

ACM 常用算法模板

therehello

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1 数据结构

1.1 并查集

```
1 struct dsu {
2     int n;
3     vector<int> fa, sz;
4     dsu(int _n) : n(_n), fa(n + 1), sz(n + 1, 1) {
5         iota(fa.begin(), fa.end(), 0);
6     }
7     int find(int x) { return x == fa[x] ? x : fa[x] = find(fa[x]); }
8     int merge(int x, int y) {
9         int fax = find(x), fay = find(y);
10        if (fax == fay) return 0; // 一个集合
11        sz[fay] += fax;
12        return fa[fax] = fay; // 合并到哪个集合了
13    }
14    int size(int x) { return sz[find(x)]; }
15};
```

1.2 树状数组

1.2.1 一维

```
1 template <class T>
2 struct fenwick {
3     int n;
4     vector<T> t;
5     fenwick(int _n) : n(_n), t(n + 1) {}
6     T query(int l, int r) {
7         auto query = [&](int pos) {
8             T res = 0;
9             while (pos) {
10                res += t[pos];
11                pos -= lowbit(pos);
12            }
13            return res;
14        };
15        return query(r) - query(l - 1);
16    }
17    void add(int pos, T num) {
18        while (pos <= n) {
19            t[pos] += num;
20            pos += lowbit(pos);
21        }
22    }
23};
```

1.2.2 二维

```

1 template <class T>
2 struct Fenwick_tree_2 {
3     Fenwick_tree_2(int n, int m) : n(n), m(m), tree(n + 1, vector<T>(m + 1)) {}
4     T query(int l1, int r1, int l2, int r2) {
5         auto query = [&](int l, int r) {
6             T res = 0;
7             for (int i = l; i; i -= lowbit(i))
8                 for (int j = r; j; j -= lowbit(j)) res += tree[i][j];
9             return res;
10        };
11        return query(l2, r2) - query(l2, r1 - 1) - query(l1 - 1, r2) +
12            query(l1 - 1, r1 - 1);
13    }
14    void update(int x, int y, T num) {
15        for (int i = x; i <= n; i += lowbit(i))
16            for (int j = y; j <= m; j += lowbit(j)) tree[i][j] += num;
17    }
18 private:
19     int n, m;
20     vector<vector<T>> tree;
21 };

```

1.2.3 三维

```

1 template <class T>
2 struct Fenwick_tree_3 {
3     Fenwick_tree_3(int n, int m, int k)
4         : n(n),
5           m(m),
6           k(k),
7           tree(n + 1, vector<vector<T>>(m + 1, vector<T>(k + 1))) {}
8     T query(int a, int b, int c, int d, int e, int f) {
9         auto query = [&](int x, int y, int z) {
10             T res = 0;
11             for (int i = x; i; i -= lowbit(i))
12                 for (int j = y; j; j -= lowbit(j))
13                     for (int p = z; p; p -= lowbit(p)) res += tree[i][j][p];
14             return res;
15        };
16        T res = query(d, e, f);
17        res -= query(a - 1, e, f) + query(d, b - 1, f) + query(d, e, c - 1);
18        res += query(a - 1, b - 1, f) + query(a - 1, e, c - 1) +
19            query(d, b - 1, c - 1);
20        res -= query(a - 1, b - 1, c - 1);
21        return res;
22    }
23    void update(int x, int y, int z, T num) {
24        for (int i = x; i <= n; i += lowbit(i))
25            for (int j = y; j <= m; j += lowbit(j))
26                for (int p = z; p <= k; p += lowbit(p)) tree[i][j][p] += num;

```

```

27     }
28 private:
29     int n, m, k;
30     vector<vector<vector<T>>> tree;
31 };

```

1.3 线段树

```

1 template <class Data, class Num>
2 struct Segment_Tree {
3     inline void update(int l, int r, Num x) { update(1, l, r, x); }
4     inline Data query(int l, int r) { return query(1, l, r); }
5     Segment_Tree(vector<Data>& a) {
6         n = a.size();
7         tree.assign(n * 4 + 1, {});
8         build(a, 1, 1, n);
9     }
10 private:
11     int n;
12     struct Tree {
13         int l, r;
14         Data data;
15     };
16     vector<Tree> tree;
17     inline void pushup(int pos) {
18         tree[pos].data = tree[pos << 1].data + tree[pos << 1 | 1].data;
19     }
20     inline void pushdown(int pos) {
21         tree[pos << 1].data = tree[pos << 1].data + tree[pos].data.lazytag;
22         tree[pos << 1 | 1].data =
23             tree[pos << 1 | 1].data + tree[pos].data.lazytag;
24         tree[pos].data.lazytag = Num::zero();
25     }
26     void build(vector<Data>& a, int pos, int l, int r) {
27         tree[pos].l = l;
28         tree[pos].r = r;
29         if (l == r) {
30             tree[pos].data = a[l - 1];
31             return;
32         }
33         int mid = (tree[pos].l + tree[pos].r) >> 1;
34         build(a, pos << 1, l, mid);
35         build(a, pos << 1 | 1, mid + 1, r);
36         pushup(pos);
37     }
38     void update(int pos, int& l, int& r, Num& x) {
39         if (l > tree[pos].r || r < tree[pos].l) return;
40         if (l <= tree[pos].l && tree[pos].r <= r) {
41             tree[pos].data = tree[pos].data + x;
42             return;
43         }

```

```

44     pushdown(pos);
45     update(pos << 1, 1, r, x);
46     update(pos << 1 | 1, 1, r, x);
47     pushup(pos);
48 }
49 Data query(int pos, int& l, int& r) {
50     if (l > tree[pos].r || r < tree[pos].l) return Data::zero();
51     if (l <= tree[pos].l && tree[pos].r <= r) return tree[pos].data;
52     pushdown(pos);
53     return query(pos << 1, l, r) + query(pos << 1 | 1, l, r);
54 }
55 };
56 struct Num {
57     ll add;
58     inline static Num zero() { return {0}; }
59     inline Num operator+(Num b) { return {add + b.add}; }
60 };
61 struct Data {
62     ll sum, len;
63     Num lazytag;
64     inline static Data zero() { return {0, 0, Num::zero()}; }
65     inline Data operator+(Num b) {
66         return {sum + len * b.add, len, lazytag + b};
67     }
68     inline Data operator+(Data b) {
69         return {sum + b.sum, len + b.len, Num::zero()};
70     }
71 };

```

1.4 普通平衡树

1.4.1 树状数组实现

需要预先处理出来所有可能的数。

```

1  template <typename T>
2  struct treap {
3      int n, size;
4      vector<int> t;
5      vector<T> t2, S;
6      treap(const vector<T>& b) {
7          S = b;
8          sort(S.begin(), S.end());
9          S.erase(unique(S.begin(), S.end()), S.end());
10         n = S.size();
11         size = 0;
12         t = vector<int>(n + 1);
13         t2 = vector<T>(n + 1);
14     }
15     int pos(T x) { return lower_bound(S.begin(), S.end(), x) - S.begin() + 1; }
16     int sum(int pos) {
17         int res = 0;

```



```

18     while (pos) {
19         res += t[pos];
20         pos -= lowbit(pos);
21     }
22     return res;
23 }
24
25 // 插入cnt个x
26 void insert(T x, int cnt) {
27     size += cnt;
28     for (int i = pos(x); i <= n; i += lowbit(i)) {
29         t[i] += cnt;
30         t2[i] += cnt * x;
31     }
32 }
33
34 // 删除cnt个x
35 void erase(T x, int cnt) { insert(x, -cnt); }
36
37 // x的排名
38 int rank(T x) { return sum(pos(x) - 1) + 1; }
39
40 // 统计出现次数
41 int count(T x) { return sum(pos(x)) - sum(pos(x) - 1); }
42
43 // 第k小
44 T kth(int k) {
45     int cnt = 0, x = 0;
46     for (int i = log2(n); i >= 0; i--) {
47         x += 1 << i;
48         if (x >= n || cnt + t[x] >= k) x -= 1 << i;
49         else cnt += t[x];
50     }
51     return S[x];
52 }
53
54 // 前k小的数之和
55 T pre_sum(int k) {
56     int cnt = 0, x = 0;
57     T res = 0;
58     for (int i = log2(n); i >= 0; i--) {
59         x += 1 << i;
60         if (x >= n || cnt + t[x] >= k) x -= 1 << i;
61         else {
62             cnt += t[x];
63             res += t2[x];
64         }
65     }
66     return res + (k - cnt) * S[x];
67 }
68
69 // 小于x, 最大的数

