ICPC Team Reference

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Contents

```
set ts=4 sw=4 sta nu rnu sc stl+=%F cindent
imap {<CR> {<CR>}<Esc>O
nmap <F2> 0V$%d
nmap <C-down> :m+1<CR>
nmap <C-up> :m-2<CR>
vmap <C-c> "+y
nmap <C-a> ggVG
syntax on
alias cmp='g++ -Wall -Wformat=2 -Wshadow -Wconversion -
  fsanitize=address -fsanitize=undefined -fno-sanitize-
  recover -std=c++14'
```

Data Structures

Merge Sort Tree

```
struct MergeTree{
    int n;
    vector<vector<int>> st;

    void build(int p, int L, int R, const int v[]){
        if(L == R){
            st[p].push_back(v[L]);
            return;
        }
        int mid = (L+R)/2;
        build(2*p, L, mid, v);
        build(2*p+1, mid+1, R, v);
        st[p].resize(R-L+1);
        merge(st[2*p].begin(), st[2*p].end(),
              st[2*p+1].begin(), st[2*p+1].end(),
              st[p].begin());
    }

    int query(int p, int L, int R, int i, int j, int x)
      const{
        if(L > j || R < i) return 0;
        if(L >= i && R <= j){
            int id = lower_bound(st[p].begin(), st[p].end
              (), x) - st[p].begin();
            return int(st[p].size()) - id;
        }
        int mid = (L+R)/2;
        return query(2*p, L, mid, i, j, x) +
            query(2*p+1, mid+1, R, i, j, x);
    }

public:
    MergeTree(int sz, const int v[]): n(sz), st(4*sz){
        build(1, 1, n, v);
    }

    //number of elements >= x on segment [i, j]
    int query(int i, int j, int x) const{
        if(i > j) swap(i, j);
        return query(1, 1, n, i, j, x);
    }
};
```

Wavelet Tree

```
template<typename T>
class wavelet{
    T L, R;
    vector<int> l;
    vector<T> sum; // <<
    wavelet *lef, *rig;
    int r(int i) const{ return i - l[i]; }

public:
    template<typename ITER>
    wavelet(ITER bg, ITER en){
        lef = rig = nullptr;
        L = *bg, R = *bg;

        for(auto it = bg; it != en; it++)
            L = min(L, *it), R = max(R, *it);
        if(L == R) return;

        T mid = L + (R - L)/2;
        l.reserve(std::distance(bg, en) + 1);
        sum.reserve(std::distance(bg, en) + 1);
        l.push_back(0), sum.push_back(0);
        for(auto it = bg; it != en; it++)
            l.push_back(l.back() + (*it <= mid)),
            sum.push_back(sum.back() + *it);

        auto tmp = stable_partition(bg, en, [mid](T x){
            return x <= mid;
        });

        if(bg != tmp) lef = new wavelet(bg, tmp);
        if(tmp != en) rig = new wavelet(tmp, en);
    }

    ~wavelet(){
        delete lef;
        delete rig;
    }

    // 1 index, first is 1st
    T kth(int i, int j, int k) const{
        if(L >= R) return L;
        int c = l[j] - l[i-1];
        if(c >= k) return lef->kth(l[i-1]+1, l[j], k);
        else return rig->kth(r(i-1)+1, r(j), k - c);
    }

    // # elements > x on [i, j]
    int cnt(int i, int j, T x) const{
        if(L > x) return j - i + 1;
        if(R <= x || L == R) return 0;
        int ans = 0;
        if(lef) ans += lef->cnt(l[i-1]+1, l[j], x);
        if(rig) ans += rig->cnt(r(i-1)+1, r(j), x);
        return ans;
    }

    // sum of elements <= k on [i, j]
    T sumk(int i, int j, T k){
        if(L == R) return R <= k ? L * (j - i + 1) : 0;
        if(R <= k) return sum[j] - sum[i-1];
        int ans = 0;
        if(lef) ans += lef->sumk(l[i-1]+1, l[j], k);
        if(rig) ans += rig->sumk(r(i-1)+1, r(j), k);
        return ans;
    }

    // swap (i, i+1) just need to update "array" l[i]
};
```

Order Set

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

```
#include <ext/pb_ds/detail/standard_policies.hpp>

using namespace __gnu_pbds; // or pb_ds;

template<typename T, typename B = null_type>
using oset = tree<T, B, less<T>, rb_tree_tag,
  tree_order_statistics_node_update>;
// find_by_order / order_of_key
```

Hash table

```
#include <ext/pb_ds/assoc_container.hpp>
using namespace __gnu_pbds;

struct custom_hash {
    static uint64_t splitmix64(uint64_t x) {
        // http://xorshift.di.unimi.it/splitmix64.c
        x += 0x9e3779b97f4a7c15;
        x = (x ^ (x >> 30)) * 0xbf58476d1ce4e5b9;
        x = (x ^ (x >> 27)) * 0x94d049bb133111eb;
        return x ^ (x >> 31);
    }

    size_t operator()(uint64_t x) const {
        static const uint64_t FIXED_RANDOM = chrono::
          steady_clock::now().time_since_epoch().count();
        return splitmix64(x + FIXED_RANDOM);
    }
};

gp_hash_table<long long, int, custom_hash> table;
unordered_map<long long, int, custom_hash> uhash;
uhash.reserve(1 << 15);
uhash.max_load_factor(0.25);
```

Convex Hull Trick Simple

```
struct Line{
    ll m, b;
    inline ll eval(ll x) const{
        return x * m + b;
    }
};

// min => cht.back().m >= L.m
// max => cht.back().m <= L.m
void push_line(vector<Line> &cht, Line L){
  while((int)cht.size() >= 2){
    int sz = (int)cht.size();
    if((long double)(L.b-cht[sz-1].b)*(cht[sz-2].m-L.m)
   <= (long double)(L.b-cht[sz-2].b)*(cht[sz-1].m-L.m)){
      cht.pop_back();
    }
    else break;
  }
  cht.push_back(L);
}

// x increasing; pos = 0 in first call
ll linear_search(const vector<Line> &cht,ll x,int &pos){
    while(pos+1 < (int)cht.size()){
/*>>*/ if(cht[pos].eval(x) >= cht[pos+1].eval(x)) pos++;
        else break;
    }
    return cht[pos].eval(x);
}

ll binary_search(const vector<Line> &cht, ll x){
    int L = 0, R = (int)cht.size()-2;
    int bans = (int)cht.size()-1;
    while(L <= R){
        int mid = (L+R)/2;
        if(cht[mid].eval(x) >= cht[mid+1].eval(x)) // <<<
            L = mid + 1;
        else bans = mid, R = mid - 1;
    }
    return cht[bans].eval(x);
}
```

Convex Hull Trick

```
const ll is_query = -(1LL<<62);
struct Line{
    ll m, b;
    mutable function<const Line*()> succ;
    bool operator<(const Line& rhs) const{
        if(rhs.b != is_query) return m < rhs.m;
        const Line* s = succ();
        if(!s) return 0;
        ll x = rhs.m;
        return b - s->b < (s->m - m) * x;
    }
};
struct Cht : public multiset<Line>{ // maintain max
    bool bad(iterator y){
        auto z = next(y);
        if(y == begin()){
            if(z == end()) return 0;
            return y->m == z->m && y->b <= z->b;
        }
        auto x = prev(y);
        if(z == end()) return y->m == x->m && y->b <= x->
          b;
        return (long double)(x->b - y->b)*(z->m - y->m)
          >= (long double)(y->b - z->b)*(y->m - x->m);
    }
    void insert_line(ll m, ll b){
        auto y = insert({ m, b });
        y->succ = [=]{ return next(y) == end() ? 0 : &*
          next(y); };
        if(bad(y)){ erase(y); return; }
        while(next(y) != end() && bad(next(y))) erase(
          next(y));
        while(y != begin() && bad(prev(y))) erase(prev(y)
          );
    }
    ll eval(ll x){
        auto l = *lower_bound((Line) { x, is_query });
        return l.m * x + l.b;
    }
};
```

