

Содержание

1 Настройка CLion	1
2 Теория чисел	1
2.1 КТО	1
2.2 Алгоритм Миллера — Рабина	1
2.3 Алгоритм Берлекэмпа — Мессис	2
2.4 Линейное решето	2
2.5 Алгоритм Шенкса	2
3 Графы	3
3.1 SCC и 2-SAT	3
3.2 Эйлеров цикл	3
3.3 Компоненты рёберной двусвязности	3
3.4 DCP offline	4
3.5 Взвешенное паросочетание	4
3.6 Дерево доминаторов	5
4 Свёртки	6
4.1 XOR свёртка	6
4.2 FFT & co	6
4.3 Быстрое FFT	7
4.4 FFT в double'ax	8
5 Структуры данных	8
5.1 Дерево Фенвика	8
5.2 Дерево отрезков в точке	8
5.3 Массовое дерево отрезков	9
5.4 Битовый бор	10
5.5 Ordered set	10
5.6 Динамический битсет	11
5.7 Convex hull trick	11
5.8 Центроиды	11
5.9 Дерево Ли Чао	11
5.10 Min-Kinetic Segment Tree	11
5.11 Декартово дерево	12
5.11.1 Декартово дерево по явному ключу. Multiset	12
6 Строковые алгоритмы	13
6.1 Префикс-функция	13
6.2 Z-функция	13
6.3 Алгоритм Манакера	13
6.4 Суфмассив	13
6.5 Алгоритм Ахо — Корасик	14
6.6 Дерево палиндромов	14
7 Потoki	15
7.1 Алгоритм Диница	15
7.2 Mincost k-flow	15
8 Алгоритм Гаусса	16
8.1 Решение $Ax = b$	16
8.2 Базис $Ax = 0$	17
9 Гамильтоновы путь и цикл	17
9.1 Link-cut tree	17
9.2 Undirected case	18
9.3 Directed case	18
10 Геометрия	19
10.1 Примитивы	19
10.2 Выпуклая оболочка	19
10.3 Точка внутри многоугольника	19
10.4 Касательные	20
10.5 Пересечение многоугольника и полуплоскости	20
10.6 События для прямой	20
10.7 Кривая Гильберта для алгоритма Мо	20
11 Цепные дроби	21
11.1 Поиск нижней огибающей, сумма и минимум по модулю	21
11.2 Простая рекурсия	21
12 Разное	21
12.1 Компараторы	21
12.2 Трюки от Сергея Копелиовича	21
12.2.1 Быстрый ввод	21
12.2.2 Быстрый аллокатор	22
12.3 Редукция Барретта	22
12.4 Флаги компиляции	22
12.4.1 Сетка в vim	22
12.5 Что сделать на пробном туре	22
12.6 Хеш файла без комментариев	22

1 Настройка CLion

- В файле CMakeLists.txt дописать строку `add_compile_definitions(LLOCAL)`. Нажать появившуюся опцию в правом верхнем углу `enable auto-reload`.

- Вбить шаблон в main.cpp:

```
#ifndef LOCAL
#define _GLIBCXX_DEBUG
#endif
#include<bits/stdc++.h>

using namespace std;

#define int long long
#define app push_back
#define all(x) x.begin(), x.end()
#ifdef LOCAL
#define debug(...) [](auto...a){ ((cout << a << ' '),
    ...) << endl; }(#__VA_ARGS__, ":", __VA_ARGS__)
#define debugv(v) do { cout << #v << ": "; for (auto x :
    v) cout << x << ' '; cout << endl; } while(0)
#else
#define debug(...)
#define debugv(v)
#endif

int32_t main() {
    cin.tie(0); ios_base::sync_with_stdio(0);
    int n = 2; vector<int> a(n, n);
    debug(n); debugv(a);
}
```

//59124c

Скомпилировать, чтобы проверить отсутствие опечаток.

- Запустить терминал (ctrl + alt + T)

```
$ cd workspace/CLionProjects
$ for c in {A..Z}; do cp main.cpp $c.cpp && echo "
    add_executable($c $c.cpp)" >> CMakeLists.txt; done
```

Далее отключаем подсветку и форматирование в настройках (ctrl+alt+S)

- Editor → Code Style → Formatter → Do not format прописать *
- Editor → Inspections → C/C++ → static analysis tools → CLang-Tidy отключить
- Editor → Inlay Hints → отключаем всё (достаточно первых трёх — code vision, parameter names, types).

Тёмная тема отключается в Appearance & Behavior → Appearance.

Чтобы добавить санитайзеры, надо дописать в CMakeLists.txt `set(CMAKE_CXX_FLAGS "-fsanitize=address -fsanitize=undefined")`

2 Теория чисел

2.1 КТО

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

int inv(int r, int m) {
    int x, y;
    gcd(r, m, x, y);
    return (x+m)%m;
}

int crt(int r, int n, int c, int m) { return r + ((c - r) % m
    + m) * inv(n, m) % m * n; }
```

//8ed8ed

2.2 Алгоритм Миллера — Рабина

```
_int128 one=1;
int po(int a, int b, int p)
{
    int res=1;
    while(b) {if(b & 1) {res=(res*one*a)%p; --b;} else {a=(a*one*
        a)%p; b>>=1;}} return res;
}

bool chprime(int n) ///miller-rabin
```

```

{
    if(n==2) return true;
    if(n<=1 || n%2==0) return false;
    int h=n-1;int d=0;while(h%2==0) {h/=2;++d;}
    for(int a:{2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37})
    {
        if(a==n) return true;
        int u=po(a,h,n);bool ok=0;
        if(u%n==1) continue;
        for(int c=0;c<d;++c)
        {
            if((u+1)%n==0) {ok=1;break;}
            u=(u*one*u)%n;
        }
        if(!ok) return false;
    }
    return true;
}

//86b2ed

```

2.3 Алгоритм Берлекэмп — Мессе

<https://mzhang2021.github.io/cp-blog/berlekamp-massey/>

```

template<typename T>
vector<T> berlekampMassey(const vector<T> &s) {
    int n = s.size(), l = 0, m = 1;
    vector<T> b(n), c(n);
    T ld = b[0] = c[0] = 1;
    for (int i=0; i<n; i++, m++) {
        T d = s[i];
        for (int j=1; j<=l; j++)
            d += c[j] * s[i-j];
        if (d == 0) continue;
        vector<T> temp = c;
        T coef = d / ld;
        for (int j=m; j<n; j++) c[j] -= coef * b[j-m];
        if (2 * l <= i) {
            l = i + 1 - l;
            b = temp;
            ld = d;
            m = 0;
        }
    }
    c.resize(l + 1);
    c.erase(c.begin());
    for (T &x : c)
        x = -x;
    return c;
}

//ff47ae

```

2.4 Линейное решето

```

const int C = 1e7+7;
vi pr, lp(C);
for (int i = 2; i < C; ++i) {
    if (lp[i] == 0) {
        lp[i] = i;
        pr.push(i);
    }
    for (int j = 0; j < (int)pr.size() && pr[j] <= lp[i] && pr[j]
        * i < C; ++j) {
        lp[pr[j] * i] = pr[j];
    }
}

//36b3d1

```

2.5 Алгоритм Шенкса

```

#define T int
int mod;
int gcd(int a, int b, int &x, int &y) {
    if (b==0) { x = 1; y = 0; return a; }
    int d = gcd(b,a%b,y,x);
    y-=a/b*x;
    return d;
}
int inv(int r, int m) {
    int x, y;
    gcd(r,m,x,y);
    return (x+m)%m;
}
int crt(int r, int n, int c, int m) { return r + ((c - r) % m
    + m) * inv(n, m) % m * n; }

```

```

T inv(T a)
{
    return inv(a,mod);
}
T mul(T a,T b)
{
    return (a*b)%mod;
}
vector<int> rasl(int x)
{
    vector<int> v;
    if(x==1) {return v;}
    for(int i=2;i*i<=x;++i)
    {
        if(x%i==0)
        {
            v=rasl(x/i);v.push(i);return v;
        }
    }
    v.push(x);return v;
}
T po(T a,int b) //b>=1
{
    if(b==1) {return a;}
    if(b%2==0)
    {
        T u=po(a,b/2);
        return mul(u,u);
    }
    else
    {
        T u=po(a,b-1);
        return mul(a,u);
    }
}
T getper(T a,T one,int per,vector<int> v)
{
    for(int p:v)
    {
        if(po(a,per/p)==one)
        {
            per/=p;
        }
    }
    return per;
}
vector<pair<int,int> > shanks(T a,vector<T> b,T one,int per)
    ///a^per=1 and b[i]^per=1 /// all right numbers in output
    are equal
{
    if(b.empty()) {return {};}
    int n=b.size();
    vector<int> vp=rasl(per);
    int pera=getper(a,one,per,vp);per=pera;
    vp=rasl(pera);
    vector<int> have(n,0);
    int cur2=per;T cura=a;T invcura=inv(a);
    int curad=1;
    vector<pair<T,int> > v;
    vector<bool> ok(n,true);
    vector<T> poinvzx;
    for(int p:vp)
    {
        T ca=po(cura,cur2/p);
        if(ca==one) {continue;}
        T invca=po(invcura,cur2/p);
        int step=sqrt(b.size()*p)+2;
        int wee=p/step+2;
        v.clear();poinvzx.clear();
        T zx=one;T invzx=one;T buba=one;
        vector<T> zhe;
        T lu=one;
        for(int i=0;i<step;++i)
        {
            v.push({zx,i});zhe.push(lu);
            zx=mul(zx,ca);invzx=mul(invzx,invca);buba=mul(buba,cura);
            lu=mul(lu,invcura);
        }
        poinvzx.push(one);
        for(int j=0;j<wee;++j)
        {
            poinvzx.push(mul(poinvzx.back(),buba));
        }
        sort(all(v));
        for(int i=0;i<n;++i)
        {
            if(!ok[i]) {continue;}
            T uu=po(b[i],cur2/p);
            bool okk=false;
            for(int j=0;j<wee;++j)

```

```

{
    auto it=lower_bound(all(v),make_pair(uu,0LL));
    if(it!=v.end() && (*it).first==uu)
    {
        okkk=true;
        have[i]--(curad*step*j);
        have[i]+=(curad*(it).second);
        have[i]%=pera;if(have[i]<0) {have[i]+=pera;}
        b[i]=mul(b[i],poinvzx[j]);b[i]=mul(b[i],zhe[(*it).
second]);
        assert(po(b[i],cur2/p)==one);
        break;
    }
    uu=mul(uu,zx);
}
if(!okkk) {ok[i]=false;}
cur2/=p;cura=po(cura,p);invcura=po(invcura,p);curad*=p;
}
vector<pair<int,int>> res;
for(int i=0;i<n;++i)
{
    if(ok[i] && b[i]==one)
    {
        res.app({(have[i]*pera+pera)*pera,pera});
    }
    else
    {
        res.app({-1,pera});
    }
}
return res;
}
int shanks2(int x,int y,int mod1) ///only for T=long long, 0^0
    = 1 by default
{
    mod=mod1;
    vector<int> v=rasl(mod);sort(all(v));
    int per=1;for(int i=0;i<v.size();++i) {if(i==0 || v[i]!=v[i-1]) {per*=(v[i]-1);} else {per*=v[i];}}
    if(y==1 || mod==1) {return 0;}
    int C=61;
    for(int i=1;i<C;++i)
    {
        if(po(x,i)==y) {return i;}
    }
    if(y==0) {return (-1);}
    T h=po(x,C);
    int lc1=gcd(h,mod);int lc2=gcd(y,mod);
    if(lc1!=lc2) {return (-1);}
    mod/=lc2;T h1=h/lc2;T y1=y/lc2;
    vector<pair<int,int>> s=shanks(x%mod,{mul(y1,inv(h1))},1,
    per);
    if(s[0].first!=(-1))
    {
        return s[0].first+C;
    }
    else
    {
        return (-1);
    }
}
}
//a75596

```

3 Графы

3.1 SCC и 2-SAT

Алгоритм ищет сильносвязные компоненты в графе g , если есть путь $i \rightarrow j$, то $scc[i] \leq scc[j]$

```

vector<int> find_scc(vector<vector<int>> g) {
    int n = g.size();
    vector<vector<int>> r(n);
    for (int i = 0; i < n; ++i) {
        for (int j : g[i]) r[j].push_back(i);
    }
    vector<int> used(n), tout(n);
    int time = 0;
    auto dfs = [&](auto dfs, int cur) -> void {
        used[cur] = 1;
        for (int nxt : g[cur]) {
            if (!used[nxt]) dfs(dfs, nxt);
        }
        tout[cur] = time++;
    };
    for (int i = 0; i < n; ++i) if (!used[i]) dfs(dfs, i);
    vector<int> ind(n);
    iota(all(ind), 0);

```

```

sort(all(ind), [&](int i, int j){return tout[i] > tout[j];});
vector<int> scc(n, -1);
auto go = [&](auto go, int cur, int color) -> void {
    scc[cur] = color;
    for (int nxt : r[cur]) {
        if (scc[nxt] == -1) go(go, nxt, color);
    }
};
int color = 0;
for (int i : ind) {
    if (scc[i] == -1) go(go, i, color++);
}
return scc;
}
//4fd51f

```

Чтобы решать 2-SAT, надо создать граф на $2n$ вершинах, рёбра $i \Rightarrow j$ и $(j \oplus 1) \Rightarrow (i \oplus 1)$ должны быть добавлены одновременно. После этого если $scc[2 * i] = scc[2 * i + 1]$, то решения нет; если $scc[2 * i + 0] < scc[2 * i + 1]$, то присутствует импликация $\neg i \Rightarrow i$, надо назначить $i = \text{true}$.

3.2 Эйлеров цикл

```

vector<int> euler(vector<vector<pair<int, int>>> g, int m, int
src) { // g[cur][i] = pair{nxt, idx}
    int n = g.size();
    vector<int> used(m), it(n), cycle;
    auto dfs = [&](auto dfs, int cur) -> void {
        while (true) {
            while (it[cur] < g[cur].size() && used[g[cur][it[cur]]].
second) it[cur]++;
            if (it[cur] == g[cur].size()) return;
            auto [nxt, idx] = g[cur][it[cur]];
            used[idx] = true;
            dfs(dfs, nxt);
            cycle.push_back(idx); // or {cur, nxt}
        }
    };
    dfs(dfs, src);
    reverse(cycle.begin(), cycle.end());
    if (cycle.size() != m) return {}; // check that all edges
are present in the cycle, fail otherwise
    return cycle;
}
//f6b9d4

```

3.3 Компоненты рёберной двусвязности

