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# 1 基础算法

## 1.1 三分

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

# 2 图论

## 2.1 图的连通性

### 2.1.1 Tarjan 割点

```
#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);
    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;
}
```

### 2.1.2 Tarjan 割边

```
#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
                    bridge.push_back({id, nxt});
                }
            } else if(eid != lid) {
                low[id] = std::min(low[id], dfn[nxt]);
            }
        }
    };
    dfs(dfs, 1, 0);
    for(auto [u, v] : bridge) {
```

```

    }
}
};
for(int i = 1; i <= n; ++i) {
    if(!dfn[i]) {
        dfs(dfs, i, 0);
    }
}
std::sort(bridge.begin(), bridge.end());
for(auto [x, y] : bridge) {
    std::cout << x << ' ' << y << '\n';
}
return 0;
}

```

### 2.1.3 Tarjan 强连通分量

```

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

//tarjan求强连通分量(scc)
//https://www.luogu.com.cn/problem/B3609
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 = 0; i < m; ++i) {
        int x, y;
        std::cin >> x >> y;
        v[x].push_back(y);
    }

    std::vector<std::vector<int>> scc(n + 1);
    std::vector<int> dfn(n + 1), low(n + 1), ins(n + 1), bel(n + 1);
    std::stack<int> stk;
    int cnt = 0, tot = 0;
    auto dfs = [&](auto self, int id) ->void {
        dfn[id] = low[id] = ++cnt;
        stk.push(id);
        ins[id] = 1;
        for(auto nxt : v[id]) {
            if(!dfn[nxt]) {
                self(self, nxt);
                low[id] = std::min(low[id], low[nxt]);
            } else if(ins[nxt]) {
                low[id] = std::min(low[id], low[nxt]);
            }
        }
    };
    for(int i = 1; i <= n; ++i) {
        if(!dfn[i]) {
            dfs(dfs, i);
        }
    }

    for(int i = 1; i <= tot; ++i) {
        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;
}

```

```

    }
}
};
if(dfn[id] == low[id]) {
    ++tot;
    while(true) {
        int num = stk.top();
        stk.pop();
        ins[num] = 0;
        bel[num] = tot;
        scc[tot].push_back(num);
        if(id == num) break;
    }
}
};
for(int i = 1; i <= n; ++i) {
    if(!dfn[i]) {
        dfs(dfs, i);
    }
}
for(int i = 1; i <= tot; ++i) {
    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;
}
}

```

### 2.1.4 Tarjan 点双连通分量

```

#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() << ' ';
    for(int j = 0; j < vcc[i].size(); ++j) {
        std::cout << vcc[i][j] << " \n"[j == vcc[i].size() - 1];
    }
}
return 0;
}

```

```
}
```

## 2.1.5 Tarjan 边双连通分量

tarjan 求边双连通分量

Link: <https://www.luogu.com.cn/problem/P8436>

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

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});
        v[y].push_back({x, i});
    }
    std::vector<std::vector<int>> ecc(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 lid) ->void {
        dfn[id] = low[id] = ++cnt;
        stk.push(id);
        for(auto [nxt, eid] : v[id]) {
            if(!dfn[nxt]) {
                self(self, nxt, eid);
                low[id] = std::min(low[id], low[nxt]);
            } else if(lid != eid) {
                low[id] = std::min(low[id], dfn[nxt]);
            }
        }
        if(dfn[id] == low[id]) {
            ++tot;
            while(true) {
                int num = stk.top();
                ecc[tot].push_back(num);
                stk.pop();
                if(id == num) break;
            }
        }
    }
}
```

```
};
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 << ecc[i].size() << ' ';
    for(int j = 0; j < ecc[i].size(); ++j) {
        std::cout << ecc[i][j] << " \n"[j == ecc[i].size() - 1];
    }
}
return 0;
}
```

## 2.2 拓扑排序

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

//拓扑排序
//https://www.luogu.com.cn/problem/B3644
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int n;
    std::cin >> n;
    std::vector<std::vector<int>> v(n + 1); //存图
    std::vector<int> d(n + 1); //统计入度数量
    for(int i = 1; i <= n; ++i) { //建图
        int x;
        while((std::cin >> x) && x != 0) {
            v[i].push_back(x);
            d[x]++;
        }
    }
    std::queue<int> q;
    for(int i = 1; i <= n; ++i) {
        if(d[i] == 0) {
            q.push(i); //将入度为0的放入队列
        }
    }
    while(!q.empty()) {
        int id = q.front();
        q.pop();
        std::cout << id << ' ';
    }
}
```

```
for(auto &nxt : v[id]) {
    d[nxt]--; //更新入度数
    if(d[nxt] == 0) { //将入度为0的放入队列
        q.push(nxt);
    }
}
return 0;
}
```

## 2.3 最小生成树 kruskal

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

//kruskal算法最小生成树(稀疏图)
//https://www.luogu.com.cn/problem/P3366
class DSU { //维护并查集
public:
    DSU(int n) { //初始构造
        v.resize(n + 1);
        std::iota(v.begin(), v.end(), 0);
    }
    int find(int x) { //找根
        return (v[x] == x ? x : (v[x] = find(v[x])));
    }
    void uniset(int x, int y) { //合并集合
        v[find(x)] = find(y);
    }
    bool query(int x, int y) { //是否在同一集合
        return find(x) == find(y);
    }
private:
    std::vector<int> v;
};

struct edge { //边
    int x, y, w; //点, 点, 边权
    bool operator<(const edge& o) const {
        return w < o.w;
    }
};

int main() {
    int n, m;
    std::cin >> n >> m;
    std::vector<edge> v(m);
}
```

```

DSU dsu(n);
for(auto &[x, y, w] : v) {
    std::cin >> x >> y >> w;
}
std::sort(v.begin(), v.end()); //对边排序
int ans = 0, tot = 0;
for(auto [x, y, w] : v) {
    if(!dsu.query(x, y)) {
        dsu.uniset(x, y);
        ans += w;
        tot++;
    }
}
if(tot != n - 1) {
    std::cout << "orz" << '\n';
} else {
    std::cout << ans << '\n';
}
return 0;
}

```

```

int ans = 0;
pq.push({1, 0});
while(!pq.empty()) {
    auto [id, w] = pq.top();
    pq.pop();
    if(!vis[id]) {
        vis[id] = 1;
        ans += w;
        for(auto [nxt, w] : v[id]) {
            if(!vis[nxt]) {
                pq.push({nxt, w});
            }
        }
    }
}
if(!std::min_element(vis.begin() + 1, vis.end())) {
    std::cout << "orz" << '\n'; //图不连通
} else {
    std::cout << ans << '\n';
}
return 0;
}

```

```

self(self, nxt, id);
weight[id] = std::max(weight[id], sz[nxt]);
sz[id] += sz[nxt];
}
weight[id] = std::max(weight[id], n - sz[id]);
ans = std::min(ans, weight[id]);
};
dfs(dfs, 1, 0);
for(int i = 1; i <= n; ++i) {
    if(weight[i] == ans) {
        std::cout << i << ' ';
        break;
    }
}
std::cout << ans << '\n';
}
//树的重心（重心最多有两个）
//http://bailian.openjudge.cn/practice/1655/
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int T = 1;
    std::cin >> T;
    while(T--) {
        solve();
    }
    return 0;
}

```

## 2.4 最小生成树 prim