```

```

70 T prev(int x) { return kth(sum(pos(x) - 1)); }
71
72 // 大于x, 最小的数
73 T next(int x) { return kth(sum(pos(x)) + 1); }
74 };

```

1.5 可持久化线段树

```

1 constexpr int MAXN = 200000;
2 vector<int> root(MAXN << 5);
3 struct Persistent_seg {
4     int n;
5     struct Data {
6         int ls, rs;
7         int val;
8     };
9     vector<Data> tree;
10    Persistent_seg(int n, vector<int>& a) : n(n) { root[0] = build(1, n, a); }
11    int build(int l, int r, vector<int>& a) {
12        if (l == r) {
13            tree.push_back({0, 0, a[l]});
14            return tree.size() - 1;
15        }
16        int mid = l + r >> 1;
17        int ls = build(l, mid, a), rs = build(mid + 1, r, a);
18        tree.push_back({ls, rs, tree[ls].val + tree[rs].val});
19        return tree.size() - 1;
20    }
21    int update(int rt, const int& idx, const int& val, int l, int r) {
22        if (l == r) {
23            tree.push_back({0, 0, tree[rt].val + val});
24            return tree.size() - 1;
25        }
26        int mid = l + r >> 1, ls = tree[rt].ls, rs = tree[rt].rs;
27        if (idx <= mid) ls = update(ls, idx, val, l, mid);
28        else rs = update(rs, idx, val, mid + 1, r);
29        tree.push_back({ls, rs, tree[ls].val + tree[rs].val});
30        return tree.size() - 1;
31    }
32    int query(int rt1, int rt2, int k, int l, int r) {
33        if (l == r) return l;
34        int mid = l + r >> 1;
35        int lcnt = tree[tree[rt2].ls].val - tree[tree[rt1].ls].val;
36        if (k <= lcnt) return query(tree[rt1].ls, tree[rt2].ls, k, l, mid);
37        else return query(tree[rt1].rs, tree[rt2].rs, k - lcnt, mid + 1, r);
38    }
39 };

```

1.6 st 表

```
1 auto lg = []() {
2     array<int, 10000001> lg;
3     lg[1] = 0;
4     for (int i = 2; i <= 10000000; i++) lg[i] = lg[i >> 1] + 1;
5     return lg;
6 }();
7 template <typename T>
8 struct st {
9     int n;
10    vector<vector<T>>> a;
11    st(vector<T>& _a) : n(_a.size()) {
12        a.assign(lg[n] + 1, vector<int>(n));
13        for (int i = 0; i < n; i++) a[0][i] = _a[i];
14        for (int j = 1; j <= lg[n]; j++)
15            for (int i = 0; i + (1 << j) - 1 < n; i++)
16                a[j][i] = max(a[j - 1][i], a[j - 1][i + (1 << (j - 1))]);
17    }
18    T query(int l, int r) {
19        int k = lg[r - l + 1];
20        return max(a[k][l], a[k][r - (1 << k) + 1]);
21    }
22 };
```

2 图论

存图

```

1 struct Graph {
2     int n;
3     struct Edge {
4         int to, w;
5     };
6     vector<vector<Edge>> graph;
7     Graph(int _n) {
8         n = _n;
9         graph.assign(n + 1, vector<Edge>());
10    };
11    void add(int u, int v, int w) { graph[u].push_back({v, w}); }
12 };

```

2.1 最短路

2.1.1 dijkstra

```

1 void dij(Graph& graph, vector<int>& dis, int t) {
2     vector<int> visit(graph.n + 1, 0);
3     priority_queue<pair<int, int>> que;
4     dis[t] = 0;
5     que.emplace(0, t);
6     while (!que.empty()) {
7         int u = que.top().second;
8         que.pop();
9         if (visit[u]) continue;
10        visit[u] = 1;
11        for (auto& [to, w] : graph.graph[u]) {
12            if (dis[to] > dis[u] + w) {
13                dis[to] = dis[u] + w;
14                que.emplace(-dis[to], to);
15            }
16        }
17    }
18 }

```

2.2 树上问题

2.2.1 最近公公祖先

倍增法

```

1 vector<int> dep;
2 vector<array<int, 21>> fa;
3 dep.assign(n + 1, 0);
4 fa.assign(n + 1, array<int, 21>{});
5 void binary_jump(int root) {
6     function<void(int)> dfs = [&](int t) {

```

```

7     dep[t] = dep[fa[t][0]] + 1;
8     for (auto& [to] : graph[t]) {
9         if (to == fa[t][0]) continue;
10        fa[to][0] = t;
11        dfs(to);
12    }
13 };
14 dfs(root);
15 for (int j = 1; j <= 20; j++)
16     for (int i = 1; i <= n; i++) fa[i][j] = fa[fa[i][j - 1]][j - 1];
17 }
18 int lca(int x, int y) {
19     if (dep[x] < dep[y]) swap(x, y);
20     for (int i = 20; i >= 0; i--)
21         if (dep[fa[x][i]] >= dep[y]) x = fa[x][i];
22     if (x == y) return x;
23     for (int i = 20; i >= 0; i--) {
24         if (fa[x][i] != fa[y][i]) {
25             x = fa[x][i];
26             y = fa[y][i];
27         }
28     }
29     return fa[x][0];
30 }

```

树剖

```

1 int lca(int x, int y) {
2     while (top[x] != top[y]) {
3         if (dep[top[x]] < dep[top[y]]) swap(x, y);
4         x = fa[top[x]];
5     }
6     if (dep[x] < dep[y]) swap(x, y);
7     return y;
8 }

```

2.2.2 树链剖分

```

1 vector<int> fa, siz, dep, son, dfn, rnk, top;
2 fa.assign(n + 1, 0);
3 siz.assign(n + 1, 0);
4 dep.assign(n + 1, 0);
5 son.assign(n + 1, 0);
6 dfn.assign(n + 1, 0);
7 rnk.assign(n + 1, 0);
8 top.assign(n + 1, 0);
9 void hld(int root) {
10     function<void(int)> dfs1 = [&](int t) {
11         dep[t] = dep[fa[t]] + 1;
12         siz[t] = 1;
13         for (auto& [to, w] : graph[t]) {
14             if (to == fa[t]) continue;

```

```

15         fa[to] = t;
16         dfs1(to);
17         if (siz[son[t]] < siz[to]) son[t] = to;
18         siz[t] += siz[to];
19     }
20 };
21 dfs1(root);
22 int dfn_tail = 0;
23 for (int i = 1; i <= n; i++) top[i] = i;
24 function<void(int)> dfs2 = [&](int t) {
25     dfn[t] = ++dfn_tail;
26     rnk[dfn_tail] = t;
27     if (!son[t]) return;
28     top[son[t]] = top[t];
29     dfs2(son[t]);
30     for (auto& [to, w] : graph[t]) {
31         if (to == fa[t] || to == son[t]) continue;
32         dfs2(to);
33     }
34 };
35 dfs2(root);
36 }

```

2.3 强连通分量

```

1 void tarjan(Graph& g1, Graph& g2) {
2     int dfn_tail = 0, cnt = 0;
3     vector<int> dfn(g1.n + 1, 0), low(g1.n + 1, 0), exist(g1.n + 1, 0),
4         belong(g1.n + 1, 0);
5     stack<int> sta;
6     function<void(int)> dfs = [&](int t) {
7         dfn[t] = low[t] = ++dfn_tail;
8         sta.push(t);
9         exist[t] = 1;
10        for (auto& [to] : g1.graph[t])
11            if (!dfn[to]) {
12                dfs(to);
13                low[t] = min(low[t], low[to]);
14            } else if (exist[to]) low[t] = min(low[t], dfn[to]);
15        if (dfn[t] == low[t]) {
16            cnt++;
17            while (int temp = sta.top()) {
18                belong[temp] = cnt;
19                exist[temp] = 0;
20                sta.pop();
21                if (temp == t) break;
22            }
23        }
24    };
25    for (int i = 1; i <= g1.n; i++)
26        if (!dfn[i]) dfs(i);

```

```
27 g2 = Graph(cnt);
28 for (int i = 1; i <= g1.n; i++) g2.w[belong[i]] += g1.w[i];
29 for (int i = 1; i <= g1.n; i++)
30     for (auto& [to] : g1.graph[i])
31         if (belong[i] != belong[to]) g2.add(belong[i], belong[to]);
32 }
```

