

# Standard Code Library

ONGLU

North Eastern University

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## 初始化

## 数据结构

### ST 表

```
1 int query(int l, int r) {
2     int p = log2(r - l + 1);
3     return max(st[p][l], st[p][r - (1 << p) + 1]);
4 }
5 void init() {
6     for(int i = 2; i <= n; i++) LOG2[i] = LOG2[i / 2] + 1;
7     for(int i = 1; i <= n; i++) st[0][i] = h[i];
8     for(int i = 1; i < 25; i++) {
9         for(int j = 1; j + (1 << i - 1) <= n; j++) {
10             st[i][j] = max(st[i - 1][j], st[i - 1][j + (1 << i - 1)]);
11         }
12     }
13 }
```

### 二维哈希

```
1 ull hs[109][109], pw1[10009], pw2[100009];
2 ull gethash(int lx, int ly, int rx, int ry) {
3     ull hs1 = hs[lx][ly] - pw2[ry - ly + 1] * hs[lx][ry + 1];
4     ull hs2 = hs[rx + 1][ly] - pw2[ry - ly + 1] * hs[rx + 1][ry + 1];
5     return hs1 - pw1[rx - lx + 1] * hs2;
6 }
7 pw1[0] = pw2[0] = 1;
8 for(int i = 1; i <= 1000; i++) pw1[i] = pw1[i - 1] * 19260817;
9 for(int i = 1; i <= 1000; i++) pw2[i] = pw2[i - 1] * 135;
10 for(int i = n; i >= 1; i--) {
11     for(int j = 1; j <= m; j++) {
12         if(i == n) hs[i][j] = sum[i][j] + 2;
13         else hs[i][j] = hs[i + 1][j] * 19260817 + sum[i][j] + 2;
14     }
15 }
16 for(int i = 1; i <= n; i++) {
17     for(int j = m - 1; j; j--) {
18         hs[i][j] = hs[i][j + 1] * 135 + hs[i][j];
19     }
20 }
```

### 轻重链剖分

```
1 void dfs1(int x, int pre) {
2     siz[x] = 1; mson[x] = 0;
3     dth[x] = dth[pre] + 1;
4     fa[x] = pre;
5     for(auto y : son[x]) if(y != pre) {
6         dfs1(y, x);
7         siz[x] += siz[y];
8         if(!mson[x] || siz[y] > siz[mson[x]])
9             mson[x] = y;
10    }
11 }
12 void dfs2(int x, int pre, int ntp) {
13     id[x] = ++idcnt;
14     ltp[x] = ntp;
15     if(mson[x]) dfs2(mson[x], x, ntp);
16     for(auto y : son[x]) {
17         if(y == mson[x] || y == pre) continue;
18         dfs2(y, x, y);
19     }
20 }
21 void link_modify(int x, int y, int z) {
22     z %= mod;
23     while(ltp[x] != ltp[y]) {
24         dth[ltp[x]] < dth[ltp[y]] && (x ^= y ^= x ^= y);
25     }
```

```

25     modify(1, n, id[ltp[x]], id[x], 1, z);
26     x = fa[ltp[x]];
27
28 }
29 dth[x] < dth[y] && (x ^ y ^ x ^ y);
30 modify(1, n, id[y], id[x], 1, z);
31 }
32 int link_query(int x, int y) {
33     int ans = 0;
34     while(ltp[x] != ltp[y]) {
35         dth[ltp[x]] < dth[ltp[y]] && (x ^ y ^ x ^ y);
36         ans = (1ll * ans + query(1, n, id[ltp[x]], id[x], 1)) % mod;
37         x = fa[ltp[x]];
38     }
39     dth[x] < dth[y] && (x ^ y ^ x ^ y);
40     ans = (1ll * ans + query(1, n, id[y], id[x], 1)) % mod;
41     return ans;
42 }

```

## 线段树合并

搞个动态开点线段树出来

```

1  #define mval(x) tree[x].mval
2  #define mpos(x) tree[x].mpos
3  #define lson(x) tree[x].lson
4  #define rson(x) tree[x].rson
5  struct node {
6      int mpos, mval, lson, rson;
7  } tree[N * 50];
8  void update(int rt) {
9      if(mval(lson(rt)) >= mval(rson(rt))) {
10         mval(rt) = mval(lson(rt));
11         mpos(rt) = mpos(lson(rt));
12     } else {
13         mval(rt) = mval(rson(rt));
14         mpos(rt) = mpos(rson(rt));
15     }
16 }
17
18 void modify(int l, int r, int x, int v, int &rt) {
19     if(!rt) rt = ++idtot;
20     if(l == r) {
21         mval(rt) += v;
22         mpos(rt) = l;
23         return ;
24     }
25     if(x <= Mid) modify(l, Mid, x, v, lson(rt));
26     else modify(Mid + 1, r, x, v, rson(rt));
27     update(rt);
28 }
29 int merge(int l, int r, int rt1, int rt2) {
30     if(!rt1 || !rt2) return rt1 + rt2;
31     if(l == r) {
32         mval(rt1) += mval(rt2);
33         mpos(rt1) = l;
34         return rt1;
35     }
36     lson(rt1) = merge(l, Mid, lson(rt1), lson(rt2));
37     rson(rt1) = merge(Mid + 1, r, rson(rt1), rson(rt2));
38     update(rt1);
39     return rt1;
40 }

```

## 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  $d[i][j] = a[i][j] - (a[i-1][j] - a[i][j-1] - a[i-1][j])$

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

```

1 void modify(int x, int y, int v) {
2     for(int rx = x; rx <= n; rx += rx & -rx) {
3         for(int ry = y; ry <= m; ry += ry & -ry) {
4             tree[rx][ry][0] += v;
5             tree[rx][ry][1] += v * x;
6             tree[rx][ry][2] += v * y;
7             tree[rx][ry][3] += v * x * y;
8         }
9     }
10 }
11 void range_modify(int x, int y, int xx, int yy, int v) {
12     modify(xx + 1, yy + 1, v);
13     modify(x, yy + 1, -v);
14     modify(xx + 1, y, -v);
15     modify(x, y, v);
16 }
17 int query(int x, int y) {
18     int ans = 0;
19     for(int rx = x; rx; rx -= rx & -rx) {
20         for(int ry = y; ry; ry -= ry & -ry) {
21             ans += (x + 1) * (y + 1) * tree[rx][ry][0]
22                 - tree[rx][ry][1] * (y + 1) - tree[rx][ry][2] * (x + 1)
23                 + tree[rx][ry][3];
24         }
25     }
26     return ans;
27 }
28 int range_query(int x, int y, int xx, int yy) {
29     return query(xx, yy) + query(x - 1, y - 1)
30         - query(x - 1, yy) - query(xx, y - 1);
31 }

```

## 平衡树

- luogu P3369 【模板】普通平衡树

```

1 #define val(x) tree[x].val
2 #define cnt(x) tree[x].cnt
3 #define siz(x) tree[x].siz
4 #define fa(x) tree[x].fa
5 #define son(x, k) tree[x].ch[k]
6 struct Tree {
7     struct node {
8         int val, cnt, siz, fa, ch[2];
9     } tree[N];
10     int root, tot;
11     int chk(int x) {
12         return son(fa(x), 1) == x;
13     }
14     void update(int x) {
15         siz(x) = siz(son(x, 0)) + siz(son(x, 1)) + cnt(x);
16     }
17     void rotate(int x) {
18         int y = fa(x), z = fa(y), k = chk(x), w = son(x, k ^ 1);
19         son(y, k) = w; fa(w) = y;
20         son(z, chk(y)) = x; fa(x) = z;
21         son(x, k ^ 1) = y; fa(y) = x;
22         update(y); update(x);
23     }
24     void splay(int x, int goal = 0) {
25         while(fa(x) != goal) {
26             int y = fa(x), z = fa(y);
27             if(z != goal) {
28                 //双旋
29                 if(chk(y) == chk(x)) rotate(y);
30                 else rotate(x);

```

```

31         }
32         rotate(x);
33     }
34     if(!goal) root = x;
35 }
36 int New(int x, int pre) {
37     tot++;
38     if(pre) son(pre, x > val(pre)) = tot;
39     val(tot) = x; fa(tot) = pre;
40     siz(tot) = cnt(tot) = 1;
41     son(tot, 0) = son(tot, 1) = 0;
42     return tot;
43 }
44 void Insert(int x) {
45     int cur = root, p = 0;
46     while(cur && val(cur) != x) {
47         p = cur;
48         cur = son(cur, x > val(cur));
49     }
50     if(cur) cnt(cur)++;
51     else cur = New(x, p);
52     splay(cur);
53 }
54 void Find(int x) {
55     if(!root) return ;
56     int cur = root;
57     while(val(cur) != x && son(cur, x > val(cur)))
58         cur = son(cur, x > val(cur));
59     splay(cur);
60 }
61 int Pre(int x) {
62     Find(x);
63     if(val(root) < x) return root;
64     int cur = son(root, 0);
65     while(son(cur, 1))
66         cur = son(cur, 1);
67     return cur;
68 }
69 int Succ(int x) {
70     Find(x);
71     if(val(root) > x) return root;
72     int cur = son(root, 1);
73     while(son(cur, 0))
74         cur = son(cur, 0);
75     return cur;
76 }
77 void Del(int x) {
78     int lst = Pre(x), nxt = Succ(x);
79     splay(lst); splay(nxt, lst);
80     int cur = son(nxt, 0);
81     if(cnt(cur) > 1) cnt(cur)--, splay(cur);
82     else son(nxt, 0) = 0, splay(nxt);
83 }
84 int Kth(int k) {
85     int cur = root;
86     while(1) {
87         if(son(cur, 0) && siz(son(cur, 0)) >= k) cur = son(cur, 0);
88         else if(siz(son(cur, 0)) + cnt(cur) >= k) return cur;
89         else k -= siz(son(cur, 0)) + cnt(cur), cur = son(cur, 1);
90     }
91 }
92 } T;

```

## K-D Tree

用方差最大的那一维坐标作为当前的划分点集，然后选取该维度的中位数点划分成左右两个点集。

```

1  #include <bits/stdc++.h>
2  #define pt(x) cout << x << endl;
3  #define Mid ((l + r) / 2)
4  #define low(x, k) tree[x].low[k]

```

```

5  #define high(x, k) tree[x].high[k]
6  #define lson(x) tree[x].lson
7  #define rson(x) tree[x].rson
8  using namespace std;
9  int read() {
10     char c; int num, f = 1;
11     while(c = getchar(), !isdigit(c)) if(c == '-') f = -1; num = c - '0';
12     while(c = getchar(), isdigit(c)) num = num * 10 + c - '0';
13     return f * num;
14 }
15 const int N = 5e5 + 1009;
16
17 namespace KD_Tree{
18
19     const int dimension = 2;
20     struct node {
21         int lson, rson;
22         int low[dimension], high[dimension];
23     } tree[N];
24     struct Point {
25         int id;
26         int v[dimension];
27     } p[N];
28     void update(int rt) {
29         for(int i = 0; i < dimension; i++) {
30             low[rt, i] = high[rt, i] = p[rt].v[i];
31             if(lson(rt)) {
32                 low[rt, i] = min(low[rt, i], low[lson(rt), i]);
33                 high[rt, i] = max(high[rt, i], high[lson(rt), i]);
34             }
35             if(rson(rt)) {
36                 low[rt, i] = min(low[rt, i], low[rson(rt), i]);
37                 high[rt, i] = max(high[rt, i], high[rson(rt), i]);
38             }
39         }
40     }
41
42     int build(int l, int r) {
43         if(l > r) return 0;
44         double av[dimension] = {0};
45         double va[dimension] = {0};
46         for(int i = 0; i < dimension; i++)
47             low[Mid, i] = high[Mid, i] = p[Mid].v[i];
48         for(int i = l; i <= r; i++)
49             for(int j = 0; j < dimension; j++)
50                 av[j] += p[i].v[j];
51         for(int i = 0; i < dimension; i++)
52             av[i] /= (double) (r - l + 1);
53         for(int i = l; i <= r; i++)
54             for(int j = 0; j < dimension; j++)
55                 va[j] += (p[i].v[j] - av[j]) * (p[i].v[j] - av[j]);
56         int maxdi = 0;
57         for(int i = 1; i < dimension; i++)
58             if(va[i] > va[maxdi])
59                 maxdi = i;
60         nth_element(p + l, p + Mid, p + 1 + r, [maxdi](const Point &a, const Point &b) -> int{return a.v[maxdi] <
↪ b.v[maxdi]});
61         lson(Mid) = build(l, Mid - 1);
62         rson(Mid) = build(Mid + 1, r);
63         update(Mid);
64         return Mid;
65     }
66     int isIn(const Point &a, const Point &ld, const Point &ru) {
67         for(int i = 0; i < dimension; i++)
68             if(a.v[i] < ld.v[i] || a.v[i] > ru.v[i])
69                 return false;
70         return true;
71     }
72     void debug(int rt, int l, int r) {
73         if(l > r) return ;
74         printf("%d\n", p[rt].id);

