Standard Code Library

ONGLU

North Eastern University

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Contents

初始化

数据结构

轻重链剖分

```
void dfs1(int x, int pre) {
    siz[x] = 1; mson[x] = 0;
    dth[x] = dth[pre] + 1;
    fa[x] = pre;
    for(auto y : son[x]) if(y != pre) {
        dfs1(y, x);
        siz[x] += siz[y];
        if(!mson[x] || siz[y] > siz[mson[x]])
            mson[x] = y;
    }
}
void dfs2(int x, int pre, int ntp) {
    id[x] = ++idcnt;
    ltp[x] = ntp;
    if(mson[x]) dfs2(mson[x], x, ntp);
    for(auto y : son[x]) {
        if(y == mson[x] || y == pre) continue;
        dfs2(y, x, y);
    }
}
void link_modify(int x, int y, int z) {
    z %= mod;
    while(ltp[x] != ltp[y]) {
        dth[ltp[x]] < dth[ltp[y]] && (x ^= y ^= x ^= y);
        modify(1, n, id[ltp[x]], id[x], 1, z);
        x = fa[ltp[x]];

    }
    dth[x] < dth[y] && (x ^= y ^= x ^= y);
    modify(1, n, id[y], id[x], 1, z);
}
int link_query(int x, int y) {
    int ans = 0;
    while(ltp[x] != ltp[y]) {
        dth[ltp[x]] < dth[ltp[y]] && (x ^= y ^= x ^= y);
        ans = (1ll * ans + query(1, n, id[ltp[x]], id[x], 1)) % mod;
        x = fa[ltp[x]];
    }
    dth[x] < dth[y] && (x ^= y ^= x ^= y);
    ans = (1ll * ans + query(1, n, id[y], id[x], 1)) % mod;
    return ans;
}
```

二维树状数组

- 矩阵修改，矩阵查询

  查询前缀和公式:

  令 $d[i][j]$ 为差分数组，定义 $d[i][j] = a[i][j] - (a[i-1][j] - a[i][j-1] - a[i-1][j])$

  $\sum_{i=1}^{x}\sum_{j-1}^{y} a[i][j] = (x+1)*(y+1)*d[i][j] - (y+1)*i*d[i][j] + d[i][j]*i*j$

```
void modify(int x, int y, int v) {
    for(int rx = x; rx <= n; rx += rx & -rx) {
        for(int ry = y; ry <= m; ry += ry & -ry) {
            tree[rx][ry][0] += v;
            tree[rx][ry][1] += v * x;
            tree[rx][ry][2] += v * y;
            tree[rx][ry][3] += v * x * y;
        }
    }
}
```

```cpp
void range_modify(int x, int y, int xx, int yy, int v) {
    modify(xx + 1, yy + 1, v);
    modify(x, yy + 1, -v);
    modify(xx + 1, y, -v);
    modify(x, y, v);
}
int query(int x, int y) {
    int ans = 0;
    for(int rx = x; rx; rx -= rx & -rx) {
        for(int ry = y; ry; ry -= ry & -ry) {
            ans += (x + 1) * (y + 1) * tree[rx][ry][0]
            - tree[rx][ry][1] * (y + 1) - tree[rx][ry][2] * (x + 1)
            + tree[rx][ry][3];
        }
    }
    return ans;
}
int range_query(int x, int y, int xx, int yy) {
    return query(xx, yy) + query(x - 1, y - 1)
        - query(x - 1, yy) - query(xx, y - 1);
}
```

平衡树

- luogu P3369 【模板】普通平衡树

```cpp
#define val(x) tree[x].val
#define cnt(x) tree[x].cnt
#define siz(x) tree[x].siz
#define fa(x) tree[x].fa
#define son(x, k) tree[x].ch[k]
struct Tree {
    struct node {
        int val, cnt, siz, fa, ch[2];
    } tree[N];
    int root, tot;
    int chk(int x) {
        return son(fa(x), 1) == x;
    }
    void update(int x) {
        siz(x) = siz(son(x, 0)) + siz(son(x, 1)) + cnt(x);
    }
    void rotate(int x) {
        int y = fa(x), z = fa(y), k = chk(x), w = son(x, k ^ 1);
        son(y, k) = w; fa(w) = y;
        son(z, chk(y)) = x; fa(x) = z;
        son(x, k ^ 1) = y; fa(y) = x;
        update(y); update(x);
    }
    void splay(int x, int goal = 0) {
        while(fa(x) != goal) {
            int y = fa(x), z = fa(y);
            if(z != goal) {
                //双旋
                if(chk(y) == chk(x)) rotate(y);
                else rotate(x);
            }
            rotate(x);
        }
        if(!goal) root = x;
    }
    int New(int x, int pre) {
        tot++;
        if(pre) son(pre, x > val(pre)) = tot;
        val(tot) = x; fa(tot) = pre;
        siz(tot) = cnt(tot) = 1;
        son(tot, 0) = son(tot, 1) = 0;
        return tot;
    }
```

```
    void Insert(int x) {
        int cur = root, p = 0;
        while(cur && val(cur) != x) {
            p = cur;
            cur = son(cur, x > val(cur));
        }
        if(cur) cnt(cur)++;
        else cur = New(x, p);
        splay(cur);
    }
    void Find(int x) {
        if(!root) return ;
        int cur = root;
        while(val(cur) != x && son(cur, x > val(cur)))
            cur = son(cur, x > val(cur));
        splay(cur);
    }
    int Pre(int x) {
        Find(x);
        if(val(root) < x) return root;
        int cur = son(root, 0);
        while(son(cur, 1))
            cur = son(cur, 1);
        return cur;
    }
    int Succ(int x) {
        Find(x);
        if(val(root) > x) return root;
        int cur = son(root, 1);
        while(son(cur, 0))
            cur = son(cur, 0);
        return cur;
    }
    void Del(int x) {
        int lst = Pre(x), nxt = Succ(x);
        splay(lst); splay(nxt, lst);
        int cur = son(nxt, 0);
        if(cnt(cur) > 1) cnt(cur)--, splay(cur);
        else son(nxt, 0) = 0, splay(nxt);
    }
    int Kth(int k) {
        int cur = root;
        while(1) {
            if(son(cur, 0) && siz(son(cur, 0)) >= k) cur = son(cur, 0);
            else if(siz(son(cur, 0)) + cnt(cur) >= k) return cur;
            else k -= siz(son(cur, 0)) + cnt(cur), cur = son(cur, 1);
        }
    }
} T;
```

可持久化数据结构

可持久化 Trie

```
namespace Trie {
    struct node {
        int ch[2], ed, siz;
    } tree[N * 40];
    int tot = 0;
    int _new() {
        tot++;
        tree[tot].ch[0] = 0;
        tree[tot].ch[1] = 0;
        tree[tot].ed = tree[tot].siz = 0;
        return tot;
    }
    void init() {
        tot = 0;
        rt[0] = _new();
    }
    int Insert(int x, int t, int i = 15) {
```

```
        int u = _new(), f = (x >> i) & 1;
        tree[u] = tree[t];
        if(i == -1) {
            ed(u)++;
            siz(u)++;
            return u;
        }
        son(u, f) = Insert(x, son(t, f), i - 1);
        siz(u) = siz(son(u, 0)) + siz(son(u, 1));
        return u;
    }
    void print(int u, int now) {
        if(u == 0) return ;
        for(int i = 1; i <= ed(u); i++) printf("%d ", now);
        if(son(u, 0)) print(son(u, 0), now * 2);
        if(son(u, 1)) print(son(u, 1), now * 2 + 1);
    }
    int query(int u1, int u2, int x, int i = 15, int now = 0) {
        if(i == -1) return now;
        int f = (x >> i) & 1;
        if(siz(son(u1, f ^ 1)) - siz(son(u2, f ^ 1)) > 0)
            return query(son(u1, f ^ 1), son(u2, f ^ 1), x, i - 1, now * 2 + (f ^ 1));
        else return query(son(u1, f), son(u2, f), x, i - 1, now * 2 + (f));
    }
}
```