2.4 拓扑排序

```
1 void toposort(Graph& g, vector<int>& dis) {
2     vector<int> in(g.n + 1, 0);
3     for (int i = 1; i <= g.n; i++)
4         for (auto& [to] : g.graph[i]) in[to]++;
5     queue<int> que;
6     for (int i = 1; i <= g.n; i++)
7         if (!in[i]) {
8             que.push(i);
9             dis[i] = g.w[i]; // dp
10        }
11    while (!que.empty()) {
12        int u = que.front();
13        que.pop();
14        for (auto& [to] : g.graph[u]) {
15            in[to]--;
16            dis[to] = max(dis[to], dis[u] + g.w[to]); // dp
17            if (!in[to]) que.push(to);
18        }
19    }
20 }
```

3 字符串

3.1 kmp

```

1 auto kmp(string& s) {
2     vector next(s.size(), -1);
3     for (int i = 1, j = -1; i < s.size(); i++) {
4         while (j >= 0 && s[i] != s[j + 1]) j = next[j];
5         if (s[i] == s[j + 1]) j++;
6         next[i] = j;
7     }
8     // next 意为长度
9     for (auto& i : next) i++;
10    return next;
11 }

```

3.2 哈希

```

1 constexpr int N = 2e6;
2 constexpr ll mod[2] = {2000000011, 2000000033}, base[2] = {20011, 20033};
3 vector<array<ll, 2>> pow_base(N);
4
5 pow_base[0][0] = pow_base[0][1] = 1;
6 for (int i = 1; i < N; i++) {
7     pow_base[i][0] = pow_base[i - 1][0] * base[0] % mod[0];
8     pow_base[i][1] = pow_base[i - 1][1] * base[1] % mod[1];
9 }
10
11 struct Hash {
12     int size;
13     vector<array<ll, 2>> hash;
14     Hash() {}
15     Hash(const string& s) {
16         size = s.size();
17         hash.resize(size);
18         hash[0][0] = hash[0][1] = s[0];
19         for (int i = 1; i < size; i++) {
20             hash[i][0] = (hash[i - 1][0] * base[0] + s[i]) % mod[0];
21             hash[i][1] = (hash[i - 1][1] * base[1] + s[i]) % mod[1];
22         }
23     }
24     array<ll, 2> operator[] (const array<int, 2>& range) const {
25         int l = range[0], r = range[1];
26         if (l == 0) return hash[r];
27         auto single_hash = [&](bool flag) {
28             return (hash[r][flag] -
29                     hash[l - 1][flag] * pow_base[r - l + 1][flag] % mod[flag] +
30                     mod[flag]) %
31                     mod[flag];
32         };
33         return {single_hash(0), single_hash(1)};

```



```
34     }  
35 };
```

3.3 manacher

```
1 void manacher(const string& _s, vector<int>& r) {  
2     string s(_s.size() * 2 + 1, '$');  
3     for (int i = 0; i < _s.size(); i++) s[2 * i + 1] = _s[i];  
4     r.resize(_s.size() * 2 + 1);  
5     for (int i = 0, maxr = 0, mid = 0; i < s.size(); i++) {  
6         if (i < maxr) r[i] = min(r[mid * 2 - i], maxr - i);  
7         while (i - r[i] - 1 >= 0 && i + r[i] + 1 < s.size() &&  
8             s[i - r[i] - 1] == s[i + r[i] + 1])  
9             ++r[i];  
10        if (i + r[i] > maxr) maxr = i + r[i], mid = i;  
11    }  
12 }
```

4 数学

4.1 扩展欧几里得

需保证 $a, b \geq 0$

$$x = x + k * dx, y = y - k * dy$$

若要求 $x \geq p$, $k \geq \lceil \frac{p-x}{dx} \rceil$

若要求 $x \leq q$, $k \leq \lfloor \frac{q-x}{dx} \rfloor$

若要求 $y \geq p$, $k \leq \lfloor \frac{y-p}{dy} \rfloor$

若要求 $y \leq q$, $k \geq \lceil \frac{y-q}{dy} \rceil$

```

1 int __exgcd(int a, int b, int& x, int& y) {
2     if (!b) {
3         x = 1;
4         y = 0;
5         return a;
6     }
7     int g = __exgcd(b, a % b, y, x);
8     y -= a / b * x;
9     return g;
10 }
11
12 array<int, 2> exgcd(int a, int b, int c) {
13     int x, y;
14     int g = __exgcd(a, b, x, y);
15     if (c % g) return {INT_MAX, INT_MAX};
16     int dx = b / g;
17     int dy = a / g;
18     x = c / g % dx * x % dx;
19     if (x < 0) x += dx;
20     y = (c - a * x) / b;
21     return {x, y};
22 }

```

4.2 线性筛法

```

1 constexpr int N = 10000000;
2 array<int, N + 1> min_prime;
3 vector<int> primes;
4 bool ok = []() {
5     for (int i = 2; i <= N; i++) {
6         if (min_prime[i] == 0) {
7             min_prime[i] = i;
8             primes.push_back(i);
9         }
10        for (auto& j : primes) {
11            if (j > min_prime[i] || j > N / i) break;
12            min_prime[j * i] = j;
13        }
14    }
15    return 1;

```

```
16 }();
```

4.3 分解质因数

```
1 auto getprimes(int n) {
2     vector<array<int, 2>> res;
3     for (auto& i : primes) {
4         if (i > n / i) break;
5         if (n % i == 0) {
6             res.push_back({i, 0});
7             while (n % i == 0) {
8                 n /= i;
9                 res.back()[1]++;
10            }
11        }
12    }
13    if (n > 1) res.push_back({n, 1});
14    return res;
15 }
```

4.4 pollard rho

```
1 using LL = __int128_t;
2
3 random_device rd;
4 mt19937 seed(rd());
5
6 ll power(ll a, ll b, ll mod) {
7     ll res = 1;
8     while (b) {
9         if (b & 1) res = (LL)res * a % mod;
10        a = (LL)a * a % mod;
11        b >>= 1;
12    }
13    return res;
14 }
15
16 bool isprime(ll n) {
17     static array primes{2, 3, 5, 7, 11, 13, 17, 19, 23};
18     static unordered_map<ll, bool> S;
19     if (n < 2) return 0;
20     if (S.count(n)) return S[n];
21     ll d = n - 1, r = 0;
22     while (!(d & 1)) {
23         r++;
24         d >>= 1;
25     }
26     for (auto& a : primes) {
27         if (a == n) return S[n] = 1;
28         ll x = power(a, d, n);
```

```

29     if (x == 1 || x == n - 1) continue;
30     for (int i = 0; i < r - 1; i++) {
31         x = (LL)x * x % n;
32         if (x == n - 1) break;
33     }
34     if (x != n - 1) return S[n] = 0;
35 }
36 return S[n] = 1;
37 }
38
39 ll pollard_rho(ll n) {
40     ll s = 0, t = 0;
41     ll c = seed() % (n - 1) + 1;
42     ll val = 1;
43     for (int goal = 1;; goal *= 2, s = t, val = 1) {
44         for (int step = 1; step <= goal; step++) {
45             t = ((LL)t * t + c) % n;
46             val = (LL)val * abs(t - s) % n;
47             if (step % 127 == 0) {
48                 ll g = gcd(val, n);
49                 if (g > 1) return g;
50             }
51         }
52         ll g = gcd(val, n);
53         if (g > 1) return g;
54     }
55 }
56 auto getprimes(ll n) {
57     unordered_set<ll> S;
58     auto get = [&](auto self, ll n) {
59         if (n < 2) return;
60         if (isprime(n)) {
61             S.insert(n);
62             return;
63         }
64         ll mx = pollard_rho(n);
65         self(self, n / mx);
66         self(self, mx);
67     };
68     get(get, n);
69     return S;
70 }

```

4.5 组合数

```

1 constexpr int N = 1e7;
2 array<modint, N + 1> fac, ifac;
3 auto _ = []() {
4     fac[0] = 1;
5     for (int i = 1; i <= N; i++) fac[i] = fac[i - 1] * i;
6     ifac[N] = fac[N].inv();

```

```

7   for (int i = N - 1; i >= 0; i--) ifac[i] = ifac[i + 1] * (i + 1);
8   return true;
9 }();
10
11 modint C(int n, int m) {
12     if (n < m) return 0;
13     if (n <= mod) return fac[n] * ifac[m] * ifac[n - m];
14     // n >= mod 时需要这个
15     return C(n % mod, m % mod) * C(n / mod, m / mod);
16 }