```

//n - number of vertices, m - number of edges, parallel edges
-- ???, color of any edge is the color of its lower end
vector<vector<int>> dfstree(n);
vector<int> used(n), cut(n), h(n), up(n);
auto findCutPoints = [&](auto self, int u) -> void {
    used[u] = 1;
    up[u] = h[u];
    for (int v : g[u]) {
        if (!used[v]) {
            dfstree[u].push_back(v);
            h[v] = h[u] + 1;
            self(self, v);
            up[u] = min(up[u], up[v]);
            if (up[v] >= h[u]) {
                cut[v] = 1;
            }
        }
        else {
            up[u] = min(up[u], h[v]);
        }
    }
};
findCutPoints(findCutPoints, 0);
vector<vector<int>> tree(n + m);
vector<int> color(n);color[0]=0;int ptr=n;
auto build = [&](auto self, int u) -> void {
    for (int v : dfstree[u]) {
        if (cut[v]) {
            color[v]=ptr++;ptr++;
            self(self, v);
        }
        else {
            color[v]=color[u];
            self(self, v);
        }
    }
};
build(build, 0);

```

```

for(int i=0;i<n;++i) {
    set<int> to;
    for(int j:g[i]) {
        int x=i,y=j;
        if(h[x]<h[y]) swap(x,y);
        to.insert(color[x]);
    }
    for(int j:to) {
        tree[i].app(j);tree[j].app(i);
    }
}

//2ebfbb

```

3.4 DCP offline

```

struct Dsu {
    int n;
    vector<pair<int, int>> s;
    vector<int> p, sz;
    // other info

    Dsu(int n) : n(n), p(n), sz(n, 1) {
        iota(all(p), 0);
    }

    int get(int u) {
        while (u != p[u]) u = p[u];
        return u;
    }

    bool merge(int u, int v) {
        u = get(u), v = get(v);
        if (u == v) return false;
        if (sz[v] < sz[u]) swap(u, v);
        s.app({p[u], p[v]});
        s.app({sz[v], sz[u]});
        // app other info like s.app({comp, comp});
        p[u] = v;
        sz[v] += sz[u];
        return true;
    }

    void rollback(int sz) {
        while (s.size() != sz) {
            s.back().first = s.back().second;
            s.pop_back();
        }
    }
};

struct DcpOffline {
    int n;
    vector<vector<pair<int, int>>> d;

    void addEdgeOnSegment(int l, int r, int a, int b) {
        for (l += n, r += n; l < r; l /= 2, r /= 2) {
            if (l & 1) d[l++].app({a, b});
            if (r & 1) d[--r].app({a, b});
        }
    }

    template<typename T>
    void dfs(Dsu &dsu, T act) {
        dfs(1, 0, n, dsu, act);
    }

    template<typename T>
    void dfs(int v, int l, int r, Dsu &dsu, T act) {
        int sz = dsu.s.size();
        for (auto [u, v]: d[v]) {
            dsu.merge(u, v);
        }
        if (l + 1 == r) {
            act(l, dsu);
        } else {
            int m = (l + r) / 2;
            dfs(v * 2, l, m, dsu, act);
            dfs(v * 2 + 1, m, r, dsu, act);
        }
        dsu.rollback(sz);
    }

    DcpOffline(int maxt) : n(2 << __lg(maxt + 1)), d(2 * n) {}
};

//3c4e2d

```

3.5 Взвешенное паросочетание

<https://judge.yosupo.jp/submission/201334>

```

#define d(x) (lab[x.u] + lab[x.v] - 2 * e[x.u][x.v].w)
const int N = 403*2;
const int inf = 1e18;
struct Q { int u, v, w; } e[N][N];
vector<int> p[N];
int n, m = 0, id, h, t, lk[N], sl[N], st[N], f[N], b[N][N], s[
    N], ed[N], q[N], lab[N];
void upd(int u, int v) { if (!sl[v] || d(e[u][v]) < d(e[sl[v]
    ][v])) sl[v] = u; }
void ss(int v) {
    sl[v] = 0;
    for (int u = 1; u <= n; ++u) if (e[u][v].w > 0 && st[u] != v
        && !s[st[u]]) upd(u, v);
}
void ins(int u) { if (u <= n) q[++t] = u; else for (int v : p[u]
    ) ins(v); }
void ch(int u, int w) { st[u] = w; if (u > n) for (int v : p[u]
    ) ch(v, w); }
int gr(int u, int v) {
    if ((v = find(all(p[u]), v) - p[u].begin()) & 1) {
        reverse(1 + all(p[u]));
        return (int)p[u].size() - v;
    }
    return v;
}
void stm(int u, int v) {
    lk[u] = e[u][v].v;
    if (u <= n) return; Q w = e[u][v];
    int x = b[u][w.u], y = gr(u, x);
    for (int i = 0; i < y; ++i) stm(p[u][i], p[u][i+1]);
    stm(x, v); rotate(p[u].begin(), y+all(p[u]));
}
void aug(int u, int v) {
    int w = st[lk[u]];stm(u, v);if (!w) return;
    stm(w, st[f[w]]);
    aug(st[f[w]], w);
}
int lca(int u, int v) {
    for (id++; u|v; swap(u, v)) {
        if (!u) continue;if(ed[u] == id) return u;
        ed[u] = id; if (u = st[lk[u]]) u = st[f[u]]; // =, not ==
    }
    return 0;
}

//cf1d55

void add(int u, int a, int v) {
    int x = n + 1; while (x <= m && st[x]) ++x;
    if (x > m) ++m;
    lab[x] = s[x] = st[x] = 0;
    lk[x] = lk[a];
    p[x].clear();
    p[x].push_back(a);
#define op(q) for (int i = q, j = 0; i != a; i=st[f[j]]) p[x].
    push_back(i), p[x].push_back(j=st[lk[i]]), ins(j) // also
    not ==
    op(u); reverse(1+all(p[x]));op(v);
    ch(x, x); for (int i = 1; i <= m; ++i) e[x][i].w = e[i][x].w
        = 0;
    fill(b[x]+1, b[x]+n+1, 0);
    for (int u : p[x]) {
        for (int v = 1; v <= m; ++v) if (!e[x][v].w || d(e[u][v])
            < d(e[x][v])) e[x][v] = e[u][v], e[v][x] = e[v][u];
        for (int v = 1; v <= n; ++v) if (b[u][v]) b[x][v] = u;
    }
    ss(x);
}
void ex(int u) {
    for (int x : p[u]) ch(x, x);
    int a = b[u][e[u][f[u]].u], r = gr(u, a);
    for (int i = 0; i < r; i += 2) {
        int x = p[u][i], y = p[u][i + 1];
        f[x] = e[y][x].u; s[x] = 1; s[y] = 0; sl[x] = 0; ss(y);
        ins(y);
    }
    s[a] = 1; f[a] = f[u];
    for (int i = r + 1; i < p[u].size(); ++i) s[p[u][i]] = -1,
        ss(p[u][i]);
    st[u] = 0;
}
bool on(const Q &e) {
    int u = st[e.u], v = st[e.v], a;
    if (s[v] == -1) {
        f[v] = e.u, s[v] = 1, a = st[lk[v]], sl[v] = sl[a] = s[a]
            = 0, ins(a);
    } else if (!s[v]) {
        a = lca(u, v); if (!a) return aug(u, v), aug(v, u), 1;
        else add(u, a, v);
    }
}

```

```

    }
    return 0;
}

//3f0f1d

bool bfs() {
    fill(s+1, s+m+1, -1); fill(sl+1, sl+m+1, 0); // s is filled
    with -1
    h = 1, t = 0; for (int i = 1; i <= m; ++i) if (st[i] == i &&
        !lk[i]) f[i] = s[i] = 0, ins(i);
    if (h > t) return 0;
    while (1) {
        while (h <= t) {
            int u = q[h++];
            if (s[st[u]] != 1) {
                for (int v = 1; v <= n; ++v) if (e[u][v].w > 0 && st[v]
                    != st[u]) {
                    if (d(e[u][v])) upd(u, st[v]); else if (on(e[u][v]))
                        return 1;
                }
            }
        }
        int x = inf;
        for (int i = n+1; i <= m; ++i) if (st[i] == i && s[i] ==
            1) x = min(x, lab[i]/2);
        for (int i = 1; i <= m; ++i) if (st[i] == i && sl[i] && s[
            i] != 1) x = min(x, d(e[sl[i]][i]) >> s[i]+1);
        for (int i = 1; i <= n; ++i) if (~s[st[i]]) if ((lab[i] +=
            (s[st[i]] * 2 - 1) * x) <= 0) return 0;
        for (int i = n+1; i <= m; ++i) if (st[i] == i && ~s[st[i]
            ]) lab[i] += (2 - 4 * s[st[i]]) * x;
        h = 1, t = 0;
        for (int i = 1; i <= m; ++i) if (st[i] == i && sl[i] && st
            [sl[i]] != i && !d(e[sl[i]][i]) && on(e[sl[i]][i]))
            return 1;
        for (int i = n+1; i <= m; ++i) if (st[i] == i && s[i] == 1
            && !lab[i]) ex(i);
    }
}

pair<int, vector<array<int, 2>>> run(int N, vector<array<int,
    3>> edges) {
    for (auto &[u, v, w] : edges) ++u, ++v;
    fill(ed+1, ed+m+1, 0);
    fill(lk+1, lk+m+1, 0);
    n = m = N;
    id = 0;
    iota(st + 1, st + n + 1, 1);
    int wm = 0, weight = 0;
    for (int i = 1; i <= n; ++i) for (int j = 1; j <= n; ++j) e[
        i][j] = {i, j, 0};
    for (auto [u, v, w] : edges) wm = max(wm, e[v][u].w = e[u][v
        ].w = max(e[u][v].w, w));
    for (int i = 1; i <= n; ++i) p[i].clear();
    for (int i = 1; i <= n; ++i) for (int j = 1; j <= n; ++j) b[
        i][j] = i==j?i:0;
    fill_n(lab+1, n, wm); while (bfs());
    vector<array<int, 2>> matching;
    for (int i = 1; i <= n; ++i) if (i < lk[i]) weight += e[i][
        lk[i]].w, matching.push_back({i - 1, lk[i] - 1});
    return {weight, matching};
}

//be682f

```

3.6 Дерево доминаторов

```

struct DominatorTree{
    struct DSU{
        struct Vert{
            int p;
            pair<int, int> val;
        };

        vector<Vert> t;
        vector<int> ord;

        DSU(vector<int> &ord): ord(ord) { t.resize(ord.size());
            for (int i = 0; i < ord.size(); i++) t[i].p = i; }

        int get(int v){
            if (t[v].p == v) return v;
            int new_p = get(t[v].p);
            if (ord[t[v].val.first] > ord[t[t[v].p].val.first]) t[v
                ].val = t[t[v].p].val;
            t[v].p = new_p;
        }
    };
};

```

```

        return t[v].p;
    }

    void merge(int a, int b){
        a = get(a); b = get(b);
        if (a != b){
            t[b].p = a;
        }
    }

    void setVal(int v, pair<int, int> val){
        t[v].val = val;
    }

    auto getVal(int v){
        get(v);
        return t[v].val;
    }
};

vector<vector<int>> g, gr, lg;
vector<int> idom, sdom, was, tin;

int timer;
void dfs(int v){
    tin[v] = timer++;
    was[v] = 1;
    for (int to : g[v]) if (!was[to]) dfs(to);
}

vector<vector<int>> req;

DominatorTree(int n, vector<pair<int, int>> &edges, int
    root){
    g.resize(n); gr.resize(n); lg.resize(n);
    idom.resize(n, -1); sdom.resize(n);
    was.resize(n, 0), tin.resize(n);
    req.resize(n);
    for (auto &e : edges){
        g[e.first].push_back(e.second);
        gr[e.second].push_back(e.first);
    }
    timer = 0; dfs(root);
    vector<int> ord;
    for (int i = 0; i < n; i++) ord.push_back(i);
    sort(ord.begin(), ord.end(), [this](int w1, int w2){
        return tin[w1] > tin[w2]; });
    DSU dsu(tin);
    for (int v : ord){
        sdom[v] = v;
        for (int to : gr[v]){
            if (v == to) continue;
            int val = tin[to] < tin[v] ? to : dsu.getVal(to).first
                ;
            if (tin[val] < tin[sdom[v]]) sdom[v] = val;
        }

        req[sdom[v]].push_back(v);
        for (auto &r : req[v]){
            auto val = dsu.getVal(r);
            if (tin[val.first] < tin[sdom[r]]){
                lg[val.second].push_back(r);
            } else {
                idom[r] = sdom[r];
            }
        }
    }

    dsu.setVal(v, make_pair(sdom[v], v));
    for (int to : g[v]){
        if (tin[to] > tin[v] && dsu.t[to].p == to){
            dsu.merge(v, to);
        }
    }
}

for (int i = 0; i < n; i++) was[i] = 0;

for (int i = 0; i < n; i++) if (!was[i] && idom[i] != -1){
    vector<int> st;
    st.push_back(i);
    was[i] = 1;
    while(st.size()){
        int v = st.back(); st.pop_back();
        idom[v] = idom[i];
        for (int to : lg[v]) if (!was[to]) was[to] = 1, st.
            push_back(to);
    }
}
};

```

```

/*
vector <pair <int, int> > e;
DominatorsTree d(n,e,0);
auto par = d.idom;
*/

//839464

```

4 Свёртки

4.1 XOR свёртка

```

vector<int> bxor(vector<int> a,vector<int> b)
{
    assert(p%2==1);int inv2=(p+1)/2;
    int n=0;while((1<<n)<a.size()) ++n;
    a.resize(1<<n);b.resize(1<<n);
    for(int i=0;i<n;++i) for(int mask=0;mask<(1<<n);++mask) if
        (!(mask & (1<<i))) {int u=a[mask],v=a[mask+(1<<i)];a[mask
        +(1<<i)]=(u+v)%p;a[mask]=(u-v)%p;}
    for(int i=0;i<n;++i) for(int mask=0;mask<(1<<n);++mask) if
        (!(mask & (1<<i))) {int u=b[mask],v=b[mask+(1<<i)];b[mask
        +(1<<i)]=(u+v)%p;b[mask]=(u-v)%p;}
    vector<int> c(1<<n,0);
    for(int mask=0;mask<(1<<n);++mask) {c[mask]=a[mask]*b[mask];
    c[mask]%p;}
    for(int i=0;i<n;++i) for(int mask=0;mask<(1<<n);++mask) if
        (!(mask & (1<<i))) {int u=c[mask],v=c[mask+(1<<i)];c[mask
        +(1<<i)]=(v-u)*inv2%p;c[mask]=(u+v)*inv2%p;}
    return c;
}