主席树（静态第 k 小）

建立权值树，那么 $[l, r]$ 的区间权值树就是第 r 个版本减去第 $l-1$ 个版本的树。

```
#include <iostream>
#include <cstdio>
#include <algorithm>
#include <cmath>
#include <assert.h>
#define Mid ((l + r) / 2)
#define lson (rt << 1)
#define rson (rt << 1 | 1)
using namespace std;
int read() {
    char c; int num, f = 1;
    while(c = getchar(),!isdigit(c)) if(c == '-') f = -1; num = c - '0';
    while(c = getchar(), isdigit(c)) num = num * 10 + c - '0';
    return f * num;
}
const int N = 1e7 + 1009;
const int M = 2e5 + 1009;
struct node {
    int ls, rs, v;
} tree[N];
int tb;
int n, m, tot, a[M], b[M], rt[M];
int _new(int ls, int rs, int v) {
    tree[++tot].ls = ls;
    tree[tot].rs = rs;
    tree[tot].v = v;
    return tot;
}
void update(int rt) {
    tree[rt].v = tree[tree[rt].ls].v + tree[tree[rt].rs].v;
}
int build(int l, int r) {
    if(l == r) return _new(0, 0, 0);
    int x = _new(build(l, Mid), build(Mid + 1, r), 0);
    update(x);
    return x;
}
int add(int l, int r, int p, int rt, int v) {
    int x = ++tot;
    tree[x] = tree[rt];
    if(l == r) {
```

```
        tree[x].v += v;
        return x;
    }
    if(p <= Mid) tree[x].ls = add(l, Mid, p, tree[x].ls, v);
    else tree[x].rs = add(Mid + 1, r, p, tree[x].rs, v);
    update(x);
    return x;
}
int query(int l, int r, int rt1, int rt2, int k) {
    if(l == r) return l;
    if(k <= tree[tree[rt1].ls].v - tree[tree[rt2].ls].v) return query(l, Mid, tree[rt1].ls, tree[rt2].ls, k);
    else return query(Mid + 1, r, tree[rt1].rs, tree[rt2].rs, k - (tree[tree[rt1].ls].v - tree[tree[rt2].ls].v));
}
void Debug(int l, int r, int rt) {
    printf("%d %d %d\n", l, r, tree[rt].v);
    if(l == r) return ;
    Debug(l, Mid, tree[rt].ls);
    Debug(Mid + 1, r, tree[rt].rs);
}
signed main()
{
    n = read(); m = read();
    for(int i = 1; i <= n; i++) a[i] = b[i] = read();
    sort(b + 1, b + 1 + n);
    tb = unique(b + 1, b + 1 + n) - b - 1;
    rt[0] = build(1, tb);
    for(int i = 1; i <= n; i++) {
        rt[i] = add(1, tb, lower_bound(b + 1, b + 1 + tb, a[i]) - b, rt[i - 1], 1);
    }
    for(int i = 1; i <= m; i++) {
        int l, r, k;
        l = read(); r = read(); k = read();
        assert(r - l + 1 >= k);
        printf("%d\n", b[query(1, tb, rt[r], rt[l - 1], k)]);
    }
    return 0;
}
```

cdq 分治三维偏序

先按照第一维排序, 然后对第二维归并, 归并时计算左对右的贡献, 先双指针, 满足当前统计出的第二维都有序

```
const int N = 1e6 + 1009;
struct node{
    int x, y, z, id, cnt;
}a[N], tmp[N];
bool operator ==(const node &a, const node &b) {
    return a.x == b.x && a.y == b.y && a.z == b.z;
}
int n, m, tot, ans[N], tt[N], tree[N];
int ttt[N];
bool cmp(node a, node b) {
    if(a.x == b.x && a.y == b.y) return a.z < b.z;
    if(a.x == b.x) return a.y < b.y;
    return a.x < b.x;
}
void add(int x, int y) {
    for( ; x <= m; x += x & -x)
        tree[x] += y;
}
int query(int x) {
    int ans = 0;
    for( ; x; x -= x & -x)
        ans += tree[x];
    return ans;
}
void cdq(int l, int r) {
    if(l == r) return ;
    cdq(l, Mid); cdq(Mid + 1, r);
    int i = l, j = Mid + 1, now = l - 1;
    while(i <= Mid && j <= r) {
```

```
        if(a[i].y <= a[j].y) {
            tmp[++now] = a[i];
            add(a[i].z, a[i].cnt);
            i++;
        } else {
            tmp[++now] = a[j];
            ans[a[j].id] += query(a[j].z);
            j++;
        }
    }
    while(i <= Mid) {
        tmp[++now] = a[i];
        add(a[i].z, a[i].cnt);
        i++;
    }
    while(j <= r) {
        tmp[++now] = a[j];
        ans[a[j].id] += query(a[j].z);
        j++;
    }
    for(int i = l; i <= Mid; i++) add(a[i].z, -a[i].cnt);
    for(int i = l; i <= r; i++) a[i] = tmp[i];
}
main()
{
    n = read(); m = read();
    for(int i = 1; i <= n; i++) {
        a[i].x = read();
        a[i].y = read();
        a[i].z = read();
        a[i].cnt = 1;
    }
    sort(a + 1, a + 1 + n, cmp);
    for(int i = 1; i <= n; i++) {
        if(i == 1 || !(a[i] == a[i - 1])){
            a[++tot] = a[i];
        }else a[tot].cnt += a[i].cnt;
    }
    for(int i = 1; i <= tot; i++) a[i].id = i, ttt[i] = a[i].cnt;
    cdq(1, tot);
    for(int i = 1; i <= tot; i++) tt[ans[i] + ttt[i] - 1] += ttt[i];
    for(int i = 0; i < n; i++) printf("%d\n", tt[i]);
    return 0;
}
```

数学

数论

逆元

线性推

```
inv[1] = inv[0] = 1;
for(int i = 2; i < N; i++)  inv[i] = (1ll * mod - mod / i) * inv[mod % i] % mod;
```

费马小定理 (模数为质数)

```
int inv(int x) {
    return Pow(x % mod, mod - 2);
}
```

exgcd(ap 互质)

```
int inv(int x) {
    int x, y;
    exgcd(x, y, a, p);
    return (x % p + p) % p;
}
```

拓展欧几里得

求解的是类似 $ax + by = gcd(a, b)$ 的一组解。

```
void exgcd(int &x, int &y, int a, int b) {
    if(b == 0) return (void)(x = 1, y = 0);
    exgcd(y, x, b, a % b);
    y = y - a / b * x;
}
```

