

Contents

1	Basic	1
1.1	vimrc	1
1.2	Default Code	1
2	Data Structure	1
2.1	Bigint	1
2.2	unordered_map	3
2.3	extc_heap	3
2.4	extc_balance_tree	3
2.5	Disjoint Set	3
2.6	Treap	3
2.7	Heavy Light Decomposition	4
2.8	Link-Cut Tree	5
3	Graph	5
3.1	BCC Edge	5
3.2	BCC Vertex	6
3.3	Strongly Connected Components	6
3.4	DMST_with_sol	6
3.5	Dominator Tree	7
3.6	Maximum Clique	7
3.7	MinimumMeanCycle	8
4	Flow	8
4.1	Dinic	8
4.2	Cost Flow	8
4.3	Kuhn Munkres - $O(n^3)$	9
4.4	SW-Mincut	9
4.5	Maximum Simple Graph Matching	10
4.6	Minimum Weight Matching (Clique version)	10
4.7	General Graph Matching	11
4.8	(+1) SW-mincut $O(NM)$	11
5	Math	12
5.1	ax+by=gcd	12
5.2	Fast Fourier Transform	12
5.3	Fast Linear Recurrence	13
5.4	(+1) ntt	13
5.5	Mod	13
5.6	(+1) Miller Rabin	14
5.7	Pollard Rho	14
5.8	Algorithms about Primes	14
5.9	(+1) PolynomialGenerator	15
5.10	Pseudoinverse of Square matrix	15
5.11	Theorem	15
5.11.1	Lucas' Theorem	15
5.11.2	Sum of Two Squares Thm (Legendre)	15
5.11.3	Difference of D1-D3 Thm	15
5.11.4	Krush-Kuhn-Tucker Conditions	15
5.11.5	Chinese remainder theorem	15
5.12	Simplex	15
6	Geometry	16
6.1	Point operators	16
6.2	Intersection of two circles	16
6.3	Intersection of two lines	16
6.4	Half Plane Intersection	16
6.5	2D Convex Hull	17
6.6	3D Convex Hull	18
6.7	Minimum Covering Circle	18
6.8	KDTree (Nearest Point)	18
6.9	Triangulation	19
7	Stringology	20
7.1	Suffix Array	20
7.2	Suffix Array (SAIS TWT514)	20
7.3	Aho-Corasick Algorithm	20
7.4	KMP	21
7.5	Z value	21
7.6	Z value (palindrome ver.)	21
7.7	palindromic tree	21
7.8	Lexicographically Smallest Rotation	22
7.9	Suffix Automaton	22
8	Problems	22
8.1	Painter	22
8.2	Mo-Algorithm on Tree	24
8.3	Manhattan MST	24
9	Other	25
9.1	__builtin__	25
9.2	bitwise operations - collection	25
9.3	Increase Stack	25
9.4	GCC Pragma	25
10	Graph paper	26

1 Basic

1.1 vimrc

```
set rnu nu ai cin ts=4 sw=4 mouse=a

map <F8> <ESC>:w<CR>:!clear && g++ "%>
++11 -Wall -Wextra -Wconversion -Wshadow -O2 -DLITE
-fsanitize=address -fsanitize=undefined && echo
success<CR>
map <F9> <ESC>:w<CR>:!clear && g++ "%>
++11 -Wall -Wextra -Wconversion -Wshadow -O2 -DLITE
&& echo success<CR>
map <F10> <ESC>:!. / "%<CR>
```

1.2 Default Code

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

#define ALL(a) begin(a), end(a)

using namespace std;

// deBuG function
// example:
// int a = 3; int b[] = {1,2}; string c = "abc";
// BG(a, b[1], c); // stderr: int main():37: a = 3, b
// [1] = 2, c = a
#ifdef LITE

void _BG(const char * s) {cerr<<s<<endl;}
template<class T, class ... TT>
void _BG(const char * s, T a, TT...b)
{
    for (size_t c = 0; *s && (c || *s != ','); cerr<<*s
        ++){
        c += count(ALL("([{"), *s) - count(ALL(")]"}),
            *s); // Implementation defined. But that's
                // ok since it only runs on local.
        cerr<<" = "<<a;
        if (*s) {
            cerr<<" ";
            ++s;
        }
        _BG(s,b...);
    }
}

#define BG(...) do { \
    cerr << __PRETTY_FUNCTION__ << ':' << __LINE__ << " \
        : "; \
    _BG(#__VA_ARGS__, __VA_ARGS__); \
} while(0)

#else
#define BG(...)
#endif

int main()
{
    ios::sync_with_stdio(0);
    cin.tie(0);

    // lite !
}
```

2 Data Structure

2.1 Bigint

```
struct Bigint{
    static const int LEN = 60;
    static const int BIGMOD = 10000;

    int s;
    int vl, v[LEN];
    // vector<int> v;
    Bigint() : s(1) { vl = 0; }
    Bigint(long long a) {
        s = 1; vl = 0;
```

```

    if (a < 0) { s = -1; a = -a; }
    while (a) {
        push_back(a % BIGMOD);
        a /= BIGMOD;
    }
}

Bigint(string str) {
    s = 1; vl = 0;
    int stPos = 0, num = 0;
    if (!str.empty() && str[0] == '-') {
        stPos = 1;
        s = -1;
    }
    for (int i=SZ(str)-1, q=1; i>=stPos; i--) {
        num += (str[i] - '0') * q;
        if ((q *= 10) >= BIGMOD) {
            push_back(num);
            num = 0; q = 1;
        }
    }
    if (num) push_back(num);
    n();
}

int len() const {
    return vl;
    // return SZ(v);
}

bool empty() const { return len() == 0; }

void push_back(int x) {
    v[vl++] = x;
    // v.PB(x);
}

void pop_back() {
    vl--;
    // v.pop_back();
}

int back() const {
    return v[vl-1];
    // return v.back();
}

void n() {
    while (!empty() && !back()) pop_back();
}

void resize(int nl) {
    vl = nl;
    fill(v, v+vl, 0);
    // v.resize(nl);
    // fill(ALL(v), 0);
}

void print() const {
    if (empty()) { putchar('0'); return; }
    if (s == -1) putchar('-');
    printf("%d", back());
    for (int i=len()-2; i>=0; i--) printf("%.4d", v[i]);
}

friend std::ostream& operator << (std::ostream& out,
    const Bigint &a) {
    if (a.empty()) { out << "0"; return out; }
    if (a.s == -1) out << "-";
    out << a.back();
    for (int i=a.len()-2; i>=0; i--) {
        char str[10];
        snprintf(str, 5, "%.4d", a.v[i]);
        out << str;
    }
    return out;
}

int cp3(const Bigint &b) const {
    if (s != b.s) return s - b.s;
    if (s == -1) return -(*this).cp3(-b);
    if (len() != b.len()) return len()-b.len(); //int
    for (int i=len()-1; i>=0; i--)
        if (v[i] != b.v[i]) return v[i]-b.v[i];
    return 0;
}

bool operator < (const Bigint &b) const { return cp3(b) < 0; }
bool operator <= (const Bigint &b) const { return cp3(b) <= 0; }
bool operator == (const Bigint &b) const { return cp3(b) == 0; }

```

```

bool operator != (const Bigint &b) const { return cp3(b) != 0; }
bool operator > (const Bigint &b) const { return cp3(b) > 0; }
bool operator >= (const Bigint &b) const { return cp3(b) >= 0; }

Bigint operator - () const {
    Bigint r = (*this);
    r.s = -r.s;
    return r;
}

Bigint operator + (const Bigint &b) const {
    if (s == -1) return -(*this)+(-b);
    if (b.s == -1) return (*this)-(-b);
    Bigint r;
    int nl = max(len(), b.len());
    r.resize(nl + 1);
    for (int i=0; i<nl; i++) {
        if (i < len()) r.v[i] += v[i];
        if (i < b.len()) r.v[i] += b.v[i];
        if (r.v[i] >= BIGMOD) {
            r.v[i+1] += r.v[i] / BIGMOD;
            r.v[i] %= BIGMOD;
        }
    }
    r.n();
    return r;
}

Bigint operator - (const Bigint &b) const {
    if (s == -1) return -(*this)-(-b);
    if (b.s == -1) return (*this)+(-b);
    if ((*this) < b) return -(b-(*this));
    Bigint r;
    r.resize(len());
    for (int i=0; i<len(); i++) {
        r.v[i] += v[i];
        if (i < b.len()) r.v[i] -= b.v[i];
        if (r.v[i] < 0) {
            r.v[i] += BIGMOD;
            r.v[i+1]--;
        }
    }
    r.n();
    return r;
}

Bigint operator * (const Bigint &b) {
    Bigint r;
    r.resize(len() + b.len() + 1);
    r.s = s * b.s;
    for (int i=0; i<len(); i++) {
        for (int j=0; j<b.len(); j++) {
            r.v[i+j] += v[i] * b.v[j];
            if (r.v[i+j] >= BIGMOD) {
                r.v[i+j+1] += r.v[i+j] / BIGMOD;
                r.v[i+j] %= BIGMOD;
            }
        }
    }
    r.n();
    return r;
}

Bigint operator / (const Bigint &b) {
    Bigint r;
    r.resize(max(1, len()-b.len()+1));
    int oriS = s;
    Bigint b2 = b; // b2 = abs(b)
    s = b2.s = r.s = 1;
    for (int i=r.len()-1; i>=0; i--) {
        int d=0, u=BIGMOD-1;
        while(d<u) {
            int m = (d+u+1)>>1;
            r.v[i] = m;
            if ((r*b2) > (*this)) u = m-1;
            else d = m;
        }
        r.v[i] = d;
    }
    s = oriS;
    r.s = s * b.s;
    r.n();
    return r;
}

Bigint operator % (const Bigint &b) {
    return (*this)-(*this)/b*b;
}

```

```
|};
```

2.2 unordered_map

```
struct Key {
    int first, second;
    Key () {}
    Key (int _x, int _y) : first(_x), second(_y) {}
    bool operator == (const Key &b) const {
        return tie(F,S) == tie(b.F,b.S);
    }
};

struct KeyHasher {
    size_t operator()(const Key& k) const {
        return k.first + k.second*100000;
    }
};

typedef unordered_map<Key,int,KeyHasher> map_t;

int main(int argc, char** argv){
    map_t mp;
    for (int i=0; i<10; i++)
        mp[Key(i,0)] = i+1;
    for (int i=0; i<10; i++)
        printf("%d\n", mp[Key(i,0)]);

    return 0;
}
```

2.3 extc_heap

```
#include <bits/extc++.h>
typedef __gnu_pbds::priority_queue<int> heap_t;
heap_t a,b;

int main() {
    a.clear();
    b.clear();
    a.push(1);
    a.push(3);
    b.push(2);
    b.push(4);
    assert(a.top() == 3);
    assert(b.top() == 4);
    // merge two heap
    a.join(b);
    assert(a.top() == 4);
    assert(b.empty());

    return 0;
}
```

2.4 extc_balance_tree

```
#include <ext/pb_ds/assoc_container.hpp>
using namespace std;
using namespace __gnu_pbds;
typedef tree<int,null_type,less<int>,rb_tree_tag,
    tree_order_statistics_node_update> set_t;

#include <ext/pb_ds/assoc_container.hpp>
using namespace __gnu_pbds;
typedef cc_hash_table<int,int> umap_t;

int main()
{
    // Insert some entries into s.
    set_t s;
    s.insert(12);
    s.insert(505);

    // The order of the keys should be: 12, 505.
    assert(*s.find_by_order(0) == 12);
    assert(s.find_by_order(2) == end(s));

    // The order of the keys should be: 12, 505.
    assert(s.order_of_key(12) == 0);
    assert(s.order_of_key(505) == 1);
}
```

```
// Erase an entry.
s.erase(12);
```

```
// The order of the keys should be: 505.
assert(*s.find_by_order(0) == 505);
```

```
// The order of the keys should be: 505.
assert(s.order_of_key(505) == 0);
}
```

2.5 Disjoint Set

```
struct DisjointSet {
    // save() is like recursive
    // undo() is like return
    int n, fa[MXN], sz[MXN];
    vector<pair<int*,int*>> h;
    vector<int> sp;
    void init(int tn) {
        n=tn;
        for (int i=0; i<n; i++) {
            fa[i]=i;
            sz[i]=1;
        }
        sp.clear(); h.clear();
    }
    void assign(int *k, int v) {
        h.PB({k, *k});
        *k=v;
    }
    void save() { sp.PB(SZ(h)); }
    void undo() {
        assert(!sp.empty());
        int last=sp.back(); sp.pop_back();
        while (SZ(h)!=last) {
            auto x=h.back(); h.pop_back();
            *x.F=x.S;
        }
    }
    int f(int x) {
        while (fa[x]!=x) x=fa[x];
        return x;
    }
    void uni(int x, int y) {
        x=f(x); y=f(y);
        if (x==y) return;
        if (sz[x]<sz[y]) swap(x, y);
        assign(&sz[x], sz[x]+sz[y]);
        assign(&fa[y], x);
    }
}djs;
```

2.6 Treap

```
const int MEM = 16000004;
struct Treap {
    static Treap nil, mem[MEM], *pmem;
    Treap *l, *r;
    char val;
    int size;
    Treap () : l(&nil), r(&nil), size(0) {}
    Treap (char _val) :
        l(&nil), r(&nil), val(_val), size(1) {}
} Treap::nil, Treap::mem[MEM], *Treap::pmem = Treap::
    mem;

int size(const Treap *t) { return t->size; }
void pull(Treap *t) {
    if (!size(t)) return;
    t->size = size(t->l) + size(t->r) + 1;
}

Treap* merge(Treap *a, Treap *b) {
    if (!size(a)) return b;
    if (!size(b)) return a;
    Treap *t;
    if (rand() % (size(a) + size(b)) < size(a)) {
        t = new (Treap::pmem++) Treap(*a);
        t->r = merge(a->r, b);
    } else {
        t = new (Treap::pmem++) Treap(*b);
        t->l = merge(a, b->l);
    }
}
```

```

    }
    pull(t);
    return t;
}

void split(Treap *t, int k, Treap *&a, Treap *&b) {
    if (!size(t)) a = b = &Treap::nil;
    else if (size(t->l) + 1 <= k) {
        a = new (Treap::pmem++) Treap(*t);
        split(t->r, k - size(t->l) - 1, a->r, b);
        pull(a);
    } else {
        b = new (Treap::pmem++) Treap(*t);
        split(t->l, k, a, b->l);
        pull(b);
    }
}

int nv;
Treap *rt[50005];

void print(const Treap *t) {
    if (!size(t)) return;
    print(t->l);
    cout << t->val;
    print(t->r);
}

int main(int argc, char** argv) {
    IOS;
    rt[nv=0] = &Treap::nil;
    Treap::pmem = Treap::mem;
    int Q, cmd, p, c, v;
    string s;
    cin >> Q;
    while (Q--) {
        cin >> cmd;
        if (cmd == 1) {
            // insert string s after position p
            cin >> p >> s;
            Treap *tl, *tr;
            split(rt[nv], p, tl, tr);
            for (int i=0; i<SZ(s); i++)
                tl = merge(tl, new (Treap::pmem++) Treap(s[i]));
            rt[++nv] = merge(tl, tr);
        } else if (cmd == 2) {
            // remove c characters starting at position
            Treap *tl, *tm, *tr;
            cin >> p >> c;
            split(rt[nv], p-1, tl, tm);
            split(tm, c, tm, tr);
            rt[++nv] = merge(tl, tr);
        } else if (cmd == 3) {
            // print c characters starting at position p, in
            // version v
            Treap *tl, *tm, *tr;
            cin >> v >> p >> c;
            split(rt[v], p-1, tl, tm);
            split(tm, c, tm, tr);
            print(tm);
            cout << "\n";
        }
    }
    return 0;
}

```

2.7 Heavy Light Decomposition