//20cc50

```

4.2 FFT & co

```

typedef long long ll;
const int p=998244353;
int po(int a,int b) {if(b==0) return 1; if(b==1) return a; if
    b%2==0) {int u=po(a,b/2);return (u*1LL*u)%p;} else {int u
    =po(a,b-1);return (a*1LL*u)%p;}}
int inv(int x) {return po(x,p-2);}
template<int M, int K, int G> struct Fft {
    // 1, 1/4, 1/8, 3/8, 1/16, 5/16, 3/16, 7/16, ...
    int g[1 << (K - 1)];
    Fft() : g() { //if t1 constexpr...
        // static_assert(K >= 2, "Fft: K >= 2 must hold");
        g[0] = 1;
        g[1 << (K - 2)] = G;
        for (int l = 1 << (K - 2); l >= 2; l >= 1) {
            g[l >> 1] = (g[l] * 1LL * g[l]) % M;
        }
        assert((g[1]*1LL * g[1]) % M == M - 1);
        for (int l = 2; l <= 1 << (K - 2); l <= 1) {
            for (int i = 1; i < l; ++i) {
                g[l + i] = (g[l] * 1LL * g[i]) % M;
            }
        }
    }
}
void fft(vector<int> &x) const {
    const int n = x.size();
    assert(n <= 1 << K);
    for (int h = __builtin_ctz(n); h--; ) {
        const int l = (1 << h);
        for (int i = 0; i < n >> (h+1); ++i) {
            for (int j = i << (h+1); j < (((i << 1) + 1) << h); ++
            j) {
                const int t = (g[i] * 1LL * x[j | l]) % M;
                x[j | l] = x[j] - t;
                if (x[j|l] < 0) x[j | l] += M;
                x[j]+=t;
                if (x[j] >= M) x[j] -= M;
            }
        }
    }
    for (int i = 0, j = 0; i < n; ++i) {
        if (i < j) std::swap(x[i], x[j]);
        for (int l = n; (l >= 1) && !((j ^ 1) & 1); ) {}
    }
}
vector<int> convolution(vector<int> a, vector<int> b) const
{
    if(a.empty() || b.empty()) return {};
    for(int& x:a) {x%=p;if(x>=p) x-=p; if(x<0) x+=p;} for(int&
    x:b) {x%=p;if(x>=p) x-=p; if(x<0) x+=p;}
    const int na = a.size(), nb = b.size();
    int n, invN = 1;

```

```

    for (n = 1; n < na + nb - 1; n <= 1) invN = ((invN & 1) ?
        (invN + M) : invN) >> 1;
    vector<int> x(n, 0), y(n, 0);
    std::copy(a.begin(), a.end(), x.begin());
    std::copy(b.begin(), b.end(), y.begin());
    fft(x);
    fft(y);
    for (int i = 0; i < n; ++i) x[i] = (((static_cast<long
        long>)(x[i]) * y[i]) % M) * invN) % M;
    std::reverse(x.begin() + 1, x.end());
    fft(x);
    x.resize(na + nb - 1);
    return x;
}
};
Fft<998244353,23,31> muls;

//alb591

vector<int> form(vector<int> v,int n)
{
    while(v.size()<n) v.push_back(0);
    while(v.size()>n) v.pop_back();
    return v;
}
vector<int> operator *(vector<int> v1,vector<int> v2)
{
    return muls.convolution(v1,v2);
}
vector<int> operator +(vector<int> v1,vector<int> v2)
{
    while(v2.size()<v1.size()) v2.push_back(0); while(v1.size()<
    v2.size()) v1.push_back(0);
    for(int i=0;i<v1.size();++i) {v1[i]+=v2[i];if(v1[i]>=p) v1[i
    ]-=p; else if(v1[i]<0) v1[i]+=p;}
    return v1;
}
vector<int> operator -(vector<int> v1,vector<int> v2)
{
    int sz=max(v1.size(),v2.size());while(v1.size()<sz) v1.
    push_back(0); while(v2.size()<sz) v2.push_back(0);
    for(int i=0;i<sz;++i) {v1[i]-=v2[i];if(v1[i]<0) v1[i]+=p;
    else if(v1[i]>=p) v1[i]-=p;} return v1;
}
vector<int> trmi(vector<int> v)
{
    for(int i=1;i<v.size();i+=2) {if(v[i]>0) v[i]=p-v[i]; else v
    [i]=(-v[i]);}
    return v;
}
vector<int> deriv(vector<int> v)
{
    if(v.empty()) return{};
    vector<int> ans(v.size()-1);
    for(int i=1;i<v.size();++i) ans[i-1]=(v[i]*1LL*i)%p;
    return ans;
}
vector<int> integ(vector<int> v)
{
    vector<int> ans(v.size()+1);ans[0]=0;
    for(int i=1;i<v.size();++i) ans[i-1]=(v[i]*1LL*i)%p;
    return ans;
}
vector<int> mul(vector<vector<int> > v)
{
    if(v.size()==1) return v[0];
    vector<vector<int> > v1,v2;for(int i=0;i<v.size()/2;++i) v1.
    push_back(v[i]); for(int i=v.size()/2;i<v.size();++i) v2.
    push_back(v[i]);
    return muls.convolution(mul(v1),mul(v2));
}
vector<int> invl(vector<int> v,int n)
{
    assert(v[0]!=0);
    int sz=1;v=form(v,n);vector<int> a={inv(v[0])};
    while(sz<n)
    {
        vector<int> vsz;for(int i=0;i<min(n,2*sz);++i) vsz.
        push_back(v[i]);
        vector<int> b=((vector<int>) {1})-muls.convolution(a,vsz);
        for(int i=0;i<sz;++i) assert(b[i]==0);
        b.erase(b.begin(),b.begin()+sz);
        vector<int> c=muls.convolution(b,a);
        for(int i=0;i<sz;++i) a.push_back(c[i]);
        sz*=2;
    }
    return form(a,n);
}

```

//12aa4e

4.3 Быстрое FFT

- Solution based on <https://codeforces.com/blog/entry/117947>
- Iterative and in-place version.
- Uses signed montgomery
- Optimized to minimize memory usage

```
const int MOD = 998244353;
const long long MOD2 = (long long) MOD * MOD;
const int root = 3;
const int alim = 64; // Bound for using O(n^2) polynomial mult

int modpow(int b, int e) {
    int ans = 1;
    for (; e; b = (long long) b * b % MOD, e /= 2)
        if (e & 1) ans = (long long) ans * b % MOD;
    return ans;
}

const int MODinv = 2 - MOD; // pow(-MOD, -1, 2**32)
inline int m_reduce(long long x) {
    int m = x * MODinv;
    return (x >> 32) - (((long long) m * MOD) >> 32);
}

const int r2 = modpow(2, 64);
inline int m_transform(int x) {
    return m_reduce((long long)x * r2);
}

inline int m_add(int x, int y) {
    int z = x + y;
    return z < 0 ? z + MOD : z - MOD;
}

inline int m_sub(int x, int y) {
    int z = x - y;
    return z < 0 ? z + MOD : z - MOD;
}

inline int m_mult(int x, int y) {
    return m_reduce((long long) x * y);
}

vector<int> rt = {1};
vector<int> transformed_rt;
vector<int> transformed_rt2;

template<int a>
void transform(vector<int> &P) {
    int m = P.size();
    int n = m / a;

    int size = rt.size();
    while (2 * size < n) {
        rt.resize(n / 2);
        int r = modpow(root, MOD / (4 * size));
        for (int i = 0; i < size; ++i)
            rt[i + size] = (long long) r * rt[i] % MOD;
        size *= 2;
    }

    // For montgomery
    for (int i = transformed_rt.size(); i < rt.size(); ++i) {
        transformed_rt.resize(rt.size());
        transformed_rt[i] = m_transform(rt[i]);
        transformed_rt2.resize(rt.size());
        transformed_rt2[i] = (unsigned int) MODinv *
            transformed_rt[i];
    }

    int k = n;
    while (k >= 4) k /= 4;

    if (k == 2) {
        int step = n * a;
        int half_step = step / 2;
        for (int j1 = 0; j1 < half_step; ++j1) {
            int j2 = j1 + half_step;

            int diff = m_sub(P[j1], P[j2]);
            P[j1] = m_add(P[j1], P[j2]);
            P[j2] = diff;
        }
        k = n/2;
    }
}
```

```
} else {
    k = n;
}

for (; k > 1; k /= 4) {
    for (int i = 0; i < n/k; ++i) {
        int step = k * a;
        int half_step = step / 2;
        int quarter_step = half_step / 2;

        int R20 = transformed_rt2[2 * i];
        int RR0 = transformed_rt[2 * i];

        int R21 = transformed_rt2[2 * i + 1];
        int RR1 = transformed_rt[2 * i + 1];

        int R2 = transformed_rt2[i];
        int RR = transformed_rt[i];

        int j1 = i * step;
        int j2 = j1 + quarter_step;
        int j3 = j2 + quarter_step;
        int j4 = j3 + quarter_step;

        for (int j = 0; j < quarter_step; ++j, ++j1, ++j2, ++j3,
            ++j4) {
            int z0;
            {
                int z = P[j3];
                int m = (unsigned int) R2 * z;
                z0 = ((long long) z * RR - (long long) m * MOD) >>
                    32;
            }

            int z1;
            {
                int z = P[j4];
                int m = (unsigned int) R2 * z;
                z1 = ((long long) z * RR - (long long) m * MOD) >>
                    32;
            }

            int sum0 = m_add(P[j1], z0);
            int diff0 = m_sub(P[j1], z0);
            int sum1 = P[j2] + z1;
            int diff1 = P[j2] - z1;

            // [sum0, sum1, diff0, diff1]

            int zz0;
            {
                int z = sum1;
                int m = (unsigned int) R20 * z;
                zz0 = ((long long) z * RR0 - (long long) m * MOD) >>
                    32;
            }

            int zz1;
            {
                int z = diff1;
                int m = (unsigned int) R21 * z;
                zz1 = ((long long) z * RR1 - (long long) m * MOD) >>
                    32;
            }

            P[j1] = m_add(sum0, zz0);
            P[j2] = m_sub(sum0, zz0);
            P[j3] = m_add(diff0, zz1);
            P[j4] = m_sub(diff0, zz1);
        }
    }

    for (int i = 0; i < m; ++i)
        if (P[i] < 0) P[i] += MOD;
}

template<int a>
void inverse_transform(vector<int> &P) {
    int m = P.size();
    int n = m / a;
    int n_inv = m_transform(modpow(n, MOD - 2));

    vector<int> rev(n);
    for (int i = 1; i < n; ++i) {
        rev[i] = rev[i / 2] / 2 + (i & 1) * n / 2;
    }

    // P = [p * n_inv for p in P]
    for (int i = 0; i < m; ++i)
```



```

P[i] = m_mult(n_inv, P[i]);

// P = [P[a * rev[i // a] + (i % a)] for i in range(m)]
for (int i = 1; i < n; ++i)
    if (i < rev[i])
        swap_ranges(P.begin() + a * i, P.begin() + a * i + a, P.
            begin() + a * rev[i]);

// P = [P[-a * (i // a) + (i % a)] for i in range(m)]
for (int i = 1; i < n/2; ++i)
    swap_ranges(P.begin() + a * i, P.begin() + a * i + a, P.
        begin() + a * (n - i));

transform<a>(P);

// P = [P[a * rev[i // a] + (i % a)] for i in range(m)]
for (int i = 1; i < n; ++i)
    if (i < rev[i])
        swap_ranges(P.begin() + a * i, P.begin() + a * i + a, P.
            begin() + a * rev[i]);
}

template<int a>
void fast_polymult_mod(vector<int> &P, vector<int> &Q) {
    int m = P.size();
    int n = m / a;

    transform<a>(P);
    transform<a>(Q);

    vector<int> &PQ = P;
    for (int i = 0; i < n; ++i) {
        vector<unsigned long long> res(2 * a);
        for (int j = 0; j < a; ++j) {
            if (j >= 10 && j % 9 == 8)
                for (int k = j; k < j + a - 10; ++k)
                    res[k] -= (res[k] >> 63) * 9 * MOD2;
            for (int k = 0; k < a; ++k)
                res[j + k] += (long long) P[i * a + j] * Q[i * a + k];
        }

        int c = rt[i/2];
        if (i & 1) c = MOD - c;
        for (int j = 0; j < a; ++j)
            PQ[i * a + j] = (res[j] + c * (res[j + a] % MOD)) % MOD;
    }

    inverse_transform<a>(PQ);
}

template <size_t... N>
void work(std::index_sequence<N...>, int x, std::vector<int>&
    a, std::vector<int>& b) {
    static void (*ptrs[]) (std::vector<int>&, std::vector<int>&)
        = {&fast_polymult_mod<N+1>...};
    ptrs[x - 1](a, b);
}

void fast_polymult(vector<int> &P, vector<int> &Q) {
    int m1 = P.size();
    int m2 = Q.size();
    int res_len = m1 + m2 - 1;

    int b = 1;
    while ((alim << b) < res_len) ++b;
    int a = ((res_len - 1) >> b) + 1;
    int m = a << b;

    P.resize(m);
    Q.resize(m);

    // Call fast_polymult_mod<a>(P, Q);
    work(std::make_index_sequence<alim>(), a, P, Q);