拓展中国剩余定理

拓展中国剩余定理用于解决同余方程组。

$$x \equiv a_i (mod\, b_i)$$

构造 $M_k = lcm_{i=1}^{k-1} b_i$
假设前面的解为 p 显然新解 $p + M_k \times y$ 仍然是前面方程的解。
exgcd 求出 $M_k \times x + b_i \times y = gcd(M_k, b_i)$ 的解。
于是 $p' = p + x \times M_k \times (a_i - p)/gcd(M_k, b_i)$。
实际处理的时候可以直接让 $b_i = b_i/gcd(b_i, M_k)$ 防止溢出。

````
#define long long ll
ll gcd(ll a, ll b) {
    return b == 0 ? a : gcd(b, a % b);
}
ll lcm(ll a, ll b) {
    return a / gcd(a, b) * b;
}
ll exgcd(ll &x, ll &y, ll a, ll b) {
    if(b == 0) return x = 1, y = 0, a;
    ll t = exgcd(y, x, b, a % b);
    y -= a / b * x;
    return t;
}
inline ll mul(ll x, ll y, ll mod){
    return (x * y - (ll)((long double)x / mod * y) * mod + mod) % mod;
}

ll excrt(ll n, ll *a, ll *b) {
    ll ans = a[1], M = b[1];
    for(ll i = 2; i <= n; i++) {
        ll c = ((a[i] - ans) % b[i] + b[i]) % b[i], x, y;
        ll t = exgcd(x, y, M, b[i]), pb = b[i] / t;
        if(c % t != 0) return -1;
        x = mul(x, c / t, pb);
        ans = ans + x * M;
        M = M *pb;
        ans = (ans % M + M) % M;
    }
    return ans;
}

### Miller_rabbin 素数测试
```cpp
namespace Isprime{
    ll mul(ll x, ll y, ll mod){
        return (x * y - (ll)((long double)x / mod * y) * mod + mod) % mod;
    }
    ll Pow(ll a, ll p, ll mod) {
        ll ans = 1;
        for( ; p; p >>= 1, a = mul(a, a, mod))
            if(p & 1)
                ans = mul(ans, a, mod);
        return ans % mod;
    }
    int check(ll P){
        const ll test[11] = {0, 2, 3, 5, 7, 11, 13, 17, 19, 23, 29};
        if(P == 1) return false;
````
````

```cpp
        if(P > 6 && P % 6 != 1 && P % 6 != 5) return false;
        ll k = 0, t = P - 1;
        while(!(t & 1)) k++, t >>= 1;
        for(int i = 1; i <= 10 && test[i] <= P; i++) {
            if(P == test[i]) return true;
            ll nxt, a = Pow(test[i], t, P);
            for(int j = 1; j <= k; j++) {
                nxt = mul(a, a, P);
                if(nxt == 1 && a != 1 && a != P - 1) return false;
                a = nxt;
            }
            if(a != 1)return false;
        }
        return true;
    }
}
```

````
## 多项式
### 结论
1. 自然数幂之和$s(n) = \sum_{i = 0}^n i^k$是关于$n$的$k+1$次多项式


### 拉格朗日插值法
令拉格朗日函数
$$l_i(x) = \prod_{j \not = i}\frac{x - x_j}{x_i-x_j}$$
注意到这个函数有一些性质：
1. 次数为$n$
2. 在$x=x_i$位置值为$1$,$x=x_j(j\not =i)$位置值为$0$
于是可以凑出唯一的多项式表达式为：
$$f(x) = \sum_{i=0}^{n}y_i\prod_{j\not = i}\frac{x - x_j}{x_i-x_j}$$
如果要取模的话得求逆元， 逆元先求好分母再一起求即可。
```cpp
int interpolation(int *x, int *y, int n) {
    int f = 0;
    for(int i = 1; i <= n; i++) {
        int s1 = 1, s2 = 1;
        for(int j = 1; j <= n; j++) {
            if(i != j) {
                s1 = 1ll * s1 * (k - x[j] + mod) % mod;
                s2 = 1ll * s2 * (x[i] - x[j] + mod) % mod;
            }
        }
        f = (f + 1ll * y[i] * s1 % mod * inv(s2) % mod) % mod;
    }
    return f;
}
````

FFT 快速傅里叶变换

FFT 的想法是把第 k 号位置变成 $f(\omega_n^k)$，注意到 $\omega_n^k = -\omega_n^{k+n/2}$，于是可以进行变换。
几条公式:

$$\omega_n^n = 1$$

$$\omega_n^k = \omega_{2n}^{2k}$$

$$\omega_{2n}^{k+n} = -\omega_{2n}^k$$

蝴蝶变换：相邻的位置为二进制的 reverse
DFT 变换公式 ($DFT(f)$ 为矩阵):
````

令

$$G(x) = a_0 + a_2 x + a_4 x^2 + ...$$
$$H(x) = a_1 + a_3 x + a_5 x^3 + ...$$

则有

$$f(x) = G(x^2) + x \times H(x^2)$$
$$DFT(f(\omega_n^k)) = DFT(G(\omega_{n/2}^k) + \omega_n^k \times DFT(H(\omega_{n/2}^k)))$$
$$DFT(f(\omega_n^{k+n/2})) = DFT(G(\omega_{n/2}^k) - \omega_n^k \times DFT(H(\omega_{n/2}^k)))$$

$DFT(G(\omega_{n/2}^k), DFT(H(\omega_{n/2}^k)))$ 可递归计算

NTT 快速数论变换

NTT 使用原根代替复数进行运算。
原根 g 的重要性质：$g^t \equiv k \mod n, t \in [0, n-2]$，$k$ 遍取 1~$n-1$
原根存在的充要条件是：模数 $n = 2, 4, p^\alpha, 2p^\alpha$($p$ 为奇质数)。
对于一个质数 $p = qn + 1 (n = 2^m)$, 原根满足性质 $g^{qn} \equiv 1 \mod p$。
它满足和复数近似的性质，我们把 q 看成复数中的 2π，就可以套用 FFT 实现 NTT 了。
$g_n^n \equiv 1, g_n^n \equiv -1$

通常取

$$p = 1004535809 = 7 \times 479 \times 2^{21} + 1, g = 3$$

$$p = 998244353 = 7 \times 17 \times 2^{23} + 1, g = 3$$

```cpp
const int P = 998244353, G = 3, Gi = 332748118;
struct Complex {double x, y;};
Complex operator+(const Complex &a, const Complex &b) {return (Complex) {a.x + b.x, a.y + b.y};}
Complex operator-(const Complex &a, const Complex &b) {return (Complex) {a.x - b.x, a.y - b.y};}
Complex operator*(const Complex &a, const Complex &b) {return (Complex) {a.x * b.x - a.y * b.y, a.x * b.y + a.y *
    b.x};}
namespace Polynomial {
    const double Pi = acos(-1.0);
    int rev[N];
    template <typename T>
    void change(T *y, int n) {
        for(int i = 0; i < n; i++) {
            rev[i] = (rev[i >> 1] >> 1) | ((i & 1) ? (n >> 1) : 0);
        }
        for(int i = 0; i < n; i++)
            if(i < rev[i])
                swap(y[i], y[rev[i]]);
    }
    void FFT(Complex *A, int n, int type) {
        //type = 1 DFT
        //type = -1 IDFT
        //确保 n 是 2 的幂次
        change(A, n);
        for(int m = 1; m < n; m <<= 1) {
            Complex Wn = (Complex) {cos(Pi / m), type * sin(Pi / m)};
            for(int i = 0; i < n; i += 2 * m) {
                Complex w = (Complex) {1.0, 0};
                for(int j = 0; j < m; j++, w = w * Wn) {
                    Complex x = A[i + j], y = w * A[i + j + m];
                    A[i + j] = x + y;
                    A[i + j + m] = x - y;
                }
            }
        }
        if(type == -1) {
            for(int i = 0; i < n; i++)
                A[i].x = A[i].x / n;
```

```
        }
    }
    void NTT(int *A, int n, int type) {
        //type = 1 DFT
        //type = -1 IDFT
        change(A, n);
        for(int m = 1; m < n; m <<= 1) {
            int Wn = qpow(type == 1 ? G : Gi, (P - 1) / (m << 1));
            for(int i = 0; i < n; i += 2 * m) {
                int w = 1;
                for(int j = 0; j < m; j++, w = 1ll * w * Wn % P) {
                    int x = A[i + j], y = 1ll * w * A[i + j + m] % P;
                    A[i + j] = (x + y) % P;
                    A[i + j + m] = (x - y + P) % P;
                }
            }
        }
        if(type == -1) {
            int inv = qpow(n, P - 2);
            for(int i = 0; i < n; i++)
                A[i] = 1ll * A[i] * inv % P;
        }
    }

}
//以下代码加在主函数内
limit = 1;
while(limit <= n + m) limit <<= 1;
Polynomial :: FFT(A, limit, 1);
Polynomial :: FFT(B, limit, 1);
for(int i = 0; i < limit; i++) A[i] = A[i] * B[i];
Polynomial :: FFT(A, limit, -1);
```