```

#include <bits/stdc++.h>

//prim算法最小生成树(稠密图)
//https://www.luogu.com.cn/problem/P3366
struct node {
    int id, w;
    bool operator<(const node& o) const {
        return w > o.w;
    }
};

int main() {
    int n, m;
    std::cin >> n >> m;
    std::vector<std::vector<std::pair<int, int>>> v(n + 1);
    std::vector<int> vis(n + 1);
    for(int i = 0; i < m; ++i) {
        int x, y, w;
        std::cin >> x >> y >> w;
        v[x].push_back({y, w});
        v[y].push_back({x, w});
    }
    std::priority_queue<node> pq; //利用优先队列不断加入最小边

```

## 2.5 树的重心

如果在树中选择某个节点并删除，这棵树将分为若干棵子树，统计子树节点数并记录最大值。取遍树上所有节点，使此最大值取到最小的节点被称为整个树的重心。

```

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

void solve() {
    int n;
    std::cin >> n;
    std::vector<std::vector<int>> v(n + 1);
    for(int i = 1; i <= n - 1; ++i) {
        int x, y;
        std::cin >> x >> y;
        v[x].push_back(y);
        v[y].push_back(x);
    }
    std::vector<int> sz(n + 1), weight(n + 1);
    int ans = n;
    auto dfs = [&](auto self, int id, int lst) ->void {
        sz[id] = 1;
        for(auto nxt : v[id]) {
            if(nxt == lst) continue;

```

## 2.6 流和匹配

# 3 数据结构

## 3.1 Splay

```

#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
}
}
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^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;
    }
}
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

```

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

template <typename T, typename Func = std::function<T(const T&, const T&)>>
struct ST {
    ST(const std::vector<T> &v, Func func = [](const T& a, const T& b) {
        return std::max(a, b);
    }) : func(std::move(func)) {
        int k = std::lg(v.size());
        st = std::vector<std::vector<T>>(k + 1, std::vector<T>(v.size()));
        st[0] = v;
        for(int i = 0; i < k; ++i) {
            for(int j = 0; j + (1 << (i + 1)) - 1 < v.size(); ++j) {
                st[i + 1][j] = this->func(st[i][j], st[i][j + (1 << i)]);
            }
        }
    }
    T range(int l, int r) {
        int t = std::lg(r - l + 1);
        return func(st[t][l], st[t][r + 1 - (1 << t)]);
    }
    std::vector<std::vector<T>> st;
    Func func;
};

//ST表(sparseTable)
//https://www.luogu.com.cn/problem/P3865
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int n, q;
    std::cin >> n >> q;
    std::vector<int> v(n + 1);
    for(int i = 1; i <= n; ++i) {
        std::cin >> v[i];
    }
    ST<int> st(v);
    while(q--) {
        int l, r;
        std::cin >> l >> r;
        std::cout << st.range(l, r) << '\n';
    }
    return 0;
}

```

## 3.3 主席树

```

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

template<typename Info, typename Tag>
struct PersistentTree {
    struct Node {
        int l = 0, r = 0;
        Info info;
        Tag tag;
    };
    #define ls(x) (node[x].l)
    #define rs(x) (node[x].r)
    PersistentTree(int n) : PersistentTree(std::vector<Info>(n + 1)) {}
    PersistentTree(const std::vector<Info> &init) : n((int)init.size() - 1) {
        node.reserve(n << 3);
        auto build = [&](auto self, int l, int r) ->int {
            node.push_back(Node());
            int id = node.size() - 1;
            if(l == r) {
                node[id].info = init[l];
            } else {
                int mid = (l + r) / 2;
                ls(id) = self(self, l, mid);
                rs(id) = self(self, mid + 1, r);
                node[id].info = node[ls(id)].info + node[rs(id)].info;
            }
            return id;
        };
        root.push_back(build(build, 1, n));
    };
    int update(int version, int pos, const Info &val) {
        root.push_back(update(root[version], 1, n, pos, val));
        return root.size() - 1;
    }
    int update(int version, int pos, const Tag &dx) {
        root.push_back(update(root[version], 1, n, pos, dx));
        return root.size() - 1;
    }
    Info query(int version, int pos) {
        return rangeQuery(version, pos, pos);
    }
    Info rangeQuery(int version, int l, int r) {
        return rangeQuery(root[version], 1, n, l, r);
    }
    int update(int lst, int l, int r, const int &pos, const Info &val) {
        node.push_back(node[lst]);
    }
}

```

```

int id = node.size() - 1;
if(l == r) {
    node[id].info = val;
} else {
    int mid = (l + r) / 2;
    if(pos <= mid) {
        ls(id) = update(ls(lst), l, mid, pos, val);
    } else if(pos > mid) {
        rs(id) = update(rs(lst), mid + 1, r, pos, val);
    }
    node[id].info = node[ls(id)].info + node[rs(id)].info;
}
return id;
}

int update(int lst, int l, int r, const int &pos, const Tag &dx) {
    node.push_back(node[lst]);
    int id = node.size() - 1;
    if(l == r) {
        node[id].info.apply(dx);
    } else {
        int mid = (l + r) / 2;
        if(pos <= mid) {
            ls(id) = update(ls(lst), l, mid, pos, dx);
        } else if(pos > mid) {
            rs(id) = update(rs(lst), mid + 1, r, pos, dx);
        }
        node[id].info = node[ls(id)].info + node[rs(id)].info;
    }
    return id;
}

Info rangeQuery(int id, int l, int r, const int &x, const int &y) {
    if(x <= l && r <= y) {
        return node[id].info;
    }
    int mid = (l + r) / 2;
    Info res;
    if(x <= mid) {
        res = res + rangeQuery(ls(id), l, mid, x, y);
    }
    if(y > mid) {
        res = res + rangeQuery(rs(id), mid + 1, r, x, y);
    }
    return res;
}

int kth(int versionl, int versionr, int k) {
    return kth(root[versionl], root[versionr], 1, n, k);
}

int kth(int idx, int idy, int l, int r, int k) { //静态区间第k小, 不支持修改

```

```

if(l >= r) return l;
int mid = (l + r) / 2;
int dx = node[ls(idy)].info.sum - node[ls(idx)].info.sum;
if(dx >= k) {
    return kth(ls(idx), ls(idy), l, mid, k);
} else {
    return kth(rs(idx), rs(idy), mid + 1, r, k - dx);
}
}

#undef ls
#undef rs
const int n;
std::vector<Node> node;
std::vector<int> root;
};

struct Tag {
    Tag(int dx = 0) : add(dx) {}
    int add = 0;
    void apply(const Tag &dx) {
        add += dx.add;
    }
};

struct Info {
    int sum = 0;
    void apply(const Tag &dx) {
        sum += dx.add;
    }
};

Info operator+(const Info &x, const Info &y) {
    Info res;
    res.sum = x.sum + y.sum;
    return res;
}

//主席树(单点修改, 历史版本区间查询, 静态区间第k小)
//https://www.luogu.com.cn/problem/P3834
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int n, q;
    std::cin >> n >> q;
    std::vector<int> v(n + 1), tmp(n + 1);
    for(int i = 1; i <= n; ++i) {
        std::cin >> v[i];
        tmp[i] = v[i];
    }
    std::sort(tmp.begin() + 1, tmp.end());