    P.resize(res_len);
}

```

4.4 FFT в double'ax

```

using cd = complex<double>;
const double PI = acos(-1);

void fft(vector<cd> &a, bool invert) {
    int n = a.size();

    for (int i = 1, j = 0; i < n; i++) {
        int bit = n >> 1;

```

```

        for (; j & bit; bit >>= 1)
            j ^= bit;
        j ^= bit;

        if (i < j)
            swap(a[i], a[j]);
    }

    for (int len = 2; len <= n; len <= 1) {
        double ang = 2 * PI / len * (invert ? -1 : 1);
        cd wlen(cos(ang), sin(ang));
        for (int i = 0; i < n; i += len) {
            cd w(1);
            for (int j = 0; j < len / 2; j++) {
                cd u = a[i+j], v = a[i+j+len/2] * w;
                a[i+j] = u + v;
                a[i+j+len/2] = u - v;
                w *= wlen;
            }
        }
    }

    if (invert) {
        for (cd &x : a)
            x /= n;
    }
}

vector<int> multiply(vector<int> const& a, vector<int> const&
    b) {
    vector<cd> fa(a.begin(), a.end()), fb(b.begin(), b.end());
    int n = 1;
    while (n < a.size() + b.size())
        n <= 1;
    fa.resize(n);
    fb.resize(n);

    fft(fa, false);
    fft(fb, false);
    for (int i = 0; i < n; i++)
        fa[i] *= fb[i];
    fft(fa, true);

    vector<int> result(n);
    for (int i = 0; i < n; i++)
        result[i] = round(fa[i].real());
    while(!result.empty() && !result.back()) result.pop_back();
    return result;
}

//35d9d0

```

5 Структуры данных

5.1 Дерево Фенвика

```

int fe[maxn];
void pl(int pos, int val) {while(pos < maxn) {fe[pos] += val; pos |=
    (pos+1);}}
int get(int pos) {int ans=0;while(pos>=0) {ans+=fe[pos];pos&=
    (pos+1);--pos;} return ans;} /// [0,pos] - vkluchitelno!!!
int get(int l, int r) {return get(r-1)-get(l-1);} /// sum of [l
    ,r)

//2991a1

```

5.2 Дерево отрезков в точке

```

template<typename T, typename U>
struct SegmentTree {
    int h, n;
    T neutral;
    U unite;
    vector<T> data;

    template<typename I>
    SegmentTree(int sz, T neutral, U unite, I init) : h(__lg(sz)
        + 1), n(1 << h), neutral(neutral), unite(unite), data(2
        * n) {
        for (int i = 0; i < sz; ++i) data[i + n] = init(i);
        for (int i = n - 1; i > 0; --i) data[i] = unite(data[2 * i
            ], data[2 * i + 1]);
    }

    SegmentTree(int sz, T neutral, U unite) : h(__lg(sz) + 1), n
        (1 << h), neutral(neutral), unite(unite), data(2 * n,
        neutral) {}

    void set(int i, T x) {

```



```

data[i += n] = x;
for (i /= 2; i > 0; i /= 2) data[i] = unite(data[2 * i],
data[2 * i + 1]);
}

T get(int l, int r) {
    T leftRes = neutral, rightRes = neutral;
    for (l += n, r += n; l < r; l /= 2, r /= 2) {
        if (l & 1) leftRes = unite(leftRes, data[l++]);
        if (r & 1) rightRes = unite(data[--r], rightRes);
    }
    return unite(leftRes, rightRes);
}

int left(int i) {
    int lvl = __lg(i);
    return (i & ((1 << lvl) - 1)) * (1 << (h - lvl));
}

int right(int i) {
    int lvl = __lg(i);
    return ((i & ((1 << lvl) - 1)) + 1) * (1 << (h - lvl));
}

// l \in [0; n) && ok(get(l, l), l);
// returns last r: ok(get(l, r), r)
template<typename C>
int lastTrue(int l, C ok) {
    T cur = neutral;
    l += n;
    do {
        l >>= __builtin_ctz(l);
        T with1 = unite(cur, data[l]);
        if (ok(with1, right(l))) {
            cur = with1;
            ++l;
        } else {
            while (l < n) {
                T with2 = unite(cur, data[2 * l]);
                if (ok(with2, right(2 * l))) {
                    cur = with2;
                    l = 2 * l + 1;
                } else {
                    l = 2 * l;
                }
            }
            return l - n;
        }
    } while (l & (l - 1));
    return n;
}

// r \in [0; n) && ok(get(r, r), r);
// returns first l: ok(get(l, r), l)
template<typename C>
int firstTrue(int r, C ok) {
    T cur = neutral;
    r += n;
    while (r & (r - 1)) {
        r >>= __builtin_ctz(r);
        T with1 = unite(data[--r], cur);
        if (ok(with1, left(r))) {
            cur = with1;
        } else {
            while (r < n) {
                T with2 = unite(data[2 * r + 1], cur);
                if (ok(with2, left(2 * r + 1))) {
                    cur = with2;
                    r = 2 * r;
                } else {
                    r = 2 * r + 1;
                }
            }
            return r - n + 1;
        }
    }
    return 0;
}
};

//64190d

```

5.3 Массовое дерево отрезков

```

template<typename T, typename M, typename Ud, typename Um,
typename A>
struct MassSegmentTree {
    int h, n;
    T zd;
    M zm;
    vector<T> data;
    vector<M> mod;

```

```

    Ud ud; // T (T, T)
    Um um; // M (M, M);
    A a; // T (T, M, int); last argument is the length of
    current segment (could be used for range += and sum
    counting, for instance)

```

```

template<typename I>
MassSegmentTree(int sz, T zd, M zm, Ud ud, Um um, A a, I
init) : h(__lg(sz) + 1), n(1 << h), zm(zm), zd(zd), data
(2 * n, zd), mod(n, zm), ud(ud), um(um), a(a) {
    for (int i = 0; i < sz; ++i) data[i + n] = init(i);
    for (int i = n - 1; i > 0; --i) data[i] = ud(data[2 *
i], data[2 * i + 1]);
}

```

```

MassSegmentTree(int sz, T zd, M zm, Ud ud, Um um, A a) : h
(__lg(sz) + 1), n(1 << h), zm(zm), zd(zd), data(2 * n, zd
), mod(n, zm), ud(ud), um(um), a(a) {}

```

```

void push(int i) {
    if (mod[i] == zm) return;
    apply(2 * i, mod[i]);
    apply(2 * i + 1, mod[i]);
    mod[i] = zm;
}

```

```

// is used only for apply
int length(int i) { return 1 << (h - __lg(i)); }

```

```

// used only for descent
int left(int i) {
    int lvl = __lg(i);
    return (i & ((1 << lvl) - 1)) * (1 << (h - lvl));
}

// used only for descent
int right(int i) {
    return left(i) + length(i);
}

```

```

template<typename S>
void apply(int i, S x) {
    data[i] = a(data[i], x, length(i));
    if (i < n) mod[i] = um(mod[i], x);
}

```

```

void update(int i) {
    if (mod[i] != zm) return;
    data[i] = ud(data[2 * i], data[2 * i + 1]);
}

```

```

template<typename S>
void update(int l, int r, S x) { // [l; r)
    l += n, r += n;
    for (int shift = h; shift > 0; --shift) {
        push(l >> shift);
        push((r - 1) >> shift);
    }
    for (int lf = l, rg = r; lf < rg; lf /= 2, rg /= 2) {
        if (lf & 1) apply(lf++, x);
        if (rg & 1) apply(--rg, x);
    }
    for (int shift = 1; shift <= h; ++shift) {
        update(l >> shift);
        update((r - 1) >> shift);
    }
}

```

```

T get(int l, int r) { // [l; r)
    l += n, r += n;
    for (int shift = h; shift > 0; --shift) {
        push(l >> shift);
        push((r - 1) >> shift);
    }
    T leftRes = zd, rightRes = zd;
    for (; l < r; l /= 2, r /= 2) {
        if (l & 1) leftRes = ud(leftRes, data[l++]);
        if (r & 1) rightRes = ud(data[--r], rightRes);
    }
    return ud(leftRes, rightRes);
}

```

```

// l \in [0; n) && ok(get(l, l), l);
// returns last r: ok(get(l, r), r)
template<typename C>
int lastTrue(int l, C ok) {
    l += n;
    for (int shift = h; shift > 0; --shift) push(l >>
shift);
    T cur = zd;

```

```

do {
    l >>= __builtin_ctz(l);
    T with = ud(cur, data[l]);
    if (ok(with, right(l))) {
        cur = with;
        ++l;
    } else {
        while (l < n) {
            push(l);
            l = 2 * l;
            with = ud(cur, data[l]);
            if (ok(with, left(l + 1))) {
                cur = with;
                ++l;
            }
        }
        return l - n;
    }
} while (l & (l - 1));
return n;
}

// r \in [0; n) && ok(get(r, r), r);
// returns first l: ok(get(l, r), l)
template<typename C>
int firstTrue(int r, C ok) {
    r += n;
    for (int shift = h; shift > 0; --shift) push((r - 1)
>> shift);
    auto cur = zd;
    while (r & (r - 1)) {
        r >>= __builtin_ctz(r);
        T with = ud(data[--r], cur);
        if (ok(with, left(r))) {
            cur = with;
        } else {
            while (r < n) {
                push(r);
                r = 2 * r;
                with = ud(data[r + 1], cur);
                if (ok(with, left(r + 1))) {
                    cur = with;
                } else {
                    ++r;
                }
            }
            return r - n + 1;
        }
    }
    return 0;
}
};
//fc0cde

```

5.4 Битовый бор

```

template<unsigned int sz, typename T=int>
struct binarytrie {
    using Bit=typename conditional<sz<=32,unsigned int,unsigned
long long>::type;
    struct node {
        T cnt;
        array<int,2>nxt;
        node():cnt(0),nxt({-1,-1}){}
    };
    vector<node>v;
    binarytrie(){v.emplace_back();}
    void insert(Bit x){add(x,1);}
    void erase(Bit x){add(x,-1);}
    void add(Bit x,T k)
    {
        assert(0<=x&&(x>>sz)==0);
        int p=0;
        v[p].cnt+=k;
        for(int i=sz;i--;)
        {
            int j=x>>i&1;
            if(v[p].nxt[j]==-1)
            {
                v[p].nxt[j]=v.size();
                v.emplace_back();
            }
            p=v[p].nxt[j];
            v[p].cnt+=k;
        }
    }
    T count(Bit x, Bit xor_val=0) const // [0, x)
    {
        assert(0<=xor_val&&(xor_val>>sz)==0);
        if(x<0) return 0;
    }
};

```

```

else if(x>>sz) return v[0].cnt;
T ret=0;
int p=0;
for(int i=sz;i--;)
{
    int j=x>>i&1,k=xor_val>>i&1;
    if(j==0)p=v[p].nxt[k];
    else
    {
        if(v[p].nxt[k]>=0)ret+=v[v[p].nxt[k]].cnt;
        p=v[p].nxt[!k];
    }
    if(p==-1)break;
}
return ret;
}
Bit max(Bit xor_val=0) const
{
    assert(0<=xor_val&&(xor_val>>sz)==0);
    int p=0;
    Bit ret=0;
    if(v[p].cnt==0) return ret;
    for(int i=sz;i--;)
    {
        ret<=1;
        int k=xor_val>>i&1;
        if(v[p].nxt[!k]>=0&&v[v[p].nxt[!k]].cnt>0)
        {
            p=v[p].nxt[!k];
            ret|=1;
        }
        else p=v[p].nxt[k];
    }
    return ret;
}
Bit min(Bit xor_val=0) const
{
    assert(0<=xor_val&&(xor_val>>sz)==0);
    int p=0;
    Bit ret=0;
    for(int i=sz;i--;)
    {
        ret<=1;
        int k=xor_val>>i&1;
        if(v[p].nxt[k]>=0&&v[v[p].nxt[k]].cnt>0)p=v[p].nxt[k];
        else
        {
            p=v[p].nxt[!k];
            ret|=1;
        }
    }
    return ret;
}
Bit find_by_order(T ord, Bit xor_val=0) const
{
    assert(0<=xor_val&&(xor_val>>sz)==0);
    assert(0<=ord&&ord<v[0].cnt);
    int p=0;
    Bit ret=0;
    for(int i=sz;i--;)
    {
        ret<=1;
        int k=xor_val>>i&1;
        if(v[p].nxt[k]>=0)
        {
            if(ord==v[v[p].nxt[k]].cnt)
            {
                ord-=v[v[p].nxt[k]].cnt;
                p=v[p].nxt[!k];
                ret|=1;
            }
            else p=v[p].nxt[k];
        }
        else
        {
            p=v[p].nxt[!k];
            ret|=1;
        }
    }
    return ret;
}
T order_of_key(Bit x, Bit xor_val=0) const {return count(x,
xor_val);}
};
binarytrie<32>bt;
//0b3855

```

5.5 Ordered set

```
#include <ext/pb_ds/assoc_container.hpp>
#include <ext/pb_ds/tree_policy.hpp>

using namespace __gnu_pbds;
using namespace std;

using ordered_set = tree<int, null_type, less<>, rb_tree_tag,
    tree_order_statistics_node_update>;

//f589b9
```

5.6 Динамический битсет

```
#include <tr2/dynamic_bitset>
using namespace tr2;
using bs=dynamic_bitset<>;

//26f8b6
```

5.7 Convex hull trick

```
int div_up(int a, int b) { return a/b+((a^b)>0&&a%b); } //
    divide a by b rounded up
const int LQ = ..., RQ = ...; //leftmost query, rightmost
    query
int in(ii L, int x) {
    return L.x * x + L.y;
}
struct Hull {
vector <pair <int, int> > lines;
vector <int> borders;
void push(ii L) {
    while (lines.size() && in(L,borders.back()) < in(lines.back()
        (),borders.back())) {
        lines.pop_back();
        borders.pop_back();
    }
    if (lines.empty()) {
        lines = {L};
        borders = {LQ};
    }
    else if (lines.back().x > L.x) {
        int x = div_up(L.y - lines.back().y, lines.back().x - L.x);
        ;
        if (x <= RQ) {
            lines.app(L);
            borders.app(x);
        }
    }
}
Hull (){}
Hull (vector <ii> a) {
    auto comp = [&] (ii u, ii v) {
        return u.x > v.x || (u.x == v.x && u.y < v.y);
    };
    sort(all(a), comp);
    for (auto L : a) {
        push(L);
    }
}
int get(int x) {
    int pos = upper_bound(all(borders), x) - borders.begin();
    assert(pos>0);
    pos--;
    return in(lines[pos],x);
}
};