```

// only one segment tree / 0-base
// should call init after input N
// getPathSeg return the segment in order u->v
// fa[root] = root

typedef pair<int,int> pii;

int N, fa[MXN], belong[MXN], dep[MXN], sz[MXN], que[MXN];
int step, line[MXN], stPt[MXN], edPt[MXN];
vector<int> E[MXN], chain[MXN];

void init() {
    REP(i, N) {
        E[i].clear();
        chain[i].clear();
    }
}

```

```

}

void DFS(int u) {
    vector<int> &c = chain[belong[u]];
    for (int i=c.size()-1; i>=0; i--){
        int v = c[i];
        stPt[v] = step;
        line[step++] = v;
    }
    for (int i=0; i<(int)c.size(); i++){
        u = c[i];
        for (auto v : E[u]){
            if (fa[u] == v || (i && v == c[i-1])) continue;
            DFS(v);
        }
        edPt[u] = step-1;
    }
}

void build_chain(int st) {
    int fr, bk;
    fr=bk=0; que[bk++]=st; fa[st]=st; dep[st]=0;
    while (fr < bk){
        int u=que[fr++];
        for (auto v : E[u]){
            if (v == fa[u]) continue;
            que[bk++] = v;
            dep[v] = dep[u]+1;
            fa[v] = u;
        }
    }
    for (int i=bk-1, u, pos; i>=0; i--){
        u = que[i]; sz[u] = 1; pos = -1;
        for (auto v : E[u]){
            if (v == fa[u]) continue;
            sz[u] += sz[v];
            if (pos==-1 || sz[v]>sz[pos]) pos=v;
        }
        if (pos == -1) belong[u] = u;
        else belong[u] = belong[pos];
        chain[belong[u]].PB(u);
    }
    step = 0;
    DFS(st);
}

int getLCA(int u, int v) {
    while (belong[u] != belong[v]){
        int a = chain[belong[u]].back();
        int b = chain[belong[v]].back();
        if (dep[a] > dep[b]) u = fa[a];
        else v = fa[b];
    }
    return sz[u] >= sz[v] ? u : v;
}

vector<pii> getPathSeg(int u, int v) {
    vector<pii> ret1, ret2;
    while (belong[u] != belong[v]){
        int a = chain[belong[u]].back();
        int b = chain[belong[v]].back();
        if (dep[a] > dep[b]){
            ret1.PB({stPt[a], stPt[u]});
            u = fa[a];
        } else {
            ret2.PB({stPt[b], stPt[v]});
            v = fa[b];
        }
    }
    if (dep[u] > dep[v]) swap(u, v);
    ret1.PB({stPt[u], stPt[v]});
    reverse(ret2.begin(), ret2.end());
    ret1.insert(ret1.end(), ret2.begin(), ret2.end());
    return ret1;
}

// Usage
void build() {
    build_chain(0); //change root
    init(0, step, 0); //init segment tree
}

int get_answer(int u, int v) {
    int ret = -2147483647;
    vector<pii> vec = getPathSeg(u, v);
    for (auto it : vec)
        // check answer with segment [it.F, it.S]
    return ret;
}

```

2.8 Link-Cut Tree

```

const int MXN = 100005;
const int MEM = 100005;

struct Splay {
    static Splay nil, mem[MEM], *pmem;
    Splay *ch[2], *f;
    int val, rev, size;
    Splay () : val(-1), rev(0), size(0) {
        f = ch[0] = ch[1] = &nil;
    }
    Splay (int _val) : val(_val), rev(0), size(1) {
        f = ch[0] = ch[1] = &nil;
    }
    bool isr() {
        return f->ch[0] != this && f->ch[1] != this;
    }
    int dir() {
        return f->ch[0] == this ? 0 : 1;
    }
    void setCh(Splay *c, int d) {
        ch[d] = c;
        if (c != &nil) c->f = this;
        pull();
    }
    void push() {
        if (rev) {
            swap(ch[0], ch[1]);
            if (ch[0] != &nil) ch[0]->rev ^= 1;
            if (ch[1] != &nil) ch[1]->rev ^= 1;
            rev=0;
        }
    }
    void pull() {
        size = ch[0]->size + ch[1]->size + 1;
        if (ch[0] != &nil) ch[0]->f = this;
        if (ch[1] != &nil) ch[1]->f = this;
    }
} Splay::nil, Splay::mem[MEM], *Splay::pmem = Splay::mem;
Splay *nil = &Splay::nil;

void rotate(Splay *x) {
    Splay *p = x->f;
    int d = x->dir();
    if (!p->isr()) p->f->setCh(x, p->dir());
    else x->f = p->f;
    p->setCh(x->ch[!d], d);
    x->setCh(p, !d);
    p->pull(); x->pull();
}

vector<Splay*> splayVec;
void splay(Splay *x) {
    splayVec.clear();
    for (Splay *q=x;; q=q->f) {
        splayVec.push_back(q);
        if (q->isr()) break;
    }
    reverse(begin(splayVec), end(splayVec));
    for (auto it : splayVec) it->push();
    while (!x->isr()) {
        if (x->f->isr()) rotate(x);
        else if (x->dir()==x->f->dir()) rotate(x->f), rotate(x);
        else rotate(x), rotate(x);
    }
}

Splay* access(Splay *x) {
    Splay *q = nil;
    for (;x!=nil;x=x->f) {
        splay(x);
        x->setCh(q, 1);
        q = x;
    }
    return q;
}

void evert(Splay *x) {
    access(x);
    splay(x);
    x->rev ^= 1;
    x->push(); x->pull();
}

void link(Splay*x, Splay *y) {

```

```

// evert(x);
access(x);
splay(x);
evert(y);
x->setCh(y, 1);
}

void cut(Splay *x, Splay *y) {
    // evert(x);
    access(y);
    splay(y);
    y->push();
    y->ch[0] = y->ch[0]->f = nil;
}

int N, Q;
Splay *vt[MXN];

int ask(Splay *x, Splay *y) {
    access(x);
    access(y);
    splay(x);
    int res = x->f->val;
    if (res == -1) res=x->val;
    return res;
}

int main(int argc, char** argv) {
    scanf("%d%d", &N, &Q);
    for (int i=1; i<=N; i++)
        vt[i] = new (Splay::pmem++) Splay(i);
    while (Q--) {
        char cmd[105];
        int u, v;
        scanf("%s", cmd);
        if (cmd[1] == 'i') {
            scanf("%d%d", &u, &v);
            link(vt[u], vt[v]);
        } else if (cmd[0] == 'c') {
            scanf("%d", &v);
            cut(vt[1], vt[v]);
        } else {
            scanf("%d%d", &u, &v);
            int res=ask(vt[u], vt[v]);
            printf("%d\n", res);
        }
    }

    return 0;
}

```

3 Graph

3.1 BCC Edge

```

struct BccEdge {
    static const int MXN = 100005;
    struct Edge { int v, eid; };
    int n, m, step, par[MXN], dfn[MXN], low[MXN];
    vector<Edge> E[MXN];
    DisjointSet djs;
    void init(int _n) {
        n = _n; m = 0;
        for (int i=0; i<n; i++) E[i].clear();
        djs.init(n);
    }
    void add_edge(int u, int v) {
        E[u].PB({v, m});
        E[v].PB({u, m});
        m++;
    }
    void DFS(int u, int f, int f_eid) {
        par[u] = f;
        dfn[u] = low[u] = step++;
        for (auto it:E[u]) {
            if (it.eid == f_eid) continue;
            int v = it.v;
            if (dfn[v] == -1) {
                DFS(v, u, it.eid);
                low[u] = min(low[u], low[v]);
            } else {
                low[u] = min(low[u], dfn[v]);
            }
        }
    }
}

```

```

}
void solve() {
    step = 0;
    memset(dfn, -1, sizeof(int)*n);
    for (int i=0; i<n; i++) {
        if (dfn[i] == -1) DFS(i, i, -1);
    }
    djs.init(n);
    for (int i=0; i<n; i++) {
        if (low[i] < dfn[i]) djs.uni(i, par[i]);
    }
}
}graph;

```

3.2 BCC Vertex

```

struct BccVertex {
    int n, nBcc, step, root, dfn[MXN], low[MXN];
    vector<int> E[MXN], ap;
    vector<pii> bcc[MXN];
    int top;
    pii stk[MXN];
    void init(int _n) {
        n = _n;
        nBcc = step = 0;
        for (int i=0; i<n; i++) E[i].clear();
    }
    void add_edge(int u, int v) {
        E[u].PB(v);
        E[v].PB(u);
    }
    void DFS(int u, int f) {
        dfn[u] = low[u] = step++;
        int son = 0;
        for (auto v:E[u]) {
            if (v == f) continue;
            if (dfn[v] == -1) {
                son++;
                stk[top++] = {u,v};
                DFS(v,u);
                if (low[v] >= dfn[u]) {
                    if (v != root) ap.PB(v);
                    do {
                        assert(top > 0);
                        bcc[nBcc].PB(stk[--top]);
                    } while (stk[top] != pii(u,v));
                    nBcc++;
                }
                low[u] = min(low[u], low[v]);
            } else {
                if (dfn[v] < dfn[u]) stk[top++] = pii(u,v);
                low[u] = min(low[u], dfn[v]);
            }
        }
        if (u == root && son > 1) ap.PB(u);
    }
    // return the edges of each bcc;
    vector<vector<pii>> solve() {
        vector<vector<pii>> res;
        for (int i=0; i<n; i++) {
            dfn[i] = low[i] = -1;
        }
        ap.clear();
        for (int i=0; i<n; i++) {
            if (dfn[i] == -1) {
                top = 0;
                root = i;
                DFS(i,i);
            }
        }
        REP(i, nBcc) res.PB(bcc[i]);
        return res;
    }
}graph;

```

3.3 Strongly Connected Components

```

struct Scc{
    int n, nScc, vst[MXN], bln[MXN];
    vector<int> E[MXN], rE[MXN], vec;
    void init(int _n){
        n = _n;

```

```

        for (int i=0; i<n; i++){
            E[i].clear();
            rE[i].clear();
        }
    }
    void add_edge(int u, int v){
        E[u].PB(v);
        rE[v].PB(u);
    }
    void DFS(int u){
        vst[u]=1;
        for (auto v : E[u])
            if (!vst[v]) DFS(v);
        vec.PB(u);
    }
    void rDFS(int u){
        vst[u] = 1;
        bln[u] = nScc;
        for (auto v : rE[u])
            if (!vst[v]) rDFS(v);
    }
    void solve(){
        nScc = 0;
        vec.clear();
        for (int i=0; i<n; i++) vst[i] = 0;
        for (int i=0; i<n; i++)
            if (!vst[i]) DFS(i);
        reverse(vec.begin(), vec.end());
        for (int i=0; i<n; i++) vst[i] = 0;
        for (auto v : vec){
            if (!vst[v]){
                rDFS(v);
                nScc++;
            }
        }
    }
}
};

```

3.4 DMST_with_sol

```

const int INF = 1029384756;

struct edge_t{
    int u,v,w;
    set< pair<int,int> > add, sub;
    edge_t() : u(-1), v(-1), w(0) {}
    edge_t(int _u, int _v, int _w) {
        u = _u; v = _v; w = _w;
        add.insert({u, v});
    }
    edge_t& operator += (const edge_t& obj) {
        w += obj.w;
        FOR (it, obj.add) {
            if (!sub.count(*it)) add.insert(*it);
            else sub.erase(*it);
        }
        FOR (it, obj.sub) {
            if (!add.count(*it)) sub.insert(*it);
            else add.erase(*it);
        }
        return *this;
    }
    edge_t& operator -= (const edge_t& obj) {
        w -= obj.w;
        FOR (it, obj.sub) {
            if (!sub.count(*it)) add.insert(*it);
            else sub.erase(*it);
        }
        for (auto it : obj.add) {
            if (!add.count(it)) sub.insert(it);
            else add.erase(it);
        }
        return *this;
    }
}
}eg[MXN*MXN], prv[MXN], EDGE_INF(-1,-1,INF);
int N,M;
int cid, incyc[MXN], contracted[MXN];
vector<int> E[MXN];

edge_t dmst(int rt){
    edge_t cost;
    for (int i=0; i<N; i++){
        contracted[i] = incyc[i] = 0;
        prv[i] = EDGE_INF;

```

```

}
cid = 0;
int u,v;
while (true){
    for (v=0; v<N; v++){
        if (v != rt && !contracted[v] && prv[v].w == INF)
            break;
    }
    if (v >= N) break; // end
    for (int i=0; i<M; i++){
        if (eg[i].v == v && eg[i].w < prv[v].w)
            prv[v] = eg[i];
    }
    if (prv[v].w == INF) // not connected
        return EDGE_INF;
    cost += prv[v];
    for (u=prv[v].u; u!=v && u!=-1; u=prv[u].u);
    if (u == -1) continue;
    incyc[v] = ++cid;
    for (u=prv[v].u; u!=v; u=prv[u].u){
        contracted[u] = 1;
        incyc[u] = cid;
    }
    for (int i=0; i<M; i++){
        if (incyc[eg[i].u] != cid && incyc[eg[i].v] == cid){
            eg[i] -= prv[eg[i].v];
        }
    }
    for (int i=0; i<M; i++){
        if (incyc[eg[i].u] == cid) eg[i].u = v;
        if (incyc[eg[i].v] == cid) eg[i].v = v;
        if (eg[i].u == eg[i].v) eg[i--] = eg[--M];
    }
    for (int i=0; i<N; i++){
        if (contracted[i]) continue;
        if (prv[i].u>=0 && incyc[prv[i].u] == cid)
            prv[i].u = v;
    }
    prv[v] = EDGE_INF;
}
return cost;
}

void solve(){
    edge_t cost = dmst(0);
    for (auto it : cost.add){ // find a solution
        E[it.F].PB(it.S);
        prv[it.S] = edge_t(it.F,it.S,0);
    }
}
}

```

```

REP1(i,1,n) {
    g[i].clear();
    pred[i].clear();
    idom[i] = 0;
}
}

void add_edge(int u, int v) {
    g[u].push_back(v);
    pred[v].push_back(u);
}

void DFS(int u) {
    ts++;
    dfn[u] = ts;
    nfd[ts] = u;
    for(int v:g[u]) if(dfn[v] == 0) {
        par[v] = u;
        DFS(v);
    }
}

void build() {
    ts = 0;
    REP1(i,1,n) {
        dfn[i] = nfd[i] = 0;
        cov[i].clear();
        mom[i] = mn[i] = sdom[i] = i;
    }
    DFS(s);
    for (int i=ts; i>=2; i--) {
        int u = nfd[i];
        if(u == 0) continue;
        for(int v:pred[u]) if(dfn[v]) {
            eval(v);
            if(cmp(sdom[mn[v]],sdom[u])) sdom[u] = sdom[mn[v]];
        }
        cov[sdom[u]].push_back(u);
        mom[u] = par[u];
        for(int w:cov[par[u]]) {
            eval(w);
            if(cmp(sdom[mn[w]],par[u])) idom[w] = mn[w];
            else idom[w] = par[u];
        }
        cov[par[u]].clear();
    }
    REP1(i,2,ts) {
        int u = nfd[i];
        if(u == 0) continue;
        if(idom[u] != sdom[u]) idom[u] = idom[idom[u]];
    }
}
}dom;

```

3.5 Dominator Tree