```



```

75         debug(lson(rt), l, Mid - 1);
76         debug(rson(rt), Mid + 1, r);
77     }
78 }
79 //只能处理二维
80 void getNodeset(int rt, int l, int r, vector<int> &v, const Point &ld, const Point &ru) {
81     if(l > r) return ;
82     for(int i = 0; i < dimension; i++) {
83         if(low(rt, i) > ru.v[i] || high(rt, i) < ld.v[i]) {
84             return ;
85         }
86     }
87     if(isIn(p[Mid], ld, ru))
88         v.push_back(p[Mid].id);
89     getNodeset(lson(rt), l, Mid - 1, v, ld, ru);
90     getNodeset(rson(rt), Mid + 1, r, v, ld, ru);
91 }
92 }
93 using namespace KD_Tree;
94 int n, q, root;
95 signed main()
96 {
97     n = read();
98     for(int i = 1; i <= n; i++) {
99         p[i].v[0] = read();
100        p[i].v[1] = read();
101        p[i].id = i - 1;
102    }
103    root = build(1, n);
104    q = read();
105    for(int i = 1; i <= q; i++) {
106        int x = read(), xx = read();
107        int y = read(), yy = read();
108        Point ld, ru;
109        ld.v[0] = x; ld.v[1] = y;
110        ru.v[0] = xx; ru.v[1] = yy;
111        vector<int> v;
112        v.clear();
113        getNodeset(root, 1, n, v, ld, ru);
114        sort(v.begin(), v.end());
115        for(auto x : v)
116            printf("%d\n", x);
117        printf("\n");
118    }
119    return 0;
120 }

```

## 可持久化数据结构

### 可持久化 Trie

```

1  namespace Trie {
2      struct node {
3          int ch[2], ed, siz;
4      } tree[N * 40];
5      int tot = 0;
6      int _new() {
7          tot++;
8          tree[tot].ch[0] = 0;
9          tree[tot].ch[1] = 0;
10         tree[tot].ed = tree[tot].siz = 0;
11         return tot;
12     }
13     void init() {
14         tot = 0;
15         rt[0] = _new();
16     }
17     int Insert(int x, int t, int i = 15) {
18         int u = _new(), f = (x >> i) & 1;
19         tree[u] = tree[t];
20         if(i == -1) {

```

```

21         ed(u)++;
22         siz(u)++;
23         return u;
24     }
25     son(u, f) = Insert(x, son(t, f), i - 1);
26     siz(u) = siz(son(u, 0)) + siz(son(u, 1));
27     return u;
28 }
29 void print(int u, int now) {
30     if(u == 0) return;
31     for(int i = 1; i <= ed(u); i++) printf("%d ", now);
32     if(son(u, 0)) print(son(u, 0), now * 2);
33     if(son(u, 1)) print(son(u, 1), now * 2 + 1);
34 }
35 int query(int u1, int u2, int x, int i = 15, int now = 0) {
36     if(i == -1) return now;
37     int f = (x >> i) & 1;
38     if(siz(son(u1, f ^ 1)) - siz(son(u2, f ^ 1)) > 0)
39         return query(son(u1, f ^ 1), son(u2, f ^ 1), x, i - 1, now * 2 + (f ^ 1));
40     else return query(son(u1, f), son(u2, f), x, i - 1, now * 2 + (f));
41 }
42 }

```

### 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。

```

1  #include <iostream>
2  #include <cstdio>
3  #include <algorithm>
4  #include <cmath>
5  #include <assert.h>
6  #define Mid ((l + r) / 2)
7  #define lson (rt << 1)
8  #define rson (rt << 1 | 1)
9  using namespace std;
10 int read() {
11     char c; int num, f = 1;
12     while(c = getchar(), !isdigit(c)) if(c == '-') f = -1; num = c - '0';
13     while(c = getchar(), isdigit(c)) num = num * 10 + c - '0';
14     return f * num;
15 }
16 const int N = 1e7 + 1009;
17 const int M = 2e5 + 1009;
18 struct node {
19     int ls, rs, v;
20 } tree[N];
21 int tb;
22 int n, m, tot, a[M], b[M], rt[M];
23 int _new(int ls, int rs, int v) {
24     tree[++tot].ls = ls;
25     tree[tot].rs = rs;
26     tree[tot].v = v;
27     return tot;
28 }
29 void update(int rt) {
30     tree[rt].v = tree[tree[rt].ls].v + tree[tree[rt].rs].v;
31 }
32 int build(int l, int r) {
33     if(l == r) return _new(0, 0, 0);
34     int x = _new(build(l, Mid), build(Mid + 1, r), 0);
35     update(x);
36     return x;
37 }
38 int add(int l, int r, int p, int rt, int v) {
39     int x = ++tot;
40     tree[x] = tree[rt];
41     if(l == r) {
42         tree[x].v += v;
43         return x;
44     }

```

```

45     if(p <= Mid) tree[x].ls = add(l, Mid, p, tree[x].ls, v);
46     else tree[x].rs = add(Mid + 1, r, p, tree[x].rs, v);
47     update(x);
48     return x;
49 }
50 int query(int l, int r, int rt1, int rt2, int k) {
51     if(l == r) return l;
52     if(k <= tree[tree[rt1].ls].v - tree[tree[rt2].ls].v) return query(l, Mid, tree[rt1].ls, tree[rt2].ls, k);
53     else return query(Mid + 1, r, tree[rt1].rs, tree[rt2].rs, k - (tree[tree[rt1].ls].v - tree[tree[rt2].ls].v));
54 }
55 void Debug(int l, int r, int rt) {
56     printf("%d %d %d\n", l, r, tree[rt].v);
57     if(l == r) return ;
58     Debug(l, Mid, tree[rt].ls);
59     Debug(Mid + 1, r, tree[rt].rs);
60 }
61 signed main()
62 {
63     n = read(); m = read();
64     for(int i = 1; i <= n; i++) a[i] = b[i] = read();
65     sort(b + 1, b + 1 + n);
66     tb = unique(b + 1, b + 1 + n) - b - 1;
67     rt[0] = build(1, tb);
68     for(int i = 1; i <= n; i++) {
69         rt[i] = add(1, tb, lower_bound(b + 1, b + 1 + tb, a[i]) - b, rt[i - 1], 1);
70     }
71     for(int i = 1; i <= m; i++) {
72         int l, r, k;
73         l = read(); r = read(); k = read();
74         assert(r - l + 1 >= k);
75         printf("%d\n", b[query(1, tb, rt[r], rt[l - 1], k)]);
76     }
77     return 0;
78 }

```

## 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, 双指针, 满足当前统计出的第二维都有序

```

1  const int N = 1e6 + 1009;
2  struct node{
3      int x, y, z, id, cnt;
4  }a[N], tmp[N];
5  bool operator ==(const node &a, const node &b) {
6      return a.x == b.x && a.y == b.y && a.z == b.z;
7  }
8  int n, m, tot, ans[N], tt[N], tree[N];
9  int ttt[N];
10 bool cmp(node a, node b) {
11     if(a.x == b.x && a.y == b.y) return a.z < b.z;
12     if(a.x == b.x) return a.y < b.y;
13     return a.x < b.x;
14 }
15 void add(int x, int y) {
16     for( ; x <= m; x += x & -x)
17         tree[x] += y;
18 }
19 int query(int x) {
20     int ans = 0;
21     for( ; x; x -= x & -x)
22         ans += tree[x];
23     return ans;
24 }
25 void cdq(int l, int r) {
26     if(l == r) return ;
27     cdq(l, Mid); cdq(Mid + 1, r);
28     int i = l, j = Mid + 1, now = l - 1;
29     while(i <= Mid && j <= r) {
30         if(a[i].y <= a[j].y) {
31             tmp[++now] = a[i];
32             add(a[i].z, a[i].cnt);

```

```

33         i++;
34     } else {
35         tmp[++now] = a[j];
36         ans[a[j].id] += query(a[j].z);
37         j++;
38     }
39 }
40 while(i <= Mid) {
41     tmp[++now] = a[i];
42     add(a[i].z, a[i].cnt);
43     i++;
44 }
45 while(j <= r) {
46     tmp[++now] = a[j];
47     ans[a[j].id] += query(a[j].z);
48     j++;
49 }
50 for(int i = l; i <= Mid; i++) add(a[i].z, -a[i].cnt);
51 for(int i = l; i <= r; i++) a[i] = tmp[i];
52 }
53 main()
54 {
55     n = read(); m = read();
56     for(int i = 1; i <= n; i++) {
57         a[i].x = read();
58         a[i].y = read();
59         a[i].z = read();
60         a[i].cnt = 1;
61     }
62     sort(a + 1, a + 1 + n, cmp);
63     for(int i = 1; i <= n; i++) {
64         if(i == 1 || !(a[i] == a[i - 1])){
65             a[++tot] = a[i];
66         } else a[tot].cnt += a[i].cnt;
67     }
68     for(int i = 1; i <= tot; i++) a[i].id = i, ttt[i] = a[i].cnt;
69     cdq(1, tot);
70     for(int i = 1; i <= tot; i++) tt[ans[i] + ttt[i] - 1] += ttt[i];
71     for(int i = 0; i < n; i++) printf("%d\n", tt[i]);
72     return 0;
73 }

```

## 数学

### 数论

#### 欧拉函数

##### 性质

1 和任何数互质。

$$+ \phi(1) = 1 + \phi(p) = p - 1 (p \text{ 为质数}) + \phi(x \times p) = \phi(x) \times p (p \mid x), \phi(x \times p) = \phi(x) \times p (p \nmid x)$$

##### 线性欧拉函数筛

```

1  int phi[N], f[N], pri[N], tot;
2  void getphi() {
3      int k;
4      phi[1] = 1;
5      for(int i = 2; i < N; i++) {
6          if(!f[i]) phi[pri[++tot] = i] = i - 1;
7          for(int j = 1; j <= tot && (k = i * pri[j]) < N; j++) {
8              f[k] = 1;
9              if(i % pri[j]) phi[k] = phi[i] * (pri[j] - 1);
10             else {
11                 phi[k] = phi[i] * pri[j];
12                 break;
13             }
14         }
15     }

```

16 }

$O(\sqrt{n})$  求欧拉函数

```
1 int getphi(int x) {
2     int phi = 1;
3     for(int i = 2; i * i <= x; i++) if(x % i == 0) {
4         while(x % i == 0) {
5             if(x / i % i == 0) phi = phi * i;
6             else phi = phi * (i - 1);
7             x /= i;
8         }
9     }
10    if(x > 1) phi *= x - 1;
11    return phi;
12 }
```

排列组合

斯特林近似求组合 ( $\geq 15$  时收敛)

精度容易不够, 推荐使用 python Demical 类

$$\ln n! \simeq n \ln n - n + \frac{1}{6} \ln(8n^3 + 4n^2 + n + \frac{1}{30}) + \frac{1}{2} \ln \pi$$

```
1 double lnfac(int n) {
2     return n * log(n) - n + 1.0 / 6 * log(8 * n * n * n + 4 * n * n + n + 1.0 / 30) + 0.5 * log(acos(-1.0));
3 }
4 double C(int n, int m) {
5     return exp(lnfac(n) - lnfac(n - m) - lnfac(m));
6 }
```

Lucas 定理

$$\binom{n}{m} = \binom{n \bmod p}{m \bmod p} \times \binom{n/p}{m/p}$$

```
1 int C(int n, int m) {
2     if(m > n) return 0;
3     if(n < mod) return 1ll * fac[n] * inv[n - m] % mod * inv[m] % mod;
4     else return 1ll * C(n / mod, m / mod) * C(n % mod, m % mod) % mod;
5 }
```

Min-Max 容斥

$$\max(S) = \sum_{T \subseteq S} (-1)^{|T|-1} \min(T)$$

逆元

线性推

```
1 inv[1] = inv[0] = 1;
2 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)

```
1 int inv(int x) {
2     return Pow(x % mod, mod - 2);
3 }
```

exgcd(ap 互质)

```
1 int inv(int x) {
2     int x, y;
3     exgcd(x, y, a, p);
4     return (x % p + p) % p;
5 }
```

## 拓展欧几里得

求解的是类似  $ax + by = \gcd(a, b)$  的一组解。