```

```

tmp.erase(std::unique(tmp.begin() + 1, tmp.end()), tmp.end());
int m = tmp.size() - 1;
PersistentTree<Info, Tag> tr(std::vector<Info>(m + 1));
std::vector<int> version(n + 1);
version[0] = tr.root.size() - 1;
for(int i = 1; i <= n; ++i) {
    int pos = std::lower_bound(tmp.begin() + 1, tmp.end(), v[i]) - tmp.begin();
    version[i] = tr.update(version[i - 1], pos, Tag(1));
}
for(int i = 1; i <= q; ++i) {
    int l, r, k;
    std::cin >> l >> r >> k;
    int pos = tr.kth(version[l - 1], version[r], k);
    std::cout << tmp[pos] << '\n';
}
return 0;
}

```

### 3.4 对顶堆

```

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

//对顶堆, 维护第k小/大
template<typename T>
struct DoubleHeap {
    DoubleHeap(int _k) : k(_k) {} //第k小, 若要第k大, 将下面比较函数反转
    std::priority_queue<T, std::vector<T>, std::less<T>> mpq; //大根堆[1, k - 1]
    std::priority_queue<T, std::vector<T>, std::greater<T>> Mpq; //小根堆[k, sz]
    void insert(T x) {
        mpq.push(x);
        while(mpq.size() >= k) {
            Mpq.push(mpq.top());
            mpq.pop();
        }
    }
    T kth() {
        assert(Mpq.empty() == false);
        return Mpq.top();
    }
    const int k;
};

```



```

struct MINT {
    int x;
    bool operator<(const MINT &o) const {
        return x < o.x;
    }
    bool operator>(const MINT &o) const {
        return x > o.x;
    }
};

void solve() {
    int n, k;
    std::cin >> n >> k;
    DoubleHeap<MINT> dpq(k);
    for(int i = 1; i <= n; ++i) {
        int opt;
        std::cin >> opt;
        if(opt == 1) {
            int x;
            std::cin >> x;
            dpq.insert({x});
        } else {
            std::cout << dpq.kth().x << '\n';
        }
    }

    int main() {
        std::ios::sync_with_stdio(false);
        std::cin.tie(nullptr);
        int T;
        std::cin >> T;
        while(T--) {
            solve();
        }
        return 0;
    }
}

```

## 3.5 并查集

```

#include <bits/stdc++.h>

//并查集(disjoint set union)
//https://www.luogu.com.cn/problem/P3367
struct DSU {

```

```

DSU(int n) { //初始构造
    v.resize(n + 1);
    std::iota(v.begin(), v.end(), 0);
}

int find(int x) { //找根
    return (v[x] == x ? x : (v[x] = find(v[x])));
}

void merge(int x, int y) { //合并集合
    v[find(x)] = find(y);
}

bool query(int x, int y) { //是否在同一集合
    return find(x) == find(y);
}

std::vector<int> v;

int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int n, m;
    std::cin >> n >> m;
    DSU dsu(n);
    for(int i = 0; i < m; ++i) {
        int z, x, y;
        std::cin >> z >> x >> y;
        if(z == 1) {
            dsu.merge(x, y);
        } else if(z == 2) {
            std::cout << (dsu.query(x, y) ? 'Y' : 'N') << '\n';
        }
    }
    return 0;
}

```

## 3.6 标记永久化主席树

```

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

template<typename Info, typename Tag>
struct PersistentTree {
    struct Node {
        int l = 0, r = 0;
        Info info;
        Tag tag;
    };
};

```

```

#define ls(x) (node[id].l)
#define rs(x) (node[id].r)

PersistentTree(int n) : n(n) {}

PersistentTree(const std::vector<Info> &init) : PersistentTree((int)init.size() - 1) {
    node.reserve(n << 3);
    auto build = [&](auto self, int l, int r) ->int {
        node.push_back(Node());
        int id = node.size() - 1;
        if(l == r) {
            node[id].info = init[l];
        } else {
            int mid = (l + r) / 2;
            ls(id) = self(self, l, mid);
            rs(id) = self(self, mid + 1, r);
            node[id].info = node[ls(id)].info + node[rs(id)].info;
        }
        return id;
    };
    root.push_back(build(build, 1, n));
}

int update(int version, int t, const Tag &dx) {
    return rangeUpdate(version, t, t, dx);
}

Info query(int version, int t) {
    return rangeQuery(version, t, t);
}

int rangeUpdate(int version, int l, int r, const Tag &dx) {
    root.push_back(rangeUpdate(root[version], 1, n, l, r, dx));
    return root.size() - 1;
}

Info rangeQuery(int version, int l, int r) {
    return rangeQuery(root[version], 1, n, l, r);
}

int rangeUpdate(int lst, int l, int r, const int &x, const int &y, const Tag &dx) {
    node.push_back(node[lst]);
    int id = node.size() - 1;
    node[id].info.apply(std::min(r, y) - std::max(l, x) + 1, dx);
    if(x <= l && r <= y) {
        node[id].tag.apply(dx);
    } else {
        int mid = (l + r) / 2;
        if(x <= mid) {
            ls(id) = rangeUpdate(ls(lst), l, mid, x, y, dx);
        }
        if(y > mid) {
            rs(id) = rangeUpdate(rs(lst), mid + 1, r, x, y, dx);
        }
    }
}

```

```

    }
    return id;
}
Info rangeQuery(int id, int l, int r, const int &x, const int &y) {
    if(x <= l && r <= y) {
        return node[id].info;
    }
    int mid = (l + r) / 2;
    Info res;
    if(x <= mid) {
        res = res + rangeQuery(ls(id), l, mid, x, y);
    }
    if(y > mid) {
        res = res + rangeQuery(rs(id), mid + 1, r, x, y);
    }
    res.apply(std::min(r, y) - std::max(l, x) + 1, node[id].tag);
    return res;
}
#undef ls
#undef rs
const int n;
std::vector<Node> node;
std::vector<int> root;
};

struct Tag {
    Tag(int dx = 0) : add(dx) {}
    int add = 0;
    void apply(const Tag &dx) {
        add += dx.add;
    }
};

struct Info {
    int sum = 0;
    void apply(int len, const Tag &dx) {
        sum += 1LL * len * dx.add;
    }
};

Info operator+(const Info &x, const Info &y) {
    Info res;
    res.sum = x.sum + y.sum;
    return res;
}

//可持久化线段树(区间修改, 区间历史查询)
//https://www.luogu.com.cn/problem/P3919
int main() {

```

```

std::ios::sync_with_stdio(false);
std::cin.tie(nullptr);
int n, q;
std::cin >> n >> q;
std::vector<Info> v(n + 1);
for(int i = 1; i <= n; ++i) {
    std::cin >> v[i].sum;
}
PersistentTree<Info, Tag> tr(v);
std::vector<int> version(q + 1);
for(int i = 1; i <= q; ++i) {
    int ver, opt, pos;
    std::cin >> ver >> opt >> pos;
    if(opt == 1) {
        int x;
        std::cin >> x;
        int lst = tr.query(version[ver], pos).sum;
        version[i] = tr.update(version[ver], pos, Tag(x - lst));
    } else if(opt == 2) {
        std::cout << tr.query(version[ver], pos).sum << '\n';
        version[i] = version[ver];
    }
}
return 0;
}