```

// idom[n] is the unique node that strictly dominates n
// but does
// not strictly dominate any other node that strictly
// dominates n.
// idom[n] = 0 if n is entry or the entry cannot reach
// n.
struct DominatorTree{
    static const int MAXN = 200010;
    int n,s;
    vector<int> g[MAXN],pred[MAXN];
    vector<int> cov[MAXN];
    int dfn[MAXN],nfd[MAXN],ts;
    int par[MAXN];
    int sdom[MAXN],idom[MAXN];
    int mom[MAXN],mn[MAXN];

    inline bool cmp(int u,int v) { return dfn[u] < dfn[v]; }

    int eval(int u) {
        if(mom[u] == u) return u;
        int res = eval(mom[u]);
        if(cmp(sdom[mn[mom[u]]],sdom[mn[u]]))
            mn[u] = mn[mom[u]];
        return mom[u] = res;
    }

    void init(int _n, int _s) {
        n = _n;
        s = _s;
    }
}

```

3.6 Maximum Clique

```

class MaxClique {
public:
    static const int MV = 210;

    int V;
    int el[MV][MV/30+1];
    int dp[MV];
    int ans;
    int s[MV][MV/30+1];
    vector<int> sol;

    void init(int v) {
        V = v; ans = 0;
        FZ(el); FZ(dp);
    }

    /* Zero Base */
    void addEdge(int u, int v) {
        if(u > v) swap(u, v);
        if(u == v) return;
        el[u][v/32] |= (1<<(v%32));
    }

    bool dfs(int v, int k) {
        int c = 0, d = 0;
        for(int i=0; i<(V+31)/32; i++) {
            s[k][i] = el[v][i];
            if(k != 1) s[k][i] &= s[k-1][i];
            c += __builtin_popcount(s[k][i]);
        }
    }
}

```

```

    if(c == 0) {
        if(k > ans) {
            ans = k;
            sol.clear();
            sol.push_back(v);
            return 1;
        }
        return 0;
    }
    for(int i=0; i<(V+31)/32; i++) {
        for(int a = s[k][i]; a ; d++) {
            if(k + (c-d) <= ans) return 0;
            int lb = a&(-a), lg = 0;
            a ^= lb;
            while(lb!=1) {
                lb = (unsigned int)(lb) >> 1;
                lg ++;
            }
            int u = i*32 + lg;
            if(k + dp[u] <= ans) return 0;
            if(dfs(u, k+1)) {
                sol.push_back(v);
                return 1;
            }
        }
    }
    return 0;
}

int solve() {
    for(int i=V-1; i>=0; i--) {
        dfs(i, 1);
        dp[i] = ans;
    }
    return ans;
}
};

```

3.7 MinimumMeanCycle

```

/* minimum mean cycle */
const int MAXE = 1805;
const int MAXN = 35;
const double inf = 1029384756;
const double eps = 1e-6;
struct Edge {
    int v,u;
    double c;
};
int n,m,prv[MAXN][MAXN], prve[MAXN][MAXN], vst[MAXN];
Edge e[MAXE];
vector<int> edgeID, cycle, rho;
double d[MAXN][MAXN];
inline void bellman_ford() {
    for(int i=0; i<n; i++) d[0][i]=0;
    for(int i=0; i<n; i++) {
        fill(d[i+1], d[i+1]+n, inf);
        for(int j=0; j<m; j++) {
            int v = e[j].v, u = e[j].u;
            if(d[i][v]<inf && d[i+1][u]>d[i][v]+e[j].c) {
                d[i+1][u] = d[i][v]+e[j].c;
                prv[i+1][u] = v;
                prve[i+1][u] = j;
            }
        }
    }
}
double karp_mmc() {
    // returns inf if no cycle, mmc otherwise
    double mmc=inf;
    int st = -1;
    bellman_ford();
    for(int i=0; i<n; i++) {
        double avg=-inf;
        for(int k=0; k<n; k++) {
            if(d[n][i]<inf-eps) avg=max(avg,(d[n][i]-d[k][i])/(n-k));
            else avg=max(avg,inf);
        }
        if (avg < mmc) tie(mmc, st) = tie(avg, i);
    }
    for(int i=0; i<n; i++) vst[i] = 0;
    edgeID.clear(); cycle.clear(); rho.clear();
    for (int i=n;!vst[st]; st=prv[i--][st]) {

```

```

        vst[st]++;
        edgeID.PB(prve[i][st]);
        rho.PB(st);
    }
    while (vst[st] != 2) {
        int v = rho.back(); rho.pop_back();
        cycle.PB(v);
        vst[v]++;
    }
    reverse(ALL(edgeID));
    edgeID.resize(SZ(cycle));
    return mmc;
}

```

4 Flow

4.1 Dinic

```

struct Dinic{
    static const int MXN = 10000;
    struct Edge{ int v,f,re; };
    int n,s,t,level[MXN];
    vector<Edge> E[MXN];
    void init(int _n, int _s, int _t){
        n = _n; s = _s; t = _t;
        for (int i=0; i<n; i++) E[i].clear();
    }
    void add_edge(int u, int v, int f){
        E[u].PB({v,f,SZ(E[v])});
        E[v].PB({u,0,SZ(E[u])-1});
    }
    bool BFS(){
        for (int i=0; i<n; i++) level[i] = -1;
        queue<int> que;
        que.push(s);
        level[s] = 0;
        while (!que.empty()){
            int u = que.front(); que.pop();
            for (auto it : E[u]){
                if (it.f > 0 && level[it.v] == -1){
                    level[it.v] = level[u]+1;
                    que.push(it.v);
                }
            }
        }
        return level[t] != -1;
    }
    int DFS(int u, int nf){
        if (u == t) return nf;
        int res = 0;
        for (auto &it : E[u]){
            if (it.f > 0 && level[it.v] == level[u]+1){
                int tf = DFS(it.v, min(nf,it.f));
                res += tf; nf -= tf; it.f -= tf;
                E[it.v][it.re].f += tf;
                if (nf == 0) return res;
            }
        }
        if (!res) level[u] = -1;
        return res;
    }
    int flow(int res=0){
        while (BFS())
            res += DFS(s,2147483647);
        return res;
    }
}flow;

```

4.2 Cost Flow

```

typedef pair<long long, long long> pll;
struct CostFlow {
    static const int MXN = 205;
    static const long long INF = 102938475610293847LL;
    struct Edge {
        int v, r;
        long long f, c;
    };
    int n, s, t, prv[MXN], prvl[MXN], inq[MXN];
    long long dis[MXN], fl, cost;

```



```

vector<Edge> E[MXN];
void init(int _n, int _s, int _t) {
    n = _n; s = _s; t = _t;
    for (int i=0; i<n; i++) E[i].clear();
    fl = cost = 0;
}
void add_edge(int u, int v, long long f, long long c) {
    E[u].PB({v, SZ(E[v]), f, c});
    E[v].PB({u, SZ(E[u])-1, 0, -c});
}
pll flow() {
    while (true) {
        for (int i=0; i<n; i++) {
            dis[i] = INF;
            inq[i] = 0;
        }
        dis[s] = 0;
        queue<int> que;
        que.push(s);
        while (!que.empty()) {
            int u = que.front(); que.pop();
            inq[u] = 0;
            for (int i=0; i<SZ(E[u]); i++) {
                int v = E[u][i].v;
                long long w = E[u][i].c;
                if (E[u][i].f > 0 && dis[v] > dis[u] + w) {
                    prv[v] = u; prvl[v] = i;
                    dis[v] = dis[u] + w;
                    if (!inq[v]) {
                        inq[v] = 1;
                        que.push(v);
                    }
                }
            }
        }
        if (dis[t] == INF) break;
        long long tf = INF;
        for (int v=t, u, l; v!=s; v=u) {
            u=prv[v]; l=prvl[v];
            tf = min(tf, E[u][l].f);
        }
        for (int v=t, u, l; v!=s; v=u) {
            u=prv[v]; l=prvl[v];
            E[u][l].f -= tf;
            E[v][E[u][l].r].f += tf;
        }
        cost += tf * dis[t];
        fl += tf;
    }
    return {fl, cost};
}
}
}flow;

```

4.3 Kuhn Munkres - $O(n^3)$

```

#define MAXN 100
#define INF INT_MAX
int g[MAXN][MAXN], lx[MAXN], ly[MAXN], slack_y[MAXN];
int px[MAXN], py[MAXN], match_y[MAXN], par[MAXN];
int n;
void adjust(int y){//把增廣路上所有邊反轉
    match_y[y]=py[y];
    if(px[match_y[y]]!=-2)
        adjust(px[match_y[y]]);
}
bool dfs(int x){//DFS找增廣路
    for(int y=0;y<n;++y){
        if(py[y]==-1)continue;
        int t=lx[x]+ly[y]-g[x][y];
        if(t==0){
            py[y]=x;
            if(match_y[y]==-1){
                adjust(y);
                return 1;
            }
            if(px[match_y[y]]!=-1)continue;
            px[match_y[y]]=y;
            if(dfs(match_y[y]))return 1;
        }else if(slack_y[y]>t){
            slack_y[y]=t;
            par[y]=x;
        }
    }
}

```

```

return 0;
}
inline int km(){
    memset(ly,0,sizeof(int)*n);
    memset(match_y,-1,sizeof(int)*n);
    for(int x=0;x<n;++x){
        lx[x]=-INF;
        for(int y=0;y<n;++y){
            lx[x]=max(lx[x],g[x][y]);
        }
    }
    for(int x=0;x<n;++x){
        for(int y=0;y<n;++y)slack_y[y]=INF;
        memset(px,-1,sizeof(int)*n);
        memset(py,-1,sizeof(int)*n);
        px[x]=-2;
        if(dfs(x))continue;
        bool flag=1;
        while(flag){
            int cut=INF;
            for(int y=0;y<n;++y)
                if(py[y]==-1&&cut>slack_y[y])cut=slack_y[y];
            for(int j=0;j<n;++j){
                if(px[j]==-1)lx[j]-=cut;
                if(py[j]==-1)ly[j]+=cut;
                else slack_y[j]-=cut;
            }
            for(int y=0;y<n;++y){
                if(py[y]==-1&&slack_y[y]==0){
                    py[y]=par[y];
                    if(match_y[y]==-1){
                        adjust(y);
                        flag=0;
                        break;
                    }
                }
                px[match_y[y]]=y;
                if(dfs(match_y[y])){
                    flag=0;
                    break;
                }
            }
        }
    }
    int ans=0;
    for(int y=0;y<n;++y)if(g[match_y[y]][y]!=-INF)ans+=g[match_y[y]][y];
    return ans;
}

```

4.4 SW-Mincut

```

struct SW{ //  $O(V^3)$  0-base
    static const int MXN = 514;
    int n,vst[MXN],del[MXN];
    int edge[MXN][MXN],wei[MXN];
    void init(int _n){
        n = _n;
        for (int i=0; i<n; i++) {
            for (int j=0; j<n; j++)
                edge[i][j] = 0;
            del[i] = 0;
        }
    }
    void add_edge(int u, int v, int w){
        edge[u][v] += w;
        edge[v][u] += w;
    }
    void search(int &s, int &t){
        for (int i=0; i<n; i++)
            vst[i] = wei[i] = 0;
        s = t = -1;
        while (true){
            int mx=-1, cur=0;
            for (int i=0; i<n; i++)
                if (!del[i] && !vst[i] && mx<wei[i])
                    cur = i, mx = wei[i];
            if (mx == -1) break;
            vst[cur] = 1;
            s = t;
            t = cur;
            for (int i=0; i<n; i++)
                if (!vst[i] && !del[i]) wei[i] += edge[cur][i];
        }
    }
}

```

```

}
int solve(){
    int res = 2147483647;
    for (int i=0,x,y; i<n-1; i++){
        search(x,y);
        res = min(res,wei[y]);
        del[y] = 1;
        for (int j=0; j<n; j++){
            edge[x][j] = (edge[j][x] += edge[y][j]);
        }
        return res;
    }
}graph;

```

4.5 Maximum Simple Graph Matching

```

struct GenMatch { // 1-base
    static const int MAXN = 514;
    int V;
    bool el[MAXN][MAXN];
    int pr[MAXN];
    bool inq[MAXN],inp[MAXN],inb[MAXN];
    queue<int> qe;
    int st,ed;
    int nb;
    int bk[MAXN],djs[MAXN];
    int ans;
    void init(int _V) {
        V = _V;
        for(int i = 0; i <= V; i++) {
            for(int j = 0; j <= V; j++) el[i][j] = 0;
            pr[i] = bk[i] = djs[i] = 0;
            inq[i] = inp[i] = inb[i] = 0;
        }
        ans = 0;
    }
    void add_edge(int u, int v) {
        el[u][v] = el[v][u] = 1;
    }
    int lca(int u,int v) {
        for(int i = 0; i <= V; i++) inp[i] = 0;
        while(1) {
            u = djs[u];
            inp[u] = true;
            if(u == st) break;
            u = bk[pr[u]];
        }
        while(1) {
            v = djs[v];
            if(inp[v]) return v;
            v = bk[pr[v]];
        }
        return v;
    }
    void upd(int u) {
        int v;
        while(djs[u] != nb) {
            v = pr[u];
            inb[djs[u]] = inb[djs[v]] = true;
            u = bk[v];
            if(djs[u] != nb) bk[u] = v;
        }
    }
    void blo(int u,int v) {
        nb = lca(u,v);
        for (int i=0; i<=V; i++) inb[i] = 0;
        upd(u); upd(v);
        if(djs[u] != nb) bk[u] = v;
        if(djs[v] != nb) bk[v] = u;
        for(int tu = 1; tu <= V; tu++){
            if(inb[djs[tu]]) {
                djs[tu] = nb;
                if(!inq[tu]){
                    qe.push(tu);
                    inq[tu] = 1;
                }
            }
        }
    }
    void flow() {
        for(int i = 1; i <= V; i++) {
            inq[i] = 0;
            bk[i] = 0;
            djs[i] = i;
        }
    }

```

```

        while(qe.size()) qe.pop();
        qe.push(st);
        inq[st] = 1;
        ed = 0;
        while(qe.size()) {
            int u = qe.front(); qe.pop();
            for(int v = 1; v <= V; v++){
                if(el[u][v] && (djs[u] != djs[v]) && (pr[u] != v)) {
                    if((v == st) || ((pr[v] > 0) && bk[pr[v]] > 0))
                        blo(u,v);
                    else if(bk[v] == 0) {
                        bk[v] = u;
                        if(pr[v] > 0) {
                            if(!inq[pr[v]]) qe.push(pr[v]);
                        } else {
                            ed = v;
                            return;
                        }
                    }
                }
            }
        }
    }
    void aug() {
        int u,v,w;
        u = ed;
        while(u > 0) {
            v = bk[u];
            w = pr[v];
            pr[v] = u;
            pr[u] = v;
            u = w;
        }
    }
    int solve() {
        for(int i = 0; i <= V; i++) pr[i] = 0;
        for(int u = 1; u <= V; u++){
            if(pr[u] == 0) {
                st = u;
                flow();
                if(ed > 0) {
                    aug();
                    ans ++;
                }
            }
        }
        return ans;
    }
}G;

int main() {
    G.init(V);
    for(int i=0; i<E; i++) {
        int u, v;
        cin >> u >> v;
        G.add_edge(u, v);
    }
    cout << G.solve() << endl;
}

```

4.6 Minimum Weight Matching (Clique version)