```

4.6 数论分块

求解形如 $\sum_{i=1}^n f(i)g(\lfloor \frac{n}{i} \rfloor)$ 的合式

$$s(n) = \sum_{i=1}^n f(i)$$

```

1 modint sqrt_decomposition(int n) {
2     auto s = [&](int x) { return x; };
3     auto g = [&](int x) { return x; };
4     modint res = 0;
5     while (l <= R) {
6         int r = n / (n / l);
7         res = res + (s(r) - s(l - 1)) * g(n / l);
8         l = r + 1;
9     }
10    return res;
11 }

```

4.7 积性函数

4.7.1 定义

函数 $f(n)$ 满足 $f(1) = 1$ 且 $\forall x, y \in \mathbf{N}^*, \gcd(x, y) = 1$ 都有 $f(xy) = f(x)f(y)$, 则 $f(n)$ 为积性函数。

函数 $f(n)$ 满足 $f(1) = 1$ 且 $\forall x, y \in \mathbf{N}^*$ 都有 $f(xy) = f(x)f(y)$, 则 $f(n)$ 为完全积性函数。

4.7.2 例子

- 单位函数: $\varepsilon(n) = [n = 1]$ 。(完全积性)
- 恒等函数: $\text{id}_k(n) = n^k$ 。(完全积性)
- 常数函数: $1(n) = 1$ 。(完全积性)
- 除数函数: $\sigma_k(n) = \sum_{d|n} d^k$ 。 $\sigma_0(n)$ 通常简记作 $d(n)$ 或 $\tau(n)$, $\sigma_1(n)$ 通常简记作 $\sigma(n)$ 。
- 欧拉函数: $\varphi(n) = \sum_{i=1}^n [\gcd(i, n) = 1]$ 。
- 莫比乌斯函数: $\mu(n) = \begin{cases} 1 & n = 1 \\ 0 & \exists d > 1, d^2 | n, \text{ 其中 } \omega(n) \text{ 表示 } n \text{ 的本质不同质因子个数, 它是} \\ (-1)^{\omega(n)} & \text{otherwise} \end{cases}$
一个加性函数。

4.8 狄利克雷卷积

对于两个数论函数 $f(x)$ 和 $g(x)$ ，则它们的狄利克雷卷积得到的结果 $h(x)$ 定义为：

$$h(x) = \sum_{d|x} f(d)g\left(\frac{x}{d}\right) = \sum_{ab=x} f(a)g(b)$$

可以简记为： $h = f * g$ 。

4.8.1 性质

交换律： $f * g = g * f$ 。

结合律： $(f * g) * h = f * (g * h)$ 。

分配律： $(f + g) * h = f * h + g * h$ 。

等式的性质： $f = g$ 的充要条件是 $f * h = g * h$ ，其中数论函数 $h(x)$ 要满足 $h(1) \neq 0$ 。

4.8.2 例子

- $\varepsilon = \mu * 1 \iff \varepsilon(n) = \sum_{d|n} \mu(d)$
- $id = \varphi * 1 \iff id(n) = \sum_{d|n} \varphi(d)$
- $d = 1 * 1 \iff d(n) = \sum_{d|n} 1$
- $\sigma = id * 1 \iff \sigma(n) = \sum_{d|n} d$
- $\varphi = \mu * id \iff \varphi(n) = \sum_{d|n} d \cdot \mu\left(\frac{n}{d}\right)$

4.9 欧拉函数

```
1 array<int, N + 1> phi;
2 auto _ = []() {
3     iota(phi.begin() + 1, phi.end(), 1);
4     for (int i = 2; i <= N; i++) {
5         if (phi[i] == i)
6             for (int j = i; j <= N; j += i) phi[j] = phi[j] / i * (i - 1);
7     }
8     return true;
9 }();
```

4.10 莫比乌斯反演

4.10.1 莫比乌斯函数性质

- $\sum_{d|n} \mu(d) = \begin{cases} 1 & n = 1 \\ 0 & n \neq 1 \end{cases}$ ，即 $\sum_{d|n} \mu(d) = \varepsilon(n)$ ， $\mu * 1 = \varepsilon$
- $[\gcd(i, j) = 1] = \sum_{d|\gcd(i, j)} \mu(d)$

```
1 array<int, N + 1> miu;
2 array<bool, N + 1> ispr;
3 auto _ = []() {
4     miu.fill(1);
5     ispr.fill(1);
```

```

6   for (int i = 2; i <= N; i++) {
7       if (!ispr[i]) continue;
8       miu[i] = -1;
9       for (int j = 2 * i; j <= N; j += i) {
10          ispr[j] = 0;
11          if ((j / i) % i == 0) miu[j] = 0;
12          else miu[j] *= -1;
13      }
14  }
15  return true;
16 }();

```

4.10.2 莫比乌斯变换/反演

$f(n) = \sum_{d|n} g(d)$, 那么有 $g(n) = \sum_{d|n} \mu(d) f(\frac{n}{d}) = \sum_{n|d} \mu(\frac{d}{n}) f(d)$ 。

用狄利克雷卷积表示则为 $f = g * 1$, 有 $g = f * \mu$ 。

$f \rightarrow g$ 称为莫比乌斯反演, $g \rightarrow f$ 称为莫比乌斯反演。

4.11 杜教筛

杜教筛被用于处理一类数论函数的前缀和问题。对于数论函数 f , 杜教筛可以在低于线性时间的复杂度内计算 $S(n) = \sum_{i=1}^n f(i)$ 。

$$S(n) = \frac{\sum_{i=1}^n (f * g)(i) - \sum_{i=2}^n g(i) S(\lfloor \frac{n}{i} \rfloor)}{g(1)}$$

可以构造恰当的数论函数 g 使得:

- 可以快速计算 $\sum_{i=1}^n (f * g)(i)$ 。
- 可以快速计算 g 的单点值, 用数论分块求解 $\sum_{i=2}^n g(i) S(\lfloor \frac{n}{i} \rfloor)$ 。

4.11.1 示例

```

1 ll sum_phi(ll n) {
2     if (n <= N) return sp[n];
3     if (sp2.count(n)) return sp2[n];
4     ll res = 0, l = 2;
5     while (l <= n) {
6         ll r = n / (n / l);
7         res = res + (r - l + 1) * sum_phi(n / l);
8         l = r + 1;
9     }
10    return sp2[n] = (ll)n * (n + 1) / 2 - res;
11 }
12 ll sum_miu(ll n) {
13     if (n <= N) return sm[n];
14     if (sm2.count(n)) return sm2[n];
15     ll res = 0, l = 2;
16     while (l <= n) {
17         ll r = n / (n / l);
18         res = res + (r - l + 1) * sum_miu(n / l);

```

```
19     l = r + 1;
20 }
21 return sm2[n] = 1 - res;
22 }
```

4.12 盒子与球

n 个球, m 个盒

球同	盒同	可空	公式
✓	✓	✓	$f_{n,m} = f_{n-1,m-1} + f_{n-m,m}$
✓	✓	✗	$f_{n-m,m}$
✗	✓	✓	$\sum_{i=1}^m g_{n,i}$
✗	✓	✗	$g_{n,m} = g_{n-1,m-1} + m * g_{n-1,m}$
✓	✗	✓	C_{n+m-1}^{m-1}
✓	✗	✗	C_{n-1}^{m-1}
✗	✗	✓	m^n
✗	✗	✗	$m! * g_{n,m}$

扩展:

n 个相同的球, m 个不同的盒, 每个盒子超过 k 个球, 问方案数?