```

### 3.7 树状数组

```

#include<bits/stdc++.h>

//树状数组(Fenwick)
//https://www.luogu.com.cn/problem/P3374
template<typename T>
struct Fenwick {
    Fenwick(int n) : v(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);
}
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;
};

```

### 3.8 树状数组 2

```

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

template<typename T>
struct Fenwick {
    Fenwick(int n) : vec(n + 1), add(n + 1) {}
    void rangeUpdate(int l, int r, T dx) {
        update(l, dx);
        update(r + 1, -dx);
    }
    T rangeQuery(int l, int r) {
        return query(r) - query(l - 1);
    }
    void update(int pos, T dx) {

```

```

        for(int i = pos; i < vec.size(); i += (i & -i)) {
            vec[i] += dx;
            add[i] += (pos - 1) * dx;
        }
    }
    T query(int pos) {
        T res{};
        for(int i = pos; i >= 1; i -= (i & -i)) {
            res += pos * vec[i] - add[i];
        }
        return res;
    }
    std::vector<T> vec, add;
};

//树状数组，区间修改，区间查询
//https://www.luogu.com.cn/problem/P3372
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int n, m;
    std::cin >> n >> m;
    Fenwick<i64> tr(n);
    for(int i = 1; i <= n; ++i) {
        int x;
        std::cin >> x;
        tr.rangeUpdate(i, i, x);
    }
    for(int i = 1; i <= m; ++i) {
        int opt;
        std::cin >> opt;
        if(opt == 1) {
            int l, r, dx;
            std::cin >> l >> r >> dx;
            tr.rangeUpdate(l, r, dx);
        } else if(opt == 2) {
            int l, r;
            std::cin >> l >> r;
            std::cout << tr.rangeQuery(l, r) << '\n';
        }
    }
    return 0;
}

```

### 3.9 波纹疾走树

```

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

struct BitRank {
    // block 管理一行一行的bit
    std::vector<unsigned long long> block;
    std::vector<unsigned int> count;
    BitRank() {}
    // 位向量长度
    void resize(const unsigned int num) {
        block.resize(((num + 1) >> 6) + 1, 0);
        count.resize(block.size(), 0);
    }
    // 设置i位bit
    void set(const unsigned int i, const unsigned long long val) {
        block[i >> 6] |= (val << (i & 63));
    }
    void build() {
        for (unsigned int i = 1; i < block.size(); i++) {
            count[i] = count[i - 1] + __builtin_popcountll(block[i - 1]);
        }
    }
    // [0, i) 1的个数
    unsigned int rank1(const unsigned int i) const {
        return count[i >> 6] + __builtin_popcountll(block[i >> 6] & ((1ULL << (i & 63)) - 1ULL));
    }
    // [i, j) 1的个数
    unsigned int rank1(const unsigned int i, const unsigned int j) const {
        return rank1(j) - rank1(i);
    }
    // [0, i) 0的个数
    unsigned int rank0(const unsigned int i) const {
        return i - rank1(i);
    }
    // [i, j) 0的个数
    unsigned int rank0(const unsigned int i, const unsigned int j) const {
        return rank0(j) - rank0(i);
    }
};

class WaveletMatrix {
private:
    unsigned int height;
    std::vector<BitRank> B;
    std::vector<int> pos;
public:
    WaveletMatrix() {}

```

```

    WaveletMatrix(std::vector<int> vec) : WaveletMatrix(vec, *std::
        max_element(vec.begin(), vec.end()) + 1) {}
    // sigma: 字母表大小(字符串的话)，数字序列的话是数的种类
    WaveletMatrix(std::vector<int> vec, const unsigned int sigma) {
        height = (sigma == 1) ? 1 : (64 - __builtin_clzll(sigma - 1));
        B.resize(height), pos.resize(height);
        for (unsigned int i = 0; i < height; ++i) {
            B[i].resize(vec.size());
            for (unsigned int j = 0; j < vec.size(); ++j) {
                B[i].set(j, get(vec[j], height - i - 1));
            }
            B[i].build();
            auto it = stable_partition(vec.begin(), vec.end(), [i](int c) {
                return !get(c, height - i - 1);
            });
            pos[i] = it - vec.begin();
        }
    }

    int get(const int val, const int i) {
        return (val >> i) & 1;
    }

    // [l, r] 中val出现的频率
    int rank(const int l, const int r, const int val) {
        return rank(r, val) - rank(l - 1, val);
    }

    // [0, i] 中val出现的频率
    int rank(int i, int val) {
        ++i;
        int p = 0;
        for (unsigned int j = 0; j < height; ++j) {
            if (get(val, height - j - 1)) {
                p = pos[j] + B[j].rank1(p);
                i = pos[j] + B[j].rank1(i);
            } else {
                p = B[j].rank0(p);
                i = B[j].rank0(i);
            }
        }
        return i - p;
    }

    // [l, r] 中k小
    int kth(int l, int r, int k) {
        ++r;
        int res = 0;
        for (unsigned int i = 0; i < height; ++i) {

```

```

const int j = B[i].rank0(l, r);
if (j >= k) {
    l = B[i].rank0(l);
    r = B[i].rank0(r);
} else {
    l = pos[i] + B[i].rank1(l);
    r = pos[i] + B[i].rank1(r);
    k -= j;
    res |= (1 << (height - i - 1));
}
}
return res;
}

// [l,r] 在[a, b] 值域的数字个数
int rangeFreq(const int l, const int r, const int a, const int b) {
    return rangeFreq(l, r + 1, a, b + 1, 0, 1 << height, 0);
}

int rangeFreq(const int i, const int j, const int a, const int b, const
int l, const int r, const int x) {
    if (i == j || r <= a || b <= l) return 0;
    const int mid = (l + r) >> 1;
    if (a <= l && r <= b) {
        return j - i;
    } else {
        const int left = rangeFreq(B[x].rank0(i), B[x].rank0(j), a, b, l,
mid, x + 1);
        const int right = rangeFreq(pos[x] + B[x].rank1(i), pos[x] + B[x
].rank1(j), a, b, mid, r, x + 1);
        return left + right;
    }
}

// [l,r] 在[a,b] 值域内存在的最小值是什么, 不存在返回-1, 只支持非负整数
int rangeMin(int l, int r, int a, int b) {
    return rangeMin(l, r + 1, a, b + 1, 0, 1 << height, 0, 0);
}

int rangeMin(const int i, const int j, const int a, const int b, const
int l, const int r, const int x, const int val) {
    if (i == j || r <= a || b <= l) return -1;
    if (r - l == 1) return val;
    const int mid = (l + r) >> 1;
    const int res = rangeMin(B[x].rank0(i), B[x].rank0(j), a, b, l, mid,
x + 1, val);
    if (res < 0) {
        return rangeMin(pos[x] + B[x].rank1(i), pos[x] + B[x].rank1(j), a
, b, mid, r, x + 1, val + (1 << (height - x - 1)));
    } else {
        return res;
    }
}