```
1 void exgcd(int &x, int &y, int a, int b) {
2     if(b == 0) return (void)(x = 1, y = 0);
3     exgcd(y, x, b, a % b);
4     y = y - a / b * x;
5 }
```

## 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。

$$x \equiv a_i \pmod{b_i}$$

构造  $M_k = \text{lcm}_{i=1}^{k-1} b_i$

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。

```
1 #define long long ll
2 ll gcd(ll a, ll b) {
3     return b == 0 ? a : gcd(b, a % b);
4 }
5 ll lcm(ll a, ll b) {
6     return a / gcd(a, b) * b;
7 }
8 ll exgcd(ll &x, ll &y, ll a, ll b) {
9     if(b == 0) return x = 1, y = 0, a;
10    ll t = exgcd(y, x, b, a % b);
11    y -= a / b * x;
12    return t;
13 }
14 inline ll mul(ll x, ll y, ll mod){
15     return (x * y - (ll)((long double)x / mod * y) * mod + mod) % mod;
16 }
17
18 ll excrt(ll n, ll *a, ll *b) {
19     ll ans = a[1], M = b[1];
20     for(ll i = 2; i <= n; i++) {
21         ll c = ((a[i] - ans) % b[i] + b[i]) % b[i], x, y;
22         ll t = exgcd(x, y, M, b[i]), pb = b[i] / t;
23         if(c % t != 0) return -1;
24         x = mul(x, c / t, pb);
25         ans = ans + x * M;
26         M = M * pb;
27         ans = (ans % M + M) % M;
28     }
29     return ans;
30 }
```

## Miller\_rabbin 素数测试

```
1 namespace Isprime{
2     ll mul(ll x, ll y, ll mod){
3         return (x * y - (ll)((long double)x / mod * y) * mod + mod) % mod;
4     }
5     ll Pow(ll a, ll p, ll mod) {
6         ll ans = 1;
7         for( ; p >= 1, a = mul(a, a, mod))
8             if(p & 1)
9                 ans = mul(ans, a, mod);
10        return ans % mod;
11    }
12    int check(ll P){
13        const ll test[11] = {0, 2, 3, 5, 7, 11, 13, 17, 19, 23, 29};
```

```

14     if(P == 1) return false;
15     if(P > 6 && P % 6 != 1 && P % 6 != 5) return false;
16     ll k = 0, t = P - 1;
17     while(!(t & 1)) k++, t >>= 1;
18     for(int i = 1; i <= 10 && test[i] <= P; i++) {
19         if(P == test[i]) return true;
20         ll nxt, a = Pow(test[i], t, P);
21         for(int j = 1; j <= k; j++) {
22             nxt = mul(a, a, P);
23             if(nxt == 1 && a != 1 && a != P - 1) return false;
24             a = nxt;
25         }
26         if(a != 1) return false;
27     }
28     return true;
29 }
30 }

```

## 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

$$l_i(x) = \prod_{j \neq i} \frac{x - x_j}{x_i - x_j}$$

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,  $x = x_j (j \neq i)$  位置值为 0
- 于是可以凑出唯一的多项式表达式为:

$$f(x) = \sum_{i=0}^n y_i \prod_{j \neq i} \frac{x - x_j}{x_i - x_j}$$

如果要取模的话得求逆元, 逆元先求好分母再一起求即可。

```

1  int interpolation(int *x, int *y, int n) {
2      int f = 0;
3      for(int i = 1; i <= n; i++) {
4          int s1 = 1, s2 = 1;
5          for(int j = 1; j <= n; j++) {
6              if(i != j) {
7                  s1 = 1ll * s1 * (x[i] - x[j] + mod) % mod;
8                  s2 = 1ll * s2 * (x[j] - x[i] + mod) % mod;
9              }
10         }
11         f = (f + 1ll * y[i] * s1 % mod * inv(s2) % mod) % mod;
12     }
13     return f;
14 }

```

### 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:

$$\begin{aligned}\omega_n^n &= 1 \\ \omega_n^k &= \omega_{2n}^{2k}\end{aligned}$$

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

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

$$G(x) = a_0 + a_2x + a_4x^2 + \dots$$

$$H(x) = a_1 + a_3x + a_5x^3 + \dots$$

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:  $g^t \equiv k \pmod n, t \in [0, n-2], k$  遍取  $1 \sim n-1$

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  $g^{qn} \equiv 1 \pmod p$ 。

它满足和复数近似的性质, 我们把  $q$  看成复数中的  $2\pi$ , 就可以套用 FFT 实现 NTT 了。

$$g_n^n \equiv 1, g_n^n \equiv -1$$

通常取

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

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

```
1  const int P = 998244353, G = 3, Gi = 332748118;
2  struct Complex {double x, y;};
3  Complex operator+(const Complex &a, const Complex &b) {return (Complex) {a.x + b.x, a.y + b.y};}
4  Complex operator-(const Complex &a, const Complex &b) {return (Complex) {a.x - b.x, a.y - b.y};}
5  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};}
6  namespace Polynomial {
7      const double Pi = acos(-1.0);
8      int rev[N];
9      template <typename T>
10     void change(T *y, int n) {
11         for(int i = 0; i < n; i++)
12             rev[i] = (rev[i >> 1] >> 1) | ((i & 1) ? (n >> 1) : 0);
13         for(int i = 0; i < n; i++)
14             if(i < rev[i])
15                 swap(y[i], y[rev[i]]);
16     }
17     void FFT(Complex *A, int n, int type) {
18         //type = 1 DFT
19         //type = -1 IDFT
20         //确保 n 是 2 的幂次
21         change(A, n);
22         for(int m = 1; m < n; m <= 1) {
23             Complex Wn = (Complex) {cos(Pi / m), type * sin(Pi / m)};
24             for(int i = 0; i < n; i += 2 * m) {
25                 Complex w = (Complex) {1.0, 0};
26                 for(int j = 0; j < m; j++, w = w * Wn) {
27                     Complex x = A[i + j], y = w * A[i + j + m];
28                     A[i + j] = x + y;
29                     A[i + j + m] = x - y;
30                 }
31             }
32         }
33         if(type == -1) {
```



```

34         for(int i = 0; i < n; i++)
35             A[i].x = A[i].x / n;
36     }
37 }
38 void NTT(int *A, int n, int type) {
39     //type = 1 DFT
40     //type = -1 IDFT
41     change(A, n);
42     for(int m = 1; m < n; m <= 1) {
43         int Wn = Pow(type == 1 ? G : Gi, (P - 1) / (m <= 1));
44         for(int i = 0; i < n; i += 2 * m) {
45             int w = 1;
46             for(int j = 0; j < m; j++, w = 1ll * w * Wn % P) {
47                 int x = A[i + j], y = 1ll * w * A[i + j + m] % P;
48                 A[i + j] = (x + y) % P;
49                 A[i + j + m] = (x - y + P) % P;
50             }
51         }
52     }
53     if(type == -1) {
54         int inv = Pow(n, P - 2);
55         for(int i = 0; i < n; i++)
56             A[i] = 1ll * A[i] * inv % P;
57     }
58 }
59
60 }
61 //以下代码加在主函数内
62 limit = 1;
63 while(limit <= n + m) limit <= 1;
64 Polynomial :: FFT(A, limit, 1);
65 Polynomial :: FFT(B, limit, 1);
66 for(int i = 0; i < limit; i++) A[i] = A[i] * B[i];
67 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  $\oplus = \text{and}$  的时候

$$FWT(A) = (FWT(A_0) + FWT(A_1), FWT(A_1))$$

$$FWT(A) = A(\text{长度为 } 1)$$

$$IFWT(A) = (IFWT(A_0) - IFWT(A_1), IFWT(A_1))$$

### 或卷积

当  $\oplus = \text{or}$  的时候

$$FWT(A) = (FWT(A_0), FWT(A_0) + FWT(A_1))$$

$$FWT(A) = A(\text{长度为 } 1)$$

$$IFWT(A) = (IFWT(A_0), IFWT(A_1) - IFWT(A_0))$$

### 异或卷积

当  $\oplus = \text{xor}$  的时候

$$FWT(A) = (FWT(A_0) + FWT(A_1), FWT(A_0) - FWT(A_1))$$

$$FWT(A) = A(\text{长度为 } 1)$$

$$IFWT(A) = (\frac{IFWT(A_0) + IFWT(A_1)}{2}, \frac{IFWT(A_0) - IFWT(A_1)}{2})$$

```

1 namespace Polynomial {
2     void FWT_or(int *A, int n, int type) {
3         for(int m = 1; m < n; m <= 1) {
4             for(int i = 0; i < n; i += 2 * m) {
5                 for(int j = 0; j < m; j++) {
6                     A[i + j + m] = (1ll * A[i + j + m] + A[i + j] * type + mod) % mod;
7                 }
8             }
9         }
10    }
11    void FWT_and(int *A, int n, int type) {
12        for(int m = 1; m < n; m <= 1) {
13            for(int i = 0; i < n; i += 2 * m) {
14                for(int j = 0; j < m; j++) {
15                    A[i + j] = (1ll * A[i + j + m] * type + A[i + j] + mod) % mod;
16                }
17            }
18        }
19    }
20    void FWT_xor(int *A, int n, int type) {
21        int inv_2 = Pow(2, mod - 2);
22        for(int m = 1; m < n; m <= 1) {
23            for(int i = 0; i < n; i += 2 * m) {
24                for(int j = 0; j < m; j++) {
25                    int x = A[i + j], y = A[i + j + m];
26                    A[i + j] = (1ll * x + y) * (type == 1 ? 1 : inv_2) % mod;
27                    A[i + j + m] = (1ll * x - y + mod) * (type == 1 ? 1 : inv_2) % mod;
28                }
29            }
30        }
31    }
32 }

```

## 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。

```

1 namespace ssc{
2     int f[21][1 << 21], g[21][1 << 21], ans[21][1 << 21];
3     void subset_convolution(int *A, int *B, int *C, int n, int lim) {
4         // memset(f, 0, sizeof(f));
5         // memset(g, 0, sizeof(g));
6         for(int i = 0; i < lim; i++) f[__builtin_popcount(i)][i] = A[i];
7         for(int i = 0; i < lim; i++) g[__builtin_popcount(i)][i] = B[i];
8         for(int i = 0; i <= n; i++) FWT_or(f[i], lim, 1), FWT_or(g[i], lim, 1);
9         for(int i = 0; i <= n; i++)
10             for(int j = 0; j <= i; j++)
11                 for(int k = 0; k < lim; k++)
12                     ans[i][k] = (ans[i][k] + 1ll * f[j][k] * g[i - j][k] % mod) % mod;
13         for(int i = 0; i <= n; i++) FWT_or(ans[i], lim, -1);
14         for(int i = 0; i < lim; i++) C[i] = ans[__builtin_popcount(i)][i];
15     }
16 }

```

## 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  $g^{-1} \cdot h \in H$ 。

### BurnSide 引理

定义  $AB$  同构为在群  $G$  中存在一个运算  $f$  使得  $f(A) = B$ , 则本质不同的元素个数为

$$\frac{\sum_{f \in G} c(f)}{|G|}$$

$c(f)$  为  $\sum[f(A) == A]$ , 也就是  $f$  的不动点数量。

### Polya 定理

在 BurnSide 的基础上, 染色数为  $m$ , 则本质不同的染色方案数为

$$\frac{\sum_{f \in G} m^{cnt_f}}{|G|}$$

$cnt_f$  为置换  $f$  的循环节个数

> 在 Burnside 的计算不动点过程中, 如果两个状态置换后相同, 那么同一个子循环置换中颜色一定相同, 不同子循环置换中颜色选取独立。

项链计数问题:

一个  $n$  元环,  $m$  染色, 旋转同构, 方案数为:

$$\frac{\sum_{i=1}^n m^{gcd(n,i)}}{n}$$

## 线性代数

### 矩阵运算全家桶

```
1 struct mat {
2     int g[5][5], n, m;
3 };
4 void operator+=(mat &a, const mat &b) {
5     if(a.n != b.n || a.m != b.m) cerr << "+= size error" << endl, exit(0);
6     for(int i = 1; i <= a.n; i++)
7         for(int j = 1; j <= a.m; j++) {
8             a.g[i][j] = (a.g[i][j] + b.g[i][j]);
9             if(a.g[i][j] >= mod) a.g[i][j] -= mod;
10        }
11 }
12 void operator-=(mat &a, const mat &b) {
13     if(a.n != b.n || a.m != b.m) cerr << "-= size error" << endl, exit(0);
14     for(int i = 1; i <= a.n; i++)
15         for(int j = 1; j <= a.m; j++) {
16             a.g[i][j] -= b.g[i][j];
17             if(a.g[i][j] < 0) a.g[i][j] += mod;
18        }
19 }
20 mat operator+(const mat &a, const mat &b) {
21     if(a.n != b.n || a.m != b.m) cerr << "+ size error" << endl, exit(0);
22     mat c;
23     c.n = a.n; c.m = a.m;
24     for(int i = 1; i <= a.n; i++)
25         for(int j = 1; j <= a.m; j++) {
26             c.g[i][j] = (a.g[i][j] + b.g[i][j]);
27             if(c.g[i][j] >= mod) c.g[i][j] -= mod;
28        }
29     return c;
30 }
```

```

31 mat operator-(const mat &a, const mat &b) {
32     if(a.n != b.n || a.m != b.m) cerr << "- size error" << endl, exit(0);
33     mat c;
34     c.n = a.n; c.m = a.m;
35     for(int i = 1; i <= a.n; i++)
36         for(int j = 1; j <= a.m; j++) {
37             c.g[i][j] = (a.g[i][j] - b.g[i][j]);
38             if(c.g[i][j] < 0) c.g[i][j] += mod;
39         }
40     return c;
41 }
42 mat operator*(const mat &a, const mat &b) {
43     if(a.m != b.n) cerr << "* size error" << endl, exit(0);
44     mat c;
45     c.n = a.n; c.m = b.m;
46     for(int i = 1; i <= a.n; i++) {
47         for(int j = 1; j <= b.m; j++) {
48             c.g[i][j] = 0;
49             for(int k = 1; k <= a.m; k++) {
50                 c.g[i][j] = c.g[i][j] + 1ll * a.g[i][k] * b.g[k][j] % mod;
51                 if(c.g[i][j] >= mod) c.g[i][j] -= mod;
52             }
53         }
54     }
55     return c;
56 }
57 mat Pow(mat a, int p) {
58     if(a.n != a.m) cerr << "* size error" << endl, exit(0);
59     mat ans;
60     ans.n = ans.m = a.n;
61     memset(ans.g, 0, sizeof(ans.g));
62     for(int i = 1; i <= ans.n; i++) ans.g[i][i] = 1;
63     for(; p; p >>= 1, a = a * a)
64         if(p & 1)
65             ans = ans * a;
66     return ans;
67 }

```

## 高斯消元

```

1 namespace Gauss {
2     int n, m;
3     double g[N][N];
4     int iszero(double x) {return fabs(x) < eps;}
5     void exchange(int i, int j) {
6         for(int k = 1; k <= m; k++)
7             swap(g[i][k], g[j][k]);
8     }
9     void minus(int i, int j, double t) {
10         for(int k = 1; k <= m; k++)
11             g[j][k] -= g[i][k] * t;
12     }
13     void div(int i, double d) {
14         for(int k = 1; k <= m; k++)
15             g[i][k] /= d;
16     }
17     void solve() {
18         for(int i = 1; i <= n; i++) {
19             if(iszero(g[i][i])) {
20                 for(int j = i + 1; j <= n; j++) {
21                     if(!iszero(g[j][i])) {
22                         exchange(i, j);
23                         break;
24                     }
25                 }
26                 if(iszero(g[i][i])) continue;
27             }
28             div(i, g[i][i]);
29             for(int j = 1; j <= n; j++) if(i != j && !iszero(g[j][i])){
30                 minus(i, j, g[j][i]);
31             }

```

```

32     }
33 }
34 }

```

## 图论

### 树论

#### 树的直径

模板: POJ - 1985

- 两遍 DFS

```

1  void dfs(int x, int fa) {
2      for(int i = 0; i < E[x].size(); i++) {
3          int y = E[x][i].ver;
4          int w = E[x][i].val;
5          if(y == fa) continue;
6          d[y] = d[x] + w;
7          if(d[y] > d[c]) c = y;
8          dfs(y, x);
9      }
10 }
11 signed main()
12 {
13     n = read();
14     for(int i = 1; i < n; i++) {
15         int x = read(), y = read(), w = read();
16         E[x].push_back((Edge) {y, w});
17         E[y].push_back((Edge) {x, w});
18     }
19     dfs(1, 0);
20     d[c] = 0;
21     dfs(c, 0);
22     printf("%d\n", d[c]);
23     return 0;
24 }

```

- 树形 DP

```

1  void dfs(int x, int fa) {
2      d1[x] = d2[x] = 0;
3      for(int i = 0; i < E[x].size(); i++) {
4          int y = E[x][i].ver;
5          int w = E[x][i].val;
6          if(y == fa) continue;
7          dfs(y, x);
8          int t = d1[y] + w;
9          if(t > d1[x]) {
10             d2[x] = d1[x];
11             d1[x] = t;
12         } else if(t > d2[x]) {
13             d2[x] = t;
14         }
15     }
16     d = max(d, d1[x] + d2[x]);
17 }
18 signed main()
19 {
20     n = read();
21     for(int i = 1; i < n; i++) {
22         int x = read(), y = read(), w = read();
23         E[x].push_back((Edge) {y, w});
24         E[y].push_back((Edge) {x, w});
25     }
26     dfs(1, 0);
27     printf("%d\n", d);

```

```

28     return 0;
29 }

```

## 求 LCA

### ● 树链剖分

```

1  namespace Tree {
2      int siz[N], mson[N], ltp[N], fa[N], dth[N];
3      vector<int> son[N];
4      void dfs1(int x, int pre) {
5          siz[x] = 1;
6          mson[x] = 0;
7          fa[x] = pre;
8          dth[x] = dth[pre] + 1;
9          for(auto y : son[x]) if(y != pre) {
10             dfs1(y, x);
11             if(mson[x] == 0 || siz[y] > siz[mson[x]]) mson[x] = y;
12         }
13     }
14     void dfs2(int x, int pre, int tp) {
15         ltp[x] = tp;
16         if(mson[x]) dfs2(mson[x], x, tp);
17         for(auto y : son[x]) if(y != pre && y != mson[x]) {
18             dfs2(y, x, y);
19         }
20     }
21     void init() {
22         dfs1(1, 0);
23         dfs2(1, 0, 1);
24     }
25     int LCA(int x, int y) {
26         while(ltp[x] != ltp[y]) {
27             if(dth[ltp[x]] > dth[ltp[y]]) x = fa[ltp[x]];
28             else y = fa[ltp[y]];
29         }
30         return dth[y] > dth[x] ? x : y;
31     }
32 }

```

### ● 倍增

```

1  namespace Tree {
2      vector<int> son[N];
3      int root, fa[N][31], dth[N];
4      void dfs(int x, int pre) {
5          fa[x][0] = pre;
6          dth[x] = dth[pre] + 1;
7          for(int i = 1; i <= 30; i++)
8              fa[x][i] = fa[fa[x][i-1]][i-1];
9          for(auto y : son[x]) if(y != pre)
10             dfs(y, x);
11     }
12     void init() {
13         dfs(root, 0);
14     }
15     int LCA(int x, int y) {
16         if(dth[x] > dth[y]) swap(x, y);
17         for(int i = 30; ~i; i--)
18             if(dth[fa[y][i]] >= dth[x])
19                 y = fa[y][i];
20         if(x == y) return x;
21         for(int i = 30; ~i; i--)
22             if(fa[y][i] != fa[x][i]) {
23                 x = fa[x][i];
24                 y = fa[y][i];
25             }
26         return fa[x][0];
27     }
28 }

```

## 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

```
1 void dfs1(int x, int pre) {
2     siz[x] = 1;
3     mson[x] = 0;
4     for(auto y : son[x]) if(y != pre) {
5         dfs1(y, x);
6         siz[x] += siz[y];
7         if(!mson[x] || siz[y] > siz[mson[x]]) mson[x] = y;
8     }
9 }
10 void add(int x, int pre, int v) {
11     cnt[col[x]] += v;
12     if(cnt[col[x]] > Mx) Mx = cnt[col[x]], sum = col[x];
13     else if(cnt[col[x]] == Mx) sum += col[x];
14     for(auto y : son[x]) {
15         if(y == pre || y == Son) continue;
16         add(y, x, v);
17     }
18 }
19 void dfs2(int x, int pre, int keep) {
20     for(auto y : son[x]) {
21         if(y == pre || y == mson[x]) continue;
22         dfs2(y, x, 0);
23     }
24     if(mson[x]) dfs2(mson[x], x, 1), Son = mson[x];
25     add(x, pre, 1); Son = 0;
26     ans[x] = sum;
27     if(!keep) add(x, pre, -1), sum = 0, Mx = 0;
28 }
29 }
```

## 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。

```
1 bool operator<(const node &a, const node &b) {
2     return a.f + a.g > b.f + b.g;
3 }
4 priority_queue<node> q;
5 signed main()
6 {
7     n = read(); m = read();
8     for(int i = 1; i <= m; i++) {
9         int x, y, w;
10        x = read(); y = read(); w = read();
11        E[x].push_back((Edge) {y, w});
12        re[y].push_back((Edge) {x, w});
13    }
14    s = read(); t = read(); k = read();
15    memset(dis, 0x3f, sizeof(dis)); dis[t] = 0;
16    q.push((node) {t, 0, 0});
17    while(q.size()) {
18        int x = q.top().x, d = q.top().f;
19        q.pop();
20        if(dis[x] < d) continue;
21        for(int i = 0; i < re[x].size(); i++) {
22            int y = re[x][i].y, w = re[x][i].w;
23            if(dis[y] > dis[x] + w) {
24                dis[y] = dis[x] + w;
25                q.push((node) {y, dis[y], 0});
26            }
27        }
28    }
29 }
```

```

26     }
27 }
28 }
29 for(int i = 1; i <= n; i++) cnt[i] = k;
30 cnt[s]++;
31 q.push((node) {s, 0, dis[s]});
32 while(q.size()) {
33     int x = q.top().x, f = q.top().f, g = q.top().g;
34     q.pop();
35     if(cnt[x] == 0) continue;
36     cnt[x]--;
37     if(x == t && cnt[x] == 0) {
38         printf("%lld\n", f);
39         return 0;
40     }
41     for(int i = 0; i < E[x].size(); i++) {
42         int y = E[x][i].y, w = E[x][i].w;
43         q.push((node) {y, f + w, dis[y]});
44     }
45 }
46 printf("-1\n");
47 return 0;
48 }

```

## 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

```

1 int dfs(int x) {
2     for(int i = head[x]; i; i = nxt[i]) {
3         int y = ver[i];
4         if(vis[y]) continue;
5         vis[y] = 1;
6         if(!match[y] || dfs(match[y])) {
7             match[y] = x;
8             return true;
9         }
10    }
11    return false;

```



```

12 }
13 for(int i = 1; i <= n; i++) {
14     memset(vis, 0, sizeof(vis));
15     if(dfs(i)) ans++;
16 }

```

## 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  $lb[y]$  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。

```

1  int la[N], lb[N], va[N], vb[N], delta, match[N], g[N][N], n;
2  int dfs(int x) {
3      va[x] = 1;
4      for(int y = 1; y <= n; y++) {
5          if(!vb[y]) {
6              if(la[x] + lb[y] - g[x][y] == 0) {
7                  vb[y] = 1;
8                  if(!match[y] || dfs(match[y])) {
9                      match[y] = x;
10                     return true;
11                 }
12             } else delta = min(delta, la[x] + lb[y] - g[x][y]);
13         }
14     }
15     return false;
16 }
17 void work() {
18     for(int i = 1; i <= n; i++)
19         for(int j = 1; j <= n; j++)
20             g[i][j] = read();
21     memset(match, 0, sizeof(match));
22     for(int i = 1; i <= n; i++) {
23         la[i] = g[i][1];
24         lb[i] = 0;
25         for(int j = 2; j <= n; j++)
26             la[i] = max(la[i], g[i][j]);
27     }
28     for(int i = 1; i <= n; i++) {
29         while(true) {
30             memset(va, 0, sizeof(va));
31             memset(vb, 0, sizeof(vb));
32             delta = 0x3f3f3f3f;
33             if(dfs(i)) break;
34             for(int j = 1; j <= n; j++) {
35                 if(va[j]) la[j] -= delta;
36                 if(vb[j]) lb[j] += delta;
37             }
38         }
39     }
40     long long ans = 0;
41     for(int i = 1; i <= n; i++)
42         ans += g[match[i]][i];
43     printf("%lld\n", ans);
44 }

```

## 网络流

### Dinic 算法

```

1  const int inf = 0x3f3f3f3f;
2  queue<int> q;
3  int d[N];
4  int bfs() {
5      memset(d, 0, sizeof(int) * (t + 10)); d[s] = 1;
6      while(q.size()) q.pop(); q.push(s);
7      while(q.size()) {