FWT 快速沃尔什变换

FWT 用于计算下列多项式

$$C[k] = \sum_{i \oplus j = k} A[i] \times B[j]$$

先通过 FWT 将 A, B 变为 $FWT(A), FWT(B)$，这样有 $FWT(C) = FWT(A) \times FWT(B)$。当然位运算符不同的时候对应的变换形式也需要改变。

$a \in S, b \in S$ 可以表示为 $a|b \in S$
FWT 为线性变换 $\sum FWT(F) = FWT(\sum F)$

与卷积
当 $\oplus = and$ 的时候
$FWT(A) = (FWT(A_0) + FWT(A_1), FWT(A_1))$
$FWT(A) = A$(长度为 1)
$IFWT(A) = (IFWT(A_0) - IFWT(A_1), IFWT(A_1))$

或卷积
当 $\oplus = or$ 的时候
$FWT(A) = (FWT(A_0), FWT(A_0) + FWT(A_1))$
$FWT(A) = A$(长度为 1)
$IFWT(A) = (IFWT(A_0), IFWT(A_1) - IFWT(A_0))$

异或卷积
当 $\oplus = xor$ 的时候
$FWT(A) = (FWT(A_0) + FWT(A_1), FWT(A_0) - FWT(A_1))$
$FWT(A) = A$(长度为 1)
$IFWT(A) = (\frac{IFWT(A_0)+IFWT(A_1)}{2}, \frac{IFWT(A_0)-IFWT(A_1)}{2})$

```
namespace Polynomial {
    void FWT_or(int *A, int n, int type) {
```

```
        for(int m = 1; m < n; m <<= 1) {
            for(int i = 0; i < n; i += 2 * m) {
                for(int j = 0; j < m; j++) {
                    A[i + j + m] = (1ll * A[i + j + m] + A[i + j] * type + mod) % mod;
                }
            }
        }
    }
    void FWT_and(int *A, int n, int type) {
        for(int m = 1; m < n; m <<= 1) {
            for(int i = 0; i < n; i += 2 * m) {
                for(int j = 0; j < m; j++) {
                    A[i + j] = (1ll * A[i + j + m] * type + A[i + j] + mod) % mod;
                }
            }
        }
    }
    void FWT_xor(int *A, int n, int type) {
        int inv_2 = Pow(2, mod - 2);
        for(int m = 1; m < n; m <<= 1) {
            for(int i = 0; i < n; i += 2 * m) {
                for(int j = 0; j < m; j++) {
                    int x = A[i + j], y = A[i + j + m];
                    A[i + j] = (1ll * x + y) * (type == 1 ? 1 : inv_2) % mod;
                    A[i + j + m] = (1ll * x - y + mod) * (type == 1 ? 1 : inv_2) % mod;
                }
            }
        }
    }
}
```

子集卷积

子集卷积求的是下面一个式子：

$$c_k = \sum_{i|j=k,i\&j=0} a_i \times b_j$$

就是把集合 k 划分成两个集合。
后面那个与的条件通过 $|k| = |i| + |j|$ 干掉，加一维集合元素个数，就变成了

$$c[i+j][mask_k] = \sum_{i|j=k} a[i][mask_i] \times b[j][mask_j]$$

这个可以用 FWT 算。

```
namespace ssc{
    int f[21][1 << 21], g[21][1 << 21], ans[21][1 << 21];
    void subset_convolution(int *A, int *B, int *C, int n, int lim) {
    //  memset(f, 0, sizeof(f));
    //  memset(g, 0, sizeof(g));
        for(int i = 0; i < lim; i++) f[__builtin_popcount(i)][i] = A[i];
        for(int i = 0; i < lim; i++) g[__builtin_popcount(i)][i] = B[i];
        for(int i = 0; i <= n; i++) FWT_or(f[i], lim, 1), FWT_or(g[i], lim, 1);
        for(int i = 0; i <= n; i++)
            for(int j = 0; j <= i; j++)
                for(int k = 0; k < lim; k++)
                    ans[i][k] = (ans[i][k] + 1ll * f[j][k] * g[i - j][k] % mod) % mod;
        for(int i = 0; i <= n; i++) FWT_or(ans[i], lim, -1);
        for(int i = 0; i < lim; i++) C[i] = ans[__builtin_popcount(i)][i];
    }
}
```

群论

结论

1. **子群检验法**: 群 G 是群 H 的子群的充分必要条件：对于所有元素 h,g，只需检查 $g^{-1} \cdot h \in H$。

图论

树论

树的直径

模板：POJ - 1985

- 两遍 DFS

```
void dfs(int x, int fa) {
    for(int i = 0; i < E[x].size(); i++) {
        int y = E[x][i].ver;
        int w = E[x][i].val;
        if(y == fa) continue;
        d[y] = d[x] + w;
        if(d[y] > d[c]) c = y;
        dfs(y, x);
    }
}
signed main()
{
    n = read();
    for(int i = 1; i < n; i++) {
        int x = read(), y = read(), w = read();
        E[x].push_back((Edge) {y, w});
        E[y].push_back((Edge) {x, w});
    }
    dfs(1, 0);
    d[c] = 0;
    dfs(c, 0);
    printf("%d\n", d[c]);
    return 0;
}
```

- 树形 DP

```
void dfs(int x, int fa) {
    d1[x] = d2[x] = 0;
    for(int i = 0; i < E[x].size(); i++) {
        int y = E[x][i].ver;
        int w = E[x][i].val;
        if(y == fa) continue;
        dfs(y, x);
        int t = d1[y] + w;
        if(t > d1[x]) {
            d2[x] = d1[x];
            d1[x] = t;
        } else if(t > d2[x]) {
            d2[x] = t;
        }
    }
    d = max(d, d1[x] + d2[x]);
}
signed main()
{
    n = read();
    for(int i = 1; i < n; i++) {
        int x = read(), y = read(), w = read();
        E[x].push_back((Edge) {y, w});
        E[y].push_back((Edge) {x, w});
    }
    dfs(1, 0);
    printf("%d\n", d);
    return 0;
}
```

求 LCA

- 树链剖分

```cpp
namespace Tree {
    int siz[N], mson[N], ltp[N], fa[N], dth[N];
    vector<int> son[N];
    void dfs1(int x, int pre) {
        siz[x] = 1;
        mson[x] = 0;
        fa[x] = pre;
        dth[x] = dth[pre] + 1;
        for(auto y : son[x]) if(y != pre) {
            dfs1(y, x);
            if(mson[x] == 0 || siz[y] > siz[mson[x]]) mson[x] = y;
        }
    }
    void dfs2(int x, int pre, int tp) {
        ltp[x] = tp;
        if(mson[x]) dfs2(mson[x], x, tp);
        for(auto y : son[x]) if(y != pre && y != mson[x]) {
            dfs2(y, x, y);
        }
    }
    void init() {
        dfs1(1, 0);
        dfs2(1, 0, 1);
    }
    int LCA(int x, int y) {
        while(ltp[x] != ltp[y]) {
            if(dth[ltp[x]] > dth[ltp[y]]) x = fa[ltp[x]];
            else y = fa[ltp[y]];
        }
        return dth[y] > dth[x] ? x : y;
    }
}
```