```

```

}
}
};

//波状疾走树(区间第k小, 区间val出现的频率, 区间在值域出现的次数和最小值)
//https://www.luogu.com.cn/problem/P3834
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(0);
    int n, q;
    std::cin >> n >> q;
    std::vector<int> v(n + 1);
    for(int i = 1; i <= n; ++i) {
        std::cin >> v[i];
    }
    WaveletMatrix wlm(v);
    for(int i = 1; i <= q; ++i) {
        int l, r, k;
        std::cin >> l >> r >> k;
        std::cout << wlm.kth(l, r, k) << '\n';
    }
    return 0;
}

```

### 3.10 线段树

```

#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((int)init.size()
- 1) {
        auto build = [&](auto self, int id, int l, int r) ->void {
            if(l == r) {
                info[id] = init[l];
                return;
            }
            int mid = (l + r) / 2;
            self(self, ls, l, mid);
            self(self, rs, mid + 1, r);

```

```

        pushup(id);
    };
    build(build, 1, 1, n);
}

void apply(int id, const Tag &dx) {
    info[id].apply(dx);
    tag[id].apply(dx);
}

void pushup(int id) {
    info[id] = info[ls] + info[rs];
}

void pushdown(int id) {
    apply(ls, tag[id]);
    apply(rs, tag[id]);
    tag[id] = Tag();
}

void rangeUpdate(int l, int r, const Tag &dx) {
    rangeUpdate(1, 1, n, l, r, dx);
}

void update(int t, const Tag &dx) {
    rangeUpdate(t, t, dx);
}

Info rangeQuery(int l, int r) {
    return rangeQuery(1, 1, n, l, r);
}

Info query(int t) {
    return rangeQuery(t, t);
}

void rangeUpdate(int id, int l, int r, int x, int y, const Tag &dx) {
    if(x <= l && r <= y) {
        apply(id, dx);
        return;
    }
    int mid = (l + r) / 2;
    pushdown(id);
    if(x <= mid) {
        rangeUpdate(ls, l, mid, x, y, dx);
    }
    if(y > mid) {
        rangeUpdate(rs, mid + 1, r, x, y, dx);
    }
    pushup(id);
}

Info rangeQuery(int id, int l, int r, int x, int y) {
    if(x <= l && r <= y) {
        return info[id];
    }
    int mid = (l + r) / 2;
    pushdown(id);

```

```

    Info res;
    if(x <= mid) {
        res = res + rangeQuery(ls, l, mid, x, y);
    }
    if(y > mid) {
        res = res + rangeQuery(rs, mid + 1, r, x, y);
    }
    return res;
}
#endif ls
#endif rs
const int n;
std::vector<Info> info;
std::vector<Tag> tag;
};

constexpr i64 INF = 1E18;

struct Tag {
    i64 add = 0;
    void apply(const Tag &dx) {
        add += dx.add;
    }
};

struct Info {
    i64 mn = INF;
    i64 mx = -INF;
    i64 sum = 0;
    i64 len = 1;
    void apply(const Tag &dx) {
        mn += dx.add;
        mx += dx.add;
        sum += len * dx.add;
    }
};

Info operator+(const Info &x, const Info &y) {
    Info res;
    res.mn = std::min(x.mn, y.mn);
    res.mx = std::max(x.mx, y.mx);
    res.sum = x.sum + y.sum;
    res.len = x.len + y.len;
    return res;
}

int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);

```

```

    int n, m;
    std::cin >> n >> m;
    std::vector<Info> v(n + 1);
    for(int i = 1; i <= n; ++i) {
        int x;
        std::cin >> x;
        v[i] = {x, x, x, 1};
    }
    SegmentTree<Info, Tag> tr(v);
    // SegmentTree<Info, Tag> tr(n);
    // for(int i = 1; i <= n; ++i) {
    //     int x;
    //     std::cin >> x;
    //     tr.update(i, Tag(x));
    // }
    while(m--) {
        int opt, x, y;
        std::cin >> opt >> x >> y;
        if(opt == 1) {
            int k;
            std::cin >> k;
            tr.rangeUpdate(x, y, Tag(k));
        } else if(opt == 2) {
            std::cout << tr.rangeQuery(x, y).sum << '\n';
        }
    }
    return 0;
}

```

### 3.11 线段树优化建图

```

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

struct STOG {
#define ls (id<<1)
#define rs (id<<1|1)
    STOG(int n) : n(n), in(n << 2), out(n << 2), v(n * 7) {
        int tot = n;
        auto build = [&](auto self, int id, int l, int r) ->void {
            if(l == r) {
                in[id] = out[id] = l;
                return;
            }
            int mid = (l + r) / 2;
            self(self, ls, l, mid);

```

```

            self(self, rs, mid + 1, r);
            in[id] = ++tot;
            out[id] = ++tot;
            update(in[id], in[ls], 0);
            update(in[id], in[rs], 0);
            update(out[ls], out[id], 0);
            update(out[rs], out[id], 0);
        };
        build(build, 1, 1, n);
    }
    void update(int x, int y, int w) { //连一条从x 到 y的边, 边权为w
        v[x].emplace_back(y, w);
    }
    //model == 0 时, 从pos 到 [x, y]连边, 边权为w
    //model == 1 时, 从[x, y] 到 pos连边, 边权为w
    void rangeUpdate(int pos, int x, int y, int w, int model) {
        rangeUpdate(1, 1, n, pos, x, y, w, model);
    }
    void rangeUpdate(int id, int l, int r, int pos, int x, int y, int w, auto model) {
        if(x <= l && r <= y) {
            if(model == 0) {
                update(pos, in[id], w);
            } else {
                update(out[id], pos, w);
            }
            return;
        }
        int mid = (l + r) / 2;
        if(x <= mid) {
            rangeUpdate(ls, l, mid, pos, x, y, w, model);
        }
        if(y > mid) {
            rangeUpdate(rs, mid + 1, r, pos, x, y, w, model);
        }
    }
#endif ls
#endif rs
int n;
std::vector<int> in, out;
std::vector<std::vector<std::pair<int, int>>> v;
};

int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int n, q, s;
    std::cin >> n >> q >> s;
    STOG tr(n);

```

```

for(int i = 1; i <= q; ++i) {
    int opt;
    std::cin >> opt;
    if(opt == 1) {
        int pos, x, w;
        std::cin >> pos >> x >> w;
        tr.update(pos, x, w);
    } else if(opt == 2) {
        int pos, x, y, w;
        std::cin >> pos >> x >> y >> w;
        tr.rangeUpdate(pos, x, y, w, 0);
    } else if(opt == 3) {
        int pos, x, y, w;
        std::cin >> pos >> x >> y >> w;
        tr.rangeUpdate(pos, x, y, w, 1);
    }
}
auto ggraph = tr.v;
int m = tr.v.size() - 1;
std::vector<i64> dp(m + 1, LLONG_MAX);
std::priority_queue<std::pair<i64, int>, std::vector<std::pair<i64, int>
    >>, std::greater<>> pq;
pq.emplace(0LL, s);
while(!pq.empty()) {
    auto [w, id] = pq.top();
    pq.pop();
    if(w >= dp[id]) continue;
    dp[id] = w;
    for(const auto &nxt, dx] : graph[id]) {
        i64 ww = w + dx;
        if(ww < dp[nxt]) {
            pq.emplace(ww, nxt);
        }
    }
}
for(int i = 1; i <= n; ++i) {
    std::cout << (dp[i] == LLONG_MAX ? -1 : dp[i]) << " \n"[i == n];
}
return 0;
}