```

```

8         int x = q.front(); q.pop();
9         for(int i = head[x]; i; i = nxt[i]) {
10             if(d[ver[i]]) continue;
11             if(edge[i] <= 0) continue;
12             d[ver[i]] = d[x] + 1;
13             q.push(ver[i]);
14         }
15     }
16     return d[t];
17 }
18 int dinic(int x, int flow) {
19     if(x == t) return flow;
20     int k, res = flow;
21     for(int i = head[x]; i && res; i = nxt[i]) {
22         if(d[ver[i]] != d[x] + 1 || edge[i] <= 0) continue;
23         k = dinic(ver[i], min(res, edge[i]));
24         if(k == 0) d[ver[i]] = 0;
25         edge[i] -= k;
26         edge[i ^ 1] += k;
27         res -= k;
28     }
29     return flow - res;
30 }

```

### EK 算法费用流

```

1 //反向边 cost 为负数, 容量为 0
2 int SPFA() {
3     queue<int> q; q.push(s);
4     memset(dis, 0x3f, sizeof(dis)); dis[s] = 0;
5     memset(vis, 0, sizeof(vis)); vis[s] = 1;
6     q.push(s); flow[s] = 0x3f3f3f3f;
7     while(q.size()) {
8         int x = q.front();
9         vis[x] = 0; q.pop();
10        for(int i = head[x]; i; i = nxt[i]) {
11            if(edge[i] <= 0) continue;
12            if(dis[ver[i]] > dis[x] + cost[i]) {
13                dis[ver[i]] = dis[x] + cost[i];
14                pre[ver[i]] = i;
15                flow[ver[i]] = min(flow[x], edge[i]);
16                if(!vis[ver[i]]) {
17                    q.push(ver[i]);
18                    vis[ver[i]] = 1;
19                }
20            }
21        }
22    }
23    return dis[t] != 0x3f3f3f3f;
24 }
25 void update() {
26     int x = t;
27     while(x != s) {
28         int i = pre[x];
29         edge[i] -= flow[t];
30         edge[i ^ 1] += flow[t];
31         x = ver[i ^ 1];
32     }
33     maxflow += flow[t];
34     minncost += dis[t] * flow[t];
35 }

```

### Dinic 算法费用流

```

1 int SPFA() {
2     while(q.size()) q.pop(); q.push(s);
3     memset(d, 0x3f, sizeof(int) * (n + 10)); d[s] = 0;
4     memset(vis, 0, sizeof(int) * (n + 10)); vis[s] = 1;
5     while(q.size()) {
6         int x = q.front(); q.pop();

```

```

7         vis[x] = 0;
8         for(int i = head[x]; i; i = nxt[i]) {
9             if(edge[i] <= 0) continue;
10            if(d[ver[i]] > d[x] + cost[i]) {
11                d[ver[i]] = d[x] + cost[i];
12                if(!vis[ver[i]]) {
13                    vis[ver[i]] = 1;
14                    q.push(ver[i]);
15                }
16            }
17        }
18    }
19    return d[t] != 0x3f3f3f3f;
20 }
21 int dinic(int x, int flow) {
22     if(x == t) return flow;
23     vis[x] = 1;
24     int k, res = flow;
25     for(int i = head[x]; i && res; i = nxt[i]) {
26         if(vis[ver[i]]) continue;
27         if(d[ver[i]] != d[x] + cost[i] || edge[i] <= 0) continue;
28         k = dinic(ver[i], min(edge[i], res));
29         if(!k) d[ver[i]] = -1;
30         edge[i] -= k;
31         edge[i ^ 1] += k;
32         res -= k;
33         mincost += cost[i] * k;
34     }
35     vis[x] = 0;
36     return flow - res;
37 }

```

## 无源汇上下界可行流

$x \rightarrow y$ , 则  $s$  向  $y$ ,  $s$  向  $x$  连  $l$ ,  $x$  向  $y$  连  $r - l$ , 有可行流的条件是  $s$  出边全满流, 解通过残量网络构造出。

```

1  for(int i = 1; i <= m; i++) {
2      int x = read(), y = read();
3      int l = read(), r = read();
4      low[i] = l;
5      add(x, y, r - l); add(y, x, 0);
6      id[i] = tot;
7      add(s, y, l); add(y, s, 0);
8      add(x, t, l); add(t, x, 0);
9  }
10 while(bfs())
11     dinic(s, inf);
12 int f = 1;
13 for(int i = head[s]; i; i = nxt[i]) {
14     f &= (edge[i] == 0);
15 }
16 printf("%s\n", f ? "YES" : "NO");
17 if(!f) return 0;
18 for(int i = 1; i <= m; i++) {
19     printf("%d\n", edge[id[i]] + low[i]);
20 }

```

## 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。

```

1  void tarjan(int x) {
2      low[x] = dfn[x] = ++dfncnt;
3      s[++t] = x; vis[x] = 1;
4      for(int i = head[x]; i; i = nxt[i]) {

```

```

5         if(!dfn[ver[i]]) {
6             tarjan(ver[i]);
7             low[x] = min(low[x], low[ver[i]]);
8         } else if(vis[ver[i]]) {
9             low[x] = min(low[x], dfn[ver[i]]);
10        }
11    }
12    if(dfn[x] == low[x]) {
13        int z = -1;
14        ++sc;
15        while(z != x) {
16            scc[s[t]] = sc;
17            siz[sc]++;
18            vis[s[t]] = 0;
19            z = s[t];
20            t--;
21        }
22    }
23 }
24 //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
25 for(int i = 1; i <= n; i++)
26     if(!dfn[i])
27         tarjan(i);

```

## 点双连通

### Tarjan 割点判定

```

1  int cut[N];
2  namespace v_dcc {
3      int root, low[N], dfn[N], dfntot;
4      void tarjan(int x) {
5          low[x] = dfn[x] = ++dfntot;
6          int flag = 0;
7          for(int i = head[x]; i; i = nxt[i]) {
8              int y = ver[i];
9              if(!dfn[y]) {
10                 tarjan(y);
11                 low[x] = min(low[x], low[y]);
12                 if(low[y] >= dfn[x]) {
13                     flag++;
14                     if(x != root || flag > 1) cut[x] = 1;
15                 }
16             } else low[x] = min(low[x], dfn[y]);
17         }
18     }
19     void getcut() {
20         for(int i = 1; i <= n; i++)
21             if(!dfn[i])
22                 tarjan(root = i);
23     }
24 }
25 }

```

### 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。

```

1  int cut[N];
2  vector<int> dcc[N];
3  namespace v_dcc {
4      int s[N], t, root;
5      int es[N], et;
6      void tarjan(int x) {
7          dfn[x] = low[x] = ++dfntot;
8          s[++t] = x;
9          if(x == root && head[x] == 0) {
10             dcc[++dc].clear();
11             dcc[dc].push_back(x);

```

```

12         return ;
13     }
14     int flag = 0;
15     for(int i = head[x]; i; i = nxt[i]) {
16         int y = ver[i];
17         if(!dfn[y]) {
18             tarjan(y);
19             low[x] = min(low[x], low[y]);
20             if(low[y] >= dfn[x]) {
21                 flag++;
22                 if(x != root || flag > 1) cut[x] = true;
23                 dcc[++dc].clear();
24                 int z = -1;
25                 while(z != y) {
26                     z = s[t--];
27                     dcc[dc].push_back(z);
28                 }
29                 dcc[dc].push_back(x);
30             }
31         } else low[x] = min(low[x], dfn[y]);
32     }
33 }
34 void get_cut() {
35     for(int i = 1; i <= n; i++)
36         if(!dfn[i])
37             tarjan(root = i);
38 }
39 }

```

## 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。

```

1 namespace e_dcc {
2     int low[N], dfn[N], dfntot;
3     vector<int> E[N];
4     void tarjan(int x, int in_edge) {
5         low[x] = dfn[x] = ++dfntot;
6         for(int i = head[x]; i; i = nxt[i]) {
7             int y = ver[i];
8             if(!dfn[y]) {
9                 tarjan(y, i);
10                low[x] = min(low[x], low[y]);
11                if(low[y] > dfn[x])
12                    bridge[i] = bridge[i ^ 1] = true;
13            } else if(i != (in_edge ^ 1))
14                //注意运算优先级
15                low[x] = min(low[x], dfn[y]);
16        }
17    }
18    void getbridge() {
19        for(int i = 1; i <= n; i++)
20            if(!dfn[i])
21                tarjan(i, 0);
22    }
23    void dfs(int x) {
24        dcc[x] = dc;
25        for(int i = head[x]; i; i = nxt[i]) {
26            if(!dcc[ver[i]] && !bridge[i]) {
27                dfs(ver[i]);
28            }
29        }
30    }
31    void getdcc() {
32        for(int i = 1; i <= n; i++) {
33            if(!dcc[i]) {
34                ++dc;
35                dfs(i);
36            }
37        }
38    }
39 }

```

```

37     }
38 }
39 void getgraphic() {
40     for(int x = 1; x <= n; x++) {
41         for(int i = head[x]; i; i = nxt[i]) {
42             if(dcc[ver[i]] != dcc[x]) {
43                 E[dcc[x]].push_back(dcc[ver[i]]);
44                 E[dcc[ver[i]]].push_back(dcc[x]);
45             }
46         }
47     }
48 }
49 }

```

## 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： $A \rightarrow B \rightarrow C$ ，那么  $C$  的编号最小。

```

1  for(int i = 1; i <= m; i++) {
2      int x = read() + 1, y = read() + 1;
3      int w = read();
4      char c[10];
5      scanf("%s", c + 1);
6      if(c[1] == 'A') {
7          if(w) {
8              add(2 * x - 0, 2 * x - 1);
9              add(2 * y - 0, 2 * y - 1);
10         } else {
11             add(2 * x - 1, 2 * y - 0);
12             add(2 * y - 1, 2 * x - 0);
13         }
14     }
15     if(c[1] == 'O') {
16         if(w) {
17             add(2 * x - 0, 2 * y - 1);
18             add(2 * y - 0, 2 * x - 1);
19         } else {
20             add(2 * x - 1, 2 * x - 0);
21             add(2 * y - 1, 2 * y - 0);
22         }
23     }
24     if(c[1] == 'X') {
25         if(w) {
26             add(2 * x - 0, 2 * y - 1);
27             add(2 * x - 1, 2 * y - 0);
28             add(2 * y - 0, 2 * x - 1);
29             add(2 * y - 1, 2 * x - 0);
30         } else {
31             add(2 * x - 0, 2 * y - 0);
32             add(2 * x - 1, 2 * y - 1);
33             add(2 * y - 0, 2 * x - 0);
34             add(2 * y - 1, 2 * x - 1);
35         }
36     }
37 }
38 for(int i = 1; i <= 2 * n; i++)
39     if(!dfn[i])
40         tarjan(i);
41 for(int i = 1; i <= n; i++) {
42     if(scc[2 * i - 0] == scc[2 * i - 1]) {
43         printf("NO\n");

```

```

44     return 0;
45 }
46 }
47 printf("YES\n");
48 //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
49
50 //输出方案
51 for(int i = 2; i <= 2 * n; i += 2) {
52     if(scc[i - 0] == scc[i - 1]) {
53         printf("NO\n");
54         return 0;
55     } else ans[(i + 1) / 2] = scc[i - 1] < scc[i - 0];
56 }

```

## 计算几何

### 公式

三角形内心和重心公式 (点为 A,B,C, 对边为 a,b,c):

+ 内心:  $\frac{aA+bB+cC}{a+b+c}$

+ 重心:  $\frac{A+B+C}{3}$

+ 外心, 垂心: 用两直线交点计算

### 结构体定义

```

1  const double Pi = acos(-1.0);
2  const double eps = 1e-11;
3  // 三态函数
4  int sgn(double x) {
5      if(fabs(x) < eps) return 0;
6      else return x < 0 ? -1 : 1;
7  }
8  struct line;
9  struct Point;
10 struct Point {
11     double x, y;
12     Point() : x(0), y(0) {}
13     Point(double x, double y) : x(x), y(y) {}
14 };
15 struct line{
16     Point s, t;
17     line() {}
18     line(const Point &s, const Point &t) : s(s), t(t) {}
19 };
20
21 struct circle{
22     Point c;
23     double r;
24     circle() : c(Point(0,0)), r(0) {}
25     circle(const Point &c, double r) : c(c), r(r) {}
26     Point point(double a) {
27         return Point(c.x + cos(a)*r, c.y + sin(a)*r);
28     }
29 };
30 typedef Point Vector;
31 Point operator+(const Point &a, const Point &b) { return Point(a.x + b.x, a.y + b.y); }
32 Point operator-(const Point &a, const Point &b) { return Point(a.x - b.x, a.y - b.y); }
33 Point operator*(const Point &a, const double &c) { return Point(c * a.x, c * a.y); }
34 Point operator/(const Point &a, const double &c) { return Point(a.x / c, a.y / c); }
35 inline bool operator < (const Point &a, const Point &b) {
36     return sgn(a.x - b.x) < 0 || (sgn(a.x - b.x) == 0 && sgn(a.y - b.y) < 0);
37 }
38 bool operator == (const Point& a, const Point& b) { return !sgn(a.x - b.x) && !sgn(a.y - b.y); }
39 // 点积
40 double dot(const Vector& a, const Vector& b) { return a.x * b.x + a.y * b.y; }
41 // 叉积
42 double det(const Vector& a, const Vector& b) { return a.x * b.y - a.y * b.x; }
43 double cross(const Point& s, const Point& t, const Point& o = Point()) { return det(s - o, t - o); }

