }
    }
    priority_queue<point,point::compare_t> *priority_q;
    if(mode=="BINARY")
    {
        priority_q=new binary_heap<point,point::compare_t>();
    }
    else if(mode=="UNSORTED")
    {
        priority_q=new unsorted_heap<point,point::compare_t>();
    }
    else if(mode=="FIBONACCI")
    {
        priority_q=new fib_heap<point,point::compare_t>();
    }
    else
    {
        exit(0);
    }
//------------------get file input-----------------
    int x_length,y_length=0;
    cin>>x_length>>y_length;
    int start_x,start_y,end_x,end_y;
```

```
    cin>>start_x>>start_y>>end_x>>end_y;
    point point_A[y_length][x_length];
    for(int h=0;h<y_length;++h){
        for(int w=0;w<x_length;++w){
            cin>>point_A[h][w].cellweight;
        }
    }
    for(int h=0;h<y_length;++h){
        for(int w=0;w<x_length;++w){
            point_A[h][w].x=w;
            point_A[h][w].y=h;
            point_A[h][w].cost=point_A[h][w].cellweight;
        }
    }
//-------------------calculate path------------------
    point_A[start_y][start_x].reached=true;
    priority_q->enqueue(point_A[start_y][start_x]);
    int step=0;
    while(priority_q->empty()==false){
        point C=priority_q->dequeue_min();
        if(verbose==1){
            cout<<"Step "<<step<<endl;
            cout<<"Choose cell ("<<point_A[C.y][C.x].x<<", "<<point_A[C.y][C.x].y
            <<") with accumulated length "<<point_A[C.y][C.x].cost<<"."<<endl;
        }
        step++;
//      The visit of the neighbors starts form the right neighbor and then goes in the
// clockwise direction, i.e., right, down, left, up. For those cells on the boundary,
they
// may not have a certain neighbor. Then you just skip it.
        int clockwise_x[4]={1,0,-1,0};
        int clockwise_y[4]={0,1,0,-1};
        for(int i=0;i<4;++i){
            int N_x=point_A[C.y][C.x].x+clockwise_x[i];
            int N_y=point_A[C.y][C.x].y+clockwise_y[i];
            if(N_x<0||N_x>x_length-1||
                N_y<0||N_y>y_length-1||
                point_A[N_y][N_x].reached==true)
                continue;
            point_A[N_y][N_x].reached=true;
            point_A[N_y][N_x].cost=point_A[C.y][C.x].cost+point_A[N_y][N_x].cellweight;
            point_A[N_y][N_x].predecessor=&point_A[C.y][C.x];
            if(point_A[end_y][end_x].x==point_A[N_y][N_x].x&&point_A[end_y]
[end_x].y==point_A[N_y][N_x].y){
                if(verbose==1){
                    cout<<"Cell ("<<point_A[N_y][N_x].x<<", "<<point_A[N_y][N_x].y
                    <<") with accumulated length "<<point_A[N_y][N_x].cost<<" is the
ending point."<<endl;
                }
```

```
                auto end_node = &point_A[end_y][end_x];
                cout<<"The shortest path from ("<<point_A[start_y][start_x].x<<", "
                <<point_A[start_y][start_x].y<<") to ("<<point_A[end_y][end_x].x
                <<", "<<point_A[end_y][end_x].y<<") is "<<point_A[N_y][N_x].cost<<"."
<<endl;
                cout<<"Path:"<<endl;
                trace_back_path(&point_A[end_y][end_x]);
                delete priority_q;
                return 0;
            }
            else{
                priority_q->enqueue(point_A[N_y][N_x]);
                if(verbose==1){
                    cout<<"Cell ("<<point_A[N_y][N_x].x<<", "<<point_A[N_y][N_x].y
                    <<") with accumulated length "<<point_A[N_y][N_x].cost
                    <<" is added into the queue."<<endl;
                }
            }
        }
    }
    delete priority_q;
    return 0;
}
```

performance.cpp

```
//
//  main.cpp
//  VE281 2018 Autumn
//  project3
//  Bingcheng HU
//
#include <iostream>
#include <getopt.h>
#include <tgmath.h>
#include "priority_queue.h"
#include "binary_heap.h"
#include "fib_heap.h"
#include "unsorted_heap.h"

using namespace std;
static int verbose;

class point {
public:
    int x;
    int y;
    int cellweight=0;
    int cost=0;
```

```
    bool reached=false;
    point *predecessor=NULL;
    friend bool operator==(const point &p1,const point &p2)
    {
        return (p1.x==p2.x&&p1.y==p2.y&&p1.cellweight==p2.cellweight&&p1.cost==p2.cost&&p1.reached==p2.reached&&p1.predecessor==p2.predecessor);
    }
    friend ostream &operator<<(ostream &out, const point &p) {
        out << "(" << p.x << ", " << p.y << ")";
        return out;
    }
//     During a dequeueMin() operation, if multiple cells have the same smallest path
// cost, choose the cell with the smallest x-coordinate. Furthermore, if there are multiple
// cells with the same x-coordinate, choose the cell with the smallest y-coordinate.
    struct compare_t
    {
        bool operator()(const point &a, const point &b) const {
            if (a.cost != b.cost) return a.cost < b.cost;
            if (a.x != b.x) return a.x < b.x;
            return a.y < b.y;
        }
    };
};

void trace_back_path(point *p){
    if(p!=NULL){
        trace_back_path(p->predecessor);
        // cout<<*p<<endl;
    }
    return;
}

void clean_matrix(point **point_A,int y_length, int x_length){
    for(int h=0;h<y_length;++h){
        for(int w=0;w<x_length;++w){
            point_A[h][w].x=w;
            point_A[h][w].y=h;
            point_A[h][w].cost=point_A[h][w].cellweight;
            point_A[h][w].reached = false;
        }
    }
}

clock_t test_time(point **point_A, int y_length, int x_length, int mode){
    int start_y = 0;
    int start_x = 0;
    int end_y = y_length-1;
```