可以考虑容斥, $f(d)$ 表示至少有 d 个盒子装了 $> k$ 个球方案数, 总方案数则为 $f(0)-f(1)+f(2)-\dots$

4.13 线性基

```
1 // 线性基
2 struct basis {
3     int rnk = 0;
4     array<ull, 64> p{};
5
6     // 将x插入此线性基中
7     void insert(ull x) {
8         for (int i = 63; i >= 0; i--) {
9             if ((x >> i) & 1) {
10                 if (p[i] x ^= p[i];
11                 else {
12                     for (int j = 0; j < i; j++)
13                         if (x >> j & 1) x ^= p[j];
14                     for (int j = i + 1; j <= 63; j++)
15                         if (p[j] >> i & 1) p[j] ^= x;
16                     p[i] = x;
17                     rnk++;
18                     break;
19                 }
20             }
```



```

21     }
22 }
23
24 // 将另一个线性基插入此线性基中
25 void insert(basis other) {
26     for (int i = 0; i <= 63; i++) {
27         if (!other.p[i]) continue;
28         insert(other.p[i]);
29     }
30 }
31
32 // 最大异或值
33 ull max_basis() {
34     ull res = 0;
35     for (int i = 63; i >= 0; i--)
36         if ((res ^ p[i]) > res) res ^= p[i];
37     return res;
38 }
39 };

```

4.14 矩阵快速幂

```

1 constexpr ll mod = 2147493647;
2 struct Mat {
3     int n, m;
4     vector<vector<ll>> mat;
5     Mat(int n, int m) : n(n), m(m), mat(n, vector<ll>(m, 0)) {}
6     Mat(vector<vector<ll>> mat) : n(mat.size()), m(mat[0].size()), mat(mat) {}
7     Mat operator*(const Mat& other) {
8         assert(m == other.n);
9         Mat res(n, other.m);
10        for (int i = 0; i < res.n; i++)
11            for (int j = 0; j < res.m; j++)
12                for (int k = 0; k < m; k++)
13                    res.mat[i][j] =
14                        (res.mat[i][j] + mat[i][k] * other.mat[k][j] % mod) %
15                        mod;
16        return res;
17    }
18 };
19 Mat ksm(Mat a, ll b) {
20     assert(a.n == a.m);
21     Mat res(a.n, a.m);
22     for (int i = 0; i < res.n; i++) res.mat[i][i] = 1;
23     while (b) {
24         if (b & 1) res = res * a;
25         b >>= 1;
26         a = a * a;
27     }
28     return res;
29 }

```

5 计算几何

5.1 整数

```

1  const double PI = acos(-1);
2  constexpr double eps = 1e-8;
3
4  // 向量
5  struct vec {
6      static bool cmp(const vec &a, const vec &b) {
7          return tie(a.x, a.y) < tie(b.x, b.y);
8      }
9
10     ll x, y;
11     vec(ll _x = 0, ll _y = 0) : x(_x), y(_y) {}
12
13     // 模
14     ll len2() const { return x * x + y * y; }
15     double len() const { return sqrt(x * x + y * y); }
16
17     // 是否在上半轴
18     bool up() const { return y > 0 || y == 0 && x >= 0; }
19
20     bool operator==(const vec &b) const { return tie(x, y) == tie(b.x, b.y); }
21
22     // 极角排序
23     bool operator<(const vec &b) const {
24         if (up() != b.up()) return up() > b.up();
25         ll tmp = (*this) ^ b;
26         return tmp ? tmp > 0 : cmp(*this, b);
27     }
28
29     vec operator+(const vec &b) const { return {x + b.x, y + b.y}; }
30     vec operator-() const { return {-x, -y}; }
31     vec operator-(const vec &b) const { return -b + (*this); }
32     vec operator*(ll b) const { return {x * b, y * b}; }
33     ll operator*(const vec &b) const { return x * b.x + y * b.y; }
34
35     // 叉积 结果大于0, a到b为逆时针, 小于0, a到b顺时针,
36     // 等于0共线, 可能同向或反向, 结果绝对值表示 a b 形成的平行四边形的面积
37     ll operator^(const vec &other) const { return x * other.y - y * other.x; }
38
39     friend istream &operator>>(istream &in, vec &data) {
40         in >> data.x >> data.y;
41         return in;
42     }
43     friend ostream &operator<<(ostream &out, const vec &data) {
44         out << fixed << setprecision(6);
45         out << data.x << " " << data.y;
46         return out;
47     }
48 };

```

```

49
50 ll cross(const vec &a, const vec &b, const vec &c) { return (a - c) ^ (b - c); }
51
52 // 判断点是否在凸包内
53 bool in_polygon(const vec &a, vector<vec> &p) {
54     int n = p.size();
55     if (n == 0) return 0;
56     if (n == 1) return a == p[0];
57     if (cross(a, p[1], p[0]) > 0 || cross(p.back(), a, p[0]) > 0) return 0;
58     auto cmp = [&p](vec &x, const vec &y) { return ((x - p[0]) ^ y) >= 0; };
59     int i = lower_bound(p.begin() + 2, p.end(), a - p[0], cmp) - p.begin() - 1;
60     return cross(p[(i + 1) % n], a, p[i]) >= 0;
61 }
62
63 // 多边形的面积
64 double polygon_area(vector<vec> &p) {
65     ll area = 0;
66     for (int i = 1; i < p.size(); i++) area += p[i - 1] ^ p[i];
67     area += p.back() ^ p[0];
68     return abs(area / 2.0);
69 }
70
71 // 多边形的周长
72 double polygon_length(vector<vec> &p) {
73     double len = 0;
74     for (int i = 1; i < p.size(); i++) len += (p[i - 1] - p[i]).len();
75     len += (p.back() - p[0]).len();
76     return len;
77 }
78
79 // 以整点为顶点的线段上的整点个数
80 ll count(const vec &a, const vec &b) {
81     vec c = a - b;
82     return gcd(abs(c.x), abs(c.y)) + 1;
83 }
84
85 // 以整点为顶点的多边形边上整点个数
86 ll count(vector<vec> &p) {
87     ll cnt = 0;
88     for (int i = 1; i < p.size(); i++) cnt += count(p[i - 1], p[i]);
89     cnt += count(p.back(), p[0]);
90     return cnt - p.size();
91 }
92
93 // 凸包直径的两个端点
94 auto polygon_dia(vector<vec> &p) {
95     int n = p.size();
96     array<vec, 2> res{};
97     if (n == 1) return res;
98     if (n == 2) return res = {p[0], p[1]};
99     ll mx = 0;
100    for (int i = 0, j = 2; i < n; i++) {

```

```

101     while (abs(cross(p[i], p[(i + 1) % n], p[j])) <=
102             abs(cross(p[i], p[(i + 1) % n], p[(j + 1) % n])))
103         j = (j + 1) % n;
104     ll tmp = (p[i] - p[j]).len2();
105     if (tmp > mx) {
106         mx = tmp;
107         res = {p[i], p[j]};
108     }
109     tmp = (p[(i + 1) % n] - p[j]).len2();
110     if (tmp > mx) {
111         mx = tmp;
112         res = {p[(i + 1) % n], p[j]};
113     }
114 }
115 return res;
116 }
117
118 // 凸包
119 auto convex_hull(vector<vec> &p) {
120     sort(p.begin(), p.end(), vec::cmp);
121     int n = p.size();
122     vector sta(n + 1, 0);
123     vector v(n, false);
124     int tp = -1;
125     sta[++tp] = 0;
126     auto update = [&](int lim, int i) {
127         while (tp > lim && cross(p[i], p[sta[tp]], p[sta[tp - 1]]) >= 0)
128             v[sta[tp--]] = 0;
129         sta[++tp] = i;
130         v[i] = 1;
131     };
132     for (int i = 1; i < n; i++) update(0, i);
133     int cnt = tp;
134     for (int i = n - 1; i >= 0; i--) {
135         if (v[i]) continue;
136         update(cnt, i);
137     }
138     vector<vec> res(tp);
139     for (int i = 0; i < tp; i++) res[i] = p[sta[i]];
140     return res;
141 }
142
143 // 闵可夫斯基和，两个点集的和构成一个凸包
144 auto minkowski(vector<vec> &a, vector<vec> &b) {
145     rotate(a.begin(), min_element(a.begin(), a.end(), vec::cmp), a.end());
146     rotate(b.begin(), min_element(b.begin(), b.end(), vec::cmp), b.end());
147     int n = a.size(), m = b.size();
148     vector<vec> c{a[0] + b[0]};
149     c.reserve(n + m);
150     int i = 0, j = 0;
151     while (i < n && j < m) {
152         vec x = a[(i + 1) % n] - a[i];