//04555a
```

5.8 Центроиды

```
vector<int> sz(n), lvl(n, -1);
auto dfs = [&](auto dfs, int cur, int prev) -> int {
    if (lvl[cur] != -1) return 0;
    sz[cur] = 1;
    for (auto [nxt, w] : g[cur]) {
        if (nxt != prev) sz[cur] += dfs(dfs, nxt, cur);
    }
    return sz[cur];
};
auto find = [&](auto find, int cur, int prev, int tot) -> int
{
    int bch = -1, bsz = 0;
    for (auto [nxt, w] : g[cur]) {
        if (nxt == prev || lvl[nxt] != -1) continue;
        if (sz[nxt] > bsz) {
            bch = nxt;

```

```
            bsz = sz[nxt];
        }
    }
    if (bsz + bsz <= tot) return cur;
    return find(find, bch, cur, tot);
};
dfs(dfs, 0, 0);
auto c = find(find, 0, 0, sz[0]);
vector<pair<int, int>> stack{{c, 0}};
while (!stack.empty()) {
    auto [centroid, l] = stack.back();
    stack.pop_back();
    lvl[centroid] = 1;
    for (auto [nxt, w] : g[centroid]) {
        if (lvl[nxt] != -1) continue;
        dfs(dfs, nxt, centroid);
        int new_centroid = find(find, nxt, centroid, sz[nxt]);
        stack.push_back({new_centroid, lvl[centroid] + 1});
    }
}

//0e1e52
```

5.9 Дерево Ли Чао

```
struct Line{
    int a, b;
    Line(){}
    Line (int a, int b) : a(a), b(b) {}
    int get(int x) { return a + b * x; }
};

struct Lichao {
    int n;
    vector<int> x;
    vector<Line> t;
    Lichao(){}
    Lichao (int n, vector<int> x) : n(n), t(n << 2, Line(Inf, 0))
        , x(x) {}

    void put(int v, int l, int r, Line L) {
        if (l + 1 == r) {
            if (L.get(x[l]) < t[v].get(x[l])) {
                t[v] = L;
            }
            return;
        }
        int m = (l + r) / 2;
        if (L.get(x[m]) < t[v].get(x[m])) {
            swap(L, t[v]);
        }
        if (L.b > t[v].b) {
            put(2 * v + 1, l, m, L);
        }
        else {
            put(2 * v + 2, m, r, L);
        }
    }

    int get(int v, int l, int r, int i) {
        if (l + 1 == r) {
            return t[v].get(x[l]);
        }
        int m = (l + r) / 2;
        int ans = t[v].get(x[i]);
        if (i < m) {
            ans = min(ans, get(2 * v + 1, l, m, i));
        }
        else {
            ans = min(ans, get(2 * v + 2, m, r, i));
        }
        return ans;
    }

    void put(Line L) {
        put(0, 0, n, L);
    }

    int get(int i) {
        return get(0, 0, n, i);
    }
};

//99f5fa
```

5.10 Min-Kinetic Segment Tree

I guess the source is <https://koosaga.com/307>

```
using lint = long long;
const lint inf = 4e18;
const int MAXT = 4100000;
```

```

using pi = array<lint, 2>;

struct line {
    lint A, B;
    int idx;

    lint eval(lint x) { return A * x + B; }

    // returns the x-intercept of intersection "strictly" larger
    // than T
    lint cross_after(line &x, lint T) {
        if (x.A == A) {
            return inf;
        }
        lint up = x.B - B;
        lint dn = A - x.A;
        if (dn < 0) {
            dn *= -1;
            up *= -1;
        }
        lint incep = (up <= 0 ? -((-up) / dn) : (up + dn - 1) / dn);
        if (incep > T)
            return incep;
        return inf;
    }
};

struct kst { // min kinetic segment tree
    line tree[MAXT];
    lint melt[MAXT], T;
    pi lazy[MAXT];
    int n;

    bool cmp(line &a, line &b) {
        lint l = a.eval(T), r = b.eval(T);
        if (l != r)
            return l > r;
        return a.A > b.A;
    }

    void pull(int p) {
        tree[p] = cmp(tree[2 * p], tree[2 * p + 1]) ? tree[2 * p + 1] : tree[2 * p];
        melt[p] = min({melt[2 * p], melt[2 * p + 1], tree[2 * p].cross_after(tree[2 * p + 1], 0)});
    }

    void init(int s, int e, int p, vector<line> &l) {
        if (s == e) {
            tree[p] = l[s];
            melt[p] = inf;
            lazy[p] = {0, 0};
            return;
        }
        lazy[p] = {0, 0};
        int m = (s + e) / 2;
        init(s, m, 2 * p, l);
        init(m + 1, e, 2 * p + 1, l);
        pull(p);
    }

    void lazydown(int p) {
        for (int i = 2 * p; i < 2 * p + 2; i++) {
            lazy[i][0] += lazy[p][0];
            lazy[i][1] += lazy[p][1];
            tree[i].B += lazy[p][0] * tree[i].A + lazy[p][1];
            melt[i] -= lazy[p][0];
        }
        lazy[p][0] = lazy[p][1] = 0;
    }

    void propagate(int p) {
        if (melt[p] > 0)
            return;
        lazydown(p);
        propagate(2 * p);
        propagate(2 * p + 1);
        pull(p);
    }

    lint query(int s, int e, int ps, int pe, int p = 1) {
        if (e < ps || pe < s)
            return inf;
        if (s <= ps && pe <= e)
            return tree[p].eval(0);
        int pm = (ps + pe) / 2;
        lazydown(p);
        return min(query(s, e, ps, pm, 2 * p), query(s, e, pm + 1, pe, 2 * p + 1));
    }
};

```

```

}

void heaten(int s, int e, int ps, int pe, int p, lint v) {
    if (e < ps || pe < s)
        return;
    if (s <= ps && pe <= e) {
        lazy[p][0] += v;
        tree[p].B += v * tree[p].A;
        melt[p] -= v;
        propagate(p);
        return;
    }
    lazydown(p);
    int pm = (ps + pe) / 2;
    heaten(s, e, ps, pm, 2 * p, v);
    heaten(s, e, pm + 1, pe, 2 * p + 1, v);
    pull(p);
}

void add(int s, int e, int ps, int pe, int p, lint v) {
    if (e < ps || pe < s)
        return;
    if (s <= ps && pe <= e) {
        lazy[p][1] += v;
        tree[p].B += v;
        return;
    }
    lazydown(p);
    int pm = (ps + pe) / 2;
    add(s, e, ps, pm, 2 * p, v);
    add(s, e, pm + 1, pe, 2 * p + 1, v);
    pull(p);
}

void init(vector<line> &l, lint _T) {
    n = l.size();
    T = _T;
    init(0, n - 1, 1, l);
}

//66f9a9

```

5.11 Декартово дерево

5.11.1 Декартово дерево по явному ключу. Multiset

```

mt19937 rng(0);

struct vertex {
    int heap = rng(), val;
    int sz = 1, cnt = 1;
    vertex *lf = nullptr, *rg = nullptr;

    vertex(int x, int cnt) : val(x), cnt(cnt), sz(cnt) {}

    friend int get_sz(vertex *v) {
        return v ? v->sz : 0;
    }

    vertex *update() {
        sz = get_sz(lf) + cnt + get_sz(rg);
        return this;
    }

    vertex *merge(vertex *l, vertex *r) {
        if (!l) return r;
        if (!r) return l;
        if (l->heap < r->heap) {
            r->lf = merge(l, r->lf);
            return r->update();
        } else {
            l->rg = merge(l->rg, r);
            return l->update();
        }
    }

    pair<vertex *, vertex *> split(vertex *v, int x) {
        if (!v) return {v, v};
        if (v->val < x) {
            auto [lf, rg] = split(v->rg, x);
            v->rg = lf;
            return {v->update(), rg};
        } else {
            auto [lf, rg] = split(v->lf, x);
            v->lf = rg;
            return {lf, v->update()};
        }
    }
};

```

```

}

vertex *add(vertex *v, int x, int cnt) {
    auto [l, mr] = split(v, x);
    auto [m, r] = split(mr, x + 1);
    if (m == nullptr) {
        m = new vertex(x, cnt);
    } else {
        m->cnt += cnt;
        if (m->cnt == 0) m = nullptr; else m->update();
    }
    return merge(l, merge(m, r));
}

//91cc3a

```

6 Строковые алгоритмы

6.1 Префикс-функция

```

vector<int> prefix_function(string s) {
    int n = s.size();
    vector<int> p(n);
    for (int i = 1; i < n; ++i) {
        p[i] = p[i - 1];
        while (p[i] && s[p[i]] != s[i]) p[i] = p[p[i] - 1];
        p[i] += s[i] == s[p[i]];
    }
    return p;
}

//91103c

```

6.2 Z-функция

```

vector<int> z_function (string s) { // z[i] - lcp of s and s[i:]
    int n = s.size();
    vector<int> z(n);
    for (int i=1, l=0, r=0; i<n; ++i) {
        if (i <= r) z[i] = min(r-i+1, z[i-l]);
        while (i+z[i] < n && s[z[i]] == s[i+z[i]]) ++z[i];
        if (i+z[i]-1 > r) {
            l = i, r = i+z[i]-1;
        }
    }
    return z;
}

//48cccc

```

6.3 Алгоритм Манакера

```

vector<int> manacher(const string &s, int even) {
    int l = 0, r = 0, n = s.size();
    vector<int> man(n, 0);
    for (int i = 1; i < n; i++) {
        int j = i - even;
        if (j <= r) {
            man[i] = min(r - j, man[l + r - j]);
        }
        while (j + man[i] + 1 < n && i - man[i] > 0 && s[j + man[i]] == s[i - man[i] - 1]) {
            man[i]++;
        }
        if (j + man[i] > r) {
            l = i - man[i];
            r = j + man[i];
        }
    }
    return man;
}

// abacaba : odd : (0 1 0 3 0 1 0); even : (0 0 0 0 0 0 0)
// abbaa : odd : (0 0 0 0 0); even : (0 0 2 0 1)
bool pal(int from, int len) {
    if (len == 0) {
        return true;
    }
    int m = len/2;
    if (len & 1) {
        return odd[from + m] >= m;
    }
    else {
        return even[from + m] >= m;
    }
}

```

```
//8a64d6
```

6.4 Суфмассив

Переработанный китайский суфмассив

```

const int inf = 1e9;
struct rmq {
    int n;
    vector<int> a;
    void build(const vector<int> &x) {
        assert(x.size() == n);
        for (int i = 0; i < n; ++i) a[n + i] = x[i];
        for (int i = n - 1; i > 0; --i) a[i] = min(a[2 * i], a[2 * i + 1]);
    }
    rmq(int n) : n(n), a(2 * n, inf) {}
    void put(int i, int x) {
        a[i + n] = min(a[i + n], x);
        for (i = (i + n) / 2; i > 0; i /= 2) {
            a[i] = min(a[i * 2], a[i * 2 + 1]);
        }
    }
    int getMin(int l, int r) { // [l; r)
        assert(l < r);
        int res = inf;
        for (l += n, r += n; l < r; l /= 2, r /= 2) {
            if (l & 1) res = min(res, a[l++]);
            if (r & 1) res = min(res, a[--r]);
        }
        return res;
    }
};

template <typename T>
vector<int> SA(const T &a) {
    int m = *max_element(all(a)) + 1, n = a.size();
    vector<int> sa(n), nsa(n), pre(max(n, m)), x(a.begin(), a.end()), y(n);
    for (int e : x) pre[e]++;
    for (int i = 1; i < m; ++i) pre[i] += pre[i - 1];
    for (int i = 0; i < n; ++i) sa[--pre[x[i]]] = i;
    int dif = 1;
    y[sa.front()] = 0;
    for (int i = 1; i < n; ++i) {
        dif += x[sa[i]] != x[sa[i-1]];
        y[sa[i]] = dif - 1;
    }
    x = y;
    for (int h = 1; dif < n; h *= 2) {
        fill(all(pre), 0);
        for (int e : x) pre[e]++;
        for (int i = 1; i < dif; ++i) pre[i] += pre[i - 1];
        for (int t = n; t--;) {
            int i = sa[t];
            if (i >= h) {
                nsa[--pre[x[i-h]]] = i-h;
            }
            else if (i + 1 != h) {
                nsa[--pre[x[i-h+n+1]]] = i-h+n+1;
            }
        }
        nsa[--pre[x[n - h]]] = n-h;
        sa = nsa;
        auto getr = [&](int i) {
            if (i + h < n) {
                return x[i + h];
            }
            else {
                return x[i + h - n - 1];
            }
        };
        dif = 1;
        y[sa.front()] = 0;
        for (int i = 1; i < n; ++i) {
            if (x[sa[i]] != x[sa[i-1]] || sa[i-1] + h == n) {
                dif++;
            }
            else {
                dif += getr(sa[i]) != getr(sa[i-1]);
            }
            y[sa[i]] = dif - 1;
        }
        x = y;
    }
    return sa;
}

template <typename T>
struct suar {
    vector<int> sa, lcp, pos; rmq t;

```

```

suar (const T &a) : t((int)a.size() - 1) {
    sa = SA(a);
    int n = (int)a.size(), k = 0;
    lcp.resize(n - 1);
    pos.resize(n);
    for (int i = 0; i < n; ++i) pos[sa[i]] = i;
    for (int i = 0; i < n; ++i) {
        if (pos[i] + 1 < n) {
            int j = sa[pos[i] + 1];
            while (i + k < n && j + k < n && a[i + k] == a[j + k]) k++;
            lcp[pos[i]] = k;
        }
        if (k) {
            k--;
        }
    }
    t.build(lcp);
}

int getLcp(int i, int j) {
    i = pos[i]; j = pos[j];
    if (j < i) {
        swap(i, j);
    }
    if (i == j) {
        return inf;
    }
    else {
        return t.getMin(i, j);
    }
}
};
//6327c9

```

6.5 Алгоритм Ахо — Корасик