```

struct Graph {
    // Minimum General Weighted Matching (Perfect Match)
    // 0-base
    static const int MXN = 105;

    int n, edge[MXN][MXN];
    int match[MXN],dis[MXN],onstk[MXN];
    vector<int> stk;

    void init(int _n) {
        n = _n;
        for (int i=0; i<n; i++)
            for (int j=0; j<n; j++)
                edge[i][j] = 0;
    }
    void add_edge(int u, int v, int w) {
        edge[u][v] = edge[v][u] = w;
    }
    bool SPFA(int u){
        if (onstk[u]) return true;
        stk.PB(u);
    }

```

```

onstk[u] = 1;
for (int v=0; v<n; v++){
    if (u != v && match[u] != v && !onstk[v]){
        int m = match[v];
        if (dis[m] > dis[u] - edge[v][m] + edge[u][v]){
            dis[m] = dis[u] - edge[v][m] + edge[u][v];
            onstk[v] = 1;
            stk.PB(v);
            if (SPFA(m)) return true;
            stk.pop_back();
            onstk[v] = 0;
        }
    }
}
onstk[u] = 0;
stk.pop_back();
return false;
}

int solve() {
    // find a match
    for (int i=0; i<n; i+=2){
        match[i] = i+1;
        match[i+1] = i;
    }
    while (true){
        int found = 0;
        for (int i=0; i<n; i++){
            dis[i] = onstk[i] = 0;
        }
        for (int i=0; i<n; i++){
            stk.clear();
            if (!onstk[i] && SPFA(i)){
                found = 1;
                while (SZ(stk)>=2){
                    int u = stk.back(); stk.pop_back();
                    int v = stk.back(); stk.pop_back();
                    match[u] = v;
                    match[v] = u;
                }
            }
        }
        if (!found) break;
    }
    int ret = 0;
    for (int i=0; i<n; i++){
        ret += edge[i][match[i]];
    }
    ret /= 2;
    return ret;
}
}graph;

```

4.7 General Graph Matching

```

// {{ general graph matching template
#define MAXN 505
vector<int> g[MAXN];
int pa[MAXN], match[MAXN], st[MAXN], S[MAXN], vis[
    MAXN];
int n;
inline int lca(int u, int v){
    static int t=0;
    for(++t; swap(u,v);){
        if(u==0) continue;
        if(vis[u]==t) return u;
        vis[u]=t;
        u=st[pa[match[u]]];
    }
}
#define qpush(u) q.push(u), S[u]=0
inline void flower(int u, int v, int l, queue<int> &q){
    while(st[u]!=l){
        pa[u]=v;
        v=match[u];
        if(S[v]==1) qpush(v);
        st[u]=st[v]=l;
        u=pa[v];
    }
}
inline bool agument(int u, int v){
    for(int lst; u=v=lst, u=pa[v]){
        lst=match[u];
        match[u]=v;
        match[v]=u;
    }
}

```

```

}
inline bool bfs(int u){
    for(int i=1; i<=n; ++i) st[i]=i;
    memset(S+1, -1, sizeof(int)*n);
    queue<int> q;
    qpush(u);
    while(q.size()){
        u=q.front(), q.pop();
        for(size_t i=0; i<g[u].size(); ++i){
            int v=g[u][i];
            if(S[v]==-1){
                pa[v]=u;
                S[v]=1;
                if(!match[v]){
                    agument(u,v);
                    return true;
                }
                qpush(match[v]);
            } else if(!S[v] && st[v]!=st[u]){
                int l=lca(v,u);
                flower(v,u,l,q);
                flower(u,v,l,q);
            }
        }
    }
    return false;
}
inline int blossom(){
    memset(pa+1, 0, sizeof(int)*n);
    memset(match+1, 0, sizeof(int)*n);
    int ans=0;
    for(int i=1; i<=n; ++i)
        if(!match[i] && bfs(i)) ++ans;
    return ans;
}
int main() {
    int t;
    RI(t);
    while(t--){
        int m;
        RI(n, m);
        REP1(i, 1, n) g[i].clear();
        REP(i, m){
            int x, y;
            RI(x, y);
            x++, y++;
            g[x].PB(y);
            g[y].PB(x);
        }
        PL(blossom());
    }
    return 0;
}

```

4.8 (+1) SW-mincut $O(NM)$

```

// {{ StoerWagner
const int inf=1000000000;
// should be larger than max.possible mincut
class StoerWagner {
public:
    int n, mc; // node id in [0, n-1]
    vector<int> adj[MAXN];
    int cost[MAXN][MAXN];
    int cs[MAXN];
    bool merged[MAXN], sel[MAXN];
    // --8-- include only if cut is explicitly needed
    DisjointSet djs;
    vector<int> cut;
    // --8--
    StoerWagner(int _n: n(_n), mc(inf), djs(_n)) {
        for(int i=0; i<n; ++i)
            merged[i]=0;
        for(int i=0; i<n; ++i)
            for(int j=0; j<n; ++j)
                cost[i][j]=cost[j][i]=0;
    }
    void append(int v, int u, int c) {
        if(v==u) return;
        if(!cost[v][u] && c) {
            adj[v].PB(u);
            adj[u].PB(v);
        }
        cost[v][u]+=c;
    }
}

```

```

    cost[u][v]+=c;
}
void merge(int v,int u) {
    merged[u]=1;
    for(int i=0;i<n;i++)
        append(v,i,cost[u][i]);
    // --8<-- include only if cut is explicitly
    //      needed
    djs.merge(v,u);
    //      --8<-----
}
void phase() {
    priority_queue<pii> pq;
    for(int v=0;v<n;v++) {
        if(merged[v]) continue;
        cs[v]=0;
        sel[v]=0;
        pq.push({0,v});
    }
    int v,s,pv;
    while(pq.size()) {
        if(cs[pq.top().S]>pq.top().F) {
            pq.pop();
            continue;
        }
        pv=v;
        v=pq.top().S;
        s=pq.top().F;
        pq.pop();
        sel[v]=1;
        for(int i=0;i<adj[v].size();i++) {
            int u=adj[v][i];
            if(merged[u]||sel[u]) continue;
            cs[u]+=cost[v][u];
            pq.push({cs[u],u});
        }
    }
    if(s<mc) {
        mc=s;
        // --8<-- include only if cut is explicitly
        //      needed -----
        cut.clear();
        for(int i=0;i<n;i++)
            if(djs.getrep(i)==djs.getrep(v)) cut.pb(i);
        // --8<-----
    }
    merge(v,pv);
}
int mincut() {
    if(mc==inf) {
        for(int t=0;t<n-1;t++)
            phase();
    }
    return mc;
}
// --8<-- include only if cut is explicitly needed
// -----
vector<int> getcut() { // return one side of the
    //      cut
    mincut();
    return cut;
}
// --8<-----
};
// }}}

```

5 Math

5.1 ax+by=gcd

```

typedef pair<int, int> pii;

pii gcd(int a, int b){
    if(b == 0) return make_pair(1, 0);
    else{
        int p = a / b;
        pii q = gcd(b, a % b);
        return make_pair(q.second, q.first - q.second * p);
    }
}

```

5.2 Fast Fourier Transform

```

// const int MAXN = 262144;
// (must be 2^k)

typedef long double ld;
typedef complex<ld> cplx;
const ld PI = acos(-1);
const cplx I(0, 1);

cplx omega[MAXN+1];
void pre_fft()
{
    for(int i=0; i<=MAXN; i++)
        omega[i] = exp(i * 2 * PI / MAXN * I);
}
void fft(int n, cplx a[], bool inv=false)
{
    int basic = MAXN / n;
    int theta = basic;
    for (int m = n; m >= 2; m >= 1) {
        int mh = m >> 1;
        for (int i = 0; i < mh; i++) {
            cplx w = omega[inv ? MAXN-(i*theta%MAXN) : i*
                theta%MAXN];
            for (int j = i; j < n; j += m) {
                int k = j + mh;
                cplx x = a[j] - a[k];
                a[j] += a[k];
                a[k] = w * x;
            }
            theta = (theta * 2) % MAXN;
        }
    }
    int i = 0;
    for (int j = 1; j < n - 1; j++) {
        for (int k = n >> 1; k > (i ^ k); k >= 1);
        if (j < i) swap(a[i], a[j]);
    }
    if (inv)
        for (i = 0; i < n; i++)
            a[i] /= n;
}

// wangyenjen
typedef complex<double> cplx;
const double PI = acos(-1.0);
const int MAX_N = 1<<20;
void fft(cplx *a, int n, int dir) {
    static cplx tmp[MAX_N];
    if(n == 1) return;
    REP(i, n) tmp[i] = a[i];
    REP(i, n) a[(i&1) ? (n>>1) + (i>>1) : (i>>1)] =
        tmp[i];
    cplx *a1 = a, *a2 = a + (n>>1);
    fft(a1, n>>1, dir);
    fft(a2, n>>1, dir);
    cplx w_base(cos(2.0 * PI / (double)n), sin(2.0 *
        PI / (double)n));
    cplx w(1.0, 0.0);
    if(dir < 0) w_base = conj(w_base);
    for(int i = 0; (i<<1) < n; i++, w *= w_base) {
        tmp[i] = a1[i] + w * a2[i];
        tmp[(n>>1) + i] = a1[i] - w * a2[i];
    }
    REP(i, n) a[i] = tmp[i];
}

inline int mult(cplx *a, int la, cplx *b, int lb,
    cplx *c) {
    int n = 2;
    while(n < la + lb) n <= 1;
    REP1(i, la, n - 1) a[i] = cplx(0.0, 0.0);
    REP1(i, lb, n - 1) b[i] = cplx(0.0, 0.0);
    fft(a, n, 1);
    fft(b, n, 1);
    REP(i, n) c[i] = a[i] * b[i];
    fft(c, n, -1);
    REP(i, n) c[i] /= n;
    return la + lb - 1;
}

cplx a[MAX_N], b[MAX_N], c[MAX_N];
int main() {
    int n, m;
    RI(n, m);
    REP(i, n + 1) {
        int x;
    }
}

```

```

    RI(x);
    a[i] = cplx((double)x , 0.0);
}
REP(i , m + 1) {
    int x;
    RI(x);
    b[i] = cplx((double)x , 0.0);
}
int len = mult(a , n + 1 , b , m + 1 , c);
REP(i , len) printf("%d%c", (int)real(c[i] + 0.5), " |n
    "[i == len - 1]);
return 0;
}

```

5.3 Fast Linear Recurrence

```

ll n,m,dp[N+N];
void pre_dp(){
    dp[0]=1;
    ll bdr = min(m+m,n);
    for(ll i=1; i<=bdr; i++)
        for(ll j=i-1; j>=max(0ll,i-m); j--)
            dp[i]= add(dp[i],dp[j]);
}
vector<ll> Mul(const vector<ll>& v1,const vector<ll>&
    v2){
    int sz1 = (int)v1.size();
    int sz2 = (int)v2.size();
    assert(sz1 == m and sz2 == m);
    vector<ll> _v(m+m);
    for(int i=0; i<m+m; i++) _v[i]= 0;
    // expand
    for(int i=0; i<sz1; i++)
        for(int j=0; j<sz2; j++)
            _v[i+j+1]= add(_v[i+j+1],mul(v1[i],v2[j]));
    // shrink
    for(int i=0; i<m; i++)
        for(int j=1; j<=m; j++)
            _v[i + j]= add(_v[i + j],_v[i]);
    for(int i=0; i<m; i++)
        _v[i]= _v[i + m];
    _v.resize(m);
    return _v;
}
vector<ll> I,A;
ll solve(){
    pre_dp();
    if(n <= m+m)return dp[n];
    I.resize(m);
    A.resize(m);
    for(int i=0; i<m; i++) I[i]=A[i]=1;
    // dp[n]= /Sum_{i=0}^{m-1} A_i * dp[n - i - 1]
    ll dlt = (n - m) / m;
    ll rdlt = dlt * m;
    while(dlt){
        if(dlt & 1ll) I = Mul(I,A);
        A = Mul(A,A);
        dlt >= 1;
    }
    ll ans = 0;
    for(int i=0; i<m; i++)
        ans = add(ans,mul(I[i],dp[n-i-1-rdlt]));
    return ans;
}

```

5.4 (+1) ntt

```

int P=605028353,root=3,MAXNUM=262144;
// Remember coefficient are mod P
/*
p=a*2^n+1

```

n	2^n	p	a	root
5	32	97	3	5
6	64	193	3	5
7	128	257	2	3
8	256	257	1	3
9	512	7681	15	17
10	1024	12289	12	11
11	2048	12289	6	11
12	4096	12289	3	11
13	8192	40961	5	3
14	16384	65537	4	3

```

15 32768 65537 2 3
16 65536 65537 1 3
17 131072 786433 6 10
18 262144 786433 3 10 (605028353,
    2308, 3)
19 524288 5767169 11 3
20 1048576 7340033 7 3
21 2097152 23068673 11 3
22 4194304 104857601 25 3
23 8388608 167772161 20 3
24 16777216 167772161 10 3
25 33554432 167772161 5 3 (1107296257, 33,
    10)
26 67108864 469762049 7 3
27 134217728 2013265921 15 31
*/
int bigmod(long long a,int b){
    if(b==0)return 1;
    return (bigmod((a*a)%P,b/2)*(b%2?a:1ll))%P;
}
int inv(int a,int b){
    if(a==1)return 1;
    return (((long long)(a-inv(b%a,a))*b+1)/a)%b;
}
std::vector<long long> ps(MAXNUM);
std::vector<int> rev(MAXNUM);
struct poly{
    std::vector<unsigned int> co;
    int n;//polynomial degree = n
    poly(int d){n=d;co.resize(n+1,0);}
    void trans2(int NN){
        int r=0,st,N;
        unsigned int a,b;
        while((1<r)<(NN>>1))++r;
        for(N=2;N<=NN;N<=1,--r){
            for(st=0;st<NN;st+=N){
                int i,ss=st+(N>>1);
                for(i=(N>>1)-1;i>=0;--i){
                    a=co[st+i]; b=(ps[i<r]*co[ss+i])%P;
                    co[st+i]=a+b; if(co[st+i]>=P)co[st+i]-=P;
                    co[ss+i]=a-P-b; if(co[ss+i]>=P)co[ss+i]-=P;
                }
            }
        }
    }
}
void trans1(int NN){
    int r=0,st,N;
    unsigned int a,b;
    for(N=NN;N>1;N>=1,++r){
        for(st=0;st<NN;st+=N){
            int i,ss=st+(N>>1);
            for(i=(N>>1)-1;i>=0;--i){
                a=co[st+i]; b=co[ss+i];
                co[st+i]=a+b; if(co[st+i]>=P)co[st+i]-=P;
                co[ss+i]=(a-P-b)*ps[i<r]%P;
            }
        }
    }
}
poly operator*(const poly& _b)const{
    poly a=*this,b=_b;
    int k=n+b.n,i,N=1;
    while(N<=k)N*=2;
    a.co.resize(N,0); b.co.resize(N,0);
    int r=bigmod(root,(P-1)/N,Ni=inv(N,P);
    ps[0]=1;
    for(i=1;i<N;++i)ps[i]=(ps[i-1]*r)%P;
    a.trans1(N);b.trans1(N);
    for(i=0;i<N;++i)a.co[i]=((long long)a.co[i]*b.co[i]
        )%P;
    r=inv(r,P);
    for(i=1;i<N/2;++i)std::swap(ps[i],ps[N-i]);
    a.trans2(N);
    for(i=0;i<N;++i)a.co[i]=((long long)a.co[i]*Ni)%P;
    a.n=n+_b.n; return a;
}
};

```

5.5 Mod