```
    int end_x = x_length-1;
    clock_t start_t, end_t;
    start_t = clock();
    // cout<<"start at "<<start_t;
    priority_queue<point,point::compare_t> *priority_q;
    if(mode== 1) //"BINARY")
    {
        priority_q=new binary_heap<point,point::compare_t>();
    }
    else if(mode== 0) //"UNSORTED")
    {
        priority_q=new unsorted_heap<point,point::compare_t>();
    }
    else if(mode== 2) //"FIBONACCI")
    {
        priority_q=new fib_heap<point,point::compare_t>();
    }
    else
    {
        exit(0);
    }

    int verbose = 0;
    point_A[start_y][start_x].reached=true;
    priority_q->enqueue(point_A[start_y][start_x]);
    int step=0;
    while(priority_q->empty()==false){
        point C=priority_q->dequeue_min();
        if(verbose==1){
            cout<<"Step "<<step<<endl;
            cout<<"Choose cell ("<<point_A[C.y][C.x].x<<", "<<point_A[C.y][C.x].y
            <<") with accumulated length "<<point_A[C.y][C.x].cost<<"."<<endl;
        }
        step++;
//      The visit of the neighbors starts form the right neighbor and then goes in the
// clockwise direction, i.e., right, down, left, up. For those cells on the boundary,
they
// may not have a certain neighbor. Then you just skip it.
        int clockwise_x[4]={1,0,-1,0};
        int clockwise_y[4]={0,1,0,-1};
        for(int i=0;i<4;++i){
            int N_x=point_A[C.y][C.x].x+clockwise_x[i];
            int N_y=point_A[C.y][C.x].y+clockwise_y[i];
            if(N_x<0||N_x>x_length-1||
                N_y<0||N_y>y_length-1||
                point_A[N_y][N_x].reached==true)
                continue;
            point_A[N_y][N_x].reached=true;
            point_A[N_y][N_x].cost=point_A[C.y][C.x].cost+point_A[N_y][N_x].cellweight;
```

```
            point_A[N_y][N_x].predecessor=&point_A[C.y][C.x];
            if(point_A[end_y][end_x].x==point_A[N_y][N_x].x&&point_A[end_y]
[end_x].y==point_A[N_y][N_x].y){

                auto end_node = &point_A[end_y][end_x];
                cerr<<"cost = "<< point_A[N_y][N_x].cost<<" ";
                trace_back_path(&point_A[end_y][end_x]);
                delete priority_q;
                end_t = clock();
                return clock() - start_t;
            }
            else{
                priority_q->enqueue(point_A[N_y][N_x]);
            }
        }
    }
    delete priority_q;

    end_t = clock();
    return 0;
}
const string heapName[] = {
    "unsorted_heap","binary_heap","fibonaci_heap", "ERROR_HEAP"
};

int main(int argc,char* argv[])
{
    std::ios::sync_with_stdio(false);
    std::cin.tie(0);
    int x_length = 0,y_length=0;
    cin>>x_length>>y_length;
    int start_x,start_y,end_x,end_y;
    cin>>start_x>>start_y>>end_x>>end_y;
    point** point_A;
    point_A = new point *[x_length];
    for (int i = 0; i < x_length; ++i)
    {
        point_A[i] = new point [y_length];
    }
    for(int h=0;h<y_length;++h){
        for(int w=0;w<x_length;++w){
            cin>>point_A[h][w].cellweight;
        }
    }
    for (int i = 0; i < 12; ++i)
    {
        int size_of_matrix = x_length*pow(2,i+1)/4096;
        cout <<size_of_matrix<<", ";
        for (int j = 0; j < 3; ++j)
```

```
        {

            int x_len = size_of_matrix;
            int y_len = size_of_matrix;
            clock_t time_run = test_time(point_A, y_len, x_len, j);
            clean_matrix(point_A, y_length, x_length);
            cerr<<"run time of "<<heapName[j]<< "  \tat size "<< size_of_matrix <<"\tis
"<<time_run<<endl;
            cout<<time_run<<",";
        }
        cout<<endl;
    }

    for(int i=0;i<y_length;i++)
        delete []point_A[i];
        delete []point_A;
    return 0;
}
```

gen_rand.cpp

```
#include <iostream>
#include <stdlib.h>
#include <assert.h>

using namespace std;
int main(int argc, char *argv[]) {

    int w = 100;

    cout<<w<<" "<<w<<endl;
    cout<<0<<" "<<0<<endl;
    cout<<99<<" "<<99<<endl;
    int k;
    for (int i = 0; i < w; ++i)
    {
        for (int j = 0; j < w; ++j)
        {
            k = mrand48()%5 + 4;
            cout << k <<" ";
        }
    }
}
```

Makefile

```
all: main

main: main.cpp
```

```
    g++ -std=c++11 -O2 -o main main.cpp

gen: gen_rand.cpp
    g++ -std=c++11 -O2 -o gen_rand_matrix gen_rand.cpp
    ./gen_rand_matrix > matrix.in

per: performance.cpp
    g++ -std=c++11 -O3 -o perform performance.cpp
    ./perform < matrix.in > out.csv

vm: all
    valgrind --leak-check=full ./main --verbose -i FIBONACCI < in.txt >1.out

clean:
    rm -f *.o fib_heap binary_heap unsorted_heap fib_heap_sw main performance


tar:
    tar czvf p3.tar Makefile main.cpp binary_heap.h fib_heap.h priority_queue.h
unsorted_heap.h

```

DataGraph