```

const int alpha = 26;
const char a = 'a';

struct node {
    int next[alpha] = {}, link[alpha] = {};
    int suf = 0;
    int visited = 0, ans = 0;
    int bad = 0; // any term is reachable by suf links
    vector<int> term;
    node() {
        fill(next, next + alpha, -1);
    }
};

vector<node> mem;

int get_next_or_create(int nd, char c) {
    if (mem[nd].next[c - a] == -1) { mem[nd].next[c - a] = mem
        .size(); mem.emplace_back(); }
    return mem[nd].next[c - a];
}

void build(vector<string> t) {
    mem.reserve(1e6 + 100); mem.clear();
    mem.emplace_back();
    // 0th element is nullptr, 1st is the root
    for (int j = 0; j < t.size(); ++j) {
        int cur = 0;
        for (char c : t[j]) cur = get_next_or_create(cur, c);
        mem[cur].term.push_back(j);
    }
    vector<int> bfs_order;
    queue<int> bfs;
    {
        node &root = mem[0];
        root.suf = 0;
        for (char c = a; c < a + alpha; ++c) {
            root.link[c - a] = (root.next[c - a] == -1 ? 0 :
            root.next[c - a]);
        }
        bfs.push(0);
    }
    while (!bfs.empty()) {
        int cur_idx = bfs.front();
        bfs.pop();
        node &cur = mem[cur_idx];
        cur.bad = cur.term.size() > 0 || mem[cur.suf].bad;
        bfs_order.push_back(cur_idx);
        for (char c = a; c < a + alpha; ++c) {
            int nxt_idx = cur.next[c - a];
            if (nxt_idx == -1) continue;
            node &nxt = mem[nxt_idx];

```

```

            nxt.suf = (cur_idx ? mem[cur.suf].link[c - a] : 0)
            ;
            for (char c = a; c < a + alpha; ++c) {
                nxt.link[c - a] = (nxt.next[c - a] == -1 ? mem
                [nxt.suf].link[c - a] : nxt.next[c - a]);
            }
            bfs.push(nxt_idx);
        }
    }
    // do something
}
//be16ed

```

6.6 Дерево палиндромов

```

const int alpha = 26;
const char a = 'a';
struct palindromic {
    int n;
    vector<int> p, suf{0, 0}, len{-1, 0};
    //d[u] is a difference of lengths of u and suf[u], go is
    jump by chain constant d
    vector<array<int, alpha>> to{}, {}{};
    int sz = 2;
    palindromic(const string &s) : n(s.size()), p(n + 1, 0) {
        suf.reserve(n);
        len.reserve(n);
        for (int i = 0; i < n; ++i) {
            auto check = [&] (int l) {
                return i > 1 && s[i] == s[i - 1 - l];
            };
            int par = p[i];
            while (!check(len[par])) {
                par = suf[par];
            }
            if (to[par][s[i] - a] == 0) {
                p[i + 1] = to[par][s[i] - a] = sz++;
                to.emplace_back();
                len.emplace_back(len[par] + 2);
                if (par == 0) {
                    suf.emplace_back(1);
                }
            }
            else {
                do {
                    par = suf[par];
                } while (!check(len[par]));
                suf.emplace_back(to[par][s[i] - a]);
            }
        }
        else {
            p[i + 1] = to[par][s[i] - a];
        }
    }
}

int partition() {
    vector<int> d(sz), up(sz, 1); //d[1] = 0 sic
    for (int i = 2; i < sz; ++i) {
        d[i] = len[i] - len[suf[i]];
        if (d[i] == d[suf[i]]) {
            up[i] = up[suf[i]];
        }
        else {
            up[i] = suf[i];
        }
    }
    vector<int> dp(n + 1, n), last(sz);
    dp[0] = 0;
    for (int i = 1; i <= n; ++i) {
        int u = p[i];
        while (u != 1) {
            if (suf[u] == up[u]) {
                last[u] = dp[i - len[u]];
            }
            else {
                last[u] = min(last[suf[u]], dp[i - len[up[u]]] - d[u
                ]);
            }
            dp[i] = min(dp[i], last[u] + 1);
            u = up[u];
        }
    }
    return dp.back();
}
//acac02

```

7 Потоки

7.1 Алгоритм Диница

```
#define pb push_back
struct Dinic{
    struct edge{
        int to, flow, cap;
    };

    const static int N = 555; //count of vertices

    vector<edge> e;
    vector<int> g[N + 7];
    int dp[N + 7];
    int ptr[N + 7];

    void clear(){
        for (int i = 0; i < N + 7; i++) g[i].clear();
        e.clear();
    }

    void addEdge(int a, int b, int cap){
        g[a].pb(e.size());
        e.pb({b, 0, cap});
        g[b].pb(e.size());
        e.pb({a, 0, 0});
    }

    int minFlow, start, finish;

    bool bfs(){
        for (int i = 0; i < N; i++) dp[i] = -1;
        dp[start] = 0;
        vector<int> st;
        int uk = 0;
        st.pb(start);
        while(uk < st.size()){
            int v = st[uk++];
            for (int to : g[v]){
                auto ed = e[to];
                if (ed.cap - ed.flow >= minFlow && dp[ed.to] == -1){
                    dp[ed.to] = dp[v] + 1;
                    st.pb(ed.to);
                }
            }
        }
        return dp[finish] != -1;
    }

    int dfs(int v, int flow){
        if (v == finish) return flow;
        for (; ptr[v] < g[v].size(); ptr[v]++){
            int to = g[v][ptr[v]];
            edge ed = e[to];
            if (ed.cap - ed.flow >= minFlow && dp[ed.to] == dp[v] + 1){
                int add = dfs(ed.to, min(flow, ed.cap - ed.flow));
                if (add){
                    e[to].flow += add;
                    e[to ^ 1].flow -= add;
                    return add;
                }
            }
        }
        return 0;
    }

    int dinic(int start, int finish){
        Dinic::start = start;
        Dinic::finish = finish;
        int flow = 0;
        for (minFlow = (1 << 30); minFlow; minFlow >>= 1){
            while(bfs()){
                for (int i = 0; i < N; i++) ptr[i] = 0;
                while(int now = dfs(start, (int)2e9 + 7)) flow += now;
            }
        }
        return flow;
    }
} dinic;

//15c079
```

7.2 Mincost k-flow

```
struct edge {
    int next, capacity, cost, flow = 0;
```

```
    edge() = default;

    edge(int next, int capacity, int cost) : next(next),
        capacity(capacity), cost(cost) {}

    int rem() const { return capacity - flow; }

    int operator+=(int f) { return flow += f; }

    int operator-=(int f) { return flow -= f; }
};

auto addEdge = [&](auto from, auto next, auto capacity, int
    cost) {
    g[from].push_back(e.size());
    e.emplace_back(next, capacity, cost);
    g[next].push_back(e.size());
    e.emplace_back(from, 0, -cost);
};

/* in case of undirected graph use this:
addEdge(u, v, capacity, cost);
addEdge(v, u, capacity, cost);
*/

vector<ll> phi(n, 0);
auto fordBellman = [&](int s, int t) {
    phi.assign(n, 0);
    for (int iter = 0; iter < n; ++iter) {
        bool changed = false;
        for (int u = 0; u < n; ++u) {
            for (auto index : g[u]) {
                auto edge = e[index];
                if (edge.rem() > 0 && phi[edge.next] > phi[u] + edge.
                    cost) {
                    phi[edge.next] = phi[u] + edge.cost;
                    changed = true;
                }
            }
        }
        if (!changed) break;
    }
};

fordBellman(s, t);
// now shortest path using dijkstra with potentials
vector<ll> dist;
vector<int> from;
vector<bool> cnt;
auto dijkstra = [&](int s, int t) {
    dist.assign(n, 1e18);
    from.assign(n, -1);
    cnt.assign(n, false);
    dist[s] = 0;
    set <pair <int, int> > se;
    se.insert({0, s});
    while ((int)(se.size())) {
        int cur = se.begin()->y;
        se.erase(se.begin());
        cnt[cur] = true;
        for (int index : g[cur]) {
            auto &edge = e[index];
            if (edge.rem() == 0) continue;
            ll weight = edge.cost + phi[cur] - phi[edge.next];
            if (dist[edge.next] > dist[cur] + weight) {
                se.erase({dist[edge.next], edge.next});
                dist[edge.next] = dist[cur] + weight;
                se.insert({dist[edge.next], edge.next});
                from[edge.next] = cur;
            }
        }
    }
    if (dist[t] == (ll) 1e18) return -1LL;
    ll cost = 0;
    for (int p = t; p != s; p = from[p]) {
        for (auto index : g[from[p]]) {
            auto &edge = e[index];
            ll weight = edge.cost + phi[from[p]] - phi[edge.next];
            if (edge.rem() > 0 && edge.next == p && dist[edge.next]
                == dist[from[p]] + weight) {
                edge += 1;
                e[index ^ 1] -= 1;
                cost += edge.cost;
                break;
            }
        }
    }
    for (int i = 0; i < n; ++i) {
        phi[i] += dist[i];
    }
    return cost;
};

ll cost = 0;
for (int flow = 0; flow < k; ++flow) {
```



```

ll a = dijkstra(s, t);
if (a == -1) {
    cout << "-1\n";
    return;
}
cost += a;
}
// now recover answer
auto findPath = [&](int s, int t) {
    vector<int> ans;
    int cur = s;
    while (cur != t) {
        for (auto index : g[cur]) {
            auto &edge = e[index];
            if (edge.flow <= 0) continue;
            edge -= 1;
            e[index ^ 1] += 1;
            ans.push_back(index / 4);
        }
        // index / 4 because each edge has 4 copies
        cur = edge.next;
        break;
    }
}
return ans;
};
for (int flow = 0; flow < k; ++flow) {
    auto p = findPath(s, t);
    cout << p.size() << ' ';
    for (int x : p) cout << x + 1 << ' ';
    cout << '\n';
}

//94b9cb

template <typename T, typename C>
class mcmf {
public:
    static constexpr T eps = (T) 1e-9;

    struct edge {
        int from;
        int to;
        T c;
        T f;
        C cost;
    };

    vector< vector<int> > g;
    vector<edge> edges;
    vector<C> d;
    vector<int> q;
    vector<bool> in_queue;
    vector<int> pe;
    int n;
    int st, fin;
    T flow;
    C cost;

    mcmf(int _n, int _st, int _fin) : n(_n), st(_st), fin(_fin)
    {
        assert(0 <= st && st < n && 0 <= fin && fin < n && st != fin);
        g.resize(n);
        d.resize(n);
        in_queue.resize(n);
        pe.resize(n);
        flow = 0;
        cost = 0;
    }

    void clear_flow() {
        for (const edge &e : edges) {
            e.f = 0;
        }
        flow = 0;
    }

    void add(int from, int to, T forward_cap, T backward_cap, C cost) {
        assert(0 <= from && from < n && 0 <= to && to < n);
        g[from].push_back((int) edges.size());
        edges.push_back({from, to, forward_cap, 0, cost});
        g[to].push_back((int) edges.size());
        edges.push_back({to, from, backward_cap, 0, -cost});
    }

    bool expath() {
        fill(d.begin(), d.end(), numeric_limits<C>::max());
        q.clear();
        q.push_back(st);

```

```

d[st] = 0;
in_queue[st] = true;
int beg = 0;
bool found = false;
while (beg < (int) q.size()) {
    int i = q[beg++];
    if (i == fin) {
        found = true;
    }
    in_queue[i] = false;
    for (int id : g[i]) {
        const edge &e = edges[id];
        if (e.c - e.f > eps && d[i] + e.cost < d[e.to]) {
            d[e.to] = d[i] + e.cost;
            pe[e.to] = id;
            if (!in_queue[e.to]) {
                q.push_back(e.to);
                in_queue[e.to] = true;
            }
        }
    }
}
if (found) {
    T push = numeric_limits<T>::max();
    int v = fin;
    while (v != st) {
        const edge &e = edges[pe[v]];
        push = min(push, e.c - e.f);
        v = e.from;
    }
    v = fin;
    while (v != st) {
        edge &e = edges[pe[v]];
        e.f += push;
        edge &back = edges[pe[v] ^ 1];
        back.f -= push;
        v = e.from;
    }
    flow += push;
    cost += push * d[fin];
}
return found;
}

pair<T, C> max_flow_min_cost() {
    while (expath()) {
        return make_pair(flow, cost);
    }
}

//b7bbb2

```

8 Алгоритм Гаусса

8.1 Решение $Av = b$

```

optional<vector<int> > gauss(vector<vector<int> > A, vector<int>
    > b) ///returns v such that Av=b
{
    int n=A.size();assert(b.size()==n);int m=A[0].size();
    for(int &x:b) {x%=p;x+=p;x%=p;}
    for(int i=0;i<n;++i) {for(int &x:A[i]) {x%=p;x+=p;x%=p;}}
    int bi=0;
    for(int i=0;i<n;++i)
    {
        if(bi==m) break;
        for(int j=i;j<n;++j)
        {
            if(A[j][bi])
            {
                if(j!=i) {swap(A[i],A[j]);swap(b[i],b[j]);}
                break;
            }
        }
        if(A[i][bi])
        {
            int o=inv(A[i][bi]);
            for(int j=i+1;j<n;++j)
            {
                int we=(A[j][bi]*o)%p;
                b[j]-=we*b[i];b[j]%=p;if(b[j]<0) b[j]+=p;
                for(int k=bi;k<m;++k)
                {
                    A[j][k]-=we*A[i][k];A[j][k]%=p;if(A[j][k]
                    <0) A[j][k]+=p;
                }
            }
        }
    }
}

```

```

    else
    {
        ++bi; --i; continue;
    }
}
vector<int> v(m);
for(int i=n-1; i>=0; --i)
{
    int bi=0;
    while(bi<m && !A[i][bi]) {++bi;}
    if(bi==m)
    {
        if(b[i]) {return nullopt;}
        else {continue;}
    }
    {
        int cur=b[i];
        for(int j=bi+1; j<m; ++j)
        {
            cur-=A[i][j]*v[j]; cur%=p;
        }
        v[bi]=cur*inv(A[i][bi]); v[bi]%=p; if(v[bi]<0) v[bi]+=p;
    }
}
return v;
}
//bcc622

```

8.2 Базис $Av = 0$