Min queue

```
template<typename T>
class minQ{
    deque<tuple<T, int, int> > p;
    T delta;
    int sz;
public:
    minQ() : delta(0), sz(0) {}
    inline int size() const{ return sz; }
    inline void add(T x){ delta += x; }
    inline void push(T x, int id){
        x -= delta, sz++;
        int t = 1;
        while(p.size() > 0 && get<0>(p.back()) >= x)
```

```
            t += get<1>(p.back()), p.pop_back();
        p.emplace_back(x, t, id);
    }
    inline void pop(){
        get<1>(p.front())--, sz--;
        if(!get<1>(p.front())) p.pop_front();
    }
    T getmin() const{ return get<0>(p.front())+delta; }
    int getid() const{ return get<2>(p.front()); }
};
```

Sparse Table

```
const int N = 100005;

int v[N], n;
int dn[N][20];
int fn(int i, int j){
    if(j == 0) return v[i];
    if(~dn[i][j]) return dn[i][j];
    return dn[i][j] = min(fn(i, j-1), fn(i + (1 << (j-1)
      ), j-1));
}

int lg(int x){ return 31 - __builtin_clz(x); }

int getmn(int l, int r){ // [l, r]
    int lz = lg(r - l + 1);
    return min(fn(l, lz), fn(r - (1 << lz) + 1, lz));
}
```

Treap

```
// source: https://github.com/victorsenam/caderno/blob/
  master/code/treap.cpp
//const int N = ; typedef int num;
num X[N]; int en = 1, Y[N], sz[N], L[N], R[N];
void calc (int u) { // update node given children info
    sz[u] = sz[L[u]] + 1 + sz[R[u]];
    // code here, no recursion
}
void unlaze (int u) {
    if(!u) return;
    // code here, no recursion
}
void split_val(int u, num x, int &l, int &r) { // l gets
    <= x, r gets > x
    unlaze(u); if(!u) return (void) (l = r = 0);
    if(X[u] <= x) { split_val(R[u], x, l, r); R[u] = l;
      l = u; }
    else { split_val(L[u], x, l, r); L[u] = r; r = u; }
    calc(u);
}
void split_sz(int u, int s, int &l, int &r) { // l gets
  first s, r gets remaining
    unlaze(u); if(!u) return (void) (l = r = 0);
    if(sz[L[u]] < s) { split_sz(R[u], s - sz[L[u]] - 1,
      l, r); R[u] = l; l = u; }
    else { split_sz(L[u], s, l, r); L[u] = r; r = u; }
    calc(u);
}
int merge(int l, int r) { // els on l <= els on r
    unlaze(l); unlaze(r); if(!l || !r) return l + r; int
       u;
    if(Y[l] > Y[r]) { R[l] = merge(R[l], r); u = l; }
    else { L[r] = merge(l, L[r]); u = r; }
    calc(u); return u;
}
void init(int n=N-1) { // XXX call before using other
  funcs
    for(int i = en = 1; i <= n; i++) { Y[i] = i; sz[i] =
       1; L[i] = R[i] = 0; }
    random_shuffle(Y + 1, Y + n + 1);
}
```

ColorUpdate

```
// source: https://github.com/tfg50/Competitive-
  Programming/tree/master/Biblioteca/Data%20Structures

#include <set>
#include <vector>

template <class Info = int>
class ColorUpdate {
public:
    struct Range {
        Range(int l = 0) { this->l = l; }
        Range(int l, int r, Info v) {
            this->l = l;
            this->r = r;
            this->v = v;
        }
        int l, r;
        Info v;

        bool operator < (const Range &b) const { return l
            < b.l; }
    };

    std::vector<Range> upd(int l, int r, Info v) {
        std::vector<Range> ans;
        if(l >= r) return ans;
        auto it = ranges.lower_bound(l);
        if(it != ranges.begin()) {
            it--;
            if(it->r > l) {
                auto cur = *it;
                ranges.erase(it);
                ranges.insert(Range(cur.l, l, cur.v));
                ranges.insert(Range(l, cur.r, cur.v));
            }
        }
        it = ranges.lower_bound(r);
        if(it != ranges.begin()) {
            it--;
            if(it->r > r) {
                auto cur = *it;
                ranges.erase(it);
                ranges.insert(Range(cur.l, r, cur.v));
                ranges.insert(Range(r, cur.r, cur.v));
            }
        }
        for(it = ranges.lower_bound(l); it != ranges.end
          () && it->l < r; it++) {
            ans.push_back(*it);
        }
        ranges.erase(ranges.lower_bound(l), ranges.
          lower_bound(r));
        ranges.insert(Range(l, r, v));
        return ans;
    }
private:
    std::set<Range> ranges;
};
```

Heavy Light Decomposition

```
void dfs_sz(int u){
    sz[u] = 1;

    for(auto &v : g[u]) if(v == p[u]){
        swap(v, g[u].back());
        g[u].pop_back();
        break;
    }

    for(auto &v : g[u]){
        p[v] = u;
        dfs_sz(v);
        sz[u] += sz[v];
        if(sz[v] > sz[ g[u][0] ])
            swap(v, g[u][0]);
    }
}

// nxt[u] = start of path with u
// set nxt[root] = root beforehand
void dfs_hld(int u){
    in[u] = t++;
    rin[in[u]] = u;
    for(auto v : g[u]){
        nxt[v] = (v == g[u][0] ? nxt[u] : v);
        dfs_hld(v);
    }
    out[u] = t;
}

// subtree of u => [ in[u], out[u] )
// path from nxt[u] to u => [ in[ nxt[u] ], in[u] ]
```

Iterative Segtree

```
T query(int l, int r, int &pos){ // [l, r]
    T rl, rr;
    for(l += n, r += n+1; l < r; l >>= 1, r >>= 1){
        if(l & 1) rl = merge(rl, st[l++]);
        if(r & 1) rr = merge(st[--r], rr);
    }
    return merge(rl, rr);
}

// initially save v[i] in st[n+i] for all i in [0, n)
void build(){
    for(int p = n-1; p > 0; p--)
        st[p] = merge(st[2*p], st[2*p+1]);
}

void update(int p, T val){
    st[p += n] = val;
    while(p >>= 1) st[p] = merge(st[2*p], st[2*p+1]);
}
```

LiChao's Segtree

```
void add_line(line nw, int v = 1, int l = 0, int r =
  maxn) { // [l, r)
    int m = (l + r) / 2;
    bool lef = nw.eval(l) < st[v].eval(l);
    bool mid = nw.eval(m) < st[v].eval(m);
    if(mid) swap(st[v], nw);
    if(r - l == 1) {
        return;
    } else if(lef != mid) {
        add_line(nw, 2 * v, l, m);
    } else {
        add_line(nw, 2 * v + 1, m, r);
    }
}

int get(int x, int v = 1, int l = 0, int r = maxn) {
    int m = (l + r) / 2;
    if(r - l == 1) {
        return st[v].eval(x);
    } else if(x < m) {
        return min(st[v].eval(x), get(x, 2*v, l, m));
    } else {
        return min(st[v].eval(x), get(x, 2*v+1, m, r));
    }
}
```