```

/// _fd(a,b) floor(a/b).
/// _rd(a,m) a-floor(a/m)*m.
/// _pv(a,m,r) largest x s.t x<=a && x%m == r.

```

```

/// _nx(a,m,r) smallest x s.t x>=a && x%m == r.
/// _ct(a,b,m,r) |A| , A = { x : a<=x<=b && x%m == r }.

int _fd(int a,int b){ return a<0?(-~a/b-1):a/b; }
int _rd(int a,int m){ return a-_fd(a,m)*m; }
int _pv(int a,int m,int r)
{
    r=(r%m+m)%m;
    return _fd(a-r,m)*m+r;
}
int _nt(int a,int m,int r)
{
    m=abs(m);
    r=(r%m+m)%m;
    return _fd(a-r-1,m)*m+r+m;
}
int _ct(int a,int b,int m,int r)
{
    m=abs(m);
    a=_nt(a,m,r);
    b=_pv(b,m,r);
    return (a>b)?0:((b-a+m)/m);
}

```

```

    if(y&1) s=modit(s+m,mod);
    y>=1;
    m=modit(m+m,mod);
}
return s;
}
long long f(long long x,long long mod) {
    return modit(mult(x,x,mod)+1,mod);
}
long long pollard_rho(long long n) {
    if(!(n&1)) return 2;
    while (true) {
        long long y=2, x=rand()%(n-1)+1, res=1;
        for (int sz=2; res==1; sz*=2) {
            for (int i=0; i<sz && res<=1; i++) {
                x = f(x, n);
                res = __gcd(abs(x-y), n);
            }
            y = x;
        }
        if (res!=0 && res!=n) return res;
    }
}
}

```

5.6 (+1) Miller Rabin

```

// n < 4,759,123,141          3 : 2, 7, 61
// n < 1,122,004,669,633     4 : 2, 13, 23, 1662803
// n < 3,474,749,660,383     6 : pimes <= 13
// n < 2^64                  7 :
// 2, 325, 9375, 28178, 450775, 9780504, 1795265022
// Make sure testing integer is in range [2, n-2] if
// you want to use magic.
long long power(long long x,long long p,long long mod){
    long long s=1,m=x;
    while(p) {
        if(p&1) s=mult(s,m,mod);
        p>>=1;
        m=mult(m,m,mod);
    }
    return s;
}
bool witness(long long a,long long n,long long u,int t)
{
    long long x=power(a,u,n);
    for(int i=0;i<t;i++) {
        long long nx=mult(x,x,n);
        if(nx==1&&x!=1&&x!=n-1) return 1;
        x=nx;
    }
    return x!=1;
}
bool miller_rabin(long long n,int s=100) {
    // iterate s times of witness on n
    // return 1 if prime, 0 otherwise
    if(n<2) return 0;
    if(!(n&1)) return n==2;
    long long u=n-1;
    int t=0;
    // n-1 = u*2^t
    while(!(u&1)) {
        u>>=1;
        t++;
    }
    while(s--) {
        long long a=randll()%(n-1)+1;
        if(witness(a,n,u,t)) return 0;
    }
    return 1;
}

```

5.7 Pollard Rho

```

// does not work when n is prime
long long modit(long long x,long long mod) {
    if(x>=mod) x-=mod;
    //if(x<0) x+=mod;
    return x;
}
long long mult(long long x,long long y,long long mod) {
    long long s=0,m=x%mod;
    while(y) {

```

5.8 Algorithms about Primes

```

/*
 * 12721
 * 13331
 * 14341
 * 75577
 * 123457
 * 222557
 * 556679
 * 999983
 * 1097774749
 * 1076767633
 * 100102021
 * 999997771
 * 1001010013
 * 1000512343
 * 987654361
 * 999991231
 * 999888733
 * 98789101
 * 987777733
 * 999991921
 * 1010101333
 * 1010102101
 * 1000000000039
 * 100000000000037
 * 2305843009213693951
 * 4611686018427387847
 * 9223372036854775783
 * 18446744073709551557
 */

int mu[MX],p_tbl[MX];
vector<int> primes;
void sieve() {
    mu[1] = p_tbl[1] = 1;
    for (int i=2; i<MX; i++) {
        if (!p_tbl[i]) {
            p_tbl[i] = i;
            primes.pb(i);
            mu[i] = -1;
        }
        for (auto p : primes) {
            int x = i*p;
            if (x >= M) break;
            p_tbl[x] = p;
            mu[x] = -mu[i];
            if (i%p==0) {
                mu[x] = 0;
                break;
            }
        }
    }
}

vector<int> factor(int x) {
    vector<int> fac{1};
    while (x > 1) {
        int fn=sz(fac), p=p_tbl[x], pos=0;

```

```

while (x%p == 0) {
    x /= p;
    for (int i=0; i<fn; i++)
        fac.PB(fac[pos++]*p);
}
return fac;
}

```

```
openssl prime -generate -bits 31
```

5.9 (+1) PolynomialGenerator

```

class PolynomialGenerator {
    /* for a nth-order polynomial f(x), *
    * given f(0), f(1), ..., f(n) *
    * express f(x) as sigma_i{c_i*C(x,i)} */
public:
    int n;
    vector<long long> coef;
    // initialize and calculate f(x), vector _fx should
    // be
    // filled with f(0) to f(n)
    PolynomialGenerator(int _n, vector<long long> _fx)
        : n(_n)
        , coef(_fx) {
        for (int i=0; i<n; i++)
            for (int j=n; j>i; j--)
                coef[j] -= coef[j-1];
    }
    // evaluate f(x), runs in O(n)
    long long eval(int x) {
        long long m=1, ret=0;
        for (int i=0; i<=n; i++) {
            ret += coef[i]*m;
            m = m*(x-i)/(i+1);
        }
        return ret;
    }
};

```

5.10 Pseudoinverse of Square matrix

```

Mat pinv(Mat m)
{
    Mat res = I;

    FZ(used);
    for (int i=0; i<W; i++)
    {
        int piv = -1;
        for (int j=0; j<W; j++)
        {
            if (used[j]) continue;
            if (abs(m.v[j][i]) > EPS)
            {
                piv = j;
                break;
            }
        }
        if (piv == -1)
            continue;
        used[i] = true;
        swap(m.v[piv], m.v[i]);
        swap(res.v[piv], res.v[i]);

        ld rat = m.v[i][i];
        for (int j=0; j<W; j++)
        {
            m.v[i][j] /= rat;
            res.v[i][j] /= rat;
        }

        for (int j=0; j<W; j++)
        {
            if (j == i) continue;
            rat = m.v[j][i];
            for (int k=0; k<W; k++)
            {
                m.v[j][k] -= rat * m.v[i][k];
                res.v[j][k] -= rat * res.v[i][k];
            }
        }
    }
}

```

```

}
}

for (int i=0; i<W; i++)
{
    if (used[i]) continue;
    for (int j=0; j<W; j++)
        res.v[i][j] = 0;
}

return res;
}

```

5.11 Theorem

5.11.1 Lucas' Theorem

For non-negative integer n, m and prime p , $\binom{m}{n} \equiv \prod_{i=0}^k \binom{m_i}{n_i} \pmod{p}$ where m_i is the i -th digit of m in base p .

5.11.2 Sum of Two Squares Thm (Legendre)

For a given positive integer n , let
 $D_1 = (\# \text{ of positive integers } d \text{ dividing } N \text{ that } 1 \equiv d \pmod{4})$
 $D_3 = (\# \text{ of positive integers } d \text{ dividing } N \text{ that } 3 \equiv d \pmod{4})$
then n can be written as a sum of two squares in exactly
 $R(n) = 4(D_1 - D_3)$ ways.

5.11.3 Difference of D1-D3 Thm

let $n = 2^t \cdot (p_1^{e_1} \cdot \dots \cdot p_r^{e_r}) \cdot \dots (q_1^{f_1} \cdot \dots \cdot q_s^{f_s})$
where p_i, q_i are primes and $1 \equiv p_i \pmod{4}, 3 \equiv q_i \pmod{4}$
then $D_1 - D_3 = \begin{cases} (e_1 + 1)(e_2 + 1) \dots (e_r + 1), & \text{if } f_i \text{ all even} \\ 0, & \text{if any } f_i \text{ is odd} \end{cases}$

5.11.4 Krush-Kuhn-Tucker Conditions

Stationarity

For maximizing $f(x)$: $\nabla f(x^*) = \sum_{i=1}^m \mu_i \nabla g_i(x^*) + \sum_{j=1}^l \lambda_j \nabla h_j(x^*)$
For minimizing $f(x)$: $-\nabla f(x^*) = \sum_{i=1}^m \mu_i \nabla g_i(x^*) + \sum_{j=1}^l \lambda_j \nabla h_j(x^*)$

Primal feasibility

$g_i(x^*) \leq 0$, for all $i = 1, \dots, m$
 $h_j(x^*) = 0$, for all $j = 1, \dots, l$

Dual feasibility

$\mu_i \geq 0$, for all $i = 1, \dots, m$

Complementary slackness

$\mu_i g_i(x^*) = 0$, for all $i = 1, \dots, m$

5.11.5 Chinese remainder theorem

$x \equiv r_i \pmod{p_i}$
 $N = \prod p_i$
 $N_i = N/p_i$
 $x \equiv \sum r_i N_i (N_i)^{-1}_{p_i} \pmod{N}$

5.12 Simplex

```

const int maxn = 111;
const int maxm = 111;
const double eps = 1E-10;

double a[maxn][maxm], b[maxn], c[maxn], d[maxn][maxm];
double x[maxn];
int ix[maxn + maxm]; // !!! array all indexed from 0
// max{cx} subject to {Ax<=b, x>=0}
// n: constraints, m: vars !!!
// x[] is the optimal solution vector
//
// usage :
// value = simplex(a, b, c, N, M);
double simplex(double a[maxn][maxm], double b[maxn],
               double c[maxn], int n, int m) {
    ++m;
    int r = n, s = m - 1;
    memset(d, 0, sizeof(d));
    for (int i = 0; i < n + m; ++i) ix[i] = i;
    for (int i = 0; i < n; ++i) {

```

```

    for (int j = 0; j < m - 1; ++j)
        d[i][j] = -a[i][j];
    d[i][m - 1] = 1;
    d[i][m] = b[i];
    if (d[r][m] > d[i][m]) r = i;
}
for (int j = 0; j < m - 1; ++j) d[n][j] = c[j];
d[n + 1][m - 1] = -1;
for (double dd;; ) {
    if (r < n) {
        int t = ix[s];
        ix[s] = ix[r + m]; ix[r + m] = t;
        d[r][s] = 1.0 / d[r][s];
        for (int j = 0; j <= m; ++j)
            if (j != s) d[r][j] *= -d[r][s];
        for (int i = 0; i <= n + 1; ++i)
            if (i != r) {
                for (int j = 0; j <= m; ++j)
                    if (j != s)
                        d[i][j] += d[r][j]*d[i][s];
                d[i][s] *= d[r][s];
            }
    }
    r = -1; s = -1;
    for (int j = 0; j < m; ++j)
        if (s < 0 || ix[s] > ix[j]) {
            if (d[n + 1][j] > eps || (d[n + 1][j] >
                -eps && d[n][j] > eps)) s = j;
        }
    if (s < 0) break;
    for (int i=0; i<n; ++i) if (d[i][s] < -eps) {
        if (r < 0 || (dd = d[r][m] / d[r][s] - d[i][m] / d[i][s]) < -eps || (dd < eps &&
            ix[r + m] > ix[i + m])) r = i;
    }
    if (r < 0) return -1; // not bounded
}
if (d[n + 1][m] < -eps) return -1; // not
executable
double ans = 0;
for(int i=0; i<m; i++) x[i] = 0;
for (int i = m; i < n + m; ++i) { // the missing
    enumerated x[i] = 0
    if (ix[i] < m - 1)
    {
        ans += d[i - m][m] * c[ix[i]];
        x[ix[i]] = d[i-m][m];
    }
}
return ans;
}

```

```

};

double abs(cpdd &p) { return hypot(p.x, p.y); }
double arg(cpdd &p) { return atan2(p.y, p.x); }
double cross(cpdd &p, cpdd &q) { return p.x*q.y - p.y*q.x; }
double cross(cpdd &p, cpdd &q, cpdd &o) { return cross(
    p-o, q-o); }
pdd operator * (double f, cpdd &p) { return p*f; } //
!! Not f*p !!

```

6.2 Intersection of two circles

```

using ld = double;
vector<pdd> interCircle(pdd o1, double r1, pdd o2,
    double r2) {
    ld d2 = (o1 - o2) * (o1 - o2);
    ld d = sqrt(d2);
    if (d < abs(r1-r2)) return {};
    if (d > r1+r2) return {};
    pdd u = 0.5*(o1+o2) + ((r2*r2-r1*r1)/(2*d2))*(o1-o2);
    double A = sqrt((r1+r2+d) * (r1-r2+d) * (r1+r2-d) *
        (-r1+r2+d));
    pdd v = A / (2*d2) * pdd(o1.S-o2.S, -o1.F+o2.F);
    return {u+v, u-v};
}

```

6.3 Intersection of two lines

```

const double EPS = 1e-9;

pdd interPnt(pdd p1, pdd p2, pdd q1, pdd q2, bool &res)
{
    double f1 = cross(p2, q1, p1);
    double f2 = -cross(p2, q2, p1);
    double f = (f1 + f2);

    if(fabs(f) < EPS) {
        res = false;
        return {};
    }

    res = true;
    return (f2 / f) * q1 + (f1 / f) * q2;
}

```

6.4 Half Plane Intersection

```

const double EPS = 1e-9;

pdd interPnt(Line l1, Line l2, bool &res){
    pdd p1, p2, q1, q2;
    tie(p1, p2) = l1;
    tie(q1, q2) = l2;
    double f1 = cross(p2, q1, p1);
    double f2 = -cross(p2, q2, p1);
    double f = (f1 + f2);

    if(fabs(f) < EPS) {
        res = false;
        return {0, 0};
    }

    res = true;
    return (f2 / f) * q1 + (f1 / f) * q2;
}

bool isin(Line l0, Line l1, Line l2) {
    // Check inter(l1, l2) in l0
    bool res;
    pdd p = interPnt(l1, l2, res);
    return cross(l0.S, p, l0.F) > EPS;
}

/* If no solution, check: 1. ret.size() < 3
 * Or more precisely, 2. interPnt(ret[0], ret[1])
 * in all the lines. (use (l.S - l.F).cross(p - l.F) >
 * 0
 */

```

6 Geometry

6.1 Point operators