- 倍增

```cpp
namespace Tree {
    vector<int> son[N];
    int root, fa[N][31], dth[N];
    void dfs(int x, int pre) {
        fa[x][0] = pre;
        dth[x] = dth[pre] + 1;
        for(int i = 1; i <= 30; i++)
            fa[x][i] = fa[fa[x][i - 1]][i - 1];
        for(auto y : son[x]) if(y != pre)
            dfs(y, x);
    }
    void init() {
        dfs(root, 0);
    }
    int LCA(int x, int y) {
        if(dth[x] > dth[y]) swap(x, y);
        for(int i = 30; ~i; i--)
            if(dth[fa[y][i]] >= dth[x])
                y = fa[y][i];
        if(x == y) return x;
        for(int i = 30; ~i; i--)
            if(fa[y][i] != fa[x][i]) {
                x = fa[x][i];
                y = fa[y][i];
            }
        return fa[x][0];
    }
}
```

树上启发式合并

长春站的痛.jpg

- 先递归计算轻儿子的答案
- 计算重儿子的答案，并且保留重儿子的状态数组
- 把其他所有轻儿子的答案加到状态数组中，更新当前点的答案

```cpp
void dfs1(int x, int pre) {
    siz[x] = 1;
    mson[x] = 0;
    for(auto y : son[x]) if(y != pre) {
        dfs1(y, x);
        siz[x] += siz[y];
        if(!mson[x] || siz[y] > siz[mson[x]]) mson[x] = y;
    }
}
void add(int x, int pre, int v) {
    cnt[col[x]] += v;
    if(cnt[col[x]] > Mx) Mx = cnt[col[x]], sum = col[x];
    else if(cnt[col[x]] == Mx) sum += col[x];
    for(auto y : son[x]) {
        if(y == pre || y == Son) continue;
        add(y, x, v);
    }
}
void dfs2(int x, int pre, int keep) {
    for(auto y : son[x]) {
        if(y == pre || y == mson[x]) continue;
        dfs2(y, x, 0);
    }
    if(mson[x]) dfs2(mson[x], x, 1), Son = mson[x];
    add(x, pre, 1); Son = 0;
    ans[x] = sum;
    if(!keep) add(x, pre, -1), sum = 0, Mx = 0;

}
```

图论

第 k 短路

模板：HDU-6351

估值函数：$h(x) = f(x) + g(x)$，其中 $f(x)$ 为从起点到现在的距离，$g(x)$ 为起点到当前点的最短路。

```cpp
bool operator<(const node &a, const node &b) {
    return a.f + a.g > b.f + b.g;
}
priority_queue<node> q;
signed main()
{
    n = read(); m = read();
    for(int i = 1; i <= m; i++) {
        int x, y, w;
        x = read(); y = read(); w = read();
        E[x].push_back((Edge) {y, w});
        re[y].push_back((Edge) {x, w});
    }
    s = read(); t = read(); k = read();
    memset(dis, 0x3f, sizeof(dis)); dis[t] = 0;
    q.push((node) {t, 0, 0});
    while(q.size()) {
        int x = q.top().x, d = q.top().f;
        q.pop();
        if(dis[x] < d) continue;
        for(int i = 0; i < re[x].size(); i++) {
            int y = re[x][i].y, w = re[x][i].w;
            if(dis[y] > dis[x] + w) {
                dis[y] = dis[x] + w;
                q.push((node) {y, dis[y], 0});
```

```
            }
        }
    }
    for(int i = 1; i <= n; i++) cnt[i] = k;
    cnt[s]++;
    q.push((node) {s, 0, dis[s]});
    while(q.size()) {
        int x = q.top().x, f = q.top().f, g = q.top().g;
        q.pop();
        if(cnt[x] == 0) continue;
        cnt[x]--;
        if(x == t && cnt[x] == 0) {
            printf("%lld\n", f);
            return 0;
        }
        for(int i = 0; i < E[x].size(); i++) {
            int y = E[x][i].y, w = E[x][i].w;
            q.push((node) {y, f + w, dis[y]});
        }
    }
    printf("-1\n");
    return 0;
}
```

二分图匹配

结论

最大匹配数：最大匹配的匹配边的数目

最小点/边覆盖数：选取最少的点/边，使任意一条边至少有一个点被选择 / 点至少连有一条边。

最大独立数：选取最多的点，使任意所选两点均不相连

最小路径覆盖数：对于一个 DAG（有向无环图），选取最少条路径，使得每个顶点属于且仅属于一条路径。路径长可以为 0（即单个点）。

1. 最大匹配数 = 最小点覆盖数（这是 Konig 定理）
2. 最大匹配数 = 最大独立数
3. 最小路径覆盖数 = 顶点数 - 最大匹配数
4. 原图的最大团 = 补图的最大独立集原图的最大独立集 = 补图的最大团
5. 最小边覆盖 = 顶点数 - 最大匹配数

在一般图中：

最小不相交路径覆盖：每个点拆点为 $2x-1, 2x$，那么一条边 (x, y)，则连边 $(2x-1, 2y)$，答案是 $n - maxmatch$

最小可相交路径覆盖：跑一遍传递闭包，按传递闭包上的边建边之后转化为最小不相交路径覆盖。

二分图最大匹配的必须边：

在完备匹配中：

匹配边从左到右方向，非匹配边从右到左方向，则一条边为必须边当且仅当边在最大匹配中，并且边所连的两个点**不在**同一个强连通分量中。

在非完备匹配中：

匈牙利算法

```
int dfs(int x) {
    for(int i = head[x]; i; i = nxt[i]) {
        int y = ver[i];
        if(vis[y]) continue;
        vis[y] = 1;
        if(!match[y] || dfs(match[y])) {
            match[y] = x;
            return true;
        }
    }
    return false;
```

```
}
for(int i = 1; i <= n; i++) {
    memset(vis, 0, sizeof(vis));
    if(dfs(i)) ans++;
}
```

KM 算法二分图最大权匹配

KM 算法只支持二分图最大权完美匹配，若图不一定存在完美匹配，注意补 0 边和补点。

KM 算法引入了顶标的概念，用 $la[x]$ 和 $lb[x]$ 分别保存两侧点的顶标，顶标必须满足大于所有边。
每次对每个点进行循环匹配，匹配中统计一个 $delta$ 表示最小的权值使得一条边可以加入。
然后修改顶标再继续匹配。

```
int la[N], lb[N], va[N], vb[N], delta, match[N], g[N][N], n;
int dfs(int x) {
    va[x] = 1;
    for(int y = 1; y <= n; y++) {
        if(!vb[y]) {
            if(la[x] + lb[y] - g[x][y] == 0) {
                vb[y] = 1;
                if(!match[y] || dfs(match[y])) {
                    match[y] = x;
                    return true;
                }
            } else delta = min(delta, la[x] + lb[y] - g[x][y]);
        }
    }
    return false;
}
void work() {
    for(int i = 1; i <= n; i++)
        for(int j = 1; j <= n; j++)
            g[i][j] = read();
    memset(match, 0, sizeof(match));
    for(int i = 1; i <= n; i++) {
        la[i] = g[i][1];
        lb[i] = 0;
        for(int j = 2; j <= n; j++)
            la[i] = max(la[i], g[i][j]);
    }
    for(int i = 1; i <= n; i++) {
        while(true) {
            memset(va, 0, sizeof(va));
            memset(vb, 0, sizeof(vb));
            delta = 0x3f3f3f3f;
            if(dfs(i)) break;
            for(int j = 1; j <= n; j++) {
                if(va[j]) la[j] -= delta;
                if(vb[j]) lb[j] += delta;
            }
        }
    }
    long long ans = 0;
    for(int i = 1; i <= n; i++)
        ans += g[match[i]][i];
    printf("%lld\n", ans);
}
```