```

## 3.12 重链剖分

```

#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, t);
            }
        }
    };
    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;
}

```

## 4 数学

### 4.1 数论

#### 4.1.1 MillerRabin

```

#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 Miller(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;
}

```

## 4.1.2 PollardRho

```

#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
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<i64_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;
    while(T--) {
        solve();
    }
    return 0;
}

```

## 4.1.3 区间筛

```

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

constexpr int MAXN = 2E5;
std::vector<int> prime;
std::vector<bool> nonPrime(MAXN + 1);
void findPrime(int n) {
    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;
        }
    }
}

```

```
//区间筛，筛区间[L, R]的质数
//https://www.luogu.com.cn/problem/UVA10140
int main() {
    i64 L, R;
    findPrime(MAXN);
    while(std::cin >> L >> R) {

        std::vector<i64> res;
        std::vector<bool> nonp(R - L + 1);
        for(auto x : prime) {
            if(x > R) break;
            for(int j = std::max((L + x - 1) / x, 2LL); 1LL * j * x <= R; ++j) {
                nonp[j * x - L] = 1;
            }
        }
        for(int i = 0; i <= R - L; ++i) {
            if(nonp[i] == 0 && i + L >= 2) {
                res.push_back(i + L);
            }
        }

        i64 mn = INT_MAX, mx = INT_MIN;
        int mnidx = -1, mxidx = -1;
        for(int i = 1; i < res.size(); ++i) {
            if(res[i] - res[i - 1] < mn) {
                mn = res[i] - res[i - 1];
                mnidx = i;
            }
            if(res[i] - res[i - 1] > mx) {
                mx = res[i] - res[i - 1];
                mxidx = i;
            }
        }
        if(res.size() <= 1) {
            std::cout << "There are no adjacent primes.\n";
        } else {
            std::cout << res[mnidx - 1] << ',' << res[mnidx] << " are closest
, "
            << res[mxidx - 1] << ',' << res[mxidx] << " are most
distant.\n";
        }
    }
    return 0;
}
```

#### 4.1.4 欧拉筛

```
#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;
}
```

### 4.2 组合数学

#### 4.2.1 卢卡斯定理

$$C_n^m \pmod{p} = C_{\lfloor \frac{n}{p} \rfloor}^{\lfloor \frac{m}{p} \rfloor} * C_{n \bmod p}^{m \bmod p}$$

```
#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 = res * a % p;
        }
        a = a * a % p;
        b >>= 1;
    }
    return res;
}

void solve() {
    int n, m, p;
    std::cin >> n >> m >> p;
    std::vector<i64> fac(p + 1, 1);
    for(int i = 2; i <= p; ++i) {
        fac[i] = fac[i - 1] * i % p;
    }
    auto comb = [&fac, &p](i64 n, i64 m) ->i64 {
        return fac[n] * qpow(fac[m], p - 2, p) % p * qpow(fac[n - m], p - 2, p) % p;
    };
    auto lucas = [&fac, &p, &comb](auto self, i64 n, i64 m) ->i64 {
        if(m == 0) return 1;
        return self(self, n / p, m / p) * comb(n % p, m % p) % p;
    };
    std::cout << lucas(lucas, n, m) << '\n';
}

//lucas定理，求大数组合数
//https://www.luogu.com.cn/problem/P3807
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int T = 1;
    std::cin >> T;
    while(T--) {
        solve();
    }
    return 0;
}
```



## 5 字符串

### 5.1 EXKMP

```
#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) {
            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';
}
```

### 5.2 KMP

```
#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;
}
```

```
return 0;
}
```

### 5.3 字符串哈希

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

const int NUM = 2, MAXLEN = 60000; //哈希次数, 字符串最大长度
const std::vector<i64> base = {31, 37, 233};
const std::vector<i64> mod = {2013265921, 1004535809, 2147483647};
std::vector<std::array<i64, NUM>> fac(MAXLEN + 1);

struct Hash {
    Hash() {}
    Hash(const std::string &s) : n(s.size()), hs(s.size() + 1) { //0-index
        for(int j = 0; j < NUM; ++j) {
            for(int i = 1; i <= n; ++i) {
                hs[i][j] = (hs[i - 1][j] * base[j] + s[i - 1]) % mod[j];
            }
        }
        std::array<i64, NUM> range(int l, int r) { //1-index
            std::array<i64, NUM> res;
            for(int i = 0; i < NUM; ++i) {
                res[i] = (hs[r][i] - hs[l - 1][i] * fac[r - l + 1][i] % mod[i] +
                    mod[i]) % mod[i];
            }
            return res;
        }
        int n;
        std::vector<std::array<i64, NUM>> hs;
    };
};

void HashInit() {
    for(int j = 0; j < NUM; ++j) {
        fac[0][j] = 1;
        for(int i = 1; i <= MAXLEN; ++i) {
            fac[i][j] = fac[i - 1][j] * base[j] % mod[j];
        }
    }
}

//字符串hash
//https://www.luogu.com.cn/problem/P3370
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    HashInit(); //预处理
    int n;
    std::cin >> n;
    std::set<std::array<i64, NUM>> st;
```

```

for(int i = 0; i < n; ++i) {
    std::string s;
    std::cin >> s;
    Hash hs(s);
    st.insert(hs.range(1, s.size()));
}
std::cout << st.size() << '\n';
return 0;
}

```

```

std::cin.tie(nullptr);
std::string s;
std::cin >> s;
std::vector<int> v = manacher(s);
int ans = 0;
for(int i = 0; i < v.size(); ++i) {
    ans = std::max(ans, v[i]); //求最长回文子串
    std::cout << v[i] << " \n"[i == v.size() - 1];
}
std::cout << ans << '\n';
return 0;
}

```

## 5.4 马拉车