```

#define x first
#define y second

#define cpdd const pdd
struct pdd : pair<double, double> {
    using pair<double, double>::pair;

    pdd operator + (cpdd &p) const {
        return {x+p.x, y+p.y};
    }

    pdd operator - ( ) const {
        return {-x, -y};
    }

    pdd operator - (cpdd &p) const {
        return (*this) + (-p);
    }

    pdd operator * (double f) const {
        return {f*x, f*y};
    }

    double operator * (cpdd &p) const {
        return x*p.x + y*p.y;
    }
}

```



```

vector<Line> halfPlaneInter(vector<Line> lines) {
    int sz = lines.size();
    vector<double> ata(sz), ord(sz);
    for (int i=0; i<sz; i++) {
        ord[i] = i;
        pdd d = lines[i].S - lines[i].F;
        ata[i] = atan2(d.y, d.x);
    }
    sort(ALL(ord), [&](int i, int j) {
        if (abs(ata[i] - ata[j]) < EPS) {
            return cross(lines[i].S, lines[j].S, lines[i].F) < 0;
        }
        return ata[i] < ata[j];
    });
    vector<Line> fin;
    for (int i=0; i<sz; i++) {
        if (!i or fabs(ata[ord[i]] - ata[ord[i-1]]) > EPS) {
            fin.PB(lines[ord[i]]);
        }
    }

    deque<Line> dq;
    for (int i=0; i<SZ(fin); i++) {
        while(SZ(dq) >= 2 and
            not isin(fin[i], dq[SZ(dq)-2], dq[SZ(dq)-1])) {
            dq.pop_back();
        }
        while(SZ(dq) >= 2 and
            not isin(fin[i], dq[0], dq[1])) {
            dq.pop_front();
        }
        dq.push_back(fin[i]);
    }

    while (SZ(dq) >= 3 and
        not isin(dq[0], dq[SZ(dq)-2], dq[SZ(dq)-1])) {
        dq.pop_back();
    }

    while (SZ(dq) >= 3 and
        not isin(dq[SZ(dq)-1], dq[0], dq[1])) {
        dq.pop_front();
    }
    vector<Line> res(ALL(dq));
    return res;
}

```

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

```
using namespace std;
```

```
const double EPS = 1e-10;
```

```

struct Point {
    double x, y;

    Point(double _x = 0.0, double _y = 0.0) : x(_x), y(_y) {}

    bool operator < (const Point &rhs) const {
        if(x != rhs.x) return x < rhs.x;
        else return y < rhs.y;
    }
};

```

```
typedef Point Vector;
```

```

inline Point operator + (Point p, Vector v) {
    return Point(p.x + v.x, p.y + v.y);
}

```

```

inline Vector operator - (Point a, Point b) {
    return Vector(a.x - b.x, a.y - b.y);
}

```

```

inline Vector operator * (Vector v, double p) {
    return Vector(v.x * p, v.y * p);
}

```

```

inline Vector operator / (Vector v, double p) {
    return Vector(v.x / p, v.y / p);
}

```

```

inline double cross(Vector a, Vector b) {
    return a.x * b.y - a.y * b.x;
}

```

```

inline double dot(Vector a, Vector b) {
    return a.x * b.x + a.y * b.y;
}

```

```

inline int dcmp(double x) {
    return fabs(x) < EPS ? 0 : x > 0 ? 1 : -1;
}

```

```

struct Line {
    Point p;
    Vector v;
    double ang;

    Line() {}
    Line(Point _p, Vector _v) : p(_p), v(_v) {
        ang = atan2(_v.y, _v.x);
    }
}

```

```

bool operator < (const Line &rhs) const {
    return ang < rhs.ang;
}

```

```

inline bool on_left(Line l, Point p) {
    return cross(l.v, p - l.p) > 0;
}

```

```

inline Point get_line_intersection(Line a, Line b) {
    Vector u = a.p - b.p;
    double t = cross(b.v, u) / cross(a.v, b.v);
    return a.p + a.v * t;
}

```

```

vector<Point> half_plane_intersection(vector<Line> ls)
{
    int n = (int)ls.size();
    sort(ls.begin(), ls.end());
    int f, r;
    vector<Point> p(n), ans;
    vector<Line> q(n);
    q[f = r = 0] = ls[0];
    for (int i = 1; i <= n - 1; i++) {
        while(f < r && !on_left(ls[i], p[r - 1])) r--;
        while(f < r && !on_left(ls[i], p[f])) f++;
        q[++r] = ls[i];
        if(dcmp(cross(q[r].v, q[r - 1].v)) == 0) {
            r--;
            if(on_left(q[r], ls[i].p)) q[r] = ls[i];
        }
        if(f < r) p[r - 1] = get_line_intersection(q[r - 1], q[r]);
    }
    while(f < r && !on_left(q[f], p[r - 1])) r--;
    if(r - f <= 1) return ans;
    p[r] = get_line_intersection(q[r], q[f]);
    for (int i = f; i <= r; i++) ans.push_back(p[i]);
    return ans;
}

```

6.5 2D Convex Hull

```

vector<pdd> convex_hull(vector<pdd> pt){
    sort(pt.begin(), pt.end());
    int top=0;
    vector<pdd> stk(2*pt.size());
    for (int i=0; i<(int)pt.size(); i++){
        while (top >= 2 && cross(stk[top-1], pt[i], stk[top-2]) <= 0)
            top--;
        stk[top++] = pt[i];
    }
    for (int i=pt.size()-2, t=top+1; i>=0; i--){
        while (top >= t && cross(stk[top-1], pt[i], stk[top-2]) <= 0)
            top--;
        stk[top++] = pt[i];
    }
    stk.resize(top-1);
    return stk;
}

```

```
|}
```

6.6 3D Convex Hull

```
// return the faces with pt indexes
int flag[MXN][MXN];
struct Point{
    ld x,y,z;
    Point operator - (const Point &b) const {
        return (Point){x-b.x,y-b.y,z-b.z};
    }
    Point operator * (const ld &b) const {
        return (Point){x*b,y*b,z*b};
    }
    ld len() const { return sqrtl(x*x+y*y+z*z); }
    ld dot(const Point &a) const {
        return x*a.x+y*a.y+z*a.z;
    }
    Point operator * (const Point &b) const {
        return (Point){y*b.z-b.y*z,z*b.x-b.z*x,x*b.y-b.x*y};
    }
};
Point ver(Point a, Point b, Point c) {
    return (b - a) * (c - a);
}
vector<Face> convex_hull_3D(const vector<Point> pt) {
    int n = SZ(pt);
    REP(i,n) REP(j,n)
        flag[i][j] = 0;

    vector<Face> now;
    now.push_back((Face){0,1,2});
    now.push_back((Face){2,1,0});
    int ftop = 0;
    for (int i=3; i<n; i++){
        ftop++;
        vector<Face> next;
        REP(j, SZ(now)) {
            Face& f=now[j];
            ld d=(pt[i]-pt[f.a]).dot(ver(pt[f.a], pt[f.b], pt[f.c]));
            if (d <= 0) next.push_back(f);
            int ff = 0;
            if (d > 0) ff=ftop;
            else if (d < 0) ff=-ftop;
            flag[f.a][f.b] = flag[f.b][f.c] = flag[f.c][f.a] = ff;
        }
        REP(j, SZ(now)) {
            Face& f=now[j];
            if (flag[f.a][f.b] > 0 and flag[f.a][f.b] != flag[f.b][f.a])
                next.push_back((Face){f.a,f.b,i});
            if (flag[f.b][f.c] > 0 and flag[f.b][f.c] != flag[f.c][f.b])
                next.push_back((Face){f.b,f.c,i});
            if (flag[f.c][f.a] > 0 and flag[f.c][f.a] != flag[f.a][f.c])
                next.push_back((Face){f.c,f.a,i});
        }
        now=next;
    }
    return now;
}
```

6.7 Minimum Covering Circle

```
struct Mcc{
    // return pair of center and r^2
    static const int MAXN = 1000100;
    int n;
    pdd p[MAXN],cen;
    double r2;

    void init(int _n, pdd _p[]){
        n = _n;
        memcpy(p,_p,sizeof(pdd)*n);
    }
    double sqr(double a){ return a*a; }
    double abs2(pdd a){ return a.a; }
    pdd center(pdd p0, pdd p1, pdd p2) {
```

```
    pdd a = p1-p0;
    pdd b = p2-p0;
    double c1=abs2(a)*0.5;
    double c2=abs2(b)*0.5;
    double d = a % b;
    double x = p0.x + (c1 * b.y - c2 * a.y) / d;
    double y = p0.y + (a.x * c2 - b.x * c1) / d;
    return pdd(x,y);
}
```

```
pair<pdd,double> solve(){
    random_shuffle(p,p+n);
    r2=0;
    for (int i=0; i<n; i++){
        if (abs2(cen-p[i]) <= r2) continue;
        cen = p[i];
        r2 = 0;
        for (int j=0; j<i; j++){
            if (abs2(cen-p[j]) <= r2) continue;
            cen = 0.5 * (p[i]+p[j]);
            r2 = abs2(cen-p[j]);
            for (int k=0; k<j; k++){
                if (abs2(cen-p[k]) <= r2) continue;
                cen = center(p[i],p[j],p[k]);
                r2 = abs2(cen-p[k]);
            }
        }
        return {cen,r2};
    }
}
}mcc;
```

6.8 KDTree (Nearest Point)

```
const int MXN = 100005;

struct KDTree {
    struct Node {
        int x,y,x1,y1,x2,y2;
        int id,f;
        Node *L, *R;
    }tree[MXN];
    int n;
    Node *root;

    long long dis2(int x1, int y1, int x2, int y2) {
        long long dx = x1-x2;
        long long dy = y1-y2;
        return dx*dx+dy*dy;
    }

    static bool cmpx(Node& a, Node& b){ return a.x<b.x; }
    static bool cmpy(Node& a, Node& b){ return a.y<b.y; }
    void init(vector<pair<int,int>> ip) {
        n = ip.size();
        for (int i=0; i<n; i++) {
            tree[i].id = i;
            tree[i].x = ip[i].first;
            tree[i].y = ip[i].second;
        }
        root = build_tree(0, n-1, 0);
    }

    Node* build_tree(int L, int R, int dep) {
        if (L>R) return nullptr;
        int M = (L+R)/2;
        tree[M].f = dep%2;
        nth_element(tree+L, tree+M, tree+R+1, tree[M].f ?
            cmpy : cmpx);
        tree[M].x1 = tree[M].x2 = tree[M].x;
        tree[M].y1 = tree[M].y2 = tree[M].y;

        tree[M].L = build_tree(L, M-1, dep+1);
        if (tree[M].L) {
            tree[M].x1 = min(tree[M].x1, tree[M].L->x1);
            tree[M].x2 = max(tree[M].x2, tree[M].L->x2);
            tree[M].y1 = min(tree[M].y1, tree[M].L->y1);
            tree[M].y2 = max(tree[M].y2, tree[M].L->y2);
        }

        tree[M].R = build_tree(M+1, R, dep+1);
        if (tree[M].R) {
            tree[M].x1 = min(tree[M].x1, tree[M].R->x1);
            tree[M].x2 = max(tree[M].x2, tree[M].R->x2);
            tree[M].y1 = min(tree[M].y1, tree[M].R->y1);
            tree[M].y2 = max(tree[M].y2, tree[M].R->y2);
        }
    }
}
```

```

    }
    return tree+M;
}
int touch(Node* r, int x, int y, long long d2){
    long long dis = sqrt(d2)+1;
    if (x<r->x1-dis || x>r->x2+dis || y<r->y1-dis || y>
        r->y2+dis)
        return 0;
    return 1;
}
void nearest(Node* r, int x, int y, int &mID, long
    long &md2) {
    if (!r || !touch(r, x, y, md2)) return;
    long long d2 = dis2(r->x, r->y, x, y);
    if (d2 < md2 || (d2 == md2 && mID < r->id)) {
        mID = r->id;
        md2 = d2;
    }
    // search order depends on split dim
    if ((r->f == 0 && x < r->x) ||
        (r->f == 1 && y < r->y)) {
        nearest(r->L, x, y, mID, md2);
        nearest(r->R, x, y, mID, md2);
    } else {
        nearest(r->R, x, y, mID, md2);
        nearest(r->L, x, y, mID, md2);
    }
}
int query(int x, int y) {
    int id = 1029384756;
    long long d2 = 102938475612345678LL;
    nearest(root, x, y, id, d2);
    return id;
}
}tree;

```

6.9 Triangulation

```

bool inCircle(pdd a, pdd b, pdd c, pdd d) {
    b = b - a;
    c = c - a;
    d = d - a;
    if (cross(b, c) < 0) swap(b, c);
    double m[3][3] = {
        {b.x, b.y, b*b},
        {c.x, c.y, c*c},
        {d.x, d.y, d*d}
    };
    double det = m[0][0] * (m[1][1]*m[2][2] - m[1][2]*m
        [2][1])
        + m[0][1] * (m[1][2]*m[2][0] - m[1][0]*m
        [2][2])
        + m[0][2] * (m[1][0]*m[2][1] - m[1][1]*m
        [2][0]);
    return det < 0;
}
bool intersect(pdd a, pdd b, pdd c, pdd d) {
    return cross(b, c, a) * cross(b, d, a) < 0 and
        cross(d, a, c) * cross(d, b, c) < 0;
}
const double EPS = 1e-12;
struct Triangulation {
    static const int MXN = 1e5+5;
    int N;
    vector<int> ord;
    vector<pdd> pts;
    set<int> E[MXN];
    vector<vector<int>> solve(vector<pdd> p) {
        N = SZ(p);
        ord.resize(N);
        for (int i=0; i<N; i++) {
            E[i].clear();
            ord[i] = i;
        }
        sort(ALL(ord), [&p](int i, int j) {
            return p[i] < p[j];
        });
        pts.resize(N);
    }
};

```

```

for (int i=0; i<N; i++) pts[i] = p[ord[i]];

go(0, N);

vector<vector<int>> res(N);
for (int i=0; i<N; i++) {
    int o = ord[i];
    for (auto x: E[i]) {
        res[o].PB(ord[x]);
    }
}
return res;

void add_edge(int u, int v) {
    E[u].insert(v);
    E[v].insert(u);
}

void remove_edge(int u, int v) {
    E[u].erase(v);
    E[v].erase(u);
}

void go(int l, int r) {
    int n = r - l;

    if (n <= 3) {
        for (int i=l; i<r; i++)
            for (int j=i+1; j<r; j++) add_edge(i, j);
        return;
    }
    int md = (l+r)/2;

    go(l, md);
    go(md, r);

    int il = l, ir = r-1;
    while (1) {
        int nx = -1;
        for (auto i: E[il]) {
            double cs = cross(pts[il], pts[i], pts[
                ir]);
            if (cs > EPS ||
                (abs(cs) < EPS and abs(pts[i]-pts[
                    ir]) < abs(pts[il]-pts[ir]))) {
                nx = i;
                break;
            }
        }
        if (nx != -1) {
            il = nx;
            continue;
        }
        for (auto i: E[ir]) {
            double cs = cross(pts[ir], pts[i], pts[
                il]);
            if (cs < -EPS ||
                (abs(cs) < EPS and abs(pts[i]-pts[
                    il]) < abs(pts[ir]-pts[il]))) {
                nx = i;
                break;
            }
        }
        if (nx != -1) {
            ir = nx;
        } else break;
    }

    add_edge(il, ir);

    while (1) {
        int nx = -1;
        bool is2 = false;
        for (int i: E[il]) {
            if (cross(pts[il], pts[i], pts[ir]) < -
                EPS and
                (nx == -1 or inCircle(pts[il], pts[
                    ir], pts[nx], pts[i]))) nx = i;
        }
        for (int i: E[ir]) {

```