Palindromic tree

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

using namespace std;

const int maxn = 3e5 + 1, sigma = 26;
int len[maxn], link[maxn], to[maxn][sigma];
int slink[maxn], diff[maxn], series_ans[maxn];
int sz, last, n;
char s[maxn];

void init()
{
    s[n++] = -1;
    link[0] = 1;
    len[1] = -1;
    sz = 2;
}

int get_link(int v)
{
    while(s[n - len[v] - 2] != s[n - 1]) v = link[v];
    return v;
}

void add_letter(char c)
{
    s[n++] = c -= 'a';
    last = get_link(last);
    if(!to[last][c])
    {
        len[sz] = len[last] + 2;
        link[sz] = to[get_link(link[last])][c];
        diff[sz] = len[sz] - len[link[sz]];
        if(diff[sz] == diff[link[sz]])
            slink[sz] = slink[link[sz]];
        else
            slink[sz] = link[sz];
        to[last][c] = sz++;
    }
    last = to[last][c];
}

int main()
{
    ios::sync_with_stdio(0);
    cin.tie(0);
    init();
    string s;
    cin >> s;
    int n = s.size();
    int ans[n + 1];
    memset(ans, 63, sizeof(ans));
```

```
    ans[0] = 0;
    for(int i = 1; i <= n; i++)
    {
        add_letter(s[i - 1]);
        for(int v = last; len[v] > 0; v = slink[v])
        {
            series_ans[v] = ans[i - (len[slink[v]] + diff
              [v])];
            if(diff[v] == diff[link[v]])
                series_ans[v] = min(series_ans[v],
                  series_ans[link[v]]);
            ans[i] = min(ans[i], series_ans[v] + 1);
        }
        cout << ans[i] << "\n";
    }
    return 0;
}
```

Math

Extended Euclidean Algorithm

```
// a*x + b*y = gcd(a, b), <gcd, x, y>
tuple<int, int, int> gcd(int a, int b) {
    if(b == 0) return make_tuple(a, 1, 0);
    int q, w, e;
    tie(q, w, e) = gcd(b, a % b);
    return make_tuple(q, e, w - e * (a / b));
}
```

Chinese Remainder Theorem

```
// x = vet[i].first (mod vet[i].second)
ll crt(vector<pair<ll, ll>> vet){

    ll ans = vet[0].first, lcm = vet[0].second;
    ll a, b, g, x, y;

    for(int i = 1; i < (int)vet.size(); i++){
        tie(a, b) = vet[i];
        tie(g, x, y) = gcd(lcm, b);
        ans = ans + x * (a - ans) / g % (b / g) * lcm;
        lcm = lcm * b / g;
        ans = (ans % lcm + lcm) % lcm;
    }

    return ans;
}
```

Preffix inverse

```
inv[1] = 1;
for(int i = 2; i < p; i++)
    inv[i] = (p - (p/i) * inv[p%i] % p) % p;
```

Pollard Rho

```
ll rho(ll n){
    if(n % 2 == 0) return 2;

    ll d, c, x, y;
    do{
        c = llrand() % n, x = llrand() % n, y = x;
        do{
            x = add(mul(x, x, n), c, n);
            y = add(mul(y, y, n), c, n);
            y = add(mul(y, y, n), c, n);
            d = __gcd(abs(x - y), n);
        }while(d == 1);
    }while(d == n);
    return d;
}

ll pollard_rho(ll n){
    ll x, c, y, d, k;
    int i;
    do{
        i = 1;
        x = llrand() % n, c = llrand() % n;
        y = x, k = 4;
        do{
            if(++i == k) y = x, k *= 2;
            x = add(mul(x, x, n), c, n);
            d = __gcd(abs(x - y), n);
        }while(d == 1);
    }while(d == n);
    return d;
}

void factorize(ll val, map<ll, int> &fac){
    if(rabin(val)) fac[ val ]++;
    else{
        ll d = pollard_rho(val);
        factorize(d, fac);
        factorize(val / d, fac);
    }
}

map<ll, int> factor(ll val){
    map<ll, int> fac;
    if(val > 1) factorize(val, fac);
    return fac;
}
```

Miller Rabin

```
bool rabin(ll n){
    if(n <= 1) return 0;
    if(n <= 3) return 1;
    ll s = 0, d = n - 1;
    while(d % 2 == 0) d /= 2, s++;
    for(int k = 0; k < 64; k++){
        ll a = (llrand() % (n - 3)) + 2;
        ll x = fexp(a, d, n);
        if(x != 1 && x != n-1){
            for(int r = 1; r < s; r++){
                x = mul(x, x, n);
                if(x == 1) return 0;
                if(x == n-1) break;
            }
            if(x != n-1) return 0;
        }
    }
    return 1;
}
```

Totiente

```
ll totiente(ll n){
    ll ans = n;
    for(ll i = 2; i*i <= n; i++){
        if(n % i == 0){
            ans = ans / i * (i - 1);
            while(n % i == 0) n /= i;
        }
    }

    if(n > 1) ans = ans / n * (n - 1);
    return ans;
```

```
}
```

Mobius Function

```
memset(mu, 0, sizeof mu);
mu[1] = 1;
for(int i = 1; i < N; i++)
    for(int j = i + i; j < N; j += i)
        mu[j] -= mu[i];
// g(n) = sum{f(d)} => f(n) = sum{mu(d)*g(n/d)}
```

Mulmod TOP

```
constexpr uint64_t mod = (1ull<<61) - 1;
uint64_t modmul(uint64_t a, uint64_t b){
    uint64_t l1 = (uint32_t)a, h1 = a>>32, l2 = (
      uint32_t)b, h2 = b>>32;
    uint64_t l = l1*l2, m = l1*h2 + l2*h1, h = h1*h2;
    uint64_t ret = (l&mod) + (l>>61) + (h << 3) + (m >>
      29) + (m << 35 >> 3) + 1;
    ret = (ret & mod) + (ret>>61);
    ret = (ret & mod) + (ret>>61);
    return ret-1;
}
```

Matrix Determinant

```
int n;
long double a[n][n];

long double gauss(){
    long double det = 1;
    for(int i = 0; i < n; i++){
        int q = i;
        for(int j = i+1; j < n; j++){
            if(abs(a[j][i]) > abs(a[q][i]))
                q = j;
        }
        if(abs(a[q][i]) < EPS){
            det = 0;
            break;
        }
        if(i != q){
            for(int w = 0; w < n; w++)
                swap(a[i][w], a[q][w]);
            det = -det;
        }
        det *= a[i][i];
        for(int j = i+1; j < n; j++) a[i][j] /= a[i][i];

        for(int j = 0; j < n; j++) if(j != i){
            if(abs(a[j][i]) > EPS)
                for(int k = i+1; k < n; k++)
                    a[j][k] -= a[i][k] * a[j][i];
        }
    }

    return det;
}
```

Simplex Method

```
typedef long double dbl;
const dbl eps = 1e-6;
const int N = , M = ;

mt19937 rng(chrono::steady_clock::now().time_since_epoch
  ().count());
struct simplex {
    int X[N], Y[M];
    dbl A[M][N], b[M], c[N];
    dbl ans;
    int n, m;
    dbl sol[N];

    void pivot(int x, int y){
        swap(X[y], Y[x]);
        b[x] /= A[x][y];
        for(int i = 0; i < n; i++)
            if(i != y)
                A[x][i] /= A[x][y];
        A[x][y] = 1. / A[x][y];
        for(int i = 0; i < m; i++)
            if(i != x && abs(A[i][y]) > eps) {
                b[i] -= A[i][y] * b[x];
                for(int j = 0; j < n; j++) if(j != y)
                    A[i][j] -= A[i][y] * A[x][j];
                A[i][y] = -A[i][y] * A[x][y];
            }
        ans += c[y] * b[x];
        for(int i = 0; i < n; i++)
            if(i != y)
                c[i] -= c[y] * A[x][i];
        c[y] = -c[y] * A[x][y];
    }