```

vector<vector<int>> > gaussbasis(vector<vector<int>> > A, int m)
    ///returns basis of Av=0
{
    int n=A.size(); if(n) assert(m==A[0].size());
    for(int i=0; i<n; ++i) {for(int &x:A[i]) {x%=p; x+=p; x%=p;}}
    int bi=0;
    for(int i=0; i<n; ++i)
    {
        if(bi==m) break;
        for(int j=i; j<n; ++j)
        {
            if(A[j][bi])
            {
                if(j!=i) {swap(A[i], A[j]);}
                break;
            }
        }
        if(A[i][bi])
        {
            int o=inv(A[i][bi]);
            for(int j=i+1; j<n; ++j)
            {
                int we=(A[j][bi]*o)%p;
                for(int k=bi; k<m; ++k)
                {
                    A[j][k]-=we*A[i][k]; A[j][k]%=p; if(A[j][k]
                ]<0) A[j][k]+=p;
                }
            }
        }
        else
        {
            ++bi; --i; continue;
        }
    }
    vector<int> indices(m); iota(all(indices), 0);
    for(int i=n-1; i>=0; --i)
    {
        int bi=0;
        while(bi<m && !A[i][bi]) {++bi;}
        if(bi<m)
        {
            indices.erase(find(all(indices), bi));
        }
    }
    vector<vector<int>> > v(indices.size(), vector<int>(m, 0));
    for(int i=0; i<indices.size(); ++i)
    {
        v[i][indices[i]]=1;
    }
    for(int i=n-1; i>=0; --i)
    {
        int bi=0;
        while(bi<m && !A[i][bi]) {++bi;}
        if(bi==m) continue;
        for(int k=0; k<indices.size(); ++k) {
            int cur=0;
            for(int j=bi+1; j<m; ++j)
            {

```

```

                cur-=A[i][j]*v[k][j]; cur%=p;
            }
            v[k][bi]=cur*inv(A[i][bi]); v[k][bi]%=p; if(v[k][bi]<0)
            v[k][bi]+=p;
        }
    }
    return v;
}
//ef40f3

```

9 Гамильтоновы путь и цикл

<https://codeforces.com/blog/entry/90513>,

<https://codeforces.com/blog/entry/90743>.

9.1 Link-cut tree

```

namespace LCT {
    vector<vi> ch;
    vi fa, rev;
    void init(int n) {
        ch.resize(n + 1);
        fa.resize(n + 1);
        rev.resize(n + 1);
        for (int i = 0; i <= n; i++)
            ch[i].resize(2),
            ch[i][0] = ch[i][1] = fa[i] = rev[i] = 0;
    }
    bool isr(int a)
    {
        return !(ch[fa[a]][0] == a || ch[fa[a]][1] == a);
    }
    void pushdown(int a)
    {
        if(rev[a])
        {
            rev[ch[a][0]] ^= 1, rev[ch[a][1]] ^= 1;
            swap(ch[a][0], ch[a][1]);
            rev[a] = 0;
        }
    }
    void push(int a)
    {
        if(!isr(a)) push(fa[a]);
        pushdown(a);
    }
    void rotate(int a)
    {
        int f = fa[a], gf = fa[f];
        int tp = ch[f][1] == a;
        int son = ch[a][tp ^ 1];
        if(!isr(f))
            ch[gf][ch[gf][1] == f] = a;
        fa[a] = gf;

        ch[f][tp] = son;
        if(son) fa[son] = f;

        ch[a][tp ^ 1] = f, fa[f] = a;
    }
    void splay(int a)
    {
        push(a);
        while(!isr(a))
        {
            int f = fa[a], gf = fa[f];
            if(isr(f)) rotate(a);
            else
            {
                int t1 = ch[gf][1] == f, t2 = ch[f][1] == a;
                if(t1 == t2) rotate(f), rotate(a);
                else rotate(a), rotate(a);
            }
        }
    }
    void access(int a)
    {
        int pr = a;
        splay(a);
        ch[a][1] = 0;
        while(1)
        {
            if(!fa[a]) break;
            int u = fa[a];
            splay(u);
            ch[u][1] = a;
            a = u;
        }
    }
}

```

```

    splay(pr);
}
void makeroot(int a)
{
    access(a);
    rev[a] ^= 1;
}
void link(int a, int b)
{
    makeroot(a);
    fa[a] = b;
}
void cut(int a, int b)
{
    makeroot(a);
    access(b);
    fa[a] = 0, ch[b][0] = 0;
}
int fdr(int a)
{
    access(a);
    while(1)
    {
        pushdown(a);
        if (ch[a][0]) a = ch[a][0];
        else {
            splay(a);
            return a;
        }
    }
}

```

//647cca

9.2 Undirected case

```

#include <bits/stdc++.h>
using namespace std;
namespace hamil {
    template <typename T> bool chkmax(T &x, T y) {return x < y ? x = y, true; false;}
    template <typename T> bool chkmin(T &x, T y) {return x > y ? x = y, true; false;}
    #define vi vector<int>
    #define pb push_back
    #define mp make_pair
    #define pi pair<int, int>
    #define fi first
    #define se second
    #define ll long long
    using namespace LCT;
    vector<vi> used;
    unordered_set<int> caneg;
    void cut(int a, int b) {
        LCT::cut(a, b);
        for (int s = 0; s < 2; s++) {
            for (int i = 0; i < used[a].size(); i++)
                if (used[a][i] == b) {
                    used[a].erase(used[a].begin() + i);
                    break;
                }
            if (used[a].size() == 1) caneg.insert(a);
            swap(a, b);
        }
    }
    void link(int a, int b) {
        LCT::link(a, b);
        for (int s = 0; s < 2; s++) {
            used[a].pb(b);
            if (used[a].size() == 2) caneg.erase(a);
            swap(a, b);
        }
    }
    vi work(int n, vector<pi> eg, ll mx_ch = -1) {
        // mx_ch : max number of adding/replacing default is (n + 100) * (n + 50)
        // n : number of vertices. 1-indexed.
        // eg: vector<pair<int, int>> storing all the edges.
        // return a vector<int> consists of all indices of
        // vertices on the path. return empty list if failed to find
        // one.

        LCT::init(n);
        if (mx_ch == -1) mx_ch = 111 * (n + 100) * (n + 50); //
        default
        used.resize(n + 1);
        caneg.clear();
        for (int i = 1; i <= n; i++) used[i].clear();
    }
}

```

```

vector<vi> edges(n + 1);
for (auto v : eg)
    edges[v.fi].pb(v.se),
    edges[v.se].pb(v.fi);

for (int i = 1; i <= n; i++)
    caneg.insert(i);

mt19937 x(chrono::steady_clock::now().time_since_epoch().
count());
int tot = 0;
while (mx_ch >= 0) {
    // cout << tot << ' ' << mx_ch << endl;
    vector<pi> eg;
    for (auto v : caneg)
        for (auto s : edges[v])
            eg.pb(mp(v, s));

    shuffle(eg.begin(), eg.end(), x);
    if (eg.size() == 0) break;
    for (auto v : eg) {
        mx_ch--;
        int a = v.fi, b = v.se;
        if (used[a].size() < used[b].size()) swap(a, b);
        if (used[b].size() >= 2) continue;
        if (x() & 1) continue;
        if (LCT::fdr(a) == LCT::fdr(b)) continue;
        if (used[a].size() < 2 && used[b].size() < 2)
            tot++;
        if (used[a].size() == 2) {
            int p = used[a][x() % 2];
            cut(a, p);
        }
        link(a, b);
    }
    if (tot == n - 1) {
        vi cur;
        for (int i = 1; i <= n; i++)
            if (used[i].size() <= 1) {
                int pl = i, ls = 0;
                while (pl) {
                    cur.pb(pl);
                    int flag = 0;
                    for (auto v : used[pl])
                        if (v != ls) {
                            ls = pl;
                            pl = v;
                            flag = 1;
                            break;
                        }
                    if (!flag) break;
                }
                break;
            }
        return cur;
    }
}
//failed to find a path
return vi();
}
}

```

//c35638

9.3 Directed case

```

namespace hamil {
    template <typename T> bool chkmax(T &x, T y) {return x < y ? x = y, true; false;}
    template <typename T> bool chkmin(T &x, T y) {return x > y ? x = y, true; false;}
    #define vi vector<int>
    #define pb push_back
    #define mp make_pair
    #define pi pair<int, int>
    #define fi first
    #define se second
    #define ll long long
    using namespace LCT;
    vi out, in;
    vi work(int n, vector<pi> eg, ll mx_ch = -1) {
        // mx_ch : max number of adding/replacing default is (n + 100) * (n + 50)
        // n : number of vertices. 1-indexed.
        // eg: vector<pair<int, int>> storing all the edges.
        // return a vector<int> consists of all indices of
        // vertices on the path. return empty list if failed to find
        // one.
        out.resize(n + 1), in.resize(n + 1);
        LCT::init(n);
    }
}

```

```

for (int i = 0; i <= n; i++) in[i] = out[i] = 0;
if (mx_ch == -1) mx_ch = 111 * (n + 100) * (n + 50); //
default
vector<vi> from(n + 1), to(n + 1);
for (auto v : eg)
    from[v.fi].pb(v.se),
    to[v.se].pb(v.fi);
unordered_set<int> canin, canout;
for (int i = 1; i <= n; i++)
    canin.insert(i),
    canout.insert(i);
mt19937 x(chrono::steady_clock::now().time_since_epoch().
count());
int tot = 0;
while (mx_ch >= 0) {
    // cout << tot << ' ' << mx_ch << endl;
    vector<pi> eg;
    for (auto v : canout)
        for (auto s : from[v])
            if (in[s] == 0) {
                assert(canin.count(s));
                continue;
            }
            else eg.pb(mp(v, s));
    for (auto v : canin)
        for (auto s : to[v])
            eg.pb(mp(s, v));
    shuffle(eg.begin(), eg.end(), x);
    if (eg.size() == 0) break;
    for (auto v : eg) {
        mx_ch--;
        if (in[v.se] && out[v.fi]) continue;
        if (LCT::fdr(v.fi) == LCT::fdr(v.se)) continue;
        if (in[v.se] || out[v.fi])
            if (x() & 1) continue;
        if (!in[v.se] && !out[v.fi])
            tot++;
        if (in[v.se]) {
            LCT::cut(in[v.se], v.se);
            canin.insert(v.se);
            canout.insert(in[v.se]);
            out[in[v.se]] = 0;
            in[v.se] = 0;
        }
        if (out[v.fi]) {
            LCT::cut(v.fi, out[v.fi]);
            canin.insert(out[v.fi]);
            canout.insert(v.fi);
            in[out[v.fi]] = 0;
            out[v.fi] = 0;
        }
        LCT::link(v.fi, v.se);
        canin.erase(v.se);
        canout.erase(v.fi);
        in[v.se] = v.fi;
        out[v.fi] = v.se;
    }
    if (tot == n - 1) {
        vi cur;
        for (int i = 1; i <= n; i++)
            if (!in[i]) {
                int pl = i;
                while (pl) {
                    cur.pb(pl);
                    pl = out[pl];
                }
                break;
            }
        return cur;
    }
}
//failed to find a path
return vi();
}
}
//43ae60

```

10 Геометрия

10.1 Примитивы

```

struct Point {
    int x, y;
    Point() {}
    Point (int x_, int y_) {
        x = x_; y = y_;
    }
    Point operator + (Point p) {

```

```

        return Point(x+p.x,y+p.y);
    }
    Point operator - (Point p) {
        return Point(x - p.x, y - p.y);
    }
    int operator * (Point p) {
        return x * p.y - y * p.x;
    }
    int operator % (Point p) {
        return x * p.x + y * p.y;
    }
    bool operator < (Point v) {
        return (*this) * v > 0;
    }
    bool operator > (Point v) {
        return v < (*this);
    };
    bool operator <= (Point v) {
        return (*this) * v >= 0;
    }
};
bool line(Point a, Point b, Point c) {
    return (b - a) * (c - b) == 0;
}
bool ord(Point a, Point p, Point b) {
    return (p - a) % (p - b) < 0;
}

int hp(Point a) {
    if (a.y == 0) return a.x >= 0;
    return a.y > 0;
}

bool comp(Point a, Point b) {
    if (hp(a) != hp(b)) return hp(a) < hp(b);
    return a.x * b.y - a.y * b.x > 0;
}

//448b68

```

10.2 Выпуклая оболочка

```

using pt = pair<int, int>;
#define x first
#define y second

int cross(pt p, pt q) { return p.x * q.y - p.y * q.x; }
pt operator-(pt a, pt b) { return {a.x - b.x, a.y - b.y}; }

vector<point> convex(vector<point> a) {
    sort(all(a));
    a.erase(unique(all(a)), a.end());
    vector<point> h;
    for (int t = 0; t < 2; ++t) {
        int sz = h.size() - t;
        for (auto p: a) {
            while (h.size() >= sz + 2 && cross(p - h.end()[-1], h.
end()[-2] - h.end()[-1]) <= 0) h.pop_back();
            h.push_back(p);
        }
        reverse(all(a));
    }
    return h; // h is circular: h.empty() || h.front() == h.back
()
}

//ef9132

```

10.3 Точка внутри многоугольника

```

auto inT = [&] (Point a, Point b, Point c, Point p) {
    a = a - p; b = b - p; c = c - p;
    int ab = a * b, bc = b * c, ca = c * a;
    return abs(ab) + abs(bc) + abs(ca) == abs(ab + bc + ca);
};
auto inP = [&] (Point p) {
    //a must be in counterclockwise order!
    //assuming no three points of a are collinear
    if (n == 1) return p == a[0];
    if (n == 2) return (p - a[0]) * (a[1] - a[0]) == 0 && (p - a[0]) %
(p - a[1]) <= 0;
    int l = 1, r = n - 1;
    while (l < r - 1) {
        int m = (l + r) / 2;
        if ((a[m] - a[0]) < (p - a[0])) {
            l = m;
        } else {
            r = m;
        }
    }
}

```

```

    }
    return inT(a[l], a[0], a[r], p);
};

