目录

1 基础算法

1.1 三分

```cpp
#include <bits/stdc++.h>
constexpr double eps = 1E-6;//eps控制精度

//三分（实数范围）凸函数
//https://www.luogu.com.cn/record/160695683
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int n;
    double l, r;
    std::cin >> n >> l >> r;
    std::vector<double> v(n + 1);
    for(int i = n; i >= 0; --i) {
        std::cin >> v[i];
    }
    auto check = [&](double t) ->double {
        double ans = 0;
        for(int i = 0; i <= n; ++i) {
            ans += v[i] * std::pow(t, i);
        }
        return ans;
    };
    while(l + eps <= r) {
        double lmid = l + (r - l) / 3;//左三分点
        double rmid = r - (r - l) / 3;//右三分点
        if(check(lmid) < check(rmid)) {
            l = lmid;
        } else {
            r = rmid;
        }
    }
```

```cpp
    std::cout << l << '\n';
    return 0;
}
```

1.2 二分

```cpp
#include <bits/stdc++.h>

//二分查找
//https://www.luogu.com.cn/record/160694930
int binaryFind(std::vector<int> &v, int t) {
    int l = 1, r = v.size() - 1, ans = -1;
    while(l <= r) {
        int mid = l + (r - l) / 2;
        if(v[mid] >= t) { //此处可换成check函数
            r = mid - 1;
            if(v[mid] == t) { //判断什么时候更新答案
                ans = mid;
            }
        } else {
            l = mid + 1;
        }
    }
    return ans;
}

int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int n, m;
    std::cin >> n >> m;
    std::vector<int> v(n + 1);
    for(int i = 1; i <= n; ++i) {
        std::cin >> v[i];
    }
```

```cpp
    for(int i = 1; i <= m; ++i) {
        int x;
        std::cin >> x;
        std::cout << binaryFind(v, x) << " \n"[i == m];
    }
    return 0;
}
```

1.3 快速幂

```cpp
#include <bits/stdc++.h>
using i64 = long long;

//快速幂（Binary Exponentiation)
i64 qpow(i64 a, i64 b, i64 p = LLONG_MAX) { //底数，指数，模数
    i64 res = 1;
    while(b > 0) {
        if(b & 1) res = res * a % p;
        a = a * a % p;
        b >>= 1;
    }
    return res;
}

int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    std::cout << qpow(2, 20) << '\n';
    std::cout << std::pow(2, 20) << '\n';
    return 0;
}
```

1.4 离散化

```cpp
#include <bits/stdc++.h>

//离散化
int main() {
    std::vector<int> arr = {1000, 500, 9999, 200, 356, 200};
    std::vector<int> tmp(arr);
    std::sort(tmp.begin(), tmp.end()); //排序
    tmp.erase(std::unique(tmp.begin(), tmp.end()), tmp.end());//去重
    for (int i = 0; i < arr.size(); ++i) { //替换
        arr[i] = std::lower_bound(tmp.begin(), tmp.end(), arr[i]) - tmp.begin() +
     1;
    }
    for(int i= 0; i < arr.size(); ++i) {
        std::cout << arr[i] << ' ';
    }
    return 0;
}
```

2 图论

2.1 Tarjan 割点

```cpp
#include <bits/stdc++.h>
using i64 = long long;

//tarjan求割点
//https://www.luogu.com.cn/problem/P3388
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int n, m;
    std::cin >> n >> m;
    std::vector<std::vector<int>> v(n + 1);
```

```cpp
    for(int i = 1; i <= m; ++i) {
        int x, y;
        std::cin >> x >> y;
        v[x].push_back(y);
        v[y].push_back(x);
    }
    std::vector<int> dfn(n + 1), low(n + 1), bel(n + 1), cutPoint(n + 1);
    int cnt = 0, root = 0;
    auto dfs = [&](auto self, int id, int lst) ->void {
        dfn[id] = low[id] = ++cnt;
        int sz = 0; //儿子个数
        for(auto nxt : v[id]) {
            if(!dfn[nxt]) {
                sz++;
                self(self, nxt, id);
                low[id] = std::min(low[id], low[nxt]);
                if(low[nxt] >= dfn[id]) {
                    cutPoint[id] = 1;
                }
            } else if(nxt != lst) {
                low[id] = std::min(low[id], dfn[nxt]);
            }
        }
        if(num <= 1 && id == root) {
            cutPoint[id] = 0;
        }
    };
    for(int i = 1; i <= n; ++i) {
        if(!dfn[i]) {
            root = i;
            dfs(dfs, i, 0);
        }
    }
    std::cout << std::count(cutPoint.begin() + 1, cutPoint.end(), 1) << '\n';
    for(int i = 1; i <= n; ++i) {
        if(cutPoint[i] == 1) {
            std::cout << i << ' ';
        }
    }
    return 0;
}
```

2.2 Tarjan 割边

```cpp
#include <bits/stdc++.h>
using i64 = long long;

//tarjan求割边
//https://www.luogu.com.cn/problem/P1656
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int n, m;
    std::cin >> n >> m;
    std::vector<std::vector<std::pair<int, int>>> v(n + 1);
    for(int i = 1; i <= m; ++i) {
        int x, y;
        std::cin >> x >> y;
        v[x].push_back({y, i});//记录边id(从1开始)，防止重边
        v[y].push_back({x, i});
    }
    std::vector<int> dfn(n + 1), low(n + 1);
    std::vector<std::pair<int, int>> bridge;
    int cnt = 0;
    auto dfs = [&](auto self, int id, int lid) ->void {
        dfn[id] = low[id] = ++cnt;
        for(auto [nxt, eid] : v[id]) {
            if(!dfn[nxt]) {
                self(self, nxt, eid);
                low[id] = std::min(low[id], low[nxt]);
                if(low[nxt] == dfn[nxt]) { //是割边
```

```
28              bridge.push_back({id, nxt});
29          }
30      } else if(eid != lid) {
31          low[id] = std::min(low[id], dfn[nxt]);
32      }
33    }
34  };
35  for(int i = 1; i <= n; ++i) {
36      if(!dfn[i]) {
37          dfs(dfs, i, 0);
38      }
39  }
40  std::sort(bridge.begin(), bridge.end());
41  for(auto [x, y] : bridge) {
42      std::cout << x << ' ' << y << '\n';
43  }
44  return 0;
45 }
```