    // maximiza sum(x[i] * c[i])
    // sujeito a
    // sum(a[i][j] * x[j]) <= b[i] para 0 <= i < m (Ax
      <= b)
    // x[i] >= 0 para 0 <= i < n (x >= 0)
    // (n variaveis, m restricoes)
    // guarda a resposta em ans e retorna o valor otimo
    dbl solve(int _n, int _m) {
        this->n = _n; this->m = _m;

        for(int i = 1; i < m; i++){
            int id = uniform_int_distribution<int>(0, i)(
              rng);
            swap(b[i], b[id]);
            for(int j = 0; j < n; j++)
                swap(A[i][j], A[id][j]);
        }

        ans = 0.;
        for(int i = 0; i < n; i++) X[i] = i;
        for(int i = 0; i < m; i++) Y[i] = i + n;
        while(true) {
            int x = min_element(b, b + m) - b;
            if(b[x] >= -eps)
                break;
            int y = find_if(A[x], A[x] + n, [](dbl d) {
              return d < -eps; }) - A[x];
            if(y == n) throw 1; // no solution
            pivot(x, y);
        }
        while(true) {
            int y = max_element(c, c + n) - c;
            if(c[y] <= eps) break;
            int x = -1;
            dbl mn = 1. / 0.;
            for(int i = 0; i < m; i++)
                if(A[i][y] > eps && b[i] / A[i][y] < mn)
                    mn = b[i] / A[i][y], x = i;
            if(x == -1) throw 2; // unbounded
            pivot(x, y);
        }
        memset(sol, 0, sizeof(dbl) * n);
```

```
        for(int i = 0; i < m; i++)
            if(Y[i] < n)
                sol[Y[i]] = b[i];
        return ans;
    }
};
```

FFT

```
struct base{
    double r, i;
    base(double _r = 0, double _i = 0) : r(_r), i(_i) {}
    base operator*(base &o) const{
        return {r*o.r - i*o.i, r*o.i + o.r*i};
    }
    double real() const{ return r; }
    void operator*=(const base &o){
        (*this) = {r*o.r-i*o.i, r*o.i+o.r*i};
    }
    void operator+=(const base &o){r += o.r, i += o.i; }
    void operator/=(const double &o){ r /= o, i /= o; }
    void operator-=(const base &o){r -= o.r, i -= o.i; }
    base operator+(const base &o){return {r+o.r,i+o.i};}
    base operator-(const base &o){return {r-o.r,i-o.i};}
};

double PI = acos(-1);

void fft(vector<base> &a, bool inv){
    int n = (int)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 sz = 2; sz <= n; sz <<= 1) {
        double ang = 2*PI/sz * (inv ? -1 : 1);
        base wlen(cos(ang), sin(ang));
        for(int i = 0; i < n; i += sz){
            base w(1);
            for(int j = 0; j < sz/2; j++){
                base u = a[i+j], v = a[i+j+sz/2] * w;
                a[i+j] = u + v;
                a[i+j+sz/2] = u - v;
                w *= wlen;
            }
        }
    }
    if(inv) for(int i = 0; i < n; i++) a[i] /= 1.0 * n;
}

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

    fft(fa, false), fft(fb, false);
    for(size_t i = 0; i < n; i++)
        fa[i] *= fb[i];
    fft(fa, true);
    res.resize (n);
    for(size_t i = 0; i < n; ++i)
        res[i] = int(fa[i].real() + 0.5);
}
```

NTT

```
const int mod = 7340033;
const int root = 5;
const int root_1 = 4404020;
const int root_pw = 1<<20;

void fft (vector<int> & a, bool invert) {
    int n = (int) 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) {
        int wlen = invert ? root_1 : root;
        for (int i=len; i<root_pw; i<<=1)
            wlen = int (wlen * 1ll * wlen % mod);
        for (int i=0; i<n; i+=len) {
            int w = 1;
            for (int j=0; j<len/2; ++j) {
                int u = a[i+j], v = int (a[i+j+len/2] * 1
                  ll * w % mod);
                a[i+j] = u+v < mod ? u+v : u+v-mod;
                a[i+j+len/2] = u-v >= 0 ? u-v : u-v+mod;
                w = int (w * 1ll * wlen % mod);
            }
        }
    }
    if (invert) {
        int nrev = reverse (n, mod);
        for (int i=0; i<n; ++i)
            a[i] = int (a[i] * 1ll * nrev % mod);
    }
}
```

Graphs

Dinic

```
const int N = 100005;
const int E = 2000006;
vector<int> g[N];

int ne;
struct Edge{
    int from, to;
    ll flow, cap;
} edge[E];

int lvl[N], vis[N], pass, start = N-2, target = N-1;
int qu[N], qt, px[N];

ll run(int s, int sink, ll minE){
    if(s == sink) return minE;

    ll ans = 0;
```

```
    for(; px[s] < (int)g[s].size(); px[s]++){
        int e = g[s][ px[s] ];
        auto &v = edge[e], &rev = edge[e^1];
        if(lvl[v.to] != lvl[s]+1 || v.flow >= v.cap)
            continue; // v.cap - v.flow < lim
        ll tmp = run(v.to, sink,min(minE, v.cap-v.flow));
        v.flow += tmp, rev.flow -= tmp;
        ans += tmp, minE -= tmp;
        if(minE == 0) break;
    }
    return ans;
}

bool bfs(int source, int sink){
    qt = 0;
    qu[qt++] = source;
    lvl[source] = 1;
    vis[source] = ++pass;

    for(int i = 0; i < qt; i++){
        int u = qu[i];
        px[u] = 0;
        if(u == sink) return true;

        for(int e : g[u]){
            auto v = edge[e];
            if(v.flow >= v.cap || vis[v.to] == pass)
                continue; // v.cap - v.flow < lim
            vis[v.to] = pass;
            lvl[v.to] = lvl[u]+1;
            qu[qt++] = v.to;
        }
    }
    return false;
}

ll flow(int source = start, int sink = target){
    ll ans = 0;
    //for(lim = (1LL << 62); lim >= 1; lim /= 2)
    while(bfs(source, sink))
        ans += run(source, sink, oo);
    return ans;
}

void addEdge(int u, int v, ll c = 1, ll rc = 0){
    edge[ne] = {u, v, 0, c};
    g[u].push_back(ne++);
    edge[ne] = {v, u, 0, rc};
    g[v].push_back(ne++);
}

void reset_flow(){
    for(int i = 0; i < ne; i++)
        edge[i].flow = 0;
}
```

Min Cost Max Flow