```

```

153     vec y = b[(j + 1) % m] - b[j];
154     c.push_back(c.back() + ((x ^ y) >= 0 ? (i++, x) : (j++, y)));
155 }
156 while (i + 1 < n) {
157     c.push_back(c.back() + a[(i + 1) % n] - a[i]);
158     i++;
159 }
160 while (j + 1 < m) {
161     c.push_back(c.back() + b[(j + 1) % m] - b[j]);
162     j++;
163 }
164 return c;
165 }
166
167 // 过凸多边形外一点求凸多边形的切线, 返回切点下标
168 auto tangent(const vec &a, vector<vec> &p) {
169     int n = p.size();
170     int l = -1, r = -1;
171     for (int i = 0; i < n; i++) {
172         ll tmp1 = cross(p[i], p[(i - 1 + n) % n], a);
173         ll tmp2 = cross(p[i], p[(i + 1) % n], a);
174         if (l == -1 && tmp1 <= 0 && tmp2 <= 0) l = i;
175         else if (r == -1 && tmp1 >= 0 && tmp2 >= 0) r = i;
176     }
177     return array{l, r};
178 }
179
180 // 直线
181 struct line {
182     vec p, d;
183     line(const vec &p = vec(), const vec &d = vec()) : p(_p), d(_d) {}
184 };
185
186 // 点到直线距离
187 double dis(const vec &a, const line &b) {
188     return abs((b.p - a) ^ (b.p + b.d - a)) / b.d.len();
189 }
190
191 // 点在直线哪边, 大于0在左边, 等于0在线上, 小于0在右边
192 ll side_line(const vec &a, const line &b) { return b.d ^ (a - b.p); }
193
194 // 两直线是否垂直
195 bool perpen(const line &a, const line &b) { return a.d * b.d == 0; }
196
197 // 两直线是否平行
198 bool parallel(const line &a, const line &b) { return (a.d ^ b.d) == 0; }
199
200 // 点的垂线是否与线段有交点
201 bool perpen(const vec &a, const line &b) {
202     vec p(-b.d.y, b.d.x);
203     bool cross1 = (p ^ (b.p - a)) > 0;
204     bool cross2 = (p ^ (b.p + b.d - a)) > 0;

```

```

205     return cross1 != cross2;
206 }
207
208 // 点到线段距离
209 double dis_seg(const vec &a, const line &b) {
210     if (perpen(a, b)) return dis(a, b);
211     return min(dis(a, b.p), dis(a, b.p + b.d));
212 }
213
214 // 两直线交点
215 vec intersection(ll A, ll B, ll C, ll D, ll E, ll F) {
216     return {(B * F - C * E) / (A * E - B * D),
217             (C * D - A * F) / (A * E - B * D)};
218 }
219
220 // 两直线交点
221 vec intersection(const line &a, const line &b) {
222     return intersection(a.d.y, -a.d.x, a.d.x * a.p.y - a.d.y * a.p.x, b.d.y,
223                        -b.d.x, b.d.x * b.p.y - b.d.y * b.p.x);
224 }

```

5.2 浮点数

```

1 constexpr double eps = 1e-8;
2 const double PI = acos(-1);
3
4 int sgn(double a, double b) {
5     double c = a - b;
6     return c < -eps ? -1 : c < eps ? 0 : 1;
7 }
8
9 // 向量
10 struct vec {
11     static bool cmp(const vec &a, const vec &b) {
12         return sgn(a.x, b.x) ? a.x < b.x : sgn(a.y, b.y) < 0;
13     }
14
15     double x, y;
16     vec(double _x = 0, double _y = 0) : x(_x), y(_y) {}
17
18     // 模
19     double len2() const { return x * x + y * y; }
20     double len() const { return sqrt(x * x + y * y); }
21
22     // 与x轴正方向的夹角
23     double angle() const {
24         double angle = atan2(y, x);
25         if (angle < 0) angle += 2 * PI;
26         return angle;
27     }
28 }

```

```

29 // 逆时针旋转
30 vec rotate(const double &theta) {
31     return {x * cos(theta) - y * sin(theta),
32            y * cos(theta) + x * sin(theta)};
33 }
34
35 bool operator==(const vec &other) const {
36     return sgn(x, other.x) == 0 && sgn(y, other.y) == 0;
37 }
38
39 // 是否在上半轴
40 bool up() const {
41     return sgn(y, 0) > 0 || sgn(y, 0) == 0 && sgn(x, 0) >= 0;
42 }
43
44 // 极角排序
45 bool operator<(const vec &b) const {
46     if (up() != b.up()) return up() > b.up();
47     double tmp = (*this) ^ b;
48     return sgn(tmp, 0) ? tmp > 0 : cmp(*this, b);
49 }
50
51 vec operator+(const vec &b) const { return {x + b.x, y + b.y}; }
52 vec operator-() const { return {-x, -y}; }
53 vec operator-(const vec &b) const { return -b + (*this); }
54 vec operator*(double b) const { return {x * b, y * b}; }
55 vec operator/(double b) const { return {x / b, y / b}; }
56 double operator*(const vec &b) const { return x * b.x + y * b.y; }
57
58 // 叉积 结果大于0, a到b为逆时针, 小于0, a到b顺时针,
59 // 等于0共线, 可能同向或反向, 结果绝对值表示 a b 形成的平行四边形的面积
60 double operator^(const vec &b) const { return x * b.y - y * b.x; }
61
62 friend istream &operator>>(istream &in, vec &data) {
63     in >> data.x >> data.y;
64     return in;
65 }
66 friend ostream &operator<<(ostream &out, const vec &data) {
67     out << fixed << setprecision(6);
68     out << data.x << " " << data.y;
69     return out;
70 }
71 };
72
73 double cross(const vec &a, const vec &b, const vec &c) {
74     return (a - c) ^ (b - c);
75 }
76
77 // 判断点是否在凸包内
78 bool in_polygon(const vec &a, vector<vec> &p) {
79     int n = p.size();
80     if (n == 1) return a == p[0];

```

```

81     if (sgn(cross(a, p[1], p[0]), 0) > 0 ||
82         sgn(cross(p.back(), a, p[0]), 0) > 0)
83         return 0;
84     auto cmp = [&p](vec &x, const vec &y) {
85         return sgn((x - p[0]) ^ y, 0) >= 0;
86     };
87     int i = lower_bound(p.begin() + 2, p.end(), a - p[0], cmp) - p.begin() - 1;
88     return sgn(cross(p[(i + 1) % n], a, p[i]), 0) >= 0;
89 }
90
91 // 多边形的面积
92 double polygon_area(vector<vec> &p) {
93     double area = 0;
94     for (int i = 1; i < p.size(); i++) area += p[i - 1] ^ p[i];
95     area += p.back() ^ p[0];
96     return abs(area / 2.0);
97 }
98
99 // 多边形的周长
100 double polygon_length(vector<vec> &p) {
101     double len = 0;
102     for (int i = 1; i < p.size(); i++) len += (p[i - 1] - p[i]).len();
103     len += (p.back() - p[0]).len();
104     return len;
105 }
106
107 // 凸包直径的两个端点
108 auto polygon_dia(vector<vec> &p) {
109     int n = p.size();
110     array<vec, 2> res{};
111     if (n == 1) return res;
112     if (n == 2) return res = {p[0], p[1]};
113     double mx = 0;
114     for (int i = 0, j = 2; i < n; i++) {
115         while (sgn(abs(cross(p[i], p[(i + 1) % n], p[j])),
116                     abs(cross(p[i], p[(i + 1) % n], p[(j + 1) % n])))) <= 0)
117             j = (j + 1) % n;
118         double tmp = (p[i] - p[j]).len();
119         if (tmp > mx) {
120             mx = tmp;
121             res = {p[i], p[j]};
122         }
123         tmp = (p[(i + 1) % n] - p[j]).len();
124         if (tmp > mx) {
125             mx = tmp;
126             res = {p[(i + 1) % n], p[j]};
127         }
128     }
129     return res;
130 }
131
132 // 凸包

```



```

133 auto convex_hull(vector<vec> &p) {
134     sort(p.begin(), p.end(), vec::cmp);
135     int n = p.size();
136     vector sta(n + 1, 0);
137     vector v(n, false);
138     int tp = -1;
139     sta[++tp] = 0;
140     auto update = [&](int lim, int i) {
141         while (tp > lim && sgn(cross(p[i], p[sta[tp]], p[sta[tp - 1]]), 0) >= 0)
142             v[sta[tp--]] = 0;
143         sta[++tp] = i;
144         v[i] = 1;
145     };
146     for (int i = 1; i < n; i++) update(0, i);
147     int cnt = tp;
148     for (int i = n - 1; i >= 0; i--) {
149         if (v[i]) continue;
150         update(cnt, i);
151     }
152     vector<vec> res(tp);
153     for (int i = 0; i < tp; i++) res[i] = p[sta[i]];
154     return res;
155 }
156
157 // 闵可夫斯基和 两个点集的和构成一个凸包
158 auto minkowski(vector<vec> &a, vector<vec> &b) {
159     rotate(a.begin(), min_element(a.begin(), a.end(), vec::cmp), a.end());
160     rotate(b.begin(), min_element(b.begin(), b.end(), vec::cmp), b.end());
161     int n = a.size(), m = b.size();
162     vector<vec> c{a[0] + b[0]};
163     c.reserve(n + m);
164     int i = 0, j = 0;
165     while (i < n && j < m) {
166         vec x = a[(i + 1) % n] - a[i];
167         vec y = b[(j + 1) % m] - b[j];
168         c.push_back(c.back() + (sgn(x ^ y, 0) >= 0 ? (i++, x) : (j++, y)));
169     }
170     while (i + 1 < n) {
171         c.push_back(c.back() + a[(i + 1) % n] - a[i]);
172         i++;
173     }
174     while (j + 1 < m) {
175         c.push_back(c.back() + b[(j + 1) % m] - b[j]);
176         j++;
177     }
178     return c;
179 }
180
181 // 过凸多边形外一点求凸多边形的切线，返回切点下标
182 auto tangent(const vec &a, vector<vec> &p) {
183     int n = p.size();
184     int l = -1, r = -1;