2.3 Tarjan 强连通分量

```
1 #include <bits/stdc++.h>
2 using i64 = long long;
3
4 //tarjan求强连通分量(scc)
5 //https://www.luogu.com.cn/problem/B3609
6 int main() {
7   std::ios::sync_with_stdio(false);
8   std::cin.tie(nullptr);
9   int n, m;
10  std::cin >> n >> m;
11  std::vector<std::vector<int>> v(n + 1);
12  for(int i = 0; i < m; ++i) {
13      int x, y;
14      std::cin >> x >> y;
15      v[x].push_back(y);
16  }
17  std::vector<std::vector<int>> scc(n + 1);
18  std::vector<int> dfn(n + 1), low(n + 1), ins(n + 1), bel(n + 1);
19  std::stack<int> stk;
20  int cnt = 0, tot = 0;
21  auto dfs = [&](auto self, int id) ->void {
22      dfn[id] = low[id] = ++cnt;
23      stk.push(id);
24      ins[id] = 1;
25      for(auto nxt : v[id]) {
26          if(!dfn[nxt]) {
27              self(self, nxt);
28              low[id] = std::min(low[id], low[nxt]);
29          } else if(ins[nxt]) {
30              low[id] = std::min(low[id], low[nxt]);
31          }
32      }
33      if(dfn[id] == low[id]) {
34          ++tot;
35          while(true) {
36              int num = stk.top();
37              stk.pop();
38              ins[num] = 0;
39              bel[num] = tot;
40              scc[tot].push_back(num);
41              if(id == num) break;
42          }
43      }
44  };
45  for(int i = 1; i <= n; ++i) {
46      if(!dfn[i]) {
47          dfs(dfs, i);
48      }
49  }
50  for(int i = 1; i <= tot; ++i) {
```

```cpp
            std::sort(scc[i].begin(), scc[i].end());
        }
        std::sort(scc.begin() + 1, scc.begin() + tot + 1);
        std::cout << tot << '\n';
        for(int i = 1; i <= tot; ++i) {
            for(int j = 0; j < scc[i].size(); ++j) {
                std::cout << scc[i][j] << " \n"[j == scc[i].size() - 1];
            }
        }
    }
    return 0;
}
```

2.4 Tarjan 点双连通分量

```cpp
#include <bits/stdc++.h>
using i64 = long long;

//tarjan求点双连通分量
//https://www.luogu.com.cn/problem/P8435
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int n, m;
    std::cin >> n >> m;
    std::vector<std::vector<int>> v(n + 1);
    for(int i = 1; i <= m; ++i) {
        int x, y;
        std::cin >> x >> y;
        v[x].push_back(y);
        v[y].push_back(x);
    }
    std::vector<std::vector<int>> vcc(n + 1);
    std::vector<int> dfn(n + 1), low(n + 1);
    std::stack<int> stk;
    int cnt = 0, tot = 0;
    auto dfs = [&](auto self, int id, int lst) ->void {
        dfn[id] = low[id] = ++cnt;
        stk.push(id);
        int num = 0;
        for(auto nxt : v[id]) {
            if(!dfn[nxt]) {
                num++;
                self(self, nxt, id);
                low[id] = std::min(low[id], low[nxt]);
                if(low[nxt] >= dfn[id]) {
                    ++tot;
                    while(true) {
                        int num = stk.top();
                        stk.pop();
                        vcc[tot].push_back(num);
                        if(num == nxt) break;
                    }
                    vcc[tot].push_back(id);
                }
            } else if(nxt != lst) {
                low[id] = std::min(low[id], dfn[nxt]);
            }
        }
        if(lst == 0 && num == 0) {
            ++tot;
            vcc[tot].push_back(id);
        }
    };
    for(int i = 1; i <= n; ++i) {
        if(!dfn[i]) {
            dfs(dfs, i, 0);
        }
    }
    std::cout << tot << '\n';
    for(int i = 1; i <= tot; ++i) {
        std::cout << vcc[i].size() << ' ';
```

5

```
58        for(int j = 0; j < vcc[i].size(); ++j) {
59            std::cout << vcc[i][j] << " \n"[j == vcc[i].size() - 1];
60        }
61    }
62    return 0;
63 }
```

2.5 Tarjan 边双连通分量

```
1  #include <bits/stdc++.h>
2  using i64 = long long;
3
4  //tarjan求边双连通分量
5  //https://www.luogu.com.cn/problem/P8436
6  int main() {
7      std::ios::sync_with_stdio(false);
8      std::cin.tie(nullptr);
9      int n, m;
10     std::cin >> n >> m;
11     std::vector<std::vector<std::pair<int, int>>> v(n + 1);
12     for(int i = 1; i <= m; ++i) {
13         int x, y;
14         std::cin >> x >> y;
15         v[x].push_back({y, i});
16         v[y].push_back({x, i});
17     }
18     std::vector<std::vector<int>> ecc(n + 1);
19     std::vector<int> dfn(n + 1), low(n + 1);
20     std::stack<int> stk;
21     int cnt = 0, tot = 0;
22     auto dfs = [&](auto self, int id, int lid) ->void {
23         dfn[id] = low[id] = ++cnt;
24         stk.push(id);
25         for(auto [nxt, eid] : v[id]) {
26             if(!dfn[nxt]) {
27                 self(self, nxt, eid);
28                 low[id] = std::min(low[id], low[nxt]);
29             } else if(lid != eid) {
30                 low[id] = std::min(low[id], dfn[nxt]);
31             }
32         }
33         if(dfn[id] == low[id]) {
34             ++tot;
35             while(true) {
36                 int num = stk.top();
37                 ecc[tot].push_back(num);
38                 stk.pop();
39                 if(id == num) break;
40             }
41         }
42     };
43     for(int i = 1; i <= n; ++i) {
44         if(!dfn[i]) {
45             dfs(dfs, i, 0);
46         }
47     }
48     std::cout << tot << '\n';
49     for(int i = 1; i <= tot; ++i) {
50         std::cout << ecc[i].size() << ' ';
51         for(int j = 0; j < ecc[i].size(); ++j) {
52             std::cout << ecc[i][j] << " \n"[j == ecc[i].size() - 1];
53         }
54     }
55     return 0;
56 }
```