```
const ll oo = 1e18;
const int N = 505;
const int E = 30006;

vector<int> g[N];

int ne;

struct Edge{
    int from, to;
    ll cap, cost;
} edge[E];

int lvl[N], vis[N], pass, source, target, p[N], px[N];

ll d[N];

ll back(int s, ll minE){
    if(s == source) return minE;

    int e = p[s];

    ll f = back(edge[e].from, min(minE, edge[e].cap));
    edge[e].cap -= f;
    edge[e^1].cap += f;
    return f;
}

int dijkstra(){
    forn(i, N) d[i] = oo;

    priority_queue<pair<ll, int> > q;

    d[source] = 0;

    q.emplace(0, source);

    while(!q.empty()){
        ll dis = -q.top().ff;
        int u = q.top().ss; q.pop();

        if(dis > d[u]) continue;

        for(int e : g[u]){
            auto v = edge[e];
            if(v.cap <= 0) continue;
            if(d[u] + v.cost < d[v.to]){
                d[v.to] = d[u] + v.cost;
                p[v.to] = e;
                q.emplace(-d[v.to], v.to);
            }
        }
    }
    return d[target] != oo;
}

pair<ll, ll> mincost(){
    ll ans = 0, mf = 0;
    while(dijkstra()){
        ll f = back(target, oo);
        mf += f;
        ans += f * d[target];
    }
    return {mf, ans};
}

void addEdge(int u, int v, ll c, ll cost){
    edge[ne] = {u, v, c, cost};
    g[u].pb(ne++);
}
```

Small to Large

```
void cnt_sz(int u, int p = -1){
    sz[u] = 1;

    for(int v : g[u]) if(v != p)
        cnt_sz(v, u), sz[u] += sz[v];
```

```
}

void add(int u, int p, int big = -1){
    // Update info about this vx in global answer

    for(int v : g[u]) if(v != p && v != big)
        add(v, u);
}

void dfs(int u, int p, int keep){

    int big = -1, mmx = -1;

    for(int v : g[u]) if(v != p && sz[v] > mmx)
        mmx = sz[v], big = v;

    for(int v : g[u]) if(v != p && v != big)
        dfs(v, u, 0);

    if(big != -1) dfs(big, u, 1);

    add(u, p, big);

    for(auto x : q[u]){
        // answer all queries for this vx
    }

    if(!keep){
        // Remove data from this subtree
    }
}
```

Junior e Falta de Ideias

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

#define ff first
#define ss second
#define mp make_pair

using namespace std;

typedef long long ll;

vector<pair<int,int>> G[500005];
int subtree[500005], treesize, k;
bool vis[500005];
ll dist[500005], ans;

int dfs(int v, int p){
    subtree[v] = 1;
    for(pair<int,int> x : G[v])
        if(x.ff != p && !vis[x.ff]) subtree[v] += dfs(x.
          ff,v);
    return subtree[v];
}

int centroid(int v, int p){
    for(pair<int,int> x : G[v]){
        if(x.ff == p || vis[x.ff]) continue;
        if(subtree[x.ff]*2 > treesize) return centroid(x.
          ff,v);
    }
    return v;
}

void procurar_ans(int v, int p, int d_atual, ll custo){
    ans = min(ans, dist[k-d_atual] + custo);
    if(d_atual == k) return;
    for(pair<int,int> x : G[v]){
        if(!vis[x.ff] && x.ff != p)
            procurar_ans(x.ff,v,d_atual+1,custo+x.ss);
    }
}

void atualiza_distancia(int v, int p, int d_atual, ll
  custo){
    dist[d_atual] = min(dist[d_atual], custo);
    if(d_atual == k) return;
    for(pair<int,int> x : G[v]){
        if(!vis[x.ff] && x.ff != p)
            atualiza_distancia(x.ff,v,d_atual+1,custo+x.
              ss);
    }
}

void decomp(int v, int p){
    treesize = dfs(v,v);
    // if(treesize < k) return;
    int cent = centroid(v,v);
    vis[cent] = 1;

    for(int i = 1; i <= treesize; i++)
        dist[i] = 1e18;

    for(pair<int,int> x : G[cent]){
        if(!vis[x.ff]){
            procurar_ans(x.ff,cent,1,x.ss);
            atualiza_distancia(x.ff,cent,1,x.ss);
        }
    }

    for(pair<int,int> x : G[cent]){
        if(!vis[x.ff])
            decomp(x.ff, cent);
    }
}

int main(){
    int n,i,a,b;

    scanf("%d%d", &n,&k);
    for(i = 2; i <= n; i++){
        scanf("%d%d", &a,&b);
        G[i].push_back(mp(a,b));
        G[a].push_back(mp(i,b));
    }
    ans = 1e18;
    decomp(1,-1);

    printf("%lld\n", ans == 1e18 ? -1 : ans);

    return 0;
}
```

Kosaraju

```
vector<int> g[N], gt[N], S;

int vis[N], cor[N], tempo = 1;

void dfs(int u){
    vis[u] = 1;
    for(int v : g[u]) if(!vis[v]) dfs(v);
    S.push_back(u);
}
```

```
int e;
void dfst(int u){
    cor[u] = e;
    for(int v : gt[u]) if(!cor[v]) dfst(v);
}

int main(){

    for(int i = 1; i <= n; i++) if(!vis[i]) dfs(i);

    e = 0;
    reverse(S.begin(), S.end());
    for(int u : S) if(!cor[u])
        e++, dfst(u);

    return 0;
}
```

Tarjan

```
int cnt = 0, root;
void dfs(int u, int p = -1){
    low[u] = num[u] = ++t;
    for(int v : g[u]){
        if(!num[v]){
            dfs(v, u);
            if(v == root) cnt++;
            if(low[v] >= num[u]) u PONTO DE ARTICULACAO;
            if(low[v] > num[u]) ARESTA u->v PONTE;
            low[u] = min(low[u], low[v]);
        }
        else if(v != p) low[u] = min(low[u], num[v]);
    }
}

root PONTO DE ARTICULACAO <=> cnt > 1

void tarjanSCC(int u){
    low[u] = num[u] = ++cnt;
    vis[u] = 1;
    S.push_back(u);
    for(int v : g[u]){
        if(!num[v]) tarjanSCC(v);
        if(vis[v]) low[u] = min(low[u], low[v]);
    }
    if(low[u] == num[u]){
        ssc[u] = ++ssc_cnt; int v;
        do{
            v = S.back(); S.pop_back(); vis[v] = 0;
            ssc[v] = ssc_cnt;
        }while(u != v);
    }
}
```

Max Clique

```
long long adj[N], dp[N];

for(int i = 0; i < n; i++){
    for(int j = 0; j < n; j++){
        int x;
        scanf("%d",&x);
        if(x || i == j)
            adj[i] |= 1LL << j;
    }
}

int resto = n - n/2;
int C = n/2;

for(int i = 1; i < (1 << resto); i++){
    int x = i;
    for(int j = 0; j < resto; j++)
        if(i & (1 << j))
            x &= adj[j + C] >> C;
    if(x == i){
        dp[i] = __builtin_popcount(i);
    }
}

for(int i = 1; i < (1 << resto); i++)
    for(int j = 0; j < resto; j++)
        if(i & (1 << j))
            dp[i] = max(dp[i], dp[i ^ (1 << j)]);

int maxCliq = 0;
for(int i = 0; i < (1 << C); i++){
    int x = i, y = (1 << resto) - 1;
    for(int j = 0; j < C; j++)
        if(i & (1 << j))
            x &= adj[j] & ((1 << C) - 1), y &= adj[j] >>
              C;
    if(x != i) continue;
    maxCliq = max(maxCliq, __builtin_popcount(i) + dp[y
      ]);
}
```