网络流

Dinic 算法

```
const int inf = 0x3f3f3f3f;
int bfs() {
    memset(d, 0, sizeof(int) * (t + 10)); d[s] = 1;
    while(q.size()) q.pop(); q.push(s);
    while(q.size()) {
        int x = q.front(); q.pop();
        for(int i = head[x]; i; i = nxt[i]) {
```

```cpp
            if(d[ver[i]]) continue;
            if(edge[i] <= 0) continue;
            d[ver[i]] = d[x] + 1;
            q.push(ver[i]);
        }
    }
    return d[t];
}
int dinic(int x, int flow) {
    if(x == t) return flow;
    int k, res = flow;
    for(int i = head[x]; i && res; i = nxt[i]) {
        if(d[ver[i]] != d[x] + 1 || edge[i] <= 0) continue;
        k = dinic(ver[i], min(res, edge[i]));
        if(k == 0) d[ver[i]] = 0;
        edge[i] -= k;
        edge[i ^ 1] += k;
        res -= k;
    }
    return flow - res;
}
```

EK 算法费用流

```cpp
//反向边 cost 为负数，容量为 0
int SPFA() {
    queue<int> q; q.push(s);
    memset(dis, 0x3f, sizeof(dis)); dis[s] = 0;
    memset(vis, 0, sizeof(vis)); vis[s] = 1;
    q.push(s); flow[s] = 0x3f3f3f3f;
    while(q.size()) {
        int x = q.front();
        vis[x] = 0; q.pop();
        for(int i = head[x]; i; i = nxt[i]) {
            if(edge[i] <= 0) continue;
            if(dis[ver[i]] > dis[x] + cost[i]) {
                dis[ver[i]] = dis[x] + cost[i];
                pre[ver[i]] = i;
                flow[ver[i]] = min(flow[x], edge[i]);
                if(!vis[ver[i]]) {
                    q.push(ver[i]);
                    vis[ver[i]] = 1;
                }
            }
        }
    }
    return dis[t] != 0x3f3f3f3f;
}
void update() {
    int x = t;
    while(x != s) {
        int i = pre[x];
        edge[i] -= flow[t];
        edge[i ^ 1] += flow[t];
        x = ver[i ^ 1];
    }
    maxflow += flow[t];
    minncost += dis[t] * flow[t];
}
```

Dinic 算法费用流

```cpp
int SPFA() {
    while(q.size()) q.pop(); q.push(s);
    memset(d, 0x3f, sizeof(int) * (n + 10)); d[s] = 0;
    memset(vis, 0, sizeof(int) * (n + 10)); vis[s] = 1;
    while(q.size()) {
        int x = q.front(); q.pop();
        vis[x] = 0;
        for(int i = head[x]; i; i = nxt[i]) {
```

```
            if(edge[i] <= 0) continue;
            if(d[ver[i]] > d[x] + cost[i]) {
                d[ver[i]] = d[x] + cost[i];
                if(!vis[ver[i]]) {
                    vis[ver[i]] = 1;
                    q.push(ver[i]);
                }
            }
        }
    }
    return d[t] != 0x3f3f3f3f;
}
int dinic(int x, int flow) {
    if(x == t) return flow;
    vis[x] = 1;
    int k, res = flow;
    for(int i = head[x]; i && res; i = nxt[i]) {
        if(vis[ver[i]]) continue;
        if(d[ver[i]] != d[x] + cost[i] || edge[i] <= 0) continue;
        k = dinic(ver[i], min(edge[i], res));
        if(!k) d[ver[i]] = -1;
        edge[i] -= k;
        edge[i ^ 1] += k;
        res -= k;
        mincost += cost[i] * k;
    }
    vis[x] = 0;
    return flow - res;
}
```

连通性算法

Tarjan 强连通分量

$dfn[x]$：dfs 序。

$low[x]$：追溯值，指 x 的子树内部，通过一条非树边能到达的最小的 dfn 值。

如果 $dfn[x] == low[x]$，当前栈中，x 以后的元素为一个强连通。

```
void tarjan(int x) {
    low[x] = dfn[x] = ++dfncnt;
    s[++t] = x; vis[x] = 1;
    for(int i = head[x]; i; i = nxt[i]) {
        if(!dfn[ver[i]]) {
            tarjan(ver[i]);
            low[x] = min(low[x], low[ver[i]]);
        } else if(vis[ver[i]]) {
            low[x] = min(low[x], dfn[ver[i]]);
        }
    }
    if(dfn[x] == low[x]) {
        int z = -1;
        ++sc;
        while(z != x) {
            scc[s[t]] = sc;
            siz[sc]++;
            vis[s[t]] = 0;
            z = s[t];
            t--;
        }
    }
}
//从任意点开始跑，但是注意如果图不连通，需要每个点跑一次
for(int i = 1; i <= n; i++)
    if(!dfn[i])
        tarjan(i);
```

点双连通

Tarjan 割点判定

```cpp
int cut[N];
namespace v_dcc {
    int root, low[N], dfn[N], dfntot;
    void tarjan(int x) {
        low[x] = dfn[x] = ++dfntot;
        int flag = 0;
        for(int i = head[x]; i; i = nxt[i]) {
            int y = ver[i];
            if(!dfn[y]) {
                tarjan(y);
                low[x] = min(low[x], low[y]);
                if(low[y] >= dfn[x]) {
                    flag++;
                    if(x != root || flag > 1) cut[x] = 1;

                }
            } else low[x] = min(low[x], dfn[y]);
        }
    }
    void getcut() {
        for(int i = 1; i <= n; i++)
            if(!dfn[i])
                tarjan(root = i);
    }
}
```

求点双连通分量

点双连通分量比较复杂，一个点可能存在于多个点双连通分量当中，一个点删除与搜索树中的儿子节点断开时，不能在栈中弹掉父亲点，但是父亲点属于儿子的 v-dcc。

```cpp
int cut[N];
vector<int> dcc[N];
namespace v_dcc {
    int s[N], t, root;
    int es[N], et;
    void tarjan(int x) {
        dfn[x] = low[x] = ++dfntot;
        s[++t] = x;
        if(x == root && head[x] == 0) {
            dcc[++dc].clear();
            dcc[dc].push_back(x);
            return ;
        }
        int flag = 0;
        for(int i = head[x]; i; i = nxt[i]) {
            int y = ver[i];
            if(!dfn[y]) {
                tarjan(y);
                low[x] = min(low[x], low[y]);
                if(low[y] >= dfn[x]) {
                    flag++;
                    if(x != root || flag > 1) cut[x] = true;
                    dcc[++dc].clear();
                    int z = -1;
                    while(z != y) {
                        z = s[t--];
                        dcc[dc].push_back(z);
                    }
                    dcc[dc].push_back(x);
                }
            } else low[x] = min(low[x], dfn[y]);
        }
    }
    void get_cut() {
        for(int i = 1; i <= n; i++)
            if(!dfn[i])
```

```
            tarjan(root = i);
    }
}
```