2.6 拓扑排序

```
1  #include <bits/stdc++.h>
2
```

```
3  //拓扑排序
4  //https://www.luogu.com.cn/problem/B3644
5  int main() {
6      std::ios::sync_with_stdio(false);
7      std::cin.tie(nullptr);
8      int n;
9      std::cin >> n;
10     std::vector<std::vector<int>> v(n + 1); //存图
11     std::vector<int> d(n + 1); //统计入度数量
12     for(int i = 1; i <= n; ++i) { //建图
13         int x;
14         while((std::cin >> x) && x != 0) {
15             v[i].push_back(x);
16             d[x]++;
17         }
18     }
19     std::queue<int> q;
20     for(int i = 1; i <= n; ++i) {
21         if(d[i] == 0) {
22             q.push(i); //将入度为0的放入队列
23         }
24     }
25     while(!q.empty()) {
26         int id = q.front();
27         q.pop();
28         std::cout << id << ' ';
29         for(auto &nxt  : v[id]) {
30             d[nxt]--; //更新入度数
31             if(d[nxt] == 0) { //将入度为0的放入队列
32                 q.push(nxt);
33             }
34         }
35     }
36     return 0;
37 }
```

2.7 最小生成树 kruskal

```
1  #include <bits/stdc++.h>
2
3  //kruskal算法最小生成树(稀疏图)
4  //https://www.luogu.com.cn/problem/P3366
5  class DSU { //维护并查集
6  public:
7      DSU(int n) { //初始构造
8          v.resize(n + 1);
9          std::iota(v.begin(), v.end(), 0);
10     }
11     int find(int x) { //找根
12         return (v[x] == x ? x : (v[x] = find(v[x])));
13     }
14     void uniset(int x, int y) { //合并集合
15         v[find(x)] = find(y);
16     }
17     bool query(int x, int y) { //是否在同一集合
18         return find(x) == find(y);
19     }
20 private:
21     std::vector<int> v;
22 };
23
24 struct edge { //边
25     int x, y, w; //点，点，边权
26     bool operator<(const edge& o) const {
27         return w < o.w;
28     }
29 };
30
31 int main() {
32     int n, m;
33     std::cin >> n >> m;
34     std::vector<edge> v(m);
```

```
35      DSU dsu(n);
36      for(auto &[x, y, w] : v) {
37          std::cin >> x >> y >> w;
38      }
39      std::sort(v.begin(), v.end()); //对边排序
40      int ans = 0, tot = 0;
41      for(auto [x, y, w] : v) {
42          if(!dsu.query(x, y)) {
43              dsu.uniset(x, y);
44              ans += w;
45              tot++;
46          }
47      }
48      if(tot != n - 1) {
49          std::cout << "orz" << '\n';
50      } else {
51          std::cout << ans << '\n';
52      }
53      return 0;
54 }
```

2.8 最小生成树 prim

```
1  #include <bits/stdc++.h>
2
3  //prim算法最小生成树(稠密图)
4  //https://www.luogu.com.cn/problem/P3366
5  struct node {
6      int id, w;
7      bool operator<(const node& o) const {
8          return w > o.w;
9      }
10 };
11
12 int main() {
13     int n, m;
14     std::cin >> n >> m;
15     std::vector<std::vector<std::pair<int, int>>> v(n + 1);
16     std::vector<int> vis(n + 1);
17     for(int i = 0; i < m; ++i) {
18         int x, y, w;
19         std::cin >> x >> y >> w;
20         v[x].push_back({y, w});
21         v[y].push_back({x, w});
22     }
23     std::priority_queue<node> pq; //利用优先队列不断加入最小边
24     int ans = 0;
25     pq.push({1, 0});
26     while(!pq.empty()) {
27         auto [id, w] = pq.top();
28         pq.pop();
29         if(!vis[id]) {
30             vis[id] = 1;
31             ans += w;
32             for(auto [nxt, w] : v[id]) {
33                 if(!vis[nxt]) {
34                     pq.push({nxt, w});
35                 }
36             }
37         }
38     }
39     if(!*std::min_element(vis.begin() + 1, vis.end())) {
40         std::cout << "orz" << '\n'; //图不连通
41     } else {
42         std::cout << ans << '\n';
43     }
44     return 0;
45 }
```