Dominator Tree

```
vector<int> g[N], gt[N], T[N];
vector<int> S;
int dsu[N], label[N];
int sdom[N], idom[N], dfs_time, id[N];

vector<int> bucket[N];
vector<int> down[N];

void prep(int u){
    S.push_back(u);
    id[u] = ++dfs_time;
    label[u] = sdom[u] = dsu[u] = u;

    for(int v : g[u]){
        if(!id[v])
            prep(v), down[u].push_back(v);
        gt[v].push_back(u);
    }
}

int fnd(int u, int flag = 0){
    if(u == dsu[u]) return u;
    int v = fnd(dsu[u], 1), b = label[ dsu[u] ];
    if(id[ sdom[b] ] < id[ sdom[ label[u] ] ])
        label[u] = b;
    dsu[u] = v;
    return flag ? v : label[u];
}

void build_dominator_tree(int root, int sz){
    // memset(id, 0, sizeof(int) * (sz + 1));
    // for(int i = 0; i <= sz; i++) T[i].clear();
    prep(root);

    reverse(S.begin(), S.end());

    int w;
    for(int u : S){
```

```
        for(int v : gt[u]){
            w = fnd(v);
            if(id[ sdom[w] ] < id[ sdom[u] ])
                sdom[u] = sdom[w];
        }
        gt[u].clear();

        if(u != root) bucket[ sdom[u] ].push_back(u);

        for(int v : bucket[u]){
            w = fnd(v);
            if(sdom[w] == sdom[v]) idom[v] = sdom[v];
            else idom[v] = w;
        }
        bucket[u].clear();

        for(int v : down[u]) dsu[v] = u;
        down[u].clear();
    }

    reverse(S.begin(), S.end());

    for(int u : S) if(u != root){
        if(idom[u] != sdom[u]) idom[u] = idom[ idom[u] ];
        T[ idom[u] ].push_back(u);
    }

    S.clear();
}
```

Min Cost Matching

```
// Min cost matching
// O(n^2 * m)
// n == nro de linhas
// m == nro de colunas
// n <= m | flow == n
// a[i][j] = custo pra conectar i a j
vector<int> u(n + 1), v(m + 1), p(m + 1), way(m + 1);
for(int i = 1; i <= n; ++i){
    p[0] = i;
    int j0 = 0;
    vector<int> minv(m + 1 , oo);
    vector<char> used(m + 1 , false);
    do{
        used[j0] = true;
        int i0 = p[j0] , delta = oo, j1;
        for(int j = 1; j <= m; ++j)
            if(! used[j]){
                int cur = a[i0][j] - u[i0] - v[j];
                if(cur < minv[j])
                    minv[j] = cur, way[j] = j0;
                if(minv[j] < delta)
                    delta = minv[j] , j1 = j;
            }
        for(int j = 0; j <= m; ++j)
            if(used[j])
                u[p[j]] += delta, v[j] -= delta;
            else
                minv[j] -= delta;
        j0 = j1;
    }while(p[j0] != 0);

    do{
        int j1 = way[j0];
        p[j0] = p[j1];
        j0 = j1;
    }while(j0);
}

// match[i] = coluna escolhida para linha i
vector<int> match(n + 1);
for(int j = 1; j <= m; ++j)
    match[p[j]] = j;

int cost = -v[0];
```

Strings

Aho Corasick

```
map<char, int> to[N];
int ne = 1, term[N], fail[N];

void add_string(char *str){
    int p = 0;

    for(int i = 0; str[i]; i++){
        if(!to[p][ str[i] ]) to[p][ str[i] ] = ne++;
        p = to[p][ str[i] ];
    }
    term[p] = 1;
}

int go(int s, char c){
    while(s && !to[s].count(c)) s = fail[s];
    if(to[s].count(c)) return to[s][c];
    return s;
}

void init(){

    queue<int> q;
    q.push(0);

    int u, v; char c;
    while(!q.empty()){
        u = q.front(); q.pop();

        for(auto w : to[u]){
            tie(c, v) = w;
            q.push(v);
            if(u){
                fail[v] = go(fail[u], c);
                term[v] |= term[ fail[v] ];
            }
        }
    }
}
```

Suffix Array

```
char s[N];
int n, sa[N], tsa[N], lcp[N], r[N], nr[N], c[N];

void sort(int k, int mx){
    mx += 2;
    memset(c, 0, sizeof(int) * mx);
    for(int i = 0; i < n; i++) c[i + k < n ? r[i+k]+2 :
      1]++;
    partial_sum(c, c+mx, c);
    int t;
    for(int i = 0; i < n; i++)
        t = sa[i]+k < n ? r[ sa[i]+k ]+1 : 0,
        tsa[ c[t]++ ] = sa[i];
    memcpy(sa, tsa, sizeof(int) * n);
```

```
}

void build_sa(){

    for(int i = 0; i < n; i++) sa[i] = i, r[i] = s[i];

    int t = 300, a, b;
    for(int sz = 1; sz < n; sz *= 2){
        sort(sz, t), sort(0, t);
        t = nr[ sa[0] ] = 0;
        for(int i = 1; i < n; i++){
            a = sa[i]+sz < n ? r[ sa[i]+sz ] : -1;
            b = sa[i-1]+sz < n ? r[ sa[i-1]+sz ] : -1;
            nr[ sa[i] ] = r[ sa[i] ] == r[ sa[i-1] ] && a
               == b ? t : ++t;
        }
        if(t == n-1) break;
        memcpy(r, nr, sizeof(int) * n);
    }
}

void build_lcp(){ // lcp[i] = lcp(s[:i], s[:i+1])
    int k = 0;
    for(int i = 0; i < n; i++) r[ sa[i] ] = i;

    for(int i = 0; i < n; i++){
        if(r[i] == n-1) k = 0;
        else{
            int j = sa[r[i]+1];
            while(i+k < n && j+k < n && s[i+k] == s[j+k])
               k++;
        }
        lcp[r[i]] = k;
        if(k) k--;
    }
}

int comp_lcp(int i, int j){
    if(i == j) return n - i;
    if(r[i] > r[j]) swap(i, j);
    return min(lcp[k] for k in [r[i], r[j]-1]);
}
```

Z Algorithm

```
vector<int> z_algo(const string &s) {
    int n = s.size(), L = 0, R = 0;
    vector<int> z(n, 0);
    for(int i = 1; i < n; i++){
        if(i <= R) z[i] = min(z[i-L], R - i + 1);
        while(z[i]+i < n && s[ z[i]+i ] == s[ z[i] ])
            z[i]++;
        if(i+z[i]-1 > R) L = i, R = i + z[i] - 1;
    }
    return z;
}
```

Prefix function/KMP

```
vector<int> preffix_function(const string &s){
    int n = s.size();
    vector<int> b(n+1);
    b[0] = -1;
    int i = 0, j = -1;
    while(i < n){
        while(j >= 0 && s[i] != s[j]) j = b[j];
        b[++i] = ++j;
    }
    return b;
}

void kmp(const string &t, const string &p){
    vector<int> b = preffix_function(p);
    int n = t.size(), m = p.size();
    int j = 0;
    for(int i = 0; i < n; i++){
        while(j >= 0 && t[i] != p[j]) j = b[j];
        j++;
        if(j == m){
            //patern of p found on t
            j = b[j];
        }
    }
}
```

Min rotation

```
int min_rotation(int *s, int N) {
  REP(i, N) s[N+i] = s[i];

  int a = 0;
  REP(b, N) REP(i, N) {
    if (a+i == b || s[a+i] < s[b+i]) { b += max(0, i-1);
       break; }
    if (s[a+i] > s[b+i]) { a = b; break; }
  }
  return a;
}
```