边双连通

搜索树上的点 x，若它的一个儿子 y，满足严格大于号 $low[y] > dfn[x]$，那么这条边就是桥。

注意由于会有重边，不能仅仅考虑他的父亲编号，而应该记录入边编号。

```
namespace e_dcc {
    int low[N], dfn[N], dfntot;
    vector<int> E[N];
    void tarjan(int x, int in_edge) {
        low[x] = dfn[x] = ++dfntot;
        for(int i = head[x]; i; i = nxt[i]) {
            int y = ver[i];
            if(!dfn[y]) {
                tarjan(y, i);
                low[x] = min(low[x], low[y]);
                if(low[y] > dfn[x])
                    bridge[i] = bridge[i ^ 1] = true;
            } else if(i != (in_edge ^ 1))
            //注意运算优先级
                low[x] = min(low[x], dfn[y]);
        }
    }
    void getbridge() {
        for(int i = 1; i <= n; i++)
            if(!dfn[i])
                tarjan(i, 0);
    }
    void dfs(int x) {
        dcc[x] = dc;
        for(int i = head[x]; i; i = nxt[i]) {
            if(!dcc[ver[i]] && !bridge[i]) {
                dfs(ver[i]);
            }
        }
    }
    void getdcc() {
        for(int i = 1; i <= n; i++) {
            if(!dcc[i]) {
                ++dc;
                dfs(i);
            }
        }
    }
    void getgraphic() {
        for(int x = 1; x <= n; x++) {
            for(int i = head[x]; i; i = nxt[i]) {
                if(dcc[ver[i]] != dcc[x]) {
                    E[dcc[x]].push_back(dcc[ver[i]]);
                    E[dcc[ver[i]]].push_back(dcc[x]);
                }
            }
        }
    }
}
```

2-SAT

2-SAT 用于解决每个变量的 01 取值问题，用于判断是否存在一种不冲突取值方法。

建边方法：假如选了 A 之后，B 的取值**确定**，那么就 A 的这个取值向 B 的这个取值建边，否则不要建边。

判定方法：如果，$\exists A$, 使得 A 和 $\neg A$ 在同一个强连通分量里面，说明不存在一种合法取值，否则存在。

输出方案：自底向上确定每个变量的取值, 由于 tarjan 求解强连通分量是自底向上，所以编号比较小的强连通是位于 DAG 底部的。

基于 tarjan 的方案输出就变得十分简单了，只要判断一个点和对立节点哪个 scc 的编号小就行了。

例如：$A->B->C$，那么 C 的编号最小。

```
for(int i = 1; i <= m; i++) {
    int x = read() + 1, y = read() + 1;
    int w = read();
    char c[10];
    scanf("%s", c + 1);
    if(c[1] == 'A') {
        if(w) {
            add(2 * x - 0, 2 * x - 1);
            add(2 * y - 0, 2 * y - 1);
        } else {
            add(2 * x - 1, 2 * y - 0);
            add(2 * y - 1, 2 * x - 0);
        }
    }
    if(c[1] == 'O') {
        if(w) {
            add(2 * x - 0, 2 * y - 1);
            add(2 * y - 0, 2 * x - 1);
        } else {
            add(2 * x - 1, 2 * x - 0);
            add(2 * y - 1, 2 * y - 0);
        }
    }
    if(c[1] == 'X') {
        if(w) {
            add(2 * x - 0, 2 * y - 1);
            add(2 * x - 1, 2 * y - 0);
            add(2 * y - 0, 2 * x - 1);
            add(2 * y - 1, 2 * x - 0);
        } else {
            add(2 * x - 0, 2 * y - 0);
            add(2 * x - 1, 2 * y - 1);
            add(2 * y - 0, 2 * x - 0);
            add(2 * y - 1, 2 * x - 1);
        }
    }
}
for(int i = 1; i <= 2 * n; i++)
    if(!dfn[i])
        tarjan(i);
for(int i = 1; i <= n; i++) {
    if(scc[2 * i - 0] == scc[2 * i - 1]) {
        printf("NO\n");
        return 0;
    }
}
printf("YES\n");
//2 * x - a -> 2 * y - b 的边表示，假如 x 取值为 a，那么 y 的取值必须为 b

//输出方案
for(int i = 2; i <= 2 * n; i += 2) {
    if(scc[i - 0] == scc[i - 1]) {
        printf("NO\n");
        return 0;
    } else ans[(i + 1) / 2] = scc[i - 1] < scc[i - 0];
}
```

计算几何

字符串

字串哈希

```
namespace String {
    const int x = 135;
    const int p1 = 1e9 + 7, p2 = 1e9 + 9;
    ull xp1[N], xp2[N], xp[N];
```

```cpp
    void init_xp() {
        xp1[0] = xp2[0] = xp[0] = 1;
        for(int i = 1; i < N; i++) {
            xp1[i] = xp1[i - 1] * x % p1;
            xp2[i] = xp2[i - 1] * x % p2;
            xp[i] = xp[i - 1] * x;
        }
    }
    struct HashString {
        char s[N];
        int length, subsize;
        bool sorted;
        ull h[N], hl[N];
        ull init(const char *t) {
            if(xp[0] != 1) init_xp();
            length = strlen(t);
            strcpy(s, t);
            ull res1 = 0, res2 = 0;
            h[length] = 0;
            for(int j = length - 1; j >= 0; j--) {
            #ifdef ENABLE_DOUBLE_HASH
                res1 = (res1 * x + s[j]) % p1;
                res2 = (res2 * x + s[j]) % p2;
                h[j] = (res1 << 32) | res2;
            #else
                res1 = res1 * x + s[j];
                h[j] = res1;
            #endif
            }
            return h[0];
        }
        //获取子串哈希，左闭右开
        ull get_substring_hash(int left, int right)  {
            int len = right - left;
        #ifdef ENABLE_DOUBLE_HASH
            unsigned int mask32 = ~(0u);
            ull left1 = h[left] >> 32, right1 = h[right] >> 32;
            ull left2 = h[left] & mask32, right2 = h[right] & mask32;
            return (((left1 - right1 * xp1[len] % p1 + p1) % p1) << 32) |
                   (((left2 - right2 * xp2[len] % p2 + p2) % p2));
        #else
            return h[left] - h[right] * xp[len];
        #endif
        }
        void get_all_subs_hash(int sublen) {
            subsize = length - sublen + 1;
            for (int i = 0; i < subsize; ++i)
                hl[i] = get_substring_hash(i, i + sublen);
            sorted = 0;
        }

        void sort_substring_hash() {
            sort(hl, hl + subsize);
            sorted = 1;
        }

        bool match(ull key) const {
            if (!sorted) assert (0);
            if (!subsize) return false;
            return binary_search(hl, hl + subsize, key);
        }
    };
}
```

Trie

```cpp
namespace trie {
    int t[N][26], sz, ed[N];
    int _new() {
        sz++;
        memset(t[sz], 0, sizeof(t[sz]));
```

```
        return sz;
    }
    void init() {
        sz = 0;
        _new();
        memset(ed, 0, sizeof(ed));
    }
    void Insert(char *s, int n) {
        int u = 1;
        for(int i = 0; i < n; i++) {
            int c = s[i] - 'a';
            if(!t[u][c]) t[u][c] = _new();
            u = t[u][c];
        }
        ed[u]++;
    }
    int find(char *s, int n) {
        int u = 1;
        for(int i = 0; i < n; i++) {
            int c = s[i] - 'a';
            if(!t[u][c]) return -1;
            u = t[u][c];
        }
        return u;
    }
}
```