```

#include <bits/stdc++.h>

//马拉车(manacher)
//https://www.luogu.com.cn/problem/P3805

// 以第i个数为中心的轴的最大回文 v[2 * i + 1]
// 以第i个数和i+1个数中间为轴的轴的最大回文 v[2 * i + 2]
// 以[L, R] 区间中轴的轴的最大回文为v[L + R + 1]
std::vector<int> manacher(const std::string& s) {
    int n = 2 * s.length() + 1;
    std::string t(n, '#'); //处理字符串
    for(int i = 0; i < s.length(); ++i) {
        t[2 * i + 1] = s[i];
    }
    std::vector<int> v(n); //记录回文半径 [l, r] <=> [mid - v[mid], mid + v[mid]]
    for(int i = 0, mid = 0; i < n; ++i) { // mid为回文中心
        if(i <= mid + v[mid]) {
            v[i] = std::min(v[2 * mid - i], mid + v[mid] - i); // (t + i) / 2 = mid <=> t = 2 * mid - i;
        }
        while(t[i - v[i] - 1] == t[i + v[i] + 1] && 0 <= i - v[i] - 1 && i + v[i] + 1 < n) {
            ++v[i];
        }
        if(i + v[i] > mid + v[mid]) {
            mid = i;
        }
    }
    return v;
}

int main() {
    std::ios::sync_with_stdio(false);
}

```

## 6 计算几何

### 6.1 凸包

```

#include <bits/stdc++.h>
using i64 = long long;
constexpr long double EPS = 1E-10;

using T = long double;
struct Point {
    T x = 0, y = 0;
    Point operator+(const Point &o) const {return {x + o.x, y + o.y};}
    Point operator-(const Point &o) const {return {x - o.x, y - o.y};}
    Point operator-() const {return {-x, -y};}
    Point operator*(T fac) const {return {x * fac, y * fac};}
    Point operator/(T fac) const {return {x / fac, y / fac};}
    bool operator<(const Point &o) const {
        return std::tie(x, y) < std::tie(o.x, o.y);
    }
    friend std::istream &operator>>(std::istream &is, Point &p) {
        return is >> p.x >> p.y;
    }
    friend std::ostream &operator<<(std::ostream &os, Point p) {
        return os << "(" << p.x << ", " << p.y << ")";
    }
};

struct Line {
    Point s, t;
    Line() = default;
    Line(Point _s, Point _t) : s(_s), t(_t) {}
}

```

```

};

int sgn(T a){
    if(fabs(a) < EPS) return 0;
    return a > 0 ? 1 : -1;
}

T dot(const Point &a, const Point &b) {
    return a.x * b.x + a.y * b.y;
}

T cross(const Point &a, const Point &b) {
    return a.x * b.y - a.y * b.x;
}

T cross(const Point &a, const Point &b, const Point &c) {
    return cross(b - a, c - a);
}

T len(const Point &a) {
    return sqrtl(a.x * a.x + a.y * a.y);
}

T angle(const Point &a, const Point &b) {
    return acosl(dot(a, b) / len(a) / len(b));
}

T dis2(const Point &a, const Point &b) {
    return (a.x - b.x) * (a.x - b.x) + (a.y - b.y) * (a.y - b.y);
}

T dis(const Point &a, const Point &b) {
    return sqrtl(dis2(a, b));
}

Point rotate(const Point &a, const Point &b, T theta) {
    return {
        (b.x - a.x) * cosl(theta) - (b.y - a.y) * sinl(theta) + a.x,
        (b.x - a.x) * sinl(theta) + (b.y - a.y) * cosl(theta) + a.y
    };
}

bool intersect(const Line &a, const Line &b) {
    return cross(a.s, a.t, b.s) * cross(a.s, a.t, b.t) <= 0
        && cross(b.s, b.t, a.s) * cross(a.s, b.t, a.t) <= 0;
}

bool intersectStrictly(const Line &a, const Line &b) {
    return cross(a.s, a.t, b.s) * cross(a.s, a.t, b.t) < 0
        && cross(b.s, b.t, a.s) * cross(a.s, b.t, a.t) < 0;
}

Point getNode(const Line &a, const Line &b) {
    T dx = cross(b.s, b.t, a.s) / cross(b.s, b.t, a.t);
    return a.s + (a.t - a.s) * std::abs(dx);
};

std::vector<Point> andrew(std::vector<Point> &v) {
}

```

```

int n = v.size();
std::sort(v.begin(), v.end());
std::vector<Point> stk;
for(int i = 0; i < n; ++i) {
    while(stk.size() > 1 && cross(stk[stk.size() - 2], stk.back(), v[i])
    <= 0) {
        stk.pop_back();
    }
    stk.push_back(v[i]);
}
int t = stk.size();
for(int i = n - 2; i >= 0; --i) {
    while(stk.size() > t && cross(stk[stk.size() - 2], stk.back(), v[i])
    <= 0) {
        stk.pop_back();
    }
    stk.push_back(v[i]);
}
stk.pop_back();
return stk;
};

T diameter(const std::vector<Point> &v) {
    int n = v.size();
    T res = 0;
    for(int i = 0, j = 1; i < n; ++i) {
        while(sgn(cross(v[i], v[(i + 1) % n], v[j]) - cross(v[i], v[(i + 1) %
n], v[(j + 1) % n])) <= 0) {
            j = (j + 1) % n;
        }
        res = std::max({res, dis(v[i], v[j]), dis(v[(i + 1) % n], v[j])});
    }
    return res;
}

T diameter2(const std::vector<Point> &v) {
    int n = v.size();
    T res = 0;
    for(int i = 0, j = 1; i < n; ++i) {
        while(sgn(cross(v[i], v[(i + 1) % n], v[j]) - cross(v[i], v[(i + 1) %
n], v[(j + 1) % n])) <= 0) {
            j = (j + 1) % n;
        }
        res = std::max({res, dis2(v[i], v[j]), dis2(v[(i + 1) % n], v[j])});
    }
    return res;
}

T grith(const std::vector<Point> &convex) {

```

```

long double ans = 0;
for(int i = 0; i < convex.size(); ++i) {
    ans += dis(convex[i], convex[(i + 1) % convex.size()]);
}
return ans;
}

void solve() {
    int n, m;
    std::cin >> n;
    std::vector<Point> A(n);
    for(int i = 0; i < n; ++i) {
        std::cin >> A[i];
    }
    std::cin >> m;
    std::vector<Point> B(m);
    for(int i = 0; i < m; ++i) {
        std::cin >> B[i];
    }
    long double ans = grith(A) + 2.0L * sqrtl(diameter2(B)) * acosl(-1.0L);
    //A周长 + 2 * B直径 * PI
    std::cout << std::fixed << std::setprecision(15) << ans << '\n';
}

int main(){
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int T = 1;
    std::cin >> T;
    while(T--) {
        solve();
    }
    return 0;
}

```

## 7 杂项

### 7.1 康托展开

```

#include <bits/stdc++.h>
using i64 = long long;
constexpr i64 P = 998244353;

template<typename T>

```

```

class Fenwick {
public:
    Fenwick(int n) : v(std::vector<T>(n + 1)) {};
    void update(int x, T dx) {
        for(int i = x; i < v.size(); i += (i & -i)) {
            v[i] += dx;
        }
    }
    T query(int x) {
        T res{};
        for(int i = x; i > 0; i -= (i & -i)) {
            res += v[i];
        }
        return res;
    }
    T range(int l, int r) {
        return query(r) - query(l - 1);
    }
private:
    std::vector<T> v;
};