```

        if (cross(pts[ir], pts[i], pts[il]) >
            EPS and
            (nx == -1 or inCircle(pts[il], pts[
                ir], pts[nx], pts[i]))) nx = i,
            is2 = 1;
    }

    if (nx == -1) break;

    int a = il, b = ir;
    if (is2) swap(a, b);

    for (auto i: E[a]) {
        if (intersect(pts[a], pts[i], pts[b],
            pts[nx])) {
            remove_edge(a, i);
        }
    }
    if (is2) {
        add_edge(il, nx);
        ir = nx;
    } else {
        add_edge(ir, nx);
        il = nx;
    }
}
} tri;

```

7 Stringology

7.1 Suffix Array

```

const int N = 1.12e5, M = 11;
const char nil = 'a' - 1;
char s[N];
int sa[N], ct[N], w[2][N], rk[N], ht[N];
void suffix_array(int n, int m)
{
    int i, j, p = 0, *x = w[0], *y = w[1], h;
    memset(ct, 0, m * sizeof(int));
    for (i = 0; i < n; ++i) ++ct[x[i] = s[i] - ('a' - 1)];
    for (i = 1; i < m; ++i) ct[i] += ct[i - 1];
    for (i = n - 1; i >= 0; --i) sa[--ct[x[i]]] = i;
    for (j = p = 1; p < n; j *= 2, m = p) {
        for (i = n - j, p = 0; i < n; ++i) y[p++] = i;
        for (i = 0; i < n; ++i) if (sa[i] >= j) y[p++] = sa[i] - j;
        memset(ct, 0, m * sizeof(int));
        for (i = 0; i < n; ++i) ++ct[x[y[i]]];
        for (i = 1; i < m; ++i) ct[i] += ct[i - 1];
        for (i = n - 1; i >= 0; --i) sa[--ct[x[y[i]]]] = y[i];
        swap(x, y);
        x[sa[0]] = 0;
        p = 1;
        for (i = 1; i < n; ++i)
            x[sa[i]] = y[sa[i]] == y[sa[i-1]] && y[sa[i] + j]
                == y[sa[i-1] + j] ? p - 1 : p++;
    }
    for (i = 0; i < n; ++i) rk[sa[i]] = i;
    ht[0] = 0;
    h = 0;
    for (i = 0; rk[i]; ++i) {
        while (s[i + h] == s[sa[rk[i] - 1] + h]) ++h;
        ht[rk[i]] = h;
        if (h) --h;
    }
}

```

7.2 Suffix Array (SAIS TWT514)

```

struct SA{
#define REP(i,n) for ( int i=0; i<int(n); i++ )
#define REP1(i,a,b) for ( int i=a; i<=int(b); i++ )
    static const int MXN = 300010;
    bool _t[MXN*2];

```

```

    int _s[MXN*2], _sa[MXN*2], _c[MXN*2], x[MXN], _p[
        MXN], _q[MXN*2], hei[MXN], r[MXN];
    int operator [] (int i){ return _sa[i]; }
    void build(int *s, int n, int m){
        memcpy(_s, s, sizeof(int) * n);
        sais(_s, _sa, _p, _q, _t, _c, n, m);
        mkhei(n);
    }
    void mkhei(int n){
        REP(i,n) r[_sa[i]] = i;
        hei[0] = 0;
        REP(i,n) if(r[i]) {
            int ans = i>0 ? max(hei[r[i-1]] - 1, 0) :
                0;
            while(_s[i+ans] == _s[_sa[r[i]-1]+ans]) ans
                ++;
            hei[r[i]] = ans;
        }
    }
    void sais(int *s, int *sa, int *p, int *q, bool *t,
        int *c, int n, int z){
        bool uniq = t[n-1] = true, neq;
        int nn = 0, nmzx = -1, *nsa = sa + n, *ns = s +
            n, lst = -1;
#define MS0(x,n) memset((x),0,n*sizeof(*(x)))
#define MAGIC(XD) MS0(sa, n); \
        memcpy(x, c, sizeof(int) * z); \
        XD; \
        memcpy(x + 1, c, sizeof(int) * (z - 1)); \
        REP(i,n) if(sa[i] && !t[sa[i]-1]) sa[x[sa[i]
            ]-1]]++ = sa[i]-1; \
        memcpy(x, c, sizeof(int) * z); \
        for(int i = n - 1; i >= 0; i--) if(sa[i] && t[
            sa[i]-1]) sa[--x[sa[i]-1]] = sa[i]-1;
        MS0(c, z);
        REP(i,n) uniq &= ++c[s[i]] < 2;
        REP(i,z-1) c[i+1] += c[i];
        if (uniq) { REP(i,n) sa[--c[s[i]]] = i; return;
        }
        for(int i = n - 2; i >= 0; i--) t[i] = (s[i]==s
            [i+1] ? t[i+1] : s[i]<s[i+1]);
        MAGIC(REP1(i,1,n-1) if(t[i] && !t[i-1]) sa[--x[
            s[i]]]=p[q[i]=nn++]=i);
        REP(i, n) if (sa[i] && t[sa[i]] && !t[sa[i]-1])
            {
                neq=lst<0||memcmp(s+sa[i],s+lst,(p[q[sa[i]
                    ]+1]-sa[i])*sizeof(int));
                ns[q[lst=sa[i]]]=nmzx+=neq;
            }
        sais(ns, nsa, p + nn, q + n, t + n, c + z, nn,
            nmzx + 1);
        MAGIC(for(int i = nn - 1; i >= 0; i--) sa[--x[s
            [p[nsa[i]]]]] = p[nsa[i]]);
    }
}sa;

void suffix_array(int* ip, int len) {
    // should padding a zero in the back
    // s is int array, n is array length
    // s[0..n-1] != 0, and s[n] = 0
    // resulting SA will be length n+1
    ip[len++] = 0;
    sa.build(ip, len, 128);
    // original 1-base
    for (int i=0; i<l; i++) {
        hei[i] = sa.hei[i + 1];
        sa[i] = sa._sa[i + 1];
    }
}

```

7.3 Aho-Corasick Algorithm

```

struct ACautomata{
    struct Node{
        int cnt,dp;
        Node *go[26], *fail;
        Node (){
            cnt = 0;
            dp = -1;
            memset(go,0,sizeof(go));
            fail = 0;
        }
    };
};

```

```

Node *root, pool[1048576];
int nMem;

Node* new_Node(){
    pool[nMem] = Node();
    return &pool[nMem++];
}

void init(){
    nMem = 0;
    root = new_Node();
}

void add(const string &str){
    insert(root, str, 0);
}

void insert(Node *cur, const string &str, int pos){
    if (pos >= (int)str.size()){
        cur->cnt++;
        return;
    }
    int c = str[pos] - 'a';
    if (cur->go[c] == 0){
        cur->go[c] = new_Node();
    }
    insert(cur->go[c], str, pos+1);
}

void make_fail(){
    queue<Node*> que;
    que.push(root);
    while (!que.empty()){
        Node* fr = que.front();
        que.pop();
        for (int i=0; i<26; i++){
            if (fr->go[i]){
                Node *ptr = fr->fail;
                while (ptr && !ptr->go[i]) ptr = ptr->fail;
                if (!ptr) fr->go[i]->fail = root;
                else fr->go[i]->fail = ptr->go[i];
                que.push(fr->go[i]);
            }
        }
    }
}
};

```

7.4 KMP

```

#include<bits/stdc++.h>
using namespace std;

void build_fail_function(string B, int *fail) {
    int len = B.length(), pos;
    pos = fail[0] = -1;
    for (int i = 1; i < len; i++) {
        while (pos != -1 and B[pos + 1] != B[i])
            pos = fail[pos];
        if (B[pos + 1] == B[i]) pos++;
        fail[i] = pos;
    }
}

void match(string A, string B, int *fail) {
    int lenA = A.length(), lenB = B.length();
    int pos = -1;
    for (int i = 0; i < lenA; i++) {
        while (pos != -1 and B[pos + 1] != A[i])
            pos = fail[pos];

        if (B[pos + 1] == A[i]) pos++;

        if (pos == lenB - 1) {
            // Match ! A[i - lenB + 1, i] = B
            pos = fail[pos];
        }
    }
}

```

7.5 Z value

```

void Zval(const char *s, int len, int *z) {
    z[0] = 0;
    for (int b=0, i=1; i<len; i++) {
        z[i] = max(min(z[i-b], z[b] + b - i), 0);
    }
}

```

```

        while (s[i + z[i]] == s[z[i]]) z[i]++;
        if (i+z[i] > b+z[b]) b=i;
    }
}

```

7.6 Z value (palindrome ver.)

```

void Zpal(const char *s, int len, int *z) {
    // Only odd palindrome len is considered
    // z[i] means that the longest odd palindrom
    // centered at
    // i is [i-z[i] .. i+z[i]]
    z[0] = 0;
    for (int b=0, i=1; i<len; i++) {
        if (z[b] + b >= i) z[i] = min(z[2*b-i], b+z[b]-i);
        else z[i] = 0;
        while (i+z[i]+1 < len and i-z[i]-1 >= 0 and
            s[i+z[i]+1] == s[i-z[i]-1]) z[i]++;
        if (z[i] + i > z[b] + b) b = i;
    }
}

```

7.7 palindromic tree

```

//bcw0x1bd2 {{{
#include<bits/stdc++.h>
#include<unistd.h>
using namespace std;
#define F first
#define S second
#define MP make_pair
#define PB push_back
#define IOS ios_base::sync_with_stdio(0); cin.tie(0);
#define SZ(x) ((int)((x).size()))
#define ALL(x) begin(x),end(x)
#define REP(i,x) for (int i=0; i<(x); i++)
#define REP1(i,a,b) for (int i=(a); i<=(b); i++)

typedef long long ll;
typedef pair<int,int> pii;
typedef pair<ll,ll> pll;
typedef long double ld;

#ifdef DARKHH
#define FILEIO(name)
#else
#define FILEIO(name) \
    freopen(name".in", "r", stdin); \
    freopen(name".out", "w", stdout);
#endif

#ifdef DARKHH
template<typename T>
void _dump( const char* s, T&& head ) { cerr<<s<<"="<<
    head<<endl; }

template<typename T, typename... Args>
void _dump( const char* s, T&& head, Args&&... tail ) {
    int c=0;
    while ( *s!=',' || c!=0 ) {
        if ( *s=='(' || *s=='[' || *s=='{' ) c++;
        if ( *s==')' || *s==']' || *s=='}' ) c--;
        cerr<<*s++;
    }
    cerr<<"="<<head<<" ";
    _dump(s+1,tail...);
}

#define dump(...) do { \
    fprintf(stderr, "%s:%d - ", __PRETTY_FUNCTION__, \
        __LINE__); \
    _dump(#__VA_ARGS__, __VA_ARGS__); \
} while (0)

template<typename Iter>
ostream& _out( ostream& s, Iter b, Iter e ) {
    s<<"[";
    for ( auto it=b; it!=e; it++ ) s<<(it==b?" ":"")<<*it
        ;
    s<<"]";
    return s;
}

```

```

}

template<typename A, typename B>
ostream& operator <<( ostream &s, const pair<A,B> &p )
{ return s<<"("<<p.first<<" "<<p.second<<")"; }
template<typename T>
ostream& operator <<( ostream &s, const vector<T> &c )
{ return _out(s,ALL(c)); }
template<typename T, size_t N>
ostream& operator <<( ostream &s, const array<T,N> &c )
{ return _out(s,ALL(c)); }
template<typename T>
ostream& operator <<( ostream &s, const set<T> &c ) {
    return _out(s,ALL(c)); }
template<typename A, typename B>
ostream& operator <<( ostream &s, const map<A,B> &c ) {
    return _out(s,ALL(c)); }
#else
#define dump(...)
#endif
// }}}

struct palindromic_tree{
    struct node{
        int next[26], fail, len;
        int cnt, num, st, ed;
        node(int l=0):fail(0), len(l), cnt(0), num(0){
            for(int i=0; i<26; ++i) next[i]=0;
        }
    };
    vector<node> state;
    vector<char> s;
    int last, n;

    void init(){
        state.clear();
        s.clear();
        last=1;
        n=0;
        state.push_back(0);
        state.push_back(-1);
        state[0].fail=1;
        s.push_back(-1);
    }
    int get_fail(int x){
        while(s[n-state[x].len-1]!=s[n])x=state[x].fail;
        return x;
    }
    void add(int c){
        s.push_back(c-'a');
        ++n;
        int cur=get_fail(last);
        if(!state[cur].next[c]){
            int now=state.size();
            state.push_back(state[cur].len+2);
            state[now].fail=state[get_fail(state[cur].fail)].next[c];
            state[cur].next[c]=now;
            state[now].num=state[state[now].fail].num+1;
        }
        last=state[cur].next[c];
        ++state[last].cnt;
    }
    int size(){
        return state.size()-2;
    }
};

int main() {
    string s;
    cin >> s;
    pt.init();
    for (int i=0; i<SZ(s); i++) {
        int prvsz = pt.size();
        pt.add(s[i]);
        if (prvsz != pt.size()) {
            int r = i;
            int l = r - pt.state[pt.last].len + 1;
            cout << "Find pal @ [" << l << " " << r << "]" : "
                << s.substr(l,r-l+1) << endl;
        }
    }
    return 0;
}

```

7.8 Lexicographically Smallest Rotation

```

string mcp(string s){
    int n = s.length();
    s += s;
    int i=0, j=1;
    while (i<n && j<n){
        int k = 0;
        while (k < n && s[i+k] == s[j+k]) k++;
        if (s[i+k] <= s[j+k]) j += k+1;
        else i += k+1;
        if (i == j) j++;
    }
    int ans = i < n ? i : j;
    return s.substr(ans, n);
}

```

7.9 Suffix Automaton

```

// par : fail link
// val : a topological order ( useful for DP )
// go[x] : automata edge ( x is integer in [0,26) )

struct SAM{
    struct State{
        int par, go[26], val;
        State() : par(0), val(0){ FZ(go); }
        State(int _val) : par(0), val(_val){ FZ(go); }
    };
    vector<State> vec;
    int root, tail;

    void init(int arr[], int len){
        vec.resize(2);
        vec[0] = vec[1] = State(0);
        root = tail = 1;
        for (int i=0; i<len; i++)
            extend(arr[i]);
    }
    void extend(int w){
        int p = tail, np = vec.size();
        vec.PB(State(vec[p].val+1));
        for ( ; p && vec[p].go[w]==0; p=vec[p].par)
            vec[p].go[w] = np;
        if (p == 0){
            vec[np].par = root;
        } else {
            if (vec[vec[p].go[w]].val == vec[p].val+1){
                vec[np].par = vec[p].go[w];
            } else {
                int q = vec[p].go[w], r = vec.size();
                vec.PB(vec[q]);
                vec[r].val = vec[p].val+1;
                vec[q].par = vec[np].par = r;
                for ( ; p && vec[p].go[w] == q; p=vec[p].par)
                    vec[p].go[w] = r;
            }
        }
        tail = np;
    }
};

```

8 Problems

8.1 Painter

```

#include<bits/stdc++.h>
using namespace std;
#define F first
#define S second
#define PB push_back
#define IOS ios_base::sync_with_stdio(0); cin.tie(0);
#define SZ(x) ((int)((x).size()))
#define ALL(x) begin(x),end(x)
#define REP(i,x) for (int i=0; i<(x); i++)
#define REP1(i,a,b) for (int i=(a); i<=(b); i++)

typedef long long ll;
typedef pair<ll,ll> pll;

```

```

typedef pll Point;
const int MXN = 100005;