3 数据结构

3.1 Splay

```cpp
#include <bits/stdc++.h>

class SplayTree {
public:
    SplayTree() {
        tr.push_back(Node());
        insert(INF);
        insert(-INF);
    }
    void insert(int t) { //插入值为t的数
        int id = root, fa = 0;
        while(id && tr[id].val != t) {
            fa = id;
            id = tr[id].nxt[t > tr[id].val];
        }
        if(id) {
            tr[id].cnt++;
        } else {
            id = ++size;
            tr[fa].nxt[t > tr[fa].val] = id;
            tr.push_back(Node(fa, t));
        }
        splay(id);
    }
    int get_pre(int t) { //查找t的前驱节点
        find(t);
        int id = root;
        if(tr[id].val < t) return id;
        id = tr[id].nxt[0];
        while(tr[id].nxt[1]) {
            id = tr[id].nxt[1];
        }
        splay(id);
        return id;
    }
    int get_suc(int t) { //查找t的后继节点
        find(t);
        int id = root;
        if(tr[id].val > t) return id;
        id = tr[id].nxt[1];
        while(tr[id].nxt[0]) {
            id = tr[id].nxt[0];
        }
        splay(id);
        return id;
    }
    void find(int t) {  //查找值为t的节点，并将该节点转到根
        int id = root;
        while(tr[id].nxt[t > tr[id].val] && t != tr[id].val) {
            id = tr[id].nxt[t > tr[id].val];
        }
        splay(id);
    }
    void erase(int t) { //删除值为t的，只删除1个
        int pre = get_pre(t);
        int suc = get_suc(t);
        splay(pre);
        splay(suc, pre);
        int tid = tr[suc].nxt[0];//目标节点
        if(tr[tid].cnt > 1) {
            tr[tid].cnt--;
            splay(tid);          //向上更新其他节点
        } else {
            tr[suc].nxt[0] = 0;
            splay(suc);          //向上更新其他节点
        }
    }
}
```

```cpp
    int get_root() {
        return root;
    }
    int get_rank(int t) { //查一个数t的排名
        insert(t);
        int res = tr[tr[root].nxt[0]].size;
        erase(t);
        return res;
    }
    int get_kth(int t) {    //查找第k个节点编号
        t++;                //有哨兵，所以++
        int id = root;
        while(true) {
            pushdown(id); //向下传递懒标记
            const auto &[x, y] = tr[id].nxt;
            if(tr[x].size + tr[id].cnt < t) {
                t -= tr[x].size + tr[id].cnt;
                id = y;
            } else {
                if(tr[x].size >= t) {
                    id = tr[id].nxt[0];
                } else {
                    return id;
                }
            }
        }
    }
    int get_val(int t) { //查找排名为t的数的数值
        int id = get_kth(t);
        splay(id);
        return tr[id].val;
    }
    void reverse(int l, int r) { //反转区间[l, r]
        l = get_kth(l - 1), r = get_kth(r + 1);
        splay(l, 0), splay(r, l);
        tr[tr[r].nxt[0]].tag ^= 1;
    }
    void output(int id) { //中序遍历
        pushdown(id);
        const auto &[x, y] = tr[id].nxt;
        if(x != 0) output(x);
        if(std::abs(tr[id].val) != INF) {
            std::cout << tr[id].val << ' ';
        }
        if(y) output(y);
    }
    int val(int id) {
        return tr[id].val;
    }
private:
    class Node {
    public:
        Node() {
            nxt = {0, 0};
            lst = val = size = cnt = tag = 0;
        }
        Node(int _lst, int _val) : lst(_lst), val(_val) {
            nxt = {0, 0};
            tag = 0;
            size = cnt = 1;
        }
        std::array<int, 2> nxt; //左右节点[0左，1右]
        int lst;                //父亲
        int val;                //权值
        int cnt;                //权值数
        int size;               //子树大小
        int tag;                //懒标记[1翻，0不翻]
    };
    void rotate(int id) {
        int pid = tr[id].lst, gid = tr[pid].lst;//父节点，爷节点
        int k = (tr[pid].nxt[1] == id);         //判断id是pid的左节点还是右节点
        tr[pid].nxt[k] = tr[id].nxt[k ^ 1];     //将父节点的k号子节点设置为id的k
```

```cpp
                              //^1号子节点
            tr[tr[id].nxt[k ^ 1]].lst = pid;        //id的k^1号子节点的父节点设为pid
            tr[id].nxt[k ^ 1] = pid;                //id的k^1号子节点设置为pid
            tr[pid].lst = id;                       //pid的父节点设置为id
            tr[id].lst = gid;                       //id的父节点设置为gid
            tr[gid].nxt[tr[gid].nxt[1] == pid] = id;//gid的子节点设为id
            pushup(pid);                            //更新pid
            pushup(id);                             //更新id
        }
        void splay(int id, int t = 0) {//将id旋转到为t的子节点，为0时id为根
            while(tr[id].lst != t) {
                int pid = tr[id].lst, gid = tr[pid].lst;
                if(gid != t) { //非根做双旋
                    if((tr[pid].nxt[0] == id) == (tr[gid].nxt[0] == pid)) { //直线式
转中
                        rotate(pid);
                    } else {    //折线式转中
                        rotate(id);
                    }
                }
                rotate(id);
            }
            if(t == 0) root = id;
        }
        void pushup(int id) {
            const auto &[x, y] = tr[id].nxt;
            tr[id].size = tr[x].size + tr[y].size + tr[id].cnt;
        }
        void pushdown(int id) {
            if(tr[id].tag) {
                auto &[x, y] = tr[id].nxt;
                std::swap(x, y);
                tr[x].tag ^= 1;
                tr[y].tag ^= 1;
                tr[id].tag = 0;
            }
```

```cpp
        }
        std::vector<Node> tr;
        int root = 0; //根节点编号
        int size = 0; //节点个数
        const int INF = INT_MAX;
};

int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int n, m;
    std::cin >> n >> m;
    SplayTree tr;
    for(int i = 1; i <= n; ++i) {
        tr.insert(i);
    }
    for(int i = 1; i <= m; ++i) {
        int l, r;
        std::cin >> l >> r;
        tr.reverse(l, r);
    }
    tr.output(tr.get_root());
    return 0;
}
```

3.2 ST 表

```cpp
#include <bits/stdc++.h>

//ST表(sparseTable)
//https://www.luogu.com.cn/problem/P3865
template<typename T>
class ST { //下标从0开始
public:
    ST(const std::vector<T> &v) { //数据
```

```cpp
 9          int k = std::__lg(v.size());
10          st = std::vector<std::vector<T>>(k + 1, std::vector<T>(v.size()));
11          st[0] = v;
12          for(int i = 0; i < k; ++i) {
13              for(int j = 0; j + (1 << (i + 1)) - 1 < v.size(); ++j) {
14                  st[i + 1][j] = std::max(st[i][j], st[i][j + (1 << i)]);
15              }
16          }
17      }
18      T query(int l, int r) { //查询[l, r]的最大值
19          int t = std::__lg(r - l + 1);
20          return std::max(st[t][l], st[t][r + 1 - (1 << t)]);
21      }
22  private:
23      std::vector<std::vector<T>> st;
24  };
25
26  int main() {
27      std::ios::sync_with_stdio(false);
28      std::cin.tie(nullptr);
29      int n, q;
30      std::cin >> n >> q;
31      std::vector<int> v(n);
32      for(int i = 0; i < n; ++i) {
33          std::cin >> v[i];
34      }
35      ST<int> st(v);
36      while(q--) {
37          int l, r;
38          std::cin >> l >> r;
39          l--, r--;
40          std::cout << st.query(l, r) << '\n';
41      }
42      return 0;
43  }
```