```

```

185     for (int i = 0; i < n; i++) {
186         double tmp1 = cross(p[i], p[(i - 1 + n) % n], a);
187         double tmp2 = cross(p[i], p[(i + 1) % n], a);
188         if (l == -1 && sgn(tmp1, 0) <= 0 && sgn(tmp2, 0) <= 0) l = i;
189         else if (r == -1 && sgn(tmp1, 0) >= 0 && sgn(tmp2, 0) >= 0) r = i;
190     }
191     return array{l, r};
192 }
193
194 // 直线
195 struct line {
196     vec p, d;
197     line(const vec &p = vec(), const vec &d = vec()) : p(_p), d(_d) {}
198 };
199
200 // 点到直线距离
201 double dis(const vec &a, const line &b) {
202     return abs((b.p - a) ^ (b.p + b.d - a)) / b.d.len();
203 }
204
205 // 判断点在直线哪边, 大于0在左边, 等于0在线上, 小于0在右边
206 int side_line(const vec &a, const line &b) { return sgn(b.d ^ (a - b.p), 0); }
207
208 // 两直线是否垂直
209 bool perpen(const line &a, const line &b) { return sgn(a.d * b.d, 0) == 0; }
210
211 // 两直线是否平行
212 bool parallel(const line &a, const line &b) { return sgn(a.d ^ b.d, 0) == 0; }
213
214 // 点的垂线是否与线段有交点
215 bool perpen(const vec &a, const line &b) {
216     vec p(-b.d.y, b.d.x);
217     bool cross1 = (p ^ (b.p - a)) > 0;
218     bool cross2 = (p ^ (b.p + b.d - a)) > 0;
219     return cross1 != cross2;
220 }
221
222 // 点到线段距离
223 double disseg(const vec &a, const line &b) {
224     if (perpen(a, b)) return dis(a, b);
225     return min(dis(a, b.p), dis(a, b.p + b.d));
226 }
227
228 // 两直线交点
229 vec intersection(double A, double B, double C, double D, double E, double F) {
230     return {(B * F - C * E) / (A * E - B * D),
231             (C * D - A * F) / (A * E - B * D)};
232 }
233
234 // 两直线交点
235 vec intersection(const line &a, const line &b) {
236     return intersection(a.d.y, -a.d.x, a.d.x * a.p.y - a.d.y * a.p.x, b.d.y,

```

```

237         -b.d.x, b.d.x * b.p.y - b.d.y * b.p.x);
238     }
239
240     struct circle {
241         vec o;
242         double r;
243         circle(const vec &o, double _r) : o(o), r(_r){};
244         // 点与圆的关系 -1在圆内, 0在圆上, 1在圆外
245         int relation(const vec &a) const {
246             double len = (a - o).len();
247             return sgn(len, r);
248         }
249         double area() { return PI * r * r; }
250     };
251
252     // 圆与直线交点
253     auto intersection(const circle &c, const line &l) {
254         double d = dis(c.o, l);
255         vector<vec> res;
256         double len = l.d.len();
257         vec mid = l.p + l.d * ((c.o - l.p) * l.d / len);
258         if (sgn(d, c.r) == 0) res.push_back(mid);
259         else if (sgn(d, c.r) < 0) {
260             d = sqrt(c.r * c.r - d * d) / len;
261             res.push_back(mid + l.d * d);
262             res.push_back(mid - l.d * d);
263         }
264         return res;
265     }

```

5.3 扫描线

```

1  #define ls (pos << 1)
2  #define rs (ls | 1)
3  #define mid ((tree[pos].l + tree[pos].r) >> 1)
4  struct Rectangle {
5      ll x_l, y_l, x_r, y_r;
6  };
7  ll area(vector<Rectangle>& rec) {
8      struct Line {
9          ll x, y_up, y_down;
10         int pd;
11     };
12     vector<Line> line(rec.size() * 2);
13     vector<ll> y_set(rec.size() * 2);
14     for (int i = 0; i < rec.size(); i++) {
15         y_set[i * 2] = rec[i].y_l;
16         y_set[i * 2 + 1] = rec[i].y_r;
17         line[i * 2] = {rec[i].x_l, rec[i].y_r, rec[i].y_l, 1};
18         line[i * 2 + 1] = {rec[i].x_r, rec[i].y_r, rec[i].y_l, -1};
19     }

```

```

20     sort(y_set.begin(), y_set.end());
21     y_set.erase(unique(y_set.begin(), y_set.end()), y_set.end());
22     sort(line.begin(), line.end(), [](Line a, Line b) { return a.x < b.x; });
23     struct Data {
24         int l, r;
25         ll len, cnt, raw_len;
26     };
27     vector<Data> tree(4 * y_set.size());
28     function<void(int, int, int)> build = [&](int pos, int l, int r) {
29         tree[pos].l = l;
30         tree[pos].r = r;
31         if (l == r) {
32             tree[pos].raw_len = y_set[r + 1] - y_set[l];
33             tree[pos].cnt = tree[pos].len = 0;
34             return;
35         }
36         build(ls, l, mid);
37         build(rs, mid + 1, r);
38         tree[pos].raw_len = tree[ls].raw_len + tree[rs].raw_len;
39     };
40     function<void(int, int, int, int)> update = [&](int pos, int l, int r,
41                                                 int num) {
42         if (l <= tree[pos].l && tree[pos].r <= r) {
43             tree[pos].cnt += num;
44             tree[pos].len = tree[pos].cnt ? tree[pos].raw_len
45                             : tree[pos].l == tree[pos].r
46                               ? 0
47                               : tree[ls].len + tree[rs].len;
48             return;
49         }
50         if (l <= mid) update(ls, l, r, num);
51         if (r > mid) update(rs, l, r, num);
52         tree[pos].len =
53             tree[pos].cnt ? tree[pos].raw_len : tree[ls].len + tree[rs].len;
54     };
55     build(1, 0, y_set.size() - 2);
56     auto find_pos = [&](ll num) {
57         return lower_bound(y_set.begin(), y_set.end(), num) - y_set.begin();
58     };
59     ll res = 0;
60     for (int i = 0; i < line.size() - 1; i++) {
61         update(1, find_pos(line[i].y_down), find_pos(line[i].y_up) - 1,
62               line[i].pd);
63         res += (line[i + 1].x - line[i].x) * tree[1].len;
64     }
65     return res;
66 }

```

6 杂项

6.1 高精度

```

1 struct bignum {
2     string num;
3
4     bignum() : num("0") {}
5     bignum(const string& num) : num(num) {
6         reverse(this->num.begin(), this->num.end());
7     }
8     bignum(ll num) : num(to_string(num)) {
9         reverse(this->num.begin(), this->num.end());
10    }
11
12    bignum operator+(const bignum& other) {
13        bignum res;
14        res.num.pop_back();
15        res.num.reserve(max(num.size(), other.num.size()) + 1);
16        for (int i = 0, j = 0, x; i < num.size() || i < other.num.size() || j;
17             i++) {
18            x = j;
19            j = 0;
20            if (i < num.size()) x += num[i] - '0';
21            if (i < other.num.size()) x += other.num[i] - '0';
22            if (x >= 10) j = 1, x -= 10;
23            res.num.push_back(x + '0');
24        }
25        res.num.capacity();
26        return res;
27    }
28
29    bignum operator*(const bignum& other) {
30        vector<int> res(num.size() + other.num.size() - 1, 0);
31        for (int i = 0; i < num.size(); i++)
32            for (int j = 0; j < other.num.size(); j++)
33                res[i + j] += (num[i] - '0') * (other.num[j] - '0');
34        int g = 0;
35        for (int i = 0; i < res.size(); i++) {
36            res[i] += g;
37            g = res[i] / 10;
38            res[i] %= 10;
39        }
40        while (g) {
41            res.push_back(g % 10);
42            g /= 10;
43        }
44        int lim = res.size();
45        while (lim > 1 && res[lim - 1] == 0) lim--;
46        bignum res2;
47        res2.num.resize(lim);
48        for (int i = 0; i < lim; i++) res2.num[i] = res[i] + '0';