```

## 基本操作

```
1 // 点到原点距离
2 double abs(const Point &a){ return sqrt(a.x * a.x + a.y * a.y); }
3 // 点旋转 theta 角度
4 Point rot(const Point &a, double theta){ return Point(a.x * cos(theta) - a.y * sin(theta), a.x * sin(theta) + a.y *
    ↪ cos(theta)); }
5 // 逆时针旋转 90 度
6 Point rotCCW90(const Point &a) { return Point(-a.y, a.x); }
7 // 顺时针旋转 90 度
8 Point rotCW90(const Point &a) { return Point(a.y, -a.x); }
9 // 点的幅角`
10 double arg(const Point &a){
11     double t = atan2(a.y, a.x);
12     return t < 0 ? t + 2 * Pi:t;
13 }
14 //极角排序
15 // 1 浮点数坐标排序
16 // 顺序 (象限): 3 -> 4 -> 1 -> 2
17 int cmp(const node &a, const node &b) {
18     if(atan2(a.y, a.x) != atan2(b.y, b.x)) {
19         return atan2(a.y, a.x) < atan2(b.y, b.x);
20     }
21     return a.x < b.x;
22 }
23 // 2 整数坐标排序
24 // 顺序 (象限): 1 -> 2 -> 3 -> 4
25 int up(const node &a) {
26     return a.y > 0 || (a.y == 0 && a.x >= 0);
27 }
28 int cmp(const node &a, const node &b) {
29     if(up(a) != up(b)) return up(a) > up(b);
30     return det(a, b) > 0;
31 }
```

## 线

```
1 // 是否平行
2 bool parallel(const line &a, const line &b) {
3     return !sgn(det(a.t - a.s, b.t - b.s));
4 }
5 // 直线是否相等
6 bool l_eq(const line& a, const line& b) {
7     return parallel(a, b) && parallel(line(a.s, b.t), line(b.s, a.t));
8 }
```

## 点与线

```
1 // 点是否在线段上, <= 包含端点
2 bool p_on_seg(const Point &p, const line &seg) {
3     return !sgn(det(p - seg.s, p - seg.t)) && sgn(dot(p - seg.s, p - seg.t)) <= 0;
4 }
5 // 点到直线距离
6 double dist_to_line(const Point &p, const line &l) {
7     return fabs(cross(l.s, l.t, p)) / abs(l.s - l.t);
8 }
9 // 点到线段距离
10 double dist_to_seg(const Point &p, const line &l) {
11     if (l.s == l.t) return abs(p - l.s);
12     Vector vs = p - l.s, vt = p - l.t;
13     if (sgn(dot(Point(l), vs)) < 0) return abs(vs);
14     else if (sgn(dot(Point(l), vt)) > 0) return abs(vt);
15     else return dist_to_line(p, l);
16 }
```

## 线与线

```
1 // 直线交点, 需保证存在
2 Point l_intersection(const Line& a, const Line& b) {
3     double s1 = det(a.t - a.s, b.s - a.s), s2 = det(a.t - a.s, b.t - a.s);
```



```

4     return (b.s * s2 - b.t * s1) / (s2 - s1);
5 }
6 // 线段和直线是否有交 1 = 规范, 2 = 不规范
7 int s_l_cross(const line &seg, const line &line) {
8     int d1 = sgn(cross(line.s, line.t, seg.s));
9     int d2 = sgn(cross(line.s, line.t, seg.t));
10    if ((d1 ^ d2) == -2) return 1; // proper
11    if (d1 == 0 || d2 == 0) return 2;
12    return 0;
13 }
14 // 线段的交 1 = 规范, 2 = 不规范
15 // 如果是不规范相交, p_on_seg 函数要改成 <=
16 int s_cross(const line &a, const line &b, Point &p) {
17     int d1 = sgn(cross(a.t, b.s, a.s)), d2 = sgn(cross(a.t, b.t, a.s));
18     int d3 = sgn(cross(b.t, a.s, b.s)), d4 = sgn(cross(b.t, a.t, b.s));
19     if ((d1 ^ d2) == -2 && (d3 ^ d4) == -2) { p = l_intersection(a, b); return 1; }
20     if (!d1 && p_on_seg(b.s, a)) { p = b.s; return 2; }
21     if (!d2 && p_on_seg(b.t, a)) { p = b.t; return 2; }
22     if (!d3 && p_on_seg(a.s, b)) { p = a.s; return 2; }
23     if (!d4 && p_on_seg(a.t, b)) { p = a.t; return 2; }
24     return 0;
25 }

```

## 多边形

```

1 #define nxt(i) ((i + 1) % s.size())
2 typedef vector<Point> Polygon;
3 // 多边形面积
4 double poly_area(const Polygon &s){
5     double area = 0;
6     for(int i = 1; i < s.size() - 1; i++)
7         area += cross(s[i], s[i + 1], s[0]);
8     return area / 2;
9 }
10 // 多边形是否为凸多边形
11 Polygon Convex_hull(Polygon &s) {
12     sort(s.begin(), s.end());
13     //去重, 如果点不会重复可以删掉
14     int un = 0;
15     for(int i = 0; i < s.size(); i++) {
16         if(i == 0 || sgn(dot(s[i] - s[i - 1], s[i] - s[i - 1])) != 0) {
17             s[un++] = s[i];
18         }
19     }
20     s.resize(un);
21     Polygon ret(s.size() * 2);
22     int sz = 0;
23     for(int i = 0; i < s.size(); i++) {
24         while(sz > 1 && sgn(cross(ret[sz - 1], s[i], ret[sz - 2])) < 0) sz--;
25         ret[sz++] = s[i];
26     }
27     int k = sz;
28     for(int i = s.size() - 2; i >= 0; i--) {
29         while(sz > 1 && sgn(cross(ret[sz - 1], s[i], ret[sz - 2])) < 0) sz--;
30         ret[sz++] = s[i];
31     }
32     ret.resize(sz - (s.size() > 1));
33     return ret;
34 }
35 // 点是否在多边形中 0 = 在外部 1 = 在内部 -1 = 在边界上
36 int p_in_poly(Point p, const Polygon &s){
37     int cnt = 0;
38     for(int i = 0; i < s.size(); i++) {
39         Point a = s[i], b = s[nxt(i)];
40         if (p_on_seg(p, line(a, b))) return -1;
41         //p 在多边形边上
42         if (sgn(a.y - b.y) <= 0) swap(a, b);
43         if (sgn(p.y - a.y) > 0) continue;
44         if (sgn(p.y - b.y) <= 0) continue;
45         //一条边包含它较高的点, 不包含较低点
46         cnt += sgn(cross(b, a, p)) > 0;

```

```

47     //如果 p 在这条线段左边
48 }
49 return bool(cnt & 1);
50 }

```

## 凸包

andrew 算法,

```

1 vector<Point> Convex_hull(vector<Point> &s) {
2     sort(s.begin(), s.end());
3     vector<Point> ret(s.size() * 2);
4     int sz = 0;
5     for(int i = 0; i < s.size(); i++) {
6         while(sz > 1 && sgn(det(ret[sz - 1] - ret[sz - 2], s[i] - ret[sz - 2])) <= 0) sz--;
7         ret[sz++] = s[i];
8     }
9     int k = sz;
10    for(int i = s.size() - 2; i >= 0; i--) {
11        while(sz > 1 && sgn(det(ret[sz - 1] - ret[sz - 2], s[i] - ret[sz - 2])) <= 0) sz--;
12        ret[sz++] = s[i];
13    }
14    ret.resize(sz - (s.size() > 1));
15    return ret;
16 }

```

## 旋转卡壳

用平行线夹多边形, 根据两个向量的叉积判断支点变化

```

1 int cmp(const Point &a, const Point &b) {
2     return sgn(a.x - b.x) < 0 || (sgn(a.x - b.x) == 0 && sgn(a.y - b.y) < 0);
3 }
4 double rotatingCalipers(const vector<Point> &s) {
5     if(s.size() == 2) return abs(s[1] - s[0]);
6     int i = 0, j = 0;
7     for(int k = 0; k < s.size(); k++) {
8         if( cmp(s[i], s[k])) i = k;
9         if(!cmp(s[j], s[k])) j = k;
10    }
11    double ans = 0;
12    int si = i, sj = j;
13    do{
14        ans = max(ans, abs(s[i] - s[j]));
15        if(sgn(det(s[(i + 1) % s.size()] - s[i], s[(j + 1) % s.size()] - s[j])) < 0)
16            i = (i + 1) % s.size();
17        else j = (j + 1) % s.size();
18    } while(i != si || j != sj);
19    return ans;
20 }

```

## 半平面交

(多边形面积交)

```

1 #include <bits/stdc++.h>
2 using namespace std;
3 const int N = 2e6 + 1009;
4 const double eps = 1e-9;
5 int sgn(double x) {
6     if(-eps < x && x < eps) return 0;
7     else return x > 0 ? 1 : -1;
8 }
9 struct Point {
10     double x, y;
11     int quad() const {return sgn(y) == 1 || (sgn(y) == 0 && sgn(x) >= 0);}
12     Point(double a, double b) : x(a), y(b) {}
13 };
14 Point operator-(const Point &a, const Point &b) {return {a.x - b.x, a.y - b.y};}
15 Point operator+(const Point &a, const Point &b) {return {a.x + b.x, a.y + b.y};}

```

```

16 Point operator*(const Point &a, double b) {return {a.x * b, a.y * b};}
17 Point operator*(double b, const Point &a) {return {a.x * b, a.y * b};}
18 Point operator/(double b, const Point &a) {return {a.x / b, a.y / b};}
19 Point operator/(const Point &a, double b) {return {a.x / b, a.y / b};}
20 double dot(const Point &a, const Point &b) {
21     return a.x * b.x + a.y * b.y;
22 }
23 double det(const Point &a, const Point &b) {
24     return a.x * b.y - a.y * b.x;
25 }
26 struct Line {
27     Point s, t;
28     bool include(const Point &p) const { return sgn(det(t - s, p - s)) >= 0;}
29     Line(Point a, Point b) : s(a), t(b) {}
30 };
31 Point l_intersection(const Line& a, const Line& b) {
32     double s1 = det(a.t - a.s, b.s - a.s), s2 = det(a.t - a.s, b.t - a.s);
33     return (b.s * s2 - b.t * s1) / (s2 - s1);
34 }
35 bool operator<(const Point &a, const Point &b) {
36     if(a.quad() != b.quad()) {
37         return a.quad() < b.quad();
38     }
39     return sgn(det(a, b)) > 0;
40 }
41 bool parallel(const Line &a, const Line &b) {
42     return !sgn(det(a.t - a.s, b.t - b.s));
43 }
44 bool sameDir(const Line &a, const Line &b) {
45     return parallel(a, b) && (sgn(dot(a.t - a.s, b.t - b.s)) == 1);
46 }
47 bool operator<(const Line &a, const Line &b) {
48     if(sameDir(a, b)) {
49         return b.include(a.s);
50     } else {
51         return (a.t - a.s) < (b.t - b.s);
52     }
53 }
54 bool check(const Line &u, const Line &v, const Line &w) {
55     return w.include(l_intersection(u, v));
56 }
57 vector<Point> half_intersection(vector<Line> &l) {
58     sort(l.begin(), l.end());
59     deque<Line> q;
60     for(int i = 0; i < l.size(); i++) {
61         if(i && sameDir(l[i], l[i - 1])) {
62             continue;
63         }
64         while(q.size() > 1 && !check(q[q.size() - 2], q[q.size() - 1], l[i])) q.pop_back();
65         while(q.size() > 1 && !check(q[1], q[0], l[i])) q.pop_front();
66         q.push_back(l[i]);
67     }
68     while(q.size() > 2 && !check(q[q.size() - 2], q[q.size() - 1], q[0])) q.pop_back();
69     while(q.size() > 2 && !check(q[1], q[0], q[q.size() - 1])) q.pop_front();
70     vector<Point> ret;
71     for (int i = 0; i < q.size(); i++) ret.push_back(l_intersection(q[i], q[(i + 1) % q.size()]));
72     return ret;
73 }
74 int n, m;
75 void work() {
76     scanf("%d", &n);
77     vector<Line> v;
78     for(int i = 1; i <= n; i++) {
79         scanf("%d", &m);
80         vector<Point> p;
81         for(int j = 1; j <= m; j++) {
82             double x, y;
83             scanf("%lf%lf", &x, &y);
84             p.push_back({x, y});
85         }
86         for(int j = 0; j < m; j++) {