3.3 对顶堆

```cpp
 1  #include <bits/stdc++.h>
 2  using i64 = long long;
 3
 4  //对顶堆，维护第k小/大
 5  template<typename T>
 6  struct DoubleHeap {
 7      DoubleHeap(int _k) : k(_k) {} //第k小，若要第k大，将下面比较函数反转
 8      std::priority_queue<T, std::vector<T>, std::less<T>> mpq; //大根堆[1, k - 1]
 9      std::priority_queue<T, std::vector<T>, std::greater<T>> Mpq; //小根堆[k, sz]
10      void insert(T x) {
11          mpq.push(x);
12          while(mpq.size() >= k) {
13              Mpq.push(mpq.top());
14              mpq.pop();
15          }
16      }
17      T kth() {
18          assert(Mpq.empty() == false);
19          return Mpq.top();
20      }
21      const int k;
22  };
23
24  struct MINT {
25      int x;
26      bool operator<(const MINT &o) const {
27          return x < o.x;
28      }
29      bool operator>(const MINT &o) const {
30          return x > o.x;
31      }
32  };
33
34  void solve() {
```

```
35        int n, k;
36        std::cin >> n >> k;
37        DoubleHeap<MINT> dpq(k);
38        for(int i = 1; i <= n; ++i) {
39            int opt;
40            std::cin >> opt;
41            if(opt == 1) {
42                int x;
43                std::cin >> x;
44                dpq.insert({x});
45            } else {
46                std::cout << dpq.kth().x << '\n';
47            }
48        }
49
50    }
51
52    int main() {
53        std::ios::sync_with_stdio(false);
54        std::cin.tie(nullptr);
55        int T;
56        std::cin >> T;
57        while(T--) {
58            solve();
59        }
60        return 0;
61    }
```

3.4 并查集

```
1   #include <bits/stdc++.h>
2
3   //并查集(disjoint set union)
4   //https://www.luogu.com.cn/problem/P3367
5   class DSU {
6   public:
7       DSU(int n) { //初始构造
8           v.resize(n + 1);
9           std::iota(v.begin(), v.end(), 0);
10      }
11      int find(int x) { //找根
12          return (v[x] == x ? x : (v[x] = find(v[x])));
13      }
14      void uniset(int x, int y) { //合并集合
15          v[find(x)] = find(y);
16      }
17      bool query(int x, int y) { //是否在同一集合
18          return find(x) == find(y);
19      }
20  private:
21      std::vector<int> v;
22  };
23
24  int main() {
25      std::ios::sync_with_stdio(false);
26      std::cin.tie(nullptr);
27      int n, m;
28      std::cin >> n >> m;
29      DSU dsu(n);
30      for(int i = 0; i < m; ++i) {
31          int z, x, y;
32          std::cin >> z >> x >> y;
33          if(z == 1) {
34              dsu.uniset(x, y);
35          } else if(z == 2) {
36              std::cout << (dsu.query(x, y) ? 'Y' : 'N') << '\n';
37          }
38      }
39      return 0;
40  }
```

3.5 树状数组

```cpp
#include<bits/stdc++.h>

//树状数组(Fenwick)
//https://www.luogu.com.cn/problem/P3374
template<typename T>
class Fenwick {
public:
    Fenwick(int n) : v(std::vector<T>(n + 1)) {}; //有参构造
    void update(int x, T dx) { //更新(index, dx)
        for(int i = x; i < v.size(); i += (i & -i)) {
            v[i] += dx;
        }
    }
    T query(int x) { //查询前缀和[0, L]
        T res{};
        for(int i = x; i > 0; i -= (i & -i)) {
            res += v[i];
        }
        return res;
    }
    T range(int l, int r) { //查询区间[L, R]
        return query(r) - query(l - 1);
    }
private:
    std::vector<T> v;
};

int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int n, m;
    std::cin >> n >> m;
    Fenwick<int> tr(n);
    for(int i = 1; i <= n; ++i) {
        int x;
        std::cin >> x;
        tr.update(i, x);
    }
    for(int i = 0; i < m; ++i) {
        int o, x, y;
        std::cin >> o >> x >> y;
        if(o == 1) {
            tr.update(x, y);
        } else if (o == 2) {
            std::cout << tr.range(x, y) << '\n';
        }
    }
    return 0;
};
```