```

```

49     return res2;
50 }
51
52 bool operator<(const bignum& other) {
53     if (num.size() == other.num.size())
54         for (int i = num.size() - 1; i >= 0; i--)
55             if (num[i] == other.num[i]) continue;
56             else return num[i] < other.num[i];
57     return num.size() < other.num.size();
58 }
59
60 friend istream& operator>>(istream& in, bignum& a) {
61     in >> a.num;
62     reverse(a.num.begin(), a.num.end());
63     return in;
64 }
65 friend ostream& operator<<(ostream& out, bignum a) {
66     reverse(a.num.begin(), a.num.end());
67     return out << a.num;
68 }
69 };

```

6.2 模运算

```

1 struct modint {
2     int x;
3     modint(ll _x = 0) : x(_x % mod) {}
4     modint inv() const { return power(*this, mod - 2); }
5     modint operator+(const modint& b) { return {x + b.x}; }
6     modint operator-() const { return {-x}; }
7     modint operator-(const modint& b) { return {-b + *this}; }
8     modint operator*(const modint& b) { return {(ll)x * b.x}; }
9     modint operator/(const modint& b) { return *this * b.inv(); }
10    friend istream& operator>>(istream& is, modint& other) {
11        ll _x;
12        is >> _x;
13        other = modint(_x);
14        return is;
15    }
16    friend ostream& operator<<(ostream& os, modint other) {
17        other.x = (other.x + mod) % mod;
18        return os << other.x;
19    }
20 };

```

6.3 分数

```

1 struct frac {
2     ll a, b;
3     frac() : a(0), b(1) {}

```

```

4   frac(ll _a, ll _b) : a(_a), b(_b) {
5       assert(b);
6       if (a) {
7           int tmp = gcd(a, b);
8           a /= tmp;
9           b /= tmp;
10      } else *this = frac();
11  }
12  frac operator+(const frac& other) {
13      return frac(a * other.b + other.a * b, b * other.b);
14  }
15  frac operator-() const {
16      frac res = *this;
17      res.a = -res.a;
18      return res;
19  }
20  frac operator-(const frac& other) const { return -other + *this; }
21  frac operator*(const frac& other) const {
22      return frac(a * other.a, b * other.b);
23  }
24  frac operator/(const frac& other) const {
25      assert(other.a);
26      return *this * frac(other.b, other.a);
27  }
28  bool operator<(const frac& other) const { return (*this - other).a < 0; }
29  bool operator<=(const frac& other) const { return (*this - other).a <= 0; }
30  bool operator>=(const frac& other) const { return (*this - other).a >= 0; }
31  bool operator>(const frac& other) const { return (*this - other).a > 0; }
32  bool operator==(const frac& other) const {
33      return a == other.a && b == other.b;
34  }
35  bool operator!=(const frac& other) const { return !(*this == other); }
36 };

```

6.4 表达式求值

```

1  // 格式化表达式
2  string format(const string& s1) {
3      stringstream ss(s1);
4      string s2;
5      char ch;
6      while ((ch = ss.get()) != EOF) {
7          if (ch == ' ') continue;
8          if (isdigit(ch)) s2 += ch;
9          else {
10             if (s2.back() != ' ') s2 += ' ';
11             s2 += ch;
12             s2 += ' ';
13         }
14     }
15     return s2;

```

```
16 }
17
18 // 中缀表达式转后缀表达式
19 string convert(const string& s1) {
20     unordered_map<char, int> rank{
21         {'+', 2}, {'-', 2}, {'*', 1}, {'/', 1}, {'^', 0}};
22     stringstream ss(s1);
23     string s2, temp;
24     stack<char> op;
25     while (ss >> temp) {
26         if (isdigit(temp[0])) s2 += temp + ' ';
27         else if (temp[0] == '(') op.push('(');
28         else if (temp[0] == ')') {
29             while (op.top() != '(') {
30                 s2 += op.top();
31                 s2 += ' ';
32                 op.pop();
33             }
34             op.pop();
35         } else {
36             while (!op.empty() && op.top() != '(' &&
37                 (temp[0] != '^' && rank[op.top()] <= rank[temp[0]] ||
38                 rank[op.top()] < rank[temp[0]])) {
39                 s2 += op.top();
40                 s2 += ' ';
41                 op.pop();
42             }
43             op.push(temp[0]);
44         }
45     }
46     while (!op.empty()) {
47         s2 += op.top();
48         s2 += ' ';
49         op.pop();
50     }
51     return s2;
52 }
53
54 // 计算后缀表达式
55 int calc(const string& s) {
56     stack<int> num;
57     stringstream ss(s);
58     string temp;
59     while (ss >> temp) {
60         if (isdigit(temp[0])) num.push(stoi(temp));
61         else {
62             int b = num.top();
63             num.pop();
64             int a = num.top();
65             num.pop();
66             if (temp[0] == '+') a += b;
67             else if (temp[0] == '-') a -= b;
```



```

68         else if (temp[0] == '*') a *= b;
69         else if (temp[0] == '/') a /= b;
70         else if (temp[0] == '^') a = ksm(a, b);
71         num.push(a);
72     }
73 }
74 return num.top();
75 }

```

6.5 日期

```

1  int month[] = {0, 31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31};
2  int pre[13];
3  vector<int> leap;
4  struct Date {
5      int y, m, d;
6      bool operator<(const Date& other) const {
7          return array<int, 3>{y, m, d} <
8              array<int, 3>{other.y, other.m, other.d};
9      }
10     Date(const string& s) {
11         stringstream ss(s);
12         char ch;
13         ss >> y >> ch >> m >> ch >> d;
14     }
15     int dis() const {
16         int yd = (y - 1) * 365 +
17             (upper_bound(leap.begin(), leap.end(), y - 1) - leap.begin());
18         int md =
19             pre[m - 1] + (m > 2 && (y % 4 == 0 && y % 100 || y % 400 == 0));
20         return yd + md + d;
21     }
22     int dis(const Date& other) const { return other.dis() - dis(); }
23 };
24 for (int i = 1; i <= 12; i++) pre[i] = pre[i - 1] + month[2];
25 for (int i = 1; i <= 1000000; i++)
26     if (i % 4 == 0 && i % 100 || i % 400 == 0) leap.push_back(i);

```

6.6 对拍

linux/Mac

```

1  g++ a.cpp -o program/a -O2 -std=c++17
2  g++ b.cpp -o program/b -O2 -std=c++17
3  g++ suiji.cpp -o program/suiji -O2 -std=c++17
4
5  cnt=0
6
7  while true; do
8      let cnt++
9      echo TEST:$cnt

```

```

10
11     ./program/suiji > in
12     ./program/a < in > out.a
13     ./program/b < in > out.b
14
15     diff out.a out.b
16     if [ $? -ne 0 ];then break;fi
17 done

```

windows

```

1 @echo off
2
3 g++ a.cpp -o program/a -O2 -std=c++17
4 g++ b.cpp -o program/b -O2 -std=c++17
5 g++ suiji.cpp -o program/suiji -O2 -std=c++17
6
7 set cnt=0
8
9 :again
10     set /a cnt=cnt+1
11     echo TEST:%cnt%
12     .\program\suiji > in
13     .\program\a < in > out.a
14     .\program\b < in > out.b
15
16     fc output.a output.b
17 if not errorlevel 1 goto again

```

6.7 编译常用选项

```

1 -Wall -Woverflow -Wextra -Wpedantic -Wfloat-equal -Wshadow -fsanitize=address,undefined

```

6.8 开栈

不同的编译器可能命令不一样

```

1 -Wl,--stack=0x10000000
2 -Wl,-stack_size -Wl,0x10000000
3 -Wl,-z,stack-size=0x10000000

```

6.9 clang-format

```

1 BasedOnStyle: Google
2 IndentWidth: 4
3 ColumnLimit: 80
4 AllowShortIfStatementsOnASingleLine: AllIfsAndElse
5 AccessModifierOffset: -4
6 EmptyLineBeforeAccessModifier: Leave
7 RemoveBracesLLVM: true

```