KMP 算法

```
namespace KMP {
    void get_next(char *t, int m, int *nxt) {
        int j = nxt[0] = 0;
        for(int i = 1; i < m; i++) {
            while(j && t[i] != t[j]) j = nxt[j - 1];
            nxt[i] = j += (t[i] == t[j]);
        }
    }
    vector<int> find(char *t, int m, int *nxt, char *s, int n) {
        vector<int> ans;
        int j = 0;
        for(int i = 0; i < n; i++) {
            while(j && s[i] != t[j]) j = nxt[j - 1];
            j += s[i] == t[j];
            if(j == m) {
                ans.push_back(i - m + 1);
                j = nxt[j - 1];
            }
        }
        return ans;
    }
}
```

manacher 算法

```
namespace manacher {
    char s[N];
    int p[N], len;
    void getp(string tmp) {
        len = 0;
        for(auto x : tmp) {
            s[len++] = '#';
            s[len++] = x;
        }
        s[len++] = '#';
        memset(p, 0, sizeof(int) * (len + 10));
        int c = 0, r = 0;
        for(int i = 0; i < len; i++) {
            if(i <= r) p[i] = min(p[2 * c - i], r - i);
            else p[i] = 1;
            while(i - p[i] >= 0 && i + p[i] < len && s[i - p[i]] == s[i + p[i]])
```

```
                p[i]++;
            if(i + p[i] - 1 > r) {
                r = i + p[i] - 1;
                c = i;
            }
        }
        for(int i = 0; i < len; i++) p[i]--;
    }
    void getp(char *tmp, int n) {
        len = 0;
        for(int i = 0; i < n; i++) {
            s[len++] = '#';
            s[len++] = tmp[i];
        }
        s[len++] = '#';
        memset(p, 0, sizeof(int) * (len + 10));
        int c = 0, r = 0;
        for(int i = 0; i < len; i++) {
            if(i <= r) p[i] = min(p[2 * c - i], r - i);
            else p[i] = 1;
            while(i - p[i] >= 0 && i + p[i] < len && s[i - p[i]] == s[i + p[i]])
                p[i]++;
            if(i + p[i] - 1 > r) {
                r = i + p[i] - 1;
                c = i;
            }
        }
        for(int i = 0; i < len; i++) p[i]--;
    }
    int getlen() {
        return *max_element(p, p + len);
    }
    int getlen(string s) {
        getp(s);
        return getlen();
    }
}
```

AC 自动机

```
struct ac_automaton {
    int t[N][26], danger[N], tot, fail[N];
    int dp[N][N];
    void init() {
        tot = -1;
        _new();
    }
    int _new() {
        tot++;
        memset(t[tot], 0, sizeof(t[tot]));
        danger[tot] = 0;
        fail[tot] = 0;
        return tot;
    }
    void Insert(const char *s) {
        int u = 0;
        for(int i = 0; s[i]; i++) {
            if(!t[u][mp[s[i]]]) t[u][s[i] - 'a'] = _new();
            u = t[u][mp[s[i]]];
        }
        danger[u] = 1;
    }
    void build() {
        queue<int> q;
        for(int i = 0; i < 26; i++) {
            if(t[0][i]) {
                fail[i] = 0;
                q.push(t[0][i]);
            }
        }
        while(q.size()) {
```

```
            int u = q.front(); q.pop();
            danger[u] |= danger[fail[u]];
            for(int i = 0; i < 26; i++) {
                if(t[u][i]) {
                    fail[t[u][i]] = t[fail[u]][i];
                    q.push(t[u][i]);
                } else t[u][i] = t[fail[u]][i];
            }
        }
    }
    int query(const char *s) {
        memset(dp, 0x3f, sizeof(dp));
        int n = strlen(s);
        dp[0][0] = 0;
        for(int i = 0; i < n; i++) {
            for(int j = 0; j <= tot; j++) if(!danger[j]) {
                for(int k = 0; k < 26; k++) if(!danger[t[j][k]]) {
                    dp[i + 1][t[j][k]] = min(dp[i + 1][t[j][k]], dp[i][j] + (s[i] - 'a' != k));
                }
            }
        }
        int ans = 0x3f3f3f3f;
        for(int i = 0; i <= tot; i++) if(!danger[i]) {
            ans = min(ans, dp[n][i]);
        }
        return ans == 0x3f3f3f3f ? -1 : ans;
    }
};
```

杂项

int128

```
typedef __uint128_t u128;
inline u128 read() {
    static char buf[100];
    scanf("%s", buf);
    // std::cin >> buf;
    u128 res = 0;
    for(int i = 0;buf[i];++i) {
        res = res << 4 | (buf[i] <= '9' ? buf[i] - '0' : buf[i] - 'a' + 10);
    }
    return res;
}
inline void output(u128 res) {
    if(res >= 16)
        output(res / 16);
    putchar(res % 16 >= 10 ? 'a' + res % 16 - 10 : '0' + res % 16);
    //std::cout.put(res % 16 >= 10 ? 'a' + res % 16 - 10 : '0' + res % 16);
}
```

奇技淫巧

**_builtin_ 内建函数 **

- __builtin_popcount(unsigned int n) 该函数是判断 n 的二进制中有多少个 1
- __builtin_parity(unsigned int n) 该函数是判断 n 的二进制中 1 的个数的奇偶性
- __builtin_ffs(unsigned int n) 该函数判断 n 的二进制末尾最后一个 1 的位置，从一开始
- __builtin_ctz(unsigned int n) 该函数判断 n 的二进制末尾后面 0 的个数，当 n 为 0 时，和 n 的类型有关
- __builtin_clz (unsigned int x) 返回前导的 0 的个数

随机数种子

```
srand(std :: chrono :: system_clock :: now().time_since_epoch().count());
```

T(5) 求任意 int log2

```
inline int LOG2_1(unsigned x){
    static const int tb[32]={0,9,1,10,13,21,2,29,11,14,16,18,22,25,3,30,8,12,20,28,15,17,24,7,19,27,23,6,26,5,4,31};
    x|=x>>1; x|=x>>2; x|=x>>4; x|=x>>8; x|=x>>16;
    return tb[x*0x07C4ACDDu>>27];
}
```

O(1) 求 2 的整幂次 log2

```
inline int LOG2(unsigned x){  //x=2^k
    static const int tb[32]={31,0,27,1,28,18,23,2,29,21,19,12,24,9,14,3,30,26,17,22,20,11,8,13,25,16,10,7,15,6,5,4};
    return tb[x*263572066>>27];
}
```

开启编译优化

```
#pragma GCC optimize(3)
#pragma GCC optimize("inline")
#pragma GCC optimize("-fgcse")
#pragma GCC target("avx","sse2")
#pragma GCC optimize("-fgcse-lm")
#pragma GCC optimize("-fipa-sra")
#pragma GCC optimize("-ftree-pre")
#pragma GCC optimize("-ftree-vrp")
#pragma GCC optimize("-fpeephole2")
#pragma GCC optimize("-ffast-math")
#pragma GCC optimize("-fsched-spec")
#pragma GCC optimize("unroll-loops")
```

快速乘

```
ll mul(ll x, ll y, ll mod){
    return (x * y - (ll)((long double)x / mod * y) * mod + mod) % mod;
}
ll mul(ll a, ll b, ll MOD) {
    __int128 x = a, y = b, m = MOD;
    return (ll)(x * y % m);
}
```

tips:

- 如果使用 sort 比较两个函数，不能出现 $a < b$ 和 $a > b$ 同时为真的情况，否则会运行错误。
- 多组数据清空线段树的时候，不要忘记清空全部数组（比如说 lazytag 数组）。
- 注意树的深度和节点到根的距离是两个不同的东西，深度是点数，距离是边长，如果求 LCA 时用距离算会出错。
- 连通性专题：注意判断 $dfn[x]$ 和 $low[y]$ 的关系时是否不小心两个都达成 low 了