3.6 线段树

```cpp
#include <bits/stdc++.h>
using i64 = long long;

//线段树，区间修改，区间查询
//https://www.luogu.com.cn/problem/P3372
template<typename Info, typename Tag>
struct SegmentTree {
#define ls (id<<1)
#define rs (id<<1|1)
    SegmentTree(int n) : n(n), info(n << 2), tag(n << 2) {}
    SegmentTree(const std::vector<Info> &init) : SegmentTree(init.size()) {
        auto build = [&](auto self, int id, int l, int r) ->void {
            if(l == r) {
                info[id] = init[l];
                return;
            }
            int mid = (l + r) / 2;
```

```
18            self(self, ls, l, mid);
19            self(self, rs, mid + 1, r);
20            pushup(id);
21        };
22        build(build, 1, 1, n);
23    }
24    void apply(int id, const Tag &dx) {
25        info[id].apply(dx);
26        tag[id].apply(dx);
27    }
28    void pushup(int id) {
29        info[id] = info[ls] + info[rs];
30    }
31    void pushdown(int id) {
32        apply(ls, tag[id]);
33        apply(rs, tag[id]);
34        tag[id] = Tag();
35    }
36    void update(int t, const Info &val) {
37        update(1, 1, n, t, val);
38    }
39    void rangeUpdate(int l, int r, const Tag &dx) {
40        rangeUpdate(1, 1, n, l, r, dx);
41    }
42    Info rangeQuery(int l, int r) {
43        return rangeQuery(1, 1, n, l, r);
44    }
45    void update(int id, int l, int r, int t, const Info &val) {
46        if(l == r) {
47            info[id] = val;
48            return;
49        }
50        int mid = (l + r) / 2;
51        pushdown(id);
52        if(t <= mid) {
53            update(ls, l, mid, t, val);
54        } else if(t > mid) {
55            update(rs, mid + 1, r, t, val);
56        }
57        pushup(id);
58    }
59    void rangeUpdate(int id, int l, int r, int x, int y, const Tag &dx) {
60        if(x <= l && r <= y) {
61            apply(id, dx);
62            return;
63        }
64        int mid = (l + r) / 2;
65        pushdown(id);
66        if(x <= mid) {
67            rangeUpdate(ls, l, mid, x, y, dx);
68        }
69        if(y > mid) {
70            rangeUpdate(rs, mid + 1, r, x, y, dx);
71        }
72        pushup(id);
73    }
74    Info rangeQuery(int id, int l, int r, int x, int y) {
75        if(x <= l && r <= y) {
76            return info[id];
77        }
78        int mid = (l + r) / 2;
79        pushdown(id);
80        Info res;
81        if(x <= mid) {
82            res = res + rangeQuery(ls, l, mid, x, y);
83        }
84        if(y > mid) {
85            res = res + rangeQuery(rs, mid + 1, r, x, y);
86        }
87        return res;
88    }
89 #undef ls
```

```cpp
 90  #undef rs
 91      const int n;
 92      std::vector<Info> info;
 93      std::vector<Tag> tag;
 94  };
 95
 96  constexpr i64 INF = 1E18;
 97
 98  struct Tag {
 99      i64 add = 0;
100      void apply(const Tag &dx) {
101          add += dx.add;
102      }
103  };
104
105  struct Info {
106      i64 mn = INF;
107      i64 mx = -INF;
108      i64 sum = 0;
109      i64 len = 0;
110      void apply(const Tag &dx) {
111          mn += dx.add;
112          mx += dx.add;
113          sum += len * dx.add;
114      }
115  };
116
117  Info operator+(const Info &x, const Info &y) {
118      Info res;
119      res.mn = std::min(x.mn, y.mn);
120      res.mx = std::max(x.mx, y.mx);
121      res.sum = x.sum + y.sum;
122      res.len = x.len + y.len;
123      return res;
124  }
125
126  int main() {
127      std::ios::sync_with_stdio(false);
128      std::cin.tie(nullptr);
129      int n, m;
130      std::cin >> n >> m;
131      // std::vector<Info> v(n + 1);
132      // for(int i = 1; i <= n; ++i) {
133      //     int x;
134      //     std::cin >> x;
135      //     v[i] = {x, x, x, 1};
136      // }
137      // SegmentTree<Info, Tag> tr(v);
138      SegmentTree<Info, Tag> tr(n);
139      for(int i = 1; i <= n; ++i) {
140          int x;
141          std::cin >> x;
142          tr.update(i, {x, x, x, 1});
143      }
144      while(m--) {
145          int opt, x, y;
146          std::cin >> opt >> x >> y;
147          if(opt == 1) {
148              int k;
149              std::cin >> k;
150              tr.rangeUpdate(x, y, {k});
151          } else if(opt == 2) {
152              std::cout << tr.rangeQuery(x, y).sum << '\n';
153          }
154      }
155      return 0;
156  }
```

4 树算法

4.1 树剖 LCA

```cpp
#include <bits/stdc++.h>

//树链剖分求LCA
//https://www.luogu.com.cn/problem/P3379
int main() {
    std::ios::sync_with_stdio(0);
    std::cin.tie(nullptr);
    int n, m, s;
    std::cin >> n >> m >> s;
    std::vector<std::vector<int>> v(n + 1);
    std::vector<int> fa(n + 1), dep(n + 1), son(n + 1), sz(n + 1), top(n + 1, 0);
    //父节点，深度，重儿子，子树节点数，所在重链的顶点
    for(int i = 0; i < n - 1; ++i) {
        int x, y;
        std::cin >> x >> y;
        v[x].push_back(y);
        v[y].push_back(x);
    }
    auto dfs1 = [&](auto self, int id, int lst) ->void {//求fa, dep, son, sz数组
        fa[id] = lst;
        dep[id] = dep[lst] + 1;
        sz[id] = 1;
        for(auto nxt : v[id]) {
            if(nxt == lst) continue;
            self(self, nxt, id);
            sz[id] += sz[nxt];
            if(sz[son[id]] < sz[nxt]) {
                son[id] = nxt;
            }
        }
    };
    auto dfs2 = [&](auto self, int id, int t) ->void {
        top[id] = t;
        if(son[id] == 0) return;
        self(self, son[id], t);
        for(auto nxt : v[id]) {
            if(nxt != fa[id] && nxt != son[id]) {
                self(self, nxt, nxt);
            }
        }
    };
    auto lca = [&](int x, int y) ->int {
        while(top[x] != top[y]) {
            if(dep[top[x]] < dep[top[y]]) {
                std::swap(x, y);
            }
            x = fa[top[x]];
        }
        return (dep[x] < dep[y] ? x : y);
    };
    dfs1(dfs1, s, 0);
    dfs2(dfs2, s, s);
    for(int i = 0; i < m; ++i) {
        int x, y;
        std::cin >> x >> y;
        std::cout << lca(x, y) << '\n';
    }
    return 0;
}
```

5 数论

5.1 MillerRabin

```cpp
#include <bits/stdc++.h>
using i64 = long long;

i64 qpow(i64 a, i64 b, i64 p) {
    i64 res = 1;
    while(b) {
        if(b & 1) {
            res = (__int128)res * a % p;
        }
        a = (__int128)a * a % p;
        b >>= 1;
    }
    return res;
}

bool Minller(i64 n) {
    if(n == 2) return true;
    if(n <= 1 || n % 2 == 0) return false;
    i64 u = n - 1, k = 0;
    while(u % 2 == 0) u /= 2, ++k;
    static std::vector<i64> base = {2, 325, 9375, 28178, 450775, 9780504,
        1795265022};
    for(auto x : base) {
        i64 res = qpow(x, u, n);
        if(res == 0 || res == 1 || res == n - 1) continue;
        for(int i = 1; i <= k; ++i) {
            res = (__int128)res * res % n;
            if(res == n - 1) break;
            if(i == k) return false;
        }
    }
    return true;
}

void solve() {
    i64 x;
    std::cin >> x;
    std::cout << (Minller(x) ? "YES" : "NO") << '\n';
}

//Miller_rabin素数测验
//https://www.luogu.com.cn/problem/SP288
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int T = 1;
    std::cin >> T;
    while(T--) {
        solve();
    }
    return 0;
}
```