All palindrome

```
void manacher(char *s, int N, int *rad) {
  static char t[2*MAX];
  int m = 2*N - 1;

  REP(i, m) t[i] = -1;
  REP(i, N) t[2*i] = s[i];

  int x = 0;
  FOR(i, 1, m) {
    int &r = rad[i] = 0;
    if (i <= x+rad[x]) r = min(rad[x+x-i], x+rad[x]-i);
    while (i-r-1 >= 0 && i+r+1 < m && t[i-r-1] == t[i+r
      +1]) ++r;
    if (i+r >= x+rad[x]) x = i;
  }

  REP(i, m) if (i-rad[i] == 0 || i+rad[i] == m-1) ++rad[
    i];
  REP(i, m) rad[i] /= 2;
}
```

Manacher

```
// odd[i] = largest palindrome with center in character
  i(0-based)
// even[i] = largest palindrome with center between
  chars i-1 and i(0-based)
// pair<even, odd>
pair<vector<int>, vector<int>> build(const string &s){
  // O(n)
    int n = (int)s.size();
    vector<int> vet[2];

    for(int add = 0; add < 2; add++){
        vet[add].resize(n);
        for(int i = 0, l = 0, r = -1; i < n; i++){
            int k = i > r ? add : min(vet[add][l + r - i
              + !add], r - i + !add);
```

```
            while(i - k - !add >= 0 && i + k < n && s[i -
               k - !add] == s[i + k]) k++;
            vet[add][i] = k--;
            if(i + k > r){
               r = i + k;
               l = i - k - !add;
            }
        }
    }

    return make_pair(vet[0], vet[1]);
}
```

Palindromic Tree

```
const int MAXN = 105000;

struct node {
    int next[26];
    int len;
    int sufflink;
    int num;
};

int len;
char s[MAXN];
node tree[MAXN];
int num; // node 1 - root with len -1, node 2 - root
  with len 0
int suff; // max suffix palindrome
long long ans;

bool addLetter(int pos) {
    int cur = suff, curlen = 0;
    int let = s[pos] - 'a';

    while(true){
        curlen = tree[cur].len;
        if (pos-1 - curlen >= 0 && s[pos-1 - curlen] == s
          [pos])
            break;
        cur = tree[cur].sufflink;
    }
    if (tree[cur].next[let]) {
        suff = tree[cur].next[let];
        return false;
    }

    num++;
    suff = num;
    tree[num].len = tree[cur].len + 2;
    tree[cur].next[let] = num;

    if (tree[num].len == 1){
        tree[num].sufflink = 2;
        tree[num].num = 1;
        return true;
    }

    while (true){
        cur = tree[cur].sufflink;
        curlen = tree[cur].len;
        if(pos-1 - curlen >= 0 && s[pos-1 - curlen] == s[
          pos]){
            tree[num].sufflink = tree[cur].next[let];
            break;
        }
    }

    tree[num].num = 1 + tree[tree[num].sufflink].num;

    return true;
}

void initTree() {
    num = 2; suff = 2;
    tree[1].len = -1; tree[1].sufflink = 1;
    tree[2].len = 0; tree[2].sufflink = 1;
}

int main() {

    initTree();

    for (int i = 0; i < len; i++) {
        addLetter(i);
    }

    return 0;
}
```

Suffix Automaton

```
map<char, int> to[2*N];
int link[2*N], len[2*N], last = 0, sz = 1;

void add_letter(char c){
    int p = last;
    last = sz++;
    len[last] = len[p] + 1;
    for(; !to[p][c]; p = link[p]) to[p][c] = last;
    if(to[p][c] == last){
        link[last] = 0;
        return;
    }
    int u = to[p][c];
    if(len[u] == len[p]+1){
        link[last] = u;
        return;
    }
    int c1 = sz++;
    to[c1] = to[u];
    link[c1] = link[u];
    len[c1] = len[p]+1;
    link[last] = link[u] = c1;
    for(; to[p][c] == u; p = link[p]) to[p][c] = c1;
}
```

Suffix Tree

```
namespace sf {
// const int NS = ; const int N = * 2;
int cn, cd, ns, en = 1, lst;
string S[NS]; int si = -1;
vector<int> sufn[N]; // sufn[si][i] no do sufixo S[si][i
  ...]
struct node {
    int l, r, si, p, suf;
    map<char, int> adj;
    node() : l(0), r(-1), suf(0), p(0) {}
    node(int L, int R, int S, int P) : l(L), r(R), si(S)
      , p(P) {}
    inline int len() { return r - l + 1; }
    inline int operator[](int i) { return S[si][l + i];
      }
    inline int& operator()(char c) { return adj[c]; }
} t[N];
```

```
inline int new_node(int L, int R, int S, int P) { t[en]
  = node(L, R, S, P); return en++; }
void add_string(string s) {
    s += '$'; S[++si] = s; sufn[si].resize(s.size() + 1)
      ; cn = cd = 0;
    int i = 0; const int n = s.size();
    for(int j = 0; j < n; j++)
        for(; i <= j; i++) {
            if(cd == t[cn].len() && t[cn](s[j])) { cn = t
              [cn](s[j]); cd = 0; }
            if(cd < t[cn].len() && t[cn][cd] == s[j]) {
                cd++;
                if(j < s.size() - 1) break;
                else {
                    if(i) t[lst].suf = cn;
                    for(; i <= j; i++) { sufn[si][i] = cn;
                      cn = t[cn].suf; }
                }
            } else if(cd == t[cn].len()) {
                sufn[si][i] = en;
                if(i) t[lst].suf = en; lst = en;
                t[cn](s[j]) = new_node(j, n - 1, si, cn);
                cn = t[cn].suf; cd = t[cn].len();
            } else {
                int mid = new_node(t[cn].l, t[cn].l + cd -
                   1, t[cn].si, t[cn].p);
                t[t[cn].p](t[cn][0]) = mid;
                if(ns) t[ns].suf = mid;
                if(i) t[lst].suf = en; lst = en;
                sufn[si][i] = en;
                t[mid](s[j]) = new_node(j, n - 1, si, mid)
                  ;
                t[mid](t[cn][cd]) = cn;
                t[cn].p = mid; t[cn].l += cd; cn = t[mid].
                  p;
                int g = cn? j - cd : i + 1; cn = t[cn].suf
                  ;
                while(g < j && g + t[t[cn](S[si][g])].len
                  () <= j) {
                  cn = t[cn](S[si][g]); g += t[cn].len();
                }
                if(g == j) { ns = 0; t[mid].suf = cn; cd =
                   t[cn].len(); }
                else { ns = mid; cn = t[cn](S[si][g]); cd
                  = j - g; }
            }
        }
    }
};
```