```

```

87         v.push_back({p[j], p[(j + 1) % m]});
88     }
89 }
90 vector<Point> p = half_intersection(v);
91 double area = 0;
92 for(int i = 0; i < p.size(); i++) {
93     area += det(p[i], p[(i + 1) % p.size()]);
94 }
95 printf("%.3f\n", fabs(area) / 2);
96
97 }

```

## 圓

### 直线和圓

```

1 // 直线与圓交点
2 vector<Point> l_c_intersection(const line &l, const circle &o) {
3     vector<Point> ret;
4     Point b = l.t - l.s, a = l.s - o.c;
5     double x = dot(b, b), y = dot(a, b), z = dot(a, a) - o.r * o.r;
6     double D = y * y - x * z;
7     if (sgn(D) < 0) return ret;
8     ret.push_back(o.c + a + b * (-y + sqrt(D + eps)) / x);
9     if (sgn(D) > 0) ret.push_back(o.c + a + b * (-y - sqrt(D)) / x);
10    return ret;
11 }
12 // 点到圓的切点
13 vector<Point> p_c_tangent(const Point &p, const circle &o) {
14     vector<Point> ret;
15     double d = abs(p - o.c), x = dot(p - o.c, p - o.c) - o.r * o.r;
16     if(sgn(x) < 0);
17     else if(sgn(x) == 0) ret.push_back(p);
18     else {
19         Vector base = p + (o.c - p) * x / dot(p - o.c, p - o.c);
20         Vector e = rotCW90(o.c - p) / d;
21         ret.push_back(base + e * sqrt(x) * o.r / d);
22         ret.push_back(base - e * sqrt(x) * o.r / d);
23     }
24     return ret;
25 }
26 // 圓与圓的交点
27 vector<Point> c_c_intersection(const circle &a, const circle &b) {
28     vector<Point> ret;
29     double d = abs(b.c - a.c);
30     if(sgn(d) == 0 || sgn(d - a.r - b.r) > 0 || sgn(d + min(a.r, b.r) - max(a.r, b.r)) < 0)
31         return ret;
32     double x = (a.r * a.r + dot(b.c - a.c, b.c - a.c) - b.r * b.r) / (2 * d);
33     double y = sqrt(a.r * a.r - x * x);
34     Point v = (b.c - a.c) / d;
35     ret.push_back(a.c + v * x + rotCW90(v) * y);
36     if(sgn(y) > 0) ret.push_back(a.c + v * x - rotCW90(v) * y);
37     return ret;
38 }

```

在 res 中存放的线上的两点分别是在 c1,c2 上的切点。

```

1 int tangent(const circle &c1, const circle &c2, vector<line> &res){
2     double d = abs(C1.c - C2.c);
3     if(d < eps) return 0;
4
5     int c=0;
6     // 内公切线
7     if(C1.r + C2.r < d - eps){
8         double t = acos((C1.r + C2.r) / d);
9         res.push_back(line(C1.c + rot(C1.r / d * (C2.c - C1.c), t), C2.c + rot(C2.r / d * (C1.c - C2.c), t)));
10        res.push_back(line(C1.c + rot(C1.r / d * (C2.c - C1.c), -t), C2.c + rot(C2.r / d * (C1.c - C2.c), -t)));
11        c += 2;
12    } else if(C1.r + C2.r < d + eps){
13        Point p = C1.c + C1.r / d * (C2.c - C1.c);
14        res.push_back(line(p, p + rot(C2.c - C1.c, Pi / 2)));

```

```

15     c++;
16 }
17
18 // 外公切线
19 if(abs(C1.r - C2.r) < d - eps){
20     double t1 = acos((C1.r - C2.r) / d), t2 = Pi - t1;
21     res.push_back(line(C1.c + rot(C1.r / d * (C2.c - C1.c), t1), C2.c + rot(C2.r / d * (C1.c - C2.c), -t2)));
22     res.push_back(line(C1.c + rot(C1.r / d * (C2.c - C1.c), -t1), C2.c + rot(C2.r / d * (C1.c - C2.c), t2)));
23     c+=2;
24 } else if(abs(C1.r - C2.r) < d + eps){
25     Point p = C1.c + C1.r / d * (C2.c - C1.c);
26     res.push_back(line(p, p + rot(C2.c - C1.c, Pi / 2)));
27     c++;
28 }
29
30 return c;
31 }

```

### 最小圆覆盖

```

1  Line norm(const Line &a) {
2      Point mid = (a.t + a.s) / 2;
3      Point dir = a.t - a.s;
4      dir = {dir.y, -dir.x};
5      return Line(mid, mid + dir);
6  }
7  double abs(const Point &a, const Point &b) {
8      return sqrt(dot(a - b, a - b));
9  }
10 struct Circle {
11     Point o;
12     double r;
13     Circle(const Point &o, const double &r) : o(o), r(r) {}
14     Circle(const Point &a, const Point &b, const Point &c) : o(0, 0) {
15         Line ab = norm(Line(b, a));
16         Line bc = norm(Line(b, c));
17         o = l_intersection(ab, bc);
18         r = abs(o, a);
19     }
20 };
21
22 int n, m, a[N];
23 vector<Point> v;
24 void work() {
25     cin >> n;
26     srand(12391278);
27     for(int i = 1; i <= n; i++) {
28         double x, y;
29         cin >> x >> y;
30         v.push_back({x, y});
31     }
32     random_shuffle(v.begin(), v.end());
33     Circle ans = {v[0], 0};
34     for(int i = 1; i < n; i++) {
35         if(abs(ans.o, v[i]) > ans.r + eps) {
36             ans = {v[i], 0};
37             for(int j = 0; j < i; j++) {
38                 if(abs(ans.o, v[j]) > ans.r + eps) {
39                     ans = {(v[i] + v[j]) / 2, abs(v[i], v[j]) / 2};
40                     for(int k = 0; k < j; k++) {
41                         if(abs(ans.o, v[k]) > ans.r + eps) {
42                             ans = Circle(v[i], v[j], v[k]);
43                         }
44                     }
45                 }
46             }
47         }
48     }
49     cout << fixed << setprecision(10) << ans.o.x << " " << ans.o.y << " " << ans.r << endl;
50 }

```

## 三维几何

### 三维凸包 (最小面积)

```
1  const double eps = 1e-10;
2  double rand_eps() {
3      return ((double)rand() / RAND_MAX - 0.5) * eps;
4  }
5  struct Point {
6      double x, y, z;
7      Point(double x, double y, double z) : x(x), y(y), z(z) {}
8      double len() {
9          return sqrt(x * x + y * y + z * z);
10     }
11     void shake() {
12         x += rand_eps();
13         y += rand_eps();
14         z += rand_eps();
15     }
16 };
17 Point operator+(const Point &a, const Point &b) { return {a.x + b.x, a.y + b.y, a.z + b.z}; }
18 Point operator-(const Point &a, const Point &b) { return {a.x - b.x, a.y - b.y, a.z - b.z}; }
19 Point operator*(const Point &a, const double &b) { return {a.x * b, a.y * b, a.z * b}; }
20 Point operator/(const Point &a, const double &b) { return {a.x / b, a.y / b, a.z / b}; }
21 double dot(const Point &a, const Point &b) {
22     return a.x * b.x + a.y * b.y + a.z * b.z;
23 }
24 Point det(const Point &a, const Point &b) {
25     return {a.y * b.z - a.z * b.y, a.z * b.x - a.x * b.z, a.x * b.y - a.y * b.x};
26 }
27 vector<Point> p;
28 struct Plane {
29     int v[3];
30     Plane(const int &a, const int &b, const int &c) : v{a, b, c} {}
31     Point norm() {
32         return det(p[v[0]] - p[v[1]], p[v[2]] - p[v[1]]);
33     }
34     int above(const Point &q) {
35         return dot((q - p[v[0]]), norm()) >= 0;
36     }
37     double area() {
38         return norm().len() / 2;
39     }
40 };
41 int n;
42 vector<Plane> convex_hull_3d() {
43     for(int i = 0; i < p.size(); i++) p[i].shake();
44     vector<Plane> plane, tmp;
45     vector<vector<int>> vis(n);
46     for(int i = 0; i < n; i++)
47         vis[i].resize(n);
48     plane.emplace_back(0, 1, 2);
49     plane.emplace_back(0, 2, 1);
50     for(int i = 3; i < n; i++) {
51         tmp = plane;
52         plane.clear();
53         for(auto t : tmp) {
54             bool f = t.above(p[i]);
55             if(!f) plane.push_back(t);
56             for(int k = 0; k < 3; k++) {
57                 vis[t.v[k]][t.v[(k + 1) % 3]] = f;
58             }
59         }
60         for(auto t : tmp) {
61             for(int k = 0; k < 3; k++) {
62                 int a = t.v[k], b = t.v[(k + 1) % 3];
63                 if(vis[a][b] != vis[b][a] && vis[a][b]) {
64                     plane.push_back(Plane{a, b, i});
65                 }
66             }
67         }
68     }
```

```

69     return plane;
70 }
71 void work() {
72     srand(12302113);
73     cin >> n;
74     for(int i = 0; i < n; i++) {
75         double x, y, z;
76         cin >> x >> y >> z;
77         p.push_back({x, y, z});
78     }
79     vector<Plane> convex = convex_hull_3d();
80     double area = 0;
81     for(auto x : convex) {
82         area += x.area();
83     }
84     cout << fixed << setprecision(6) << area << endl;
85 }
86 }

```

## tips

- atan2(y, x) 函数: 点  $(x, y)$  到原点的方位角, 值域在  $(-\pi, \pi)$  在一二象限为正, 三四象限为负。

## 字符串

### 字串哈希

```

1 namespace String {
2     const int x = 135;
3     const int p1 = 1e9 + 7, p2 = 1e9 + 9;
4     ull xp1[N], xp2[N], xp[N];
5     void init_xp() {
6         xp1[0] = xp2[0] = xp[0] = 1;
7         for(int i = 1; i < N; i++) {
8             xp1[i] = xp1[i - 1] * x % p1;
9             xp2[i] = xp2[i - 1] * x % p2;
10            xp[i] = xp[i - 1] * x;
11        }
12    }
13    struct HashString {
14        char s[N];
15        int length, subsize;
16        bool sorted;
17        ull h[N], hl[N];
18        ull init(const char *t) {
19            if(xp[0] != 1) init_xp();
20            length = strlen(t);
21            strcpy(s, t);
22            ull res1 = 0, res2 = 0;
23            h[length] = 0;
24            for(int j = length - 1; j >= 0; j--) {
25                #ifdef ENABLE_DOUBLE_HASH
26                    res1 = (res1 * x + s[j]) % p1;
27                    res2 = (res2 * x + s[j]) % p2;
28                    h[j] = (res1 << 32) | res2;
29                #else
30                    res1 = res1 * x + s[j];
31                    h[j] = res1;
32                #endif
33            }
34            return h[0];
35        }
36        //获取子串哈希, 左闭右开
37        ull get_substring_hash(int left, int right) {
38            int len = right - left;
39            #ifdef ENABLE_DOUBLE_HASH
40                unsigned int mask32 = ~(0u);
41                ull left1 = h[left] >> 32, right1 = h[right] >> 32;
42                ull left2 = h[left] & mask32, right2 = h[right] & mask32;

```

```

43         return (((left1 - right1 * xp1[len] % p1 + p1) % p1) << 32 |
44                (((left2 - right2 * xp2[len] % p2 + p2) % p2)));
45     #else
46         return h[left] - h[right] * xp[len];
47     #endif
48 }
49 void get_all_subs_hash(int sublen) {
50     subsize = length - sublen + 1;
51     for (int i = 0; i < subsize; ++i)
52         hl[i] = get_substring_hash(i, i + sublen);
53     sorted = 0;
54 }
55
56 void sort_substring_hash() {
57     sort(hl, hl + subsize);
58     sorted = 1;
59 }
60
61 bool match(ull key) const {
62     if (!sorted) assert (0);
63     if (!subsize) return false;
64     return binary_search(hl, hl + subsize, key);
65 }
66 };
67 }