5.2 PollardRho

```cpp
#include <bits/stdc++.h>
using i64 = long long;

i64 qpow(i64 a, i64 b, i64 p) {
    i64 res = 1;
    while(b) {
        if(b & 1) {
            res = (__int128)res * a % p;
        }
        a = (__int128)a * a % p;
        b >>= 1;
    }
    return res;
}

//Miller_rabin判断质数
```

```cpp
bool Miller(i64 n) {
    if(n <= 1 || n % 2 == 0) return (n == 2);
    i64 u = n - 1, k = 0;
    while(u % 2 == 0) u /= 2, ++k;
    static std::vector<i64> base = {2, 325, 9375, 28178, 450775, 9780504,
      1795265022};
    for(auto x : base) {
        i64 res = qpow(x, u, n);
        if(res == 0 || res == 1 || res == n - 1) continue;
        for(int i = 1; i <= k; ++i) {
            res = (__int128)res * res % n;
            if(res == n - 1) break;
            if(i == k) return false;
        }
    }
    return true;
}

//Pollard_rho找因子
i64 Pollard_rho(i64 n) {
    assert(n >= 2);
    if(n == 4) return 2;
    static std::mt19937_64 rnd(std::chrono::steady_clock::now().time_since_epoch
      ().count());
    std::uniform_int_distribution<int64_t> rangeRand(1, n - 1);
    i64 c = rangeRand(rnd);
    auto f = [&](i64 x) {
        return ((__int128)x * x + c) % n;
    };
    i64 x = f(0), y = f(x);
    while(x != y) {
        i64 gd = std::gcd(std::abs(x - y), n);
        if(gd != 1) return gd;
        x = f(x), y = f(f(y));
    }
    return n;
}

void solve() {
    i64 x;
    std::cin >> x;
    i64 res = 0;
    auto max_factor = [&](auto self, i64 x) ->void {
        if(x <= res || x < 2) return;
        if(Miller(x)) {
            res = std::max(res, x);
            return;
        }
        i64 p = x;
        while(p == x) {
            p = Pollard_rho(x);
        }
        while(x % p == 0) {
            x /= p;
        }
        self(self, x), self(self, p);
    };
    max_factor(max_factor, x);
    if(res == x) {
        std::cout << "Prime\n";
    } else {
        std::cout << res << '\n';
    }
}

//Pollard_rho快速求大数因子
//https://www.luogu.com.cn/problem/P4718
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int T = 1;
    std::cin >> T;
```

```cpp
87      while(T--) {
88          solve();
89      }
90      return 0;
91  }
```

5.3 区间筛

```cpp
1   #include <bits/stdc++.h>
2   using i64 = long long;
3
4   constexpr int MAXN = 2E5;
5   std::vector<int> prime;
6   std::vector<bool> nonPrime(MAXN + 1);
7   void findPrime(int n) {
8       nonPrime[0] = nonPrime[1] = 1;
9       for(int i = 2; i <= n; ++i) {
10          if(nonPrime[i] == false) {
11              prime.push_back(i);
12          }
13          for(int j = 0; i * prime[j] <= n; ++j) {
14              nonPrime[i * prime[j]] = true;
15              if(i % prime[j] == 0) break;
16          }
17      }
18  }
19  //区间筛，筛区间[L，R]的质数
20  //
21
22  int main() {
23      i64 L, R;
24      findPrime(MAXN);
25      while(std::cin >> L >> R) {
26
27          std::vector<i64> res;
28          std::vector<bool> nonp(R - L + 1);
29          for(auto x : prime) {
30              if(x > R) break;
31              for(int j = std::max((L + x - 1) / x, 2LL); 1LL * j * x <= R; ++j) {
32                  nonp[j * x - L] = 1;
33              }
34          }
35          for(int i = 0; i <= R - L; ++i) {
36              if(nonp[i] == 0 && i + L >= 2) {
37                  res.push_back(i + L);
38              }
39          }
40
41          i64 mn = INT_MAX, mx = INT_MIN;
42          int mnidx = -1, mxidx = -1;
43          for(int i = 1; i < res.size(); ++i) {
44              if(res[i] - res[i - 1] < mn) {
45                  mn = res[i] - res[i - 1];
46                  mnidx = i;
47              }
48              if(res[i] - res[i - 1] > mx) {
49                  mx = res[i] - res[i - 1];
50                  mxidx = i;
51              }
52          }
53          if(res.size() <= 1) {
54              std::cout << "There are no adjacent primes.\n";
55          } else {
56              std::cout << res[mnidx - 1] << ',' << res[mnidx] << " are closest, "
57                        << res[mxidx - 1] << ',' << res[mxidx] << " are most
    distant.\n";
58          }
59      }
60      return 0;
61  }
```

5.4 欧拉筛

```cpp
#include <bits/stdc++.h>
using i64 = long long;
constexpr int MAXN = 1E8;
std::vector<int> prime;
std::vector<bool> nonPrime(MAXN + 1);

void findPrime(int n) { //[0, n]之间素数
    nonPrime[0] = nonPrime[1] = 1;
    for(int i = 2; i <= n; ++i) {
        if(nonPrime[i] == false) {
            prime.push_back(i);
        }
        for(int j = 0; i * prime[j] <= n; ++j) {
            nonPrime[i * prime[j]] = true;
            if(i % prime[j] == 0) break;
        }
    }
}

//线性筛
//https://www.luogu.com.cn/problem/P3383
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int n, q;
    std::cin >> n >> q;
    findPrime(n);
    while(q--) {
        int idx;
        std::cin >> idx;
        std::cout << prime[idx - 1] << '\n';
    }
    return 0;
}
```