//9e04bc

```

10.4 Касательные

```

auto max = [&] (auto cmp) {
    int k = 0;
    for (int lg = 18; lg >= 0; --lg) {
        int i = k + (1 << lg), j = k - (1 << lg);
        i = (i % n + n) % n;
        j = (j % n + n) % n;
        array<int, 3> ind{i, j, k};
        sort(all(ind), cmp);
        k = ind[2];
    }
    return k;
};

auto uppert = [&](Point p) { //last vertex in counterclockwise
    order about p
    auto cmp = [&] (int i, int j) {return (a[i] - p) < (a[j] - p)
    }; };
    return max(cmp);
};

auto lowert = [&](Point p) { //first vertex in
    counterclockwise order about p
    auto cmp = [&] (int i, int j) {return (a[i] - p) > (a[j] - p)
    }; };
    return max(cmp);
};

auto uppertinf = [&](Point p) { //upper tangent line parallel
    to vector p
    swap(p.x, p.y);
    p.x = -p.x;
    auto cmp = [&] (int i, int j) { return a[i] % p < a[j] % p;
    };
    return max(cmp);
};

auto lowertinf = [&](Point p) { //lower tangent line parallel
    to vector p
    swap(p.x, p.y);
    p.x = -p.x;
    auto cmp = [&] (int i, int j) { return a[i] % p > a[j] % p;
    };
    return max(cmp);
};

//90f89d

```

10.5 Пересечение многоугольника и полу-плоскости

```

template<typename Check>
vector<point> intersect(vector<point> h, Check value) {
    int n = h.size();
    vector<int> pos(n);
    for (int i = 0; i < n; ++i) {
        pos[i] = value(h[i]) >= 0;
    }
    if (count(all(pos), 0) == 0) return h;
    if (count(all(pos), 1) == 0) return {};
    auto intersect = [&](point p, point q) {
        auto s = value(p);
        auto t = value(q);
        assert(s < 0 && t >= 0);
        return q + (p - q) * (t / (t - s));
    };
    int t01 = -1, t10 = -1;

    for (int i = 0; i < n; ++i) {
        h.push_back(h[i]);
        pos.push_back(pos[i]);
        if (pos[i] == 0 && pos[i + 1] == 1) t01 = i;
        if (pos[i] == 1 && pos[i + 1] == 0) t10 = i;
    }
    if (t10 < t01) t10 += n;
    //for (int i = t01 + 1; i <= t10; ++i) assert(pos[i] == 1);
    //for (int i = t10 + 1; i <= t01 + n; ++i) assert(pos[i] == 0);
    vector<point> res{intersect(h[t01], h[t01 + 1])};
    for (int i = t01 + 1; i <= t10; ++i) {
        res.push_back(h[i]);
    }
    res.push_back(intersect(h[t10 + 1], h[t10]));
    return res;
}

```

```

// Usage example:
void solve() {
    vector<point> p, q;
    // ... q must be in counterclockwise order; q[0] == q[m]
    for (int i = 0; i < m; ++i) {
        p = intersect(p, [&](point pt) { return cross(q[i + 1]
        - q[i], pt - q[i]); });
    }
}

//bd15f0

```

10.6 События для прямой

```

int cross(point p, point q) { return p.x * q.y - q.x * p.y; }
point operator-(point p, point q) { return {p.x - q.x, p.y - q
.y}; }
int sgn(int x) { return x < 0 ? -1 : (x > 0); }
double dist(point p) { return sqrt(p.x * p.x + p.y * p.y); }
const __int128 one = 1;

double solve(vector<point> a, point p, point q) {
    int n = a.size();
    a.push_back(a[0]);
    point pq = q - p;
    vector<array<int, 3>> ev;
    for (int i = 0; i < n; ++i) {
        point u = a[i], v = a[i + 1];
        int s = sgn(cross(u - p, pq)), t = sgn(cross(v - p, pq));
        if (s == t) continue;
        int top = cross(u - p, v - u), bot = cross(pq, v - u);
        ev.push_back({sgn(bot) * top, abs(bot), t - s});
    }
    sort(all(ev), [](auto e, auto f) {
        return e[0] * one * f[1] < f[0] * one * e[1];
    });
    int bal = 0;
    for (int i = 0; i + 1 < ev.size(); ++i) {
        if (bal + ev[i][2] < 0 || bal + ev[i][2] > 2) {
            assert(ev[i][0] * ev[i + 1][1] == ev[i + 1][0] * ev[i][1]);
            swap(ev[i], ev[i + 1]);
        }
        bal += ev[i][2];
    }
    // example usage: now calculating length of longest segment
    // inside
    bal = 0;
    double from = 0, ans = 0;
    for (auto [t, b, w] : ev) {
        double x = t * 1.0 / b;
        if (bal == 0) from = x;
        bal += w;
        assert(0 <= bal && bal <= 2);
        if (bal == 0) ans = max(ans, x - from);
    }
    return ans * dist(pq);
}

//fe0649

```

10.7 Кривая Гильберта для алгоритма Мо

```

const int logn = 30; // any number, such that maxn is greater
    than coordinates. 20 is ok.
const int maxn = 1 << logn;
int hilbertorder(int x, int y) { // returns long long
    int d = 0; // long long
    for (int s = 1 << (logn - 1); s; s >= 1)
    {
        bool rx = x & s, ry = y & s;
        d = (4 * d) | ((3 * rx) ^ ry);
        if (!ry) {
            if (rx) {
                x = maxn - x;
                y = maxn - y;
            }
            swap(x, y);
        }
    }
    return d;
}

// Usage example:
vector<int> sort_indices(int q, vector<pair<int, int>> &qs) {
    vector<int> ind(q), ord(q);
    iota(all(ind), 0);
    for (int i = 0; i < q; ++i) ord[i] = hilbertorder(qs[i].
    first, qs[i].second);
    sort(all(ind), [&](int i, int j) { return ord[i] < ord[j];
    });
    return ind;
}

```

//134578

11 Цепные дроби

<https://cp-algorithms.com/algebra/continued-fractions.html>

11.1 Поиск нижней огибающей, сумма и минимум по модулю

```
int floor(int a, int b) {
    return a / b - ((a ^ b) < 0 && a % b);
}

vector<int> decompose(int p, int q) {
    vector<int> f;
    while (q != 0) {
        f.push_back(floor(p, q));
        p -= q * f.back();
        swap(p, q);
    }
    return f;
}

using matrix = array<int, 4>;

matrix operator*(matrix a, matrix b) {
    matrix c{0,0,0,0};
    for (int i = 0; i < 2; ++i) {
        for (int j = 0; j < 2; ++j) {
            for (int k = 0; k < 2; ++k) {
                c[2 * i + k] += a[2 * i + j] * b[2 * j + k];
            }
        }
    }
    return c;
}

#define x first
#define y second

// computes lower convex hull for 0 <= x <= N, 0 <= y <= (ax + b) / c
vector<pair<int, int>> lower_convex_hull(int a, int b, int c,
int n) {
    matrix m = {1, 0, 0, 1};
    auto f = decompose(a, c);
    vector<pair<int, int>> conv{{1, 0}, {0, 1}};
    for (int x : f) {
        m = m * matrix{x, 1, 1, 0};
        conv.emplace_back(m[2], m[0]);
        if (m[2] > n) break; // there should be one (if any) with
        .x > n
    }
    auto diff = [&](int x, int y) {
        return c * y - a * x;
    };
    int x = 0, y = b / c;
    vector<pair<int, int>> res{{x, y}};
    int i;
    for (i = 2; i + 1 < conv.size(); i += 2) {
        while (diff(x + conv[i + 1].x, y + conv[i + 1].y) <= b) {
            int t = 1 + (diff(x + conv[i - 1].x, y + conv[i - 1].y)
            - b - 1) / abs(diff(conv[i].x, conv[i].y));
            auto [dx, dy] = tuple(conv[i - 1].x + t * conv[i].x,
            conv[i - 1].y + t * conv[i].y);
            int k = (n - x) / dx;
            if (k == 0) break;
            if (diff(dx, dy)) k = min(k, (b - diff(x, y)) / diff(dx,
            dy));
            x += k * dx, y += k * dy;
            res.push_back({x, y});
        }
    }
    if (i >= conv.size()) i -= 2;
    for (; i > 0; i -= 2) {
        auto [dx1, dy1] = conv[i];
        if (x + dx1 > n) continue;
        x += dx1, y += dy1;
        if (i + 1 < conv.size()) {
            auto [dx2, dy2] = conv[i + 1];
            int k = (n - x) / dx2;
            x += k * dx2;
            y += k * dy2;
        }
        res.emplace_back(x, y);
        int k = (n - x) / dx1;
        if (k == 0) continue;
        x += k * dx1;
```

```
y += k * dy1;
res.emplace_back(x, y);
}
return res;
}

// number of (x, y) under pq line such that p.x <= x < q.x &&
0 < y
int area(auto p, auto q) {
    int integers = gcd(q.x - p.x, q.y - p.y);
    return ((p.y + q.y - 1) * (q.x - p.x + 1) + integers + 1) /
    2 - q.y;
}

// sum of (ax + b) / c for 0 <= x <= n
int get_area(int a, int b, int c, int n) { // SUM (ax + b) / c
    for 0 <= x <= n
    auto ch = lower_convex_hull(a, b, c, n + 1);
    int sum = 0;
    for (int i = 0; i + 1 < ch.size(); ++i) {
        sum += area(ch[i], ch[i + 1]);
    }
    return sum;
}

// min of (ax + b) % c for 0 <= x <= n
int get_min(int a, int b, int c, int n) {
    auto ch = lower_convex_hull(a, b, c, n);
    // in fact, here we need only the last point of the first
    half of the algo (that is going up)
    int mn = c;
    for (auto [x, y] : ch) mn = min(mn, (a * x + b) % c);
    return mn;
}

//87941e
```

11.2 Простая рекурсия

Число точек $(x, y) : 0 \leq x < n, 0 < y \leq (kx + b)/d$. То есть $\sum_{x=0}^{n-1} \lfloor \frac{kx+b}{d} \rfloor$.

```
int cnt (int n, int k, int b, int d)
{
    if (k == 0) return (b / d) * n;
    if (k >= d || b >= d) {
        return (k / d) * n * (n - 1) / 2 + (b / d) * n + cnt(n, k
        % d, b % d, d);
    }
    return cnt((k * n + b) / d, d, (k * n + b) % d, k);
}

//11a6a0
```

12 Разное

12.1 Компараторы

```
bool cmp1(int x, int y) { return x > y; }

struct cmp2{
    bool operator()(int x, int y) const { return x > y; }
};

int32_t main() {
    set<int, decltype(cmp1)> s1({1, 2, 3}, cmp1);
    for (int x : s1) cout << x << ' '; cout << '\n';
    set<int, cmp2> s2({4, 5, 6});
    for (int x : s2) cout << x << ' '; cout << '\n';
    auto cmp3 = [&](int x, int y) { return x > y; };
    set<int, decltype(cmp3)> s3({7, 8, 9}, cmp3); // second
    cmp3 could be omitted if cmp3 = [ ](...) { ... }
    for (int x : s3) cout << x << ' '; cout << '\n';

    vector<int> v{3, 2, 1};
    cout << lower_bound(all(v), 2, cmp1) - v.begin();
    cout << lower_bound(all(v), 2, cmp2) - v.begin();
    cout << lower_bound(all(v), 2, cmp3) - v.begin();
}

//adea08
```

12.2 Трюки от Сергея Копелиовича

12.2.1 Быстрый ввод

<https://acm.math.spbu.ru/~skl/algo/input-output>

```

const int buf_size = 4096;

int getChar() {
    static char buf[buf_size];
    static int len = 0, pos = 0;
    if (pos == len)
        pos = 0, len = fread(buf, 1, buf_size, stdin);
    if (pos == len)
        return -1;
    return buf[pos++];
}

int readChar() {
    while (1) {
        int c = getChar();
        if (c > 32) return c;
    }
}

int readInt() {
    int s = 1, c = readChar(), x = 0;
    if (c == '-')
        s = -1, c = getChar();
    while (isdigit(c))
        x = x * 10 + c - '0', c = getChar();
    return s * x;
}

//dc0a77

double read_double() {
    string s;
    cin >> s;
    double sgn = 1, p10 = 0, num = 0;
    for (char c : s) {
        if (c == '-') {
            sgn = -1;
        } else if (c == '.') {
            p10 = 1;
        } else {
            p10 *= 10;
            num = (num * 10 + c - '0');
        }
    }
    if (p10 < 0.5) p10 = 1;
    return sgn * num / p10;
}

//b77b67

```

<https://acm.math.spbu.ru/~sk1/algo/memory.cpp.html>

12.2.2 Быстрый аллокатор

```

const int MAX_MEM = 1e8;
int mpos = 0;
char mem[MAX_MEM];
inline void * operator new (size_t n) {
    assert((mpos += n) <= MAX_MEM);
    return (void *) (mem + mpos - n);
}
void operator delete (void *) noexcept { }
void operator delete (void *, size_t) noexcept { }

//8726b1

```

12.3 Редукция Барретта

```

using u64 = unsigned long long;
using u128 = __uint128_t;
struct barrett{
    u64 p, m;
    barrett() {}
    barrett(u64 p) : p(p), m((-1ULL / p) {}
    int reduce(u64 x) {
        u64 q = (u128(m) * x) >> 64, r = x - q * p;
        return r - p * (r >= p);
    }
} ba;

// Usage example:
void solve() {
    int p = ...;
    ba = barrett(p);
    int x = ..., y = ...;
    int prod = ba.reduce(x * y);
}

//a8b4c7

```

12.4 Флаги компиляции

```

-DLOCAL -Wall -Wextra -pedantic -Wshadow -Wformat=2
-Wfloat-equal -Wconversion -Wlogical-op -Wshift-
overflow=2 -Wduplicated-cond -Wcast-qual -Wcast-align -
D_GLIBCXX_DEBUG -D_GLIBCXX_DEBUG_PEDANTIC -D_FORTIFY_SOURCE=2
-fsanitize=address -fsanitize=undefined -fno-sanitize-recover
-fstack-protector -std=c++2a

```

12.4.1 Сеточка в vim

<https://codeforces.com/blog/entry/122540>

```

i|<esc>25A    |<esc>
o+<esc>25A---+<esc>
Vky35Pdd

```

12.5 Что сделать на пробном туре

- Послать клар
- Распечатать что-то
- Получить ML (stack & heap)
- Максимальный размер отправляемого файла?
- Убедиться, что чекер регистронезависимый (yes/YES)
- Позапустить Флойда — Варшалла
- Посмотреть, насколько быстр быстрый ввод
- Перебить что-то, проверить хеш
- Проверить санитайзеры

12.6 Хеш файла без комментариев

Хеш файла, игнорирующий переводы строк и комментарии:

```

$ cpp -dD -P -fpreprocessed "$filename" | tr -d '[:space:]' |
md5sum | cut -c-6

```