Point operator + (const Point &a, const Point &b) {
    return Point(a.F+b.F, a.S+b.S); }
Point operator - (const Point &a, const Point &b) {
    return Point(a.F-b.F, a.S-b.S); }
ll operator * (const Point &a, const Point &b) { return
    a.F*b.F + a.S*b.S; }
ll operator % (const Point &a, const Point &b) { return
    a.F*b.S - a.S*b.F; }

struct Segment {
    int v,id;
    Point p,q;
    Segment () {}
    Segment (int _v, int _id, Point _p, Point _q) :
        v(_v), id(_id), p(_p), q(_q) {}
};
bool operator < (const Segment &a, const Segment &b) {
    if (a.p == b.q) return false;
    if (a.q == b.p) return true;
    if (a.p == b.p) return (a.q-a.p) % (b.q-a.p) > 0;
    if (a.q == b.q) return (a.p-a.q) % (b.p-a.q) < 0;
    if (a.p.F == b.p.F) return a.p.S < b.p.S;
    if (a.q.F == b.q.F) return a.q.S < b.q.S;
    if (a.p.F < b.p.F) return (a.q-a.p) % (b.p-a.p) > 0;
    else return (b.q-b.p) % (a.p-b.p) < 0;
}
bool operator == (const Segment &a, const Segment &b) {
    return tie(a.v,a.id,a.p,a.q) == tie(b.v,b.id,b.p,b.q)
    ;
}
struct Triangle {
    Point pt[3];
}ip[MXN];

const int MEM = 350004;
struct Treap {
    static Treap nil, mem[MEM], *pmem;
    Treap *l, *r;
    int sum,presum,size;
    Segment seg;
    Treap () : l(&nil), r(&nil), sum(0), presum(0), size
        (0), seg() {}
    Treap (Segment _val) :
        l(&nil), r(&nil), sum(_val.v), presum(max(_val.v,0)
        ), size(1), seg(_val) {}
} Treap::nil, Treap::mem[MEM], *Treap::pmem = Treap::
    mem;

int size(const Treap *t) { return t->size; }
void pull(Treap *t) {
    if (!size(t)) return;
    t->size = size(t->l) + size(t->r) + 1;
    t->sum = t->l->sum + t->seg.v + t->r->sum;
    t->presum = max(t->l->presum, t->l->sum + t->seg.v);
    t->presum = max(t->presum, t->l->sum + t->seg.v + t->
        r->presum);
}
Treap* merge(Treap *a, Treap *b) {
    if (!size(a)) return b;
    if (!size(b)) return a;
    Treap *t;
    if (rand() % (size(a) + size(b)) < size(a)) {
        t = a;
        t->r = merge(a->r, b);
    } else {
        t = b;
        t->l = merge(a, b->l);
    }
    pull(t);
    return t;
}
void split(Treap *t, int k, Treap *&a, Treap *&b) {
    if (!size(t)) a = b = &Treap::nil;
    else if (size(t->l) + 1 <= k) {
        a = t;
        split(t->r, k - size(t->l) - 1, a->r, b);
        pull(a);
    } else {
        b = t;
        split(t->l, k, a, b->l);
        pull(b);
    }
}

int get_rank(Treap *t, Segment x) {
    if (!size(t)) return 0;
    if (x < t->seg) return get_rank(t->l, x);
    return get_rank(t->r,x) + size(t->l) + 1;
}
Treap* find_leftist(Treap *t) {
    while (size(t->l)) t = t->l;
    return t;
}
Treap* find_rightist(Treap *t) {
    while (size(t->r)) t = t->r;
    return t;
}

int N;
vector<int> allx;
vector<Segment> _seg[3*MXN];
#define seg(x) _seg[(x)+100000]

inline void add_seg(Segment s) {
    seg(s.p.F).PB(s);
    if (s.q.F != s.p.F) seg(s.q.F).PB(s);
}
void predo() {
    allx.clear();
    REP(i,N) REP(j,3) {
        seg(ip[i].pt[j].F).clear();
        allx.PB(ip[i].pt[j].F);
    }
    sort(ALL(allx));
    allx.resize(unique(ALL(allx))-begin(allx));
    REP(i,N) {
        sort(ip[i].pt, ip[i].pt+3);
        Point *pt = ip[i].pt;
        Segment seg1 = Segment(1,i,pt[0],pt[1]);
        Segment seg2 = Segment(1,i,pt[0],pt[2]);
        Segment seg3 = Segment(1,i,pt[1],pt[2]);
        if (seg2 < seg1) seg1.v = -1;
        else seg2.v = -1;
        seg3.v = seg1.v;
        add_seg(seg1);
        add_seg(seg2);
        add_seg(seg3);
    }
}
inline int sgn(ll x) { return x < 0 ? -1 : x > 0; }
bool interPnt(Point p1, Point p2, Point q1, Point q2){
    ll c1 = (p2-p1)%(q1-p1), c2 = (p2-p1)%(q2-p1);
    ll c3 = (q2-q1)%(p1-q1), c4 = (q2-q1)%(p2-q1);
    return sgn(c1) * sgn(c2) <= 0 and sgn(c3) * sgn(c4)
        <= 0;
}
bool check_error(Segment a, Segment b) {
    if (a.id == b.id) return false;
    return interPnt(a.p,a.q,b.p,b.q);
}
int solve() {
    Treap::pmem = Treap::mem;
    Treap *rt = &Treap::nil;
    int res = 0;
    for (auto i:allx) {
        for (auto l:seg(i)) {
            int k = get_rank(rt, l);
            Treap *t,*tl,*tm,*tr;
            split(rt,k,tl,tr);
            t = find_rightist(tl);
            if (size(t) and check_error(t->seg,l)) return -1;
            t = find_leftist(tr);
            if (size(t) and check_error(t->seg,l)) return -1;
            rt = merge(tl,tr);
            if (l.p.F == i and l.p.F != l.q.F) {
                k = get_rank(rt, l);
                split(rt,k,tl,tr);
                tm = new (Treap::pmem++) Treap(l);
                rt = merge(merge(tl,tm),tr);
            }
        }
        for (auto l:seg(i)) {
            if (l.q.F == i and l.p.F != l.q.F) {
                Treap *tl,*tm,*tr;
                int k = get_rank(rt, l);
                split(rt,k-1,tl,tm);
                split(tm,1,tm,tr);
                Treap *t1=find_rightist(tl),*t2=find_leftist(tr
                );
            }
        }
    }
}

```



```

        if (size(t1) and size(t2) and check_error(t1->
            seg,t2->seg)) return -1;
        rt = merge(tl,tr);
    }
    res = max(res, rt->presum);
}
res++;
return res;
}
int main() {
    IOS;
    int cas = 0;
    while (cin >> N) {
        if (N == -1) break;
        REP(i,N) {
            REP(j,3) cin >> ip[i].pt[j].F >> ip[i].pt[j].S;
        }
        predo();
        int ans = solve();
        cas++;
        cout << "Case " << cas << ": ";
        if (ans == -1) cout << "ERROR\n";
        else cout << ans << " shades\n";
    }

    return 0;
}

```

8.2 Mo-Algorithm on Tree

```

#include<bits/stdc++.h>
using namespace std;
#define IOS ios_base::sync_with_stdio(0); cin.tie(0);
#define SZ(x) ((int)((x).size()))

const int MX = 500005;
const int SQ = 1400;
const int LOG = 17;

struct BIT {
    int bit[MX];
    int lb(int x) { return x & -x; }
    void add(int p, int v) {
        p++;
        for (int i=p; i<MX; i+=lb(i)) bit[i] += v;
    }
    int qry() {
        int v = 0;
        for (int i=1<<LOG; i>0; i>>=1) {
            if ((v|i) < MX and bit[v|i]==i) v |= i;
        }
        return v;
    }
}bit;

struct Query {
    int l,r,qid;
}qry[MX];
struct Edge {
    int v,x;
};

int N,Q,timestamp[MX],ans[MX];
int in[MX],cnt[MX];
vector<Edge> E[MX];
vector<Edge> seq;

void DFS(int u, int f) {
    timestamp[u] = SZ(seq);
    for (auto it:E[u]) {
        if (it.v == f) continue;
        seq.push_back(it);
        DFS(it.v,u);
        seq.push_back(it);
    }
}

void poke(int id) {
    int v = seq[id].v;
    int x = seq[id].x;
    in[v] ^= 1;
    cnt[x] += in[v] ? 1 : -1;
    if (in[v] and cnt[x] == 1) bit.add(x, 1);
    if (!in[v] and cnt[x] == 0) bit.add(x, -1);
}

```

```

}
int main() {
    IOS;
    cin >> N >> Q;
    for (int i=0; i<N-1; i++) {
        int u,v,x;
        cin >> u >> v >> x;
        x = min(x,N);
        E[u].push_back({v,x});
        E[v].push_back({u,x});
    }
    DFS(1,1);
    for (int i=1; i<=Q; i++) {
        int u,v;
        cin >> u >> v;
        int l = timestamp[u], r = timestamp[v];
        if (l > r) swap(l,r);
        r--;
        qry[i] = {l,r,i};
    }
    sort(qry+1,qry+1+Q, [](Query a, Query b) {
        return make_pair(a.l/SQ,a.r) < make_pair(b.l/SQ,b.r);
    });

    int curL = 1, curR = 0;
    for (int i=1; i<=Q; i++) {
        int ql=qry[i].l,qr=qry[i].r;
        while (curL > ql) poke(--curL);
        while (curR < qr) poke(++curR);
        while (curL < ql) poke(curL++);
        while (curR > qr) poke(curR--);
        ans[qry[i].qid] = bit.qry();
    }

    for (int i=1; i<=Q; i++) cout << ans[i] << "\n";

    return 0;
}

```

8.3 Manhattan MST

```

#include<bits/stdc++.h>
#define REP(i,n) for(int i=0;i<n;i++)
using namespace std;
typedef long long LL;
const int N=200100;
int n,m;
struct PT {int x,y,z,w,id;}p[N];
inline int dis(const PT &a,const PT &b){return abs(a.x-b.x)+abs(a.y-b.y);}
inline bool cpx(const PT &a,const PT &b){return a.x!=b.x? a.x>b.x:a.y>b.y;}
inline bool cpz(const PT &a,const PT &b){return a.z<b.z;}

struct E{int a,b,c;}e[8*N];
bool operator<(const E&a,const E&b){return a.c<b.c;}
struct Node{
    int L,R,key;
}node[4*N];
int s[N];
int F(int x){return s[x]==x?s[x]:F(s[x]);}
void U(int a,int b){s[F(b)]=F(a);}
void init(int id,int L,int R) {
    node[id]=(Node){L,R,-1};
    if(L==R)return;
    init(id*2,L,(L+R)/2);
    init(id*2+1,(L+R)/2+1,R);
}

void ins(int id,int x) {
    if(node[id].key==-1 || p[node[id].key].w>p[x].w)node[id].key=x;
    if(node[id].L==node[id].R)return;
    if(p[x].z<=(node[id].L+node[id].R)/2)ins(id*2,x);
    else ins(id*2+1,x);
}

int Q(int id,int L,int R){
    if(R<node[id].L || L>node[id].R)return -1;
    if(L<=node[id].L && node[id].R<=R)return node[id].key;
    ;
    int a=Q(id*2,L,R),b=Q(id*2+1,L,R);
    if(b!=-1 || (a!=-1 && p[a].w<p[b].w)) return a;
    else return b;
}

```



```

void calc() {
    REP(i,n) {
        p[i].z=p[i].y-p[i].x;
        p[i].w=p[i].x+p[i].y;
    }
    sort(p,p+n,cpz);
    int cnt=0,j,k;
    for(int i=0;i<n;i=j){
        for(j=i+1;p[j].z==p[i].z && j<n;j++);
        for(k=i,cnt++;k<j;k++)p[k].z=cnt;
    }
    init(1,1,cnt);
    sort(p,p+n,cpx);
    REP(i,n) {
        j=Q(1,p[i].z,cnt);
        if(j!=-1)e[m++]=(E){p[i].id,p[j].id,dis(p[i],p[j])};
        ins(1,i);
    }
}
LL MST() {
    LL r=0;
    sort(e,e+m);
    REP(i,m) {
        if(F(e[i].a)==F(e[i].b))continue;
        U(e[i].a,e[i].b);
        r+=e[i].c;
    }
    return r;
}
int main(){
    int ts;
    scanf("%d",&ts);
    while (ts--){
        m = 0;
        scanf("%d",&n);
        REP(i,n) {
            scanf("%d%d",&p[i].x,&p[i].y);
            p[i].id=s[i]=i;
        }
        calc();
        REP(i,n)p[i].y= -p[i].y;
        calc();
        REP(i,n)swap(p[i].x,p[i].y);
        calc();
        REP(i,n)p[i].x=-p[i].x;
        calc();
        printf("%lld\n",MST()*2);
    }
    return 0;
}

```

Similar to `__builtin_clz`, except the argument type is `unsigned long long`.

```
int __builtin_ctzll (unsigned long long)
```

Similar to `__builtin_ctz`, except the argument type is `unsigned long long`.

```
int __builtin_popcountll (unsigned long long)
```

Similar to `__builtin_popcount`, except the argument type is `unsigned long long`.

```
int __builtin_parityll (unsigned long long)
```

Similar to `__builtin_parity`, except the argument type is `unsigned long long`.

9.2 bitwise operations - collection

// https://blog.kuo00.tw/posts/2012/01/28/bitwise-operation-set-operation/

// 列舉集合 S 的所有子集合

```

int temp = S;
do {
    // process
    temp = (temp - 1) & S;
} while (temp != S);

```

// 列舉有 n 個元素的字集合 U 中所有大小為 k 的子集合

```

int temp = (1 << k) - 1;
while (temp < (1 << n)) {
    // process
    int last_1 = temp & -temp;
    int carry = temp + last_1;
    int cont_bits = temp & (~carry);
    int trail = (cont_bit / last_1) >> 1;
    temp = carry | trail;
}

```

9 Other

9.1 __builtin__

```
int __builtin_ffs (unsigned int x)
```

Returns one plus the index of the least significant 1-bit of x, or if x is zero, returns zero.

```
int __builtin_clz (unsigned int x)
```

Returns the number of leading 0-bits in x, starting at the most significant bit position. If x is 0, the result is undefined.

```
int __builtin_ctz (unsigned int x)
```

Returns the number of trailing 0-bits in x, starting at the least significant bit position. If x is 0, the result is undefined.

```
int __builtin_popcount (unsigned int x)
```

Returns the number of 1-bits in x.

```
int __builtin_parity (unsigned int x)
```

Returns the parity of x, i.e. the number of 1-bits in x modulo 2.

```
int __builtin_ffsll (unsigned long long)
```

Similar to `__builtin_ffs`, except the argument type is `unsigned long long`.

```
int __builtin_clzll (unsigned long long)
```

//stack resize

```
asm( "mov %0,%esp\n" :: "g"(mem+10000000) );
//change esp to rsp if 64-bit system
```

//stack resize (linux)

```

#include <sys/resource.h>
void increase_stack_size() {
    const rlim_t ks = 64*1024*1024;
    struct rlimit rl;
    int res=getrlimit(RLIMIT_STACK, &rl);
    if(res==0){
        if(rl.rlim_cur<ks){
            rl.rlim_cur=ks;
            res=setrlimit(RLIMIT_STACK, &rl);
        }
    }
}

```

9.4 GCC Pragma

```

#pragma GCC optimize ("O3")
#pragma GCC target("avx,tune=native")

```

10 Graph paper