6 字符串

6.1 EXKMP

```cpp
#include <bits/stdc++.h>
using i64 = long long;

int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    std::string a, b;
    std::cin >> a >> b;
    int n = a.size(), m = b.size();
    a = '#' + a, b = '#' + b;
    std::vector<int> z(m + 1), p(n + 1);
    z[1] = m;
    for(int i = 2, l = 0, r = 0; i <= m; ++i) {
        if(i <= r) {
            z[i] = std::min(z[i - l + 1], r - i + 1);
        }
        while(i + z[i] <= m && b[i + z[i]] == b[1 + z[i]]) {
            z[i]++;
        }
        if(i + z[i] - 1 > r) {
            l = i, r = i + z[i] - 1;
        }
    }
    for(int i = 1, l = 0, r = 0; i <= n; ++i) {
        if(i <= r) {
            p[i] = std::min(z[i - l + 1], r - i + 1);
        }
        while(1 + p[i] <= m && i + p[i] <= n && b[1 + p[i]] == a[i + p[i]]) {
            p[i]++;
        }
        if(i + p[i] - 1 > r) {
```

```cpp
            l = i, r = i + p[i] - 1;
        }
    }
    i64 ans1 = 0, ans2 = 0;
    for(int i = 1; i <= m; ++i) {
        ans1 ^= 1LL * i * (z[i] + 1);
    }
    for(int i = 1; i <= n; ++i) {
        ans2 ^= 1LL * i * (p[i] + 1);
    }
    std::cout << ans1 << '\n' << ans2 << '\n';
    return 0;
}
```

6.2 KMP

```cpp
#include <bits/stdc++.h>
using i64 = long long;

int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    std::string s, p;
    std::cin >> s >> p;
    int n = s.size(), m = p.size();
    s = '#' + s, p = '#' + p;
    std::vector<int> kmp(m + 1);
    for(int i = 2, j = 0; i <= m; ++i) { //求kmp数组
        while(j > 0 && p[i] != p[j + 1]) {
            j = kmp[j];
        }
        if(p[j + 1] == p[i]) {
            j++;
        }
        kmp[i] = j;
    }
    for(int i = 1, j = 0; i <= n; ++i) {
        while(j > 0 && s[i] != p[j + 1]) {
            j = kmp[j];
        }
        if(s[i] == p[j + 1]) {
            j++;
        }
        if(j == m) {
            std::cout << i - j + 1 << '\n';
            j = kmp[j];
        }
    }
    for(int i = 1; i <= m; ++i) {
        std::cout << kmp[i] << " \n"[i == m];
    }
    return 0;
}
```

6.3 字符串哈希

```cpp
#include <bits/stdc++.h>
using i64 = long long;

//字符串hash
//https://www.luogu.com.cn/problem/P3370
struct Hash {
    std::vector<i64> h1, p1, h2, p2;
    const i64 base1 = 31, base2 = 37;
    const i64 mod1 = 2013265921, mod2 = 1004535809;
    Hash(const std::string &s) //0-index
    : n(s.size()), h1(s.size() + 1), h2(s.size() + 1), p1(s.size() + 1), p2(s.size() + 1) {
        p1[0] = p2[0] = 1;
        for (i64 i = 1; i <= n; i++) {
```

```
14              p1[i] = p1[i - 1] * base1 % mod1;
15              p2[i] = p2[i - 1] * base2 % mod2;
16          }
17          for (i64 i = 1; i <= n; i++) {
18              h1[i] = (h1[i - 1] * base1 % mod1 + s[i - 1]) % mod1;
19              h2[i] = (h2[i - 1] * base2 % mod2 + s[i - 1]) % mod2;
20          }
21      }
22      std::pair<i64, i64> get(int l, int r) {//1-index
23          i64 hash1 = (h1[r] - h1[l - 1] * p1[r - l + 1] % mod1 + mod1) % mod1;
24          i64 hash2 = (h2[r] - h2[l - 1] * p2[r - l + 1] % mod2 + mod2) % mod2;
25          return {hash1, hash2};
26      }
27      int n;
28 };
29
30 int main() {
31     std::ios::sync_with_stdio(false);
32     std::cin.tie(nullptr);
33     int n;
34     std::cin >> n;
35     std::set<std::pair<i64, i64>> st;
36     for(int i = 0; i < n; ++i) {
37         std::string s;
38         std::cin >> s;
39         Hash hs(s);
40         st.insert(hs.get(1, s.size()));
41     }
42     std::cout << st.size() << '\n';
43     return 0;
44 }
```

6.4 马拉车

```
1 #include <bits/stdc++.h>
2
3 //马拉车(manacher)
4 //https://www.luogu.com.cn/problem/P3805
5
6 // 以第i个数为轴的最大回文 v[2 * i + 1]
7 // 以第i个数和i+1个数中间为轴的最大回文 v[2 * i + 2]
8 // 以[L, R] 区间中轴的最大回文为v[L + R + 1]
9 std::vector<int> manacher(const std::string& s) {
10     int n = 2 * s.length() + 1;
11     std::string t(n, '#');//处理字符串
12     for(int i = 0; i < s.length(); ++i) {
13         t[2 * i + 1] = s[i];
14     }
15     std::vector<int> v(n);//记录回文半径 [l, r] <=> [mid - v[mid], mid - v[mid]]
16     for(int i = 0, mid = 0; i < n; ++i) { // mid为回文中心
17         if(i <= mid + v[mid]) {
18             v[i] = std::min(v[2 * mid - i], mid + v[mid] - i);// (t + i) / 2 =
    mid <=> t = 2 * mid - i;
19         }
20         while(t[i - v[i] - 1] == t[i + v[i] + 1] && 0 <= i - v[i] - 1 && i + v[i]
    + 1 < n) {
21             ++v[i];
22         }
23         if(i + v[i] > mid + v[mid]) {
24             mid = i;
25         }
26     }
27     return v;
28 }
29
30 int main() {
31     std::ios::sync_with_stdio(false);
32     std::cin.tie(nullptr);
33     std::string s;
34     std::cin >> s;
35     std::vector<int> v = manacher(s);
```

```
36    int ans = 0;
37    for(int i = 0; i < v.size(); ++i) {
38        ans = std::max(ans, v[i]);//求最长回文子串
39        std::cout << v[i] << " \n"[i == v.size() - 1];
40    }
41    std::cout << ans << '\n';
42    return 0;
43 }
```