```

## Trie

```

1  namespace trie {
2      int t[N][26], sz, ed[N];
3      int _new() {
4          sz++;
5          memset(t[sz], 0, sizeof(t[sz]));
6          return sz;
7      }
8      void init() {
9          sz = 0;
10         _new();
11         memset(ed, 0, sizeof(ed));
12     }
13     void Insert(char *s, int n) {
14         int u = 1;
15         for(int i = 0; i < n; i++) {
16             int c = s[i] - 'a';
17             if(!t[u][c]) t[u][c] = _new();
18             u = t[u][c];
19         }
20         ed[u]++;
21     }
22     int find(char *s, int n) {
23         int u = 1;
24         for(int i = 0; i < n; i++) {
25             int c = s[i] - 'a';
26             if(!t[u][c]) return -1;
27             u = t[u][c];
28         }
29         return u;
30     }
31 }

```

## KMP 算法

```

1  namespace KMP {
2      void get_next(char *t, int m, int *nxt) {
3          int j = nxt[0] = 0;
4          for(int i = 1; i < m; i++) {
5              while(j && t[i] != t[j]) j = nxt[j - 1];
6              nxt[i] = j += (t[i] == t[j]);
7          }
8      }

```



```

9     vector<int> find(char *t, int m, int *nxt, char *s, int n) {
10         vector<int> ans;
11         int j = 0;
12         for(int i = 0; i < n; i++) {
13             while(j && s[i] != t[j]) j = nxt[j - 1];
14             j += s[i] == t[j];
15             if(j == m) {
16                 ans.push_back(i - m + 1);
17                 j = nxt[j - 1];
18             }
19         }
20         return ans;
21     }
22 }

```

## manacher 算法

```

1     namespace manacher {
2         char s[N];
3         int p[N], len;
4         void getp(string tmp) {
5             len = 0;
6             for(auto x : tmp) {
7                 s[len++] = '#';
8                 s[len++] = x;
9             }
10            s[len++] = '#';
11            memset(p, 0, sizeof(int) * (len + 10));
12            int c = 0, r = 0;
13            for(int i = 0; i < len; i++) {
14                if(i <= r) p[i] = min(p[2 * c - i], r - i);
15                else p[i] = 1;
16                while(i - p[i] >= 0 && i + p[i] < len && s[i - p[i]] == s[i + p[i]])
17                    p[i]++;
18                if(i + p[i] - 1 > r) {
19                    r = i + p[i] - 1;
20                    c = i;
21                }
22            }
23            for(int i = 0; i < len; i++) p[i]--;
24        }
25        void getp(char *tmp, int n) {
26            len = 0;
27            for(int i = 0; i < n; i++) {
28                s[len++] = '#';
29                s[len++] = tmp[i];
30            }
31            s[len++] = '#';
32            memset(p, 0, sizeof(int) * (len + 10));
33            int c = 0, r = 0;
34            for(int i = 0; i < len; i++) {
35                if(i <= r) p[i] = min(p[2 * c - i], r - i);
36                else p[i] = 1;
37                while(i - p[i] >= 0 && i + p[i] < len && s[i - p[i]] == s[i + p[i]])
38                    p[i]++;
39                if(i + p[i] - 1 > r) {
40                    r = i + p[i] - 1;
41                    c = i;
42                }
43            }
44            for(int i = 0; i < len; i++) p[i]--;
45        }
46        int getlen() {
47            return *max_element(p, p + len);
48        }
49        int getlen(string s) {
50            getp(s);
51            return getlen();
52        }
53    }

```

## AC 自动机

```
1 struct ac_automaton {
2     int t[N][26], danger[N], tot, fail[N];
3     int dp[N][N];
4     void init() {
5         tot = -1;
6         _new();
7     }
8     int _new() {
9         tot++;
10        memset(t[tot], 0, sizeof(t[tot]));
11        danger[tot] = 0;
12        fail[tot] = 0;
13        return tot;
14    }
15    void Insert(const char *s) {
16        int u = 0;
17        for(int i = 0; s[i]; i++) {
18            if(!t[u][mp[s[i]]]) t[u][s[i] - 'a'] = _new();
19            u = t[u][mp[s[i]]];
20        }
21        danger[u] = 1;
22    }
23    void build() {
24        queue<int> q;
25        for(int i = 0; i < 26; i++) {
26            if(t[0][i]) {
27                fail[i] = 0;
28                q.push(t[0][i]);
29            }
30        }
31        while(q.size()) {
32            int u = q.front(); q.pop();
33            danger[u] |= danger[fail[u]];
34            for(int i = 0; i < 26; i++) {
35                if(t[u][i]) {
36                    fail[t[u][i]] = t[fail[u]][i];
37                    q.push(t[u][i]);
38                } else t[u][i] = t[fail[u]][i];
39            }
40        }
41    }
42    int query(const char *s) {
43        memset(dp, 0x3f, sizeof(dp));
44        int n = strlen(s);
45        dp[0][0] = 0;
46        for(int i = 0; i < n; i++) {
47            for(int j = 0; j <= tot; j++) if(!danger[j]) {
48                for(int k = 0; k < 26; k++) if(!danger[t[j][k]]) {
49                    dp[i + 1][t[j][k]] = min(dp[i + 1][t[j][k]], dp[i][j] + (s[i] - 'a' != k));
50                }
51            }
52        }
53        int ans = 0x3f3f3f3f;
54        for(int i = 0; i <= tot; i++) if(!danger[i]) {
55            ans = min(ans, dp[n][i]);
56        }
57        return ans == 0x3f3f3f3f ? -1 : ans;
58    }
59 };
```

## 杂项

### 取模还原成分数

摘自 EI 的博客

```
1 pair<int, int> approx(int p, int q, int A) {
2     int x = q, y = p, a = 1, b = 0;
```

```

3   while (x > A) {
4       swap(x, y); swap(a, b);
5       a -= x / y * b;
6       x %= y;
7   }
8   return make_pair(x, a);
9 }

```

## 快读

```

1  #define gc() (is==it?it=(is=in)+fread(in,1,Q,stdin),(is==it?EOF:*is++):*is++)
2  const int Q=(1<<24)+1;
3  char in[Q],*is=in,*it=in,c;
4  void read(int &n){
5      for(n=0;(c=gc())<'0' || c>'9';);
6      for(;c<='9'&& c>='0';c=gc()) n=n*10+c-48;
7  }

```

## int128

```

1  typedef __uint128_t u128;
2  inline u128 read() {
3      static char buf[100];
4      scanf("%s", buf);
5      // std::cin >> buf;
6      u128 res = 0;
7      for(int i = 0; buf[i]; ++i) {
8          res = res << 4 | (buf[i] <= '9' ? buf[i] - '0' : buf[i] - 'a' + 10);
9      }
10     return res;
11 }
12 inline void output(u128 res) {
13     if(res >= 16)
14         output(res / 16);
15     putchar(res % 16 >= 10 ? 'a' + res % 16 - 10 : '0' + res % 16);
16     //std::cout.put(res % 16 >= 10 ? 'a' + res % 16 - 10 : '0' + res % 16);
17 }

```

## Java, BigInteger

```

1  public BigInteger add(BigInteger val)    返回当前大整数对象与参数指定的大整数对象的和
2  public BigInteger subtract(BigInteger val)  返回当前大整数对象与参数指定的大整数对象的差
3  public BigInteger multiply(BigInteger val)  返回当前大整数对象与参数指定的大整数对象的积
4  public BigInteger divide(BigInteger val)    返回当前大整数对象与参数指定的大整数对象的商
5  public BigInteger remainder(BigInteger val)  返回当前大整数对象与参数指定的大整数对象的余
6  public int compareTo(BigInteger val)      返回当前大整数对象与参数指定的大整数对象的比较结果, 返回值是 1, -1, 0, 分别表示当前大整数对象大
   于, 小于或等于参数指定的大整数。
7  public BigInteger abs()                  返回当前大整数对象的绝对值
8  public BigInteger pow(int exponent)      返回当前大整数对象的 exponent 次幂。
9  public String toString()                 返回当前大整数对象十进制的字符串表示。
10 public String toString(int p)            返回当前大整数对象 p 进制的字符串表示。
11 public BigInteger negate()               返回当前大整数的相反数。

```

## 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

真·popcount

```
1 int _popcount(int x) {
2     return __builtin_popcount(x & (0ull - 1)) + __builtin_popcount(x >> 32);
3 }
```

随机数种子

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

T(5) 求任意 int log2

```
1 inline int LOG2_1(unsigned x){
2     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};
3     x|=x>>1; x|=x>>2; x|=x>>4; x|=x>>8; x|=x>>16;
4     return tb[x*0x07C4ACDDu>>27];
5 }
```

O(1) 求 2 的整幂次 log2

```
1 inline int LOG2(unsigned x){ //x=2^k
2     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};
3     return tb[x*263572066>>27];
4 }
```

开启编译优化

```
1 #pragma GCC optimize(2)
2 #pragma GCC optimize(3)
3 #pragma GCC optimize("Ofast")
4 #pragma GCC optimize("inline")
5 #pragma GCC optimize("-fgcse")
6 #pragma GCC optimize("-fgcse-lm")
7 #pragma GCC optimize("-fipa-sra")
8 #pragma GCC optimize("-ftree-pre")
9 #pragma GCC optimize("-ftree-vrp")
10 #pragma GCC optimize("-fpeephole2")
11 #pragma GCC optimize("-ffast-math")
12 #pragma GCC optimize("-fsched-spec")
13 #pragma GCC optimize("unroll-loops")
14 #pragma GCC optimize("-falign-jumps")
15 #pragma GCC optimize("-falign-loops")
16 #pragma GCC optimize("-falign-labels")
17 #pragma GCC optimize("-fdevirtualize")
18 #pragma GCC optimize("-fcaller-saves")
19 #pragma GCC optimize("-fcrossjumping")
20 #pragma GCC optimize("-fthread-jumps")
21 #pragma GCC optimize("-funroll-loops")
22 #pragma GCC optimize("-fwhole-program")
23 #pragma GCC optimize("-freorder-blocks")
24 #pragma GCC optimize("-fschedule-insns")
25 #pragma GCC optimize("inline-functions")
26 #pragma GCC optimize("-ftree-tail-merge")
27 #pragma GCC optimize("-fschedule-insns2")
28 #pragma GCC optimize("-fstrict-aliasing")
29 #pragma GCC optimize("-fstrict-overflow")
30 #pragma GCC optimize("-falign-functions")
31 #pragma GCC optimize("-fcse-skip-blocks")
32 #pragma GCC optimize("-fcse-follow-jumps")
33 #pragma GCC optimize("-fsched-interblock")
34 #pragma GCC optimize("-fpartial-inlining")
35 #pragma GCC optimize("no-stack-protector")
36 #pragma GCC optimize("-freorder-functions")
37 #pragma GCC optimize("-findirect-inlining")
38 #pragma GCC optimize("-fhoist-adjacent-loads")
39 #pragma GCC optimize("-frerun-cse-after-loop")
40 #pragma GCC optimize("inline-small-functions")
41 #pragma GCC optimize("-finline-small-functions")
42 #pragma GCC optimize("-ftree-switch-conversion")
43 #pragma GCC optimize("-foptimize-sibling-calls")
44 #pragma GCC optimize("-fexpensive-optimizations")
45 #pragma GCC optimize("-funsafe-loop-optimizations")
```

```

46 #pragma GCC optimize("inline-functions-called-once")
47 #pragma GCC optimize("-fdelete-null-pointer-checks")

```

## 快速乘

```

1 ll mul(ll x, ll y, ll mod){
2     return (x * y - (ll)((long double)x / mod * y) * mod + mod) % mod;
3 }
4 ll mul(ll a, ll b, ll MOD) {
5     __int128 x = a, y = b, m = MOD;
6     return (ll)(x * y % m);
7 }

```

## 子集枚举

枚举  $s$  的子集

```

1 for(int i = s; i; i = (i - 1) & s)

```

枚举所有大小为  $r$  的集合

```

1 for(int s = (1 << r) - 1; s < (1 << n); ) {
2     int x = s & -s;
3     int y = s + x;
4     s = ((y ^ s) >> __builtin_ctz(x) + 2) | y;
5 }

```

## mt19937\_64 随机数生成器

```

1 std::mt19937_64 rng(std::chrono::steady_clock::now().time_since_epoch().count());
2 template <typename T>
3 T rd(T l, T r) {
4     std::uniform_int_distribution<T> u(l, r);
5     return u(rng);
6 }
7 template <>
8 double rd<double>(double l, double r) {
9     std::uniform_real_distribution<double> u(l, r);
10    return u(rng);
11 }

```

## 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
- 推不等式确定范围的时候，仅需要考虑所有不等式限定的范围，然后判断左端点是否大于右端点，不要加额外的臆想条件。
- 矩阵快速幂如果常数十分大的时候，可以考虑 unordered\_map 保存结果，可以明显加速。
- **\*\*\_\_builtin\_popcount\*\*** 只支持 unsigned int 型，不支持 long long!!!!!!