//康托展开(求排列的排名)
//https://www.luogu.com.cn/problem/P5367
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int n;
    std::cin >> n;
    Fenwick<int> tr(n);
    std::vector<int> p(n + 1);
    std::vector<i64> fac(n + 1, 1);
    for(int i = 1; i <= n; ++i) {
        std::cin >> p[i];
        tr.update(p[i], 1);
        fac[i] = fac[i - 1] * i % P;
    }
    i64 ans = 1;
    for(int i = 1; i <= n; ++i) {
        ans = (ans + fac[n - i] * tr.query(p[i] - 1)) % P;
        tr.update(p[i], -1);
    }
    std::cout << ans << '\n';
    return 0;
}

```

## 7.2 逆康托展开

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

template<typename T>
class Fenwick {
public:
    Fenwick(int n) : v(std::vector<T>(n + 1)) {};
    void update(int x, T dx) {
        for(int i = x; i < v.size(); i += (i & -i)) {
            v[i] += dx;
        }
    }
    T query(int x) {
        T res{};
        for(int i = x; i > 0; i -= (i & -i)) {
            res += v[i];
        }
        return res;
    }
    T range(int l, int r) {
        return query(r) - query(l - 1);
    }
private:
    std::vector<T> v;
};

//逆康托展开
//https://acm.hdu.edu.cn/showproblem.php?pid=1027
int main() {
    std::ios::sync_with_stdio(false);
    std::cin.tie(nullptr);
    int n, m;
    while(std::cin >> n >> m) {
        Fenwick<int> tr(n);
        std::vector<i64> fac(n + 1, 1);
        for(int i = 1; i <= n; ++i) {
            if(fac[i - 1] > m) {
                fac[i] = fac[i - 1];
            } else {
                fac[i] = fac[i - 1] * i;
            }
            tr.update(i, 1);
        }
        m--;
        for(int i = 1; i <= n; ++i) {
            int k = m / fac[n - i];
```

```
int l = k + 1, r = n, res = 1;
while(l <= r) {
    int mid = (l + r) / 2;
    if(tr.query(mid - 1) <= k) {
        res = mid;
        l = mid + 1;
    } else {
        r = mid - 1;
    }
}
tr.update(res, -1);
m = m % fac[n - i];
std::cout << res << " \n"[i == n];
}
return 0;
}
```

## 7.3 高精度

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

// using i128= __int128;
// std::istream&operator>>(std::istream &is,i128 &n){
//     std::string s;is>>s;
//     n=0;
//     for(char i:s) n=n*10+i-'0';
//     return is;
// }
// std::ostream &operator<<(std::ostream &os,i128 n){
//     std::string s;
//     while(n){
//         s+='0'+n%10;
//         n/=10;
//     }
//     std::reverse(s.begin(),s.end());
//     return os<<s;
// }

struct Bigint {
    std::string a;
    int sign;
    Bigint() {}
    Bigint(std::string b) {
        (*this) = b;
    }
};
```

```

}

int size() {
    return a.size();
}

Bigint normalize(int newSign) { //removes leading 0, fixes sign
    for(int i = a.size() - 1; i > 0 && a[i] == '0'; --i) {
        a.erase(a.begin() + i);
    }
    sign = (a.size() == 1 && a[0] == '0') ? 1 : newSign;
    return (*this);
}

void operator=(std::string b) {
    a = b[0] == '-' ? b.substr(1) : b;
    reverse(a.begin(), a.end());
    this->normalize(b[0] == '-' ? -1 : 1);
}

bool operator<(const Bigint &b) const {
    if(sign != b.sign) {
        return sign < b.sign;
    }
    if(a.size() != b.a.size()) {
        return sign == 1 ? a.size() < b.a.size() : a.size() > b.a.size();
    }
    for(int i = a.size() - 1; i >= 0; --i) {
        if(a[i] != b.a[i]) {
            return sign == 1 ? a[i] < b.a[i] : a[i] > b.a[i];
        }
    }
    return false;
}

bool operator==(const Bigint &b) const {
    return (a == b.a && sign == b.sign);
}

bool operator!=(const Bigint &b) const {
    return !operator==(b);
}

Bigint operator+(Bigint b) {
    if(sign != b.sign) {
        return (*this) - (-b); //don't modify here
    }
    Bigint c;
    for(int i = 0, carry = 0; i < a.size() || i < b.size() || carry; ++i) {
        carry += (i < a.size() ? a[i] - 48 : 0) + (i < b.a.size() ? b.a[i] - 48 : 0);
        c.a += (carry % 10 + 48);
        carry /= 10;
    }
    return c.normalize(sign);
}
```

```

}
Bigint operator-() {
    sign *= -1;
    return (*this);
}
Bigint operator-(Bigint b) {
    if(sign != b.sign) {
        return (*this) + (-b);
    }
    int s = sign; sign = b.sign = 1;
    if((*this) < b) {
        return (b - (-(*this))).normalize(-s);
    }
    Bigint c;
    for(int i = 0, borrow = 0; i < a.size(); ++i) {
        borrow = (a[i] - borrow - (i < b.size() ? b.a[i] : 48));
        c.a += (borrow >= 0 ? borrow + 48 : borrow + 58);
        borrow = (borrow >= 0 ? 0 : 1);
    }
    return c.normalize(s);
}
Bigint operator*(Bigint b) {
    Bigint c("0");
    for(int i = 0, k = a[i] - 48; i < a.size(); ++i, k = a[i] - 48) {
        while(k--) c = c + b;
        b.a.insert(b.a.begin(), '0');
    }
    return c.normalize(sign * b.sign);
}
Bigint operator/(Bigint b) {
    assert(b != Bigint("0"));
    if(b.size() == 1 && b.a[0] == '0') {
        b.a[0] /= (b.a[0] - 48);
    }
    Bigint c("0"), d;
    for(int j = 0; j < a.size(); ++j) {
        d.a += "0";
    }
    int dSign = sign * b.sign; b.sign = 1;
    for(int i = a.size() - 1; i >= 0; --i) {
        c.a.insert(c.a.begin(), '0');
        c = c + a.substr(i, 1);
        while(!(c < b)) {
            c = c - b, d.a[i]++;
        }
    }
    return d.normalize(dSign);
}
Bigint operator%(Bigint b) {

```

```

    assert(b != Bigint("0"));
    if(b.size() == 1 && b.a[0] == '0') {
        b.a[0] /= (b.a[0] - 48);
    }
    Bigint c("0");
    b.sign = 1;
    for(int i = a.size() - 1; i >= 0; --i) {
        c.a.insert(c.a.begin(), '0');
        c = c + a.substr(i, 1);
        while(!(c < b)) c = c - b;
    }
    return c.normalize(sign);
}
friend std::istream& operator>>(std::istream& is, Bigint& integer) {
    std::string input;
    std::cin >> input;
    integer = input;
    return is;
}
friend std::ostream& operator<<(std::ostream& os, const Bigint& integer)
{
    if (integer.sign == -1) {
        os << "-";
    }
    for (int i = integer.a.size() - 1; i >= 0; --i) {
        os << integer.a[i];
    }
    return os;
}
};

int main() {
    Bigint a, b;
    std::cin >> a >> b;
    std::cout << a + b << '\n';
    std::cout << a - b << '\n';
    std::cout << a * b << '\n';
    std::cout << a / b << '\n';
    std::cout << a % b << '\n';
    std::cout << (a == b ? "" : "not ") << "equal\n";
    std::cout << "a is " << (a < b ? "" : "not") << "smaller than b\n";
    std::cout << "the max number is:" << std::max(a, b) << '\n';
    std::cout << "the min number is:" << std::min(a, b) << '\n';
    return 0;
}

```