Geometry

2D basics

```
typedef double cod;
double eps = 1e-7;
bool eq(cod a, cod b){ return abs(a - b) <= eps; }

struct vec{
    cod x, y; int id;
    vec(cod a = 0, cod b = 0) : x(a), y(b) {}
    vec operator+(const vec &o) const{
        return {x + o.x, y + o.y};
    }
    vec operator-(const vec &o) const{
        return {x - o.x, y - o.y};
    }
    vec operator*(cod t) const{
        return {x * t, y * t};
    }
    vec operator/(cod t) const{
        return {x / t, y / t};
    }
    cod operator*(const vec &o) const{ // cos
        return x * o.x + y * o.y;
    }
    cod operator^(const vec &o) const{ // sin
        return x * o.y - y * o.x;
    }
    bool operator==(const vec &o) const{
        return eq(x, o.x) && eq(y, o.y);
    }
    bool operator<(const vec &o) const{
        if(!eq(x, o.x)) return x < o.x;
        return y < o.y;
    }
    cod cross(const vec &a, const vec &b) const{
        return (a-(*this)) ^ (b-(*this));
    }
    int ccw(const vec &a, const vec &b) const{
        cod tmp = cross(a, b);
        return (tmp > eps) - (tmp < -eps);
    }
    cod dot(const vec &a, const vec &b) const{
        return (a-(*this)) * (b-(*this));
    }
    cod len() const{
        return sqrt(x * x + y * y); // <
    }
    double angle(const vec &a, const vec &b) const{
        return atan2(cross(a, b), dot(a, b));
    }
    double tan(const vec &a, const vec &b) const{
        return cross(a, b) / dot(a, b);
    }
    vec unit() const{
        return operator/(len());
    }
    int quad() const{
        if(x > 0 && y >=0) return 0;
        if(x <=0 && y > 0) return 1;
        if(x < 0 && y <=0) return 2;
        return 3;
    }
    bool comp(const vec &a, const vec &b) const{
        return (a - *this).comp(b - *this);
    }
    bool comp(vec b){
        if(quad() != b.quad()) return quad() < b.quad();
        if(!eq(operator^(b), 0)) return operator^(b) > 0;
        return (*this) * (*this) < b * b;
    }
    template<class T>
    void sort_by_angle(T first, T last) const{
        std::sort(first, last, [=](const vec &a, const
          vec &b){
            return comp(a, b);
        });
    }
    vec rot90() const{ return {-y, x}; }
    vec rot(double a) const{
        return {cos(a)*x -sin(a)*y, sin(a)*x +cos(a)*y};
    }
};
```

```
struct line{
    cod a, b, c; vec n;
    line(vec q, vec w){ // q.cross(w, (x, y)) = 0
        a = -(w.y-q.y);
        b = w.x-q.x;
        c = -(a * q.x + b * q.y);
        n = {a, b};
    }
    cod dist(const vec &o) const{
        return abs(eval(o)) / n.len();
    }
    bool contains(const vec &o) const{
        return eq(a * o.x + b * o.y + c, 0);
    }
    cod dist(const line &o) const{
        if(!parallel(o)) return 0;
        if(!eq(o.a * b, o.b * a)) return 0;
        if(!eq(a, 0))
            return abs(c - o.c * a / o.a) / n.len();
        if(!eq(b, 0))
            return abs(c - o.c * b / o.b) / n.len();
        return abs(c - o.c);
    }
    bool parallel(const line &o) const{
        return eq(n ^ o.n, 0);
    }
    bool operator==(const line &o) const{
        if(!eq(a*o.b, b*o.a)) return false;
        if(!eq(a*o.c, c*o.a)) return false;
        if(!eq(c*o.b, b*o.c)) return false;
        return true;
    }
    bool intersect(const line &o) const{
        return !parallel(o) || *this == o;
    }
    vec inter(const line &o) const{
        if(parallel(o)){
            if(*this == o){ }
            else{ /* dont intersect */ }
        }

        auto tmp = n ^ o.n;
        return {(o.c*b -c*o.b)/tmp, (o.a*c -a*o.c)/tmp};
    }
    vec at_x(cod x) const{
        return {x, (-c-a*x)/b};
    }
    vec at_y(cod y) const{
        return {(-c-b*y)/a, y};
    }
    cod eval(const vec &o) const{
        return a * o.x + b * o.y + c;
    }
};

struct segment{
    vec p, q;
    segment(vec a = vec(), vec b = vec()): p(a), q(b) {}
    bool onstrip(const vec &o) const{ // onstrip strip
        return p.dot(o, q) >= -eps && q.dot(o, p) >= -eps
          ;
    }
    cod len() const{
        return (p-q).len();
    }
    cod dist(const vec &o) const{
        if(onstrip(o)) return line(p, q).dist(o);
        return min((o-q).len(), (o-p).len());
    }
    bool contains(const vec &o) const{
        return eq(p.cross(q, o), 0) && onstrip(o);
    }
    bool intersect(const segment &o) const{
        if(contains(o.p)) return true;
        if(contains(o.q)) return true;
        if(o.contains(q)) return true;
        if(o.contains(p)) return true;
        return p.ccw(q, o.p) * p.ccw(q, o.q) == -1
        && o.p.ccw(o.q, q) * o.p.ccw(o.q, p) == -1;
    }
    bool intersect(const line &o) const{
        return o.eval(p) * o.eval(q) <= 0;
    }
    cod dist(const segment &o) const{
        if(line(p, q).parallel(line(o.p, o.q))){
            if(onstrip(o.p) || onstrip(o.q)
            || o.onstrip(p) || o.onstrip(q))
                return line(p, q).dist(line(o.p, o.q));
        }
        else if(intersect(o)) return 0;
        return min(min(dist(o.p), dist(o.q)),
                   min(o.dist(p), o.dist(q)));
    }
    cod dist(const line &o) const{
        if(line(p, q).parallel(o))
            return line(p, q).dist(o);
        else if(intersect(o)) return 0;
        return min(o.dist(p), o.dist(q));
    }
};

struct hray{
    vec p, q;
    hray(vec a = vec(), vec b = vec()): p(a), q(b){}
    bool onstrip(const vec &o) const{ // onstrip strip
        return p.dot(q, o) >= -eps;
    }
    cod dist(const vec &o) const{
        if(onstrip(o)) return line(p, q).dist(o);
        return (o-p).len();
    }
    bool intersect(const segment &o) const{
        if(!o.intersect(line(p,q))) return false;
        if(line(o.p, o.q).parallel(line(p,q)))
            return contains(o.p) || contains(o.q);
        return contains(line(p,q).inter(line(o.p,o.q)));
    }
    bool contains(const vec &o) const{
        return eq(line(p, q).eval(o), 0) && onstrip(o);
    }
    cod dist(const segment &o) const{
        if(line(p, q).parallel(line(o.p, o.q))){
            if(onstrip(o.p) || onstrip(o.q))
                return line(p, q).dist(line(o.p, o.q));
            return o.dist(p);
        }
        else if(intersect(o)) return 0;
        return min(min(dist(o.p), dist(o.q)),
                   o.dist(p));
    }
    bool intersect(const hray &o) const{
        if(!line(p, q).parallel(line(o.p, o.q)))
            return false;
        auto pt = line(p, q).inter(line(o.p, o.q));
```

```
        return contains(pt) && o.contains(pt); // <<
    }
    bool intersect(const line &o) const{
        if(line(p, q).parallel(o)) return line(p, q)== o;
        if(o.contains(p) || o.contains(q)) return true;
        return (o.eval(p) >= -eps)^(o.eval(p)<o.eval(q));
        return contains(o.inter(line(p, q)));
    }
    cod dist(const line &o) const{
        if(line(p,q).parallel(o))
            return line(p,q).dist(o);
        else if(intersect(o)) return 0;
        return o.dist(p);
    }
    cod dist(const hray &o) const{
        if(line(p, q).parallel(line(o.p, o.q))){
            if(onstrip(o.p) || o.onstrip(p))
                return line(p,q).dist(line(o.p, o.q));
            return (p-o.p).len();
        }
        else if(intersect(o)) return 0;
        return min(dist(o.p), o.dist(p));
    }
};

double heron(cod a, cod b, cod c){
    cod s = (a + b + c) / 2;
    return sqrt(s * (s - a) * (s - b) * (s - c));
}
```

Nearest Points

```
struct pt {
    int x, y, id;
};

inline bool cmp_x (const pt & a, const pt & b) {
    return a.x < b.x || a.x == b.x && a.y < b.y;
}

inline bool cmp_y (const pt & a, const pt & b) {
    return a.y < b.y;
}

pt a[MAXN];

double mindist;
int ansa, ansb;

inline void upd_ans (const pt & a, const pt & b) {
    double dist = sqrt ((a.x-b.x)*(a.x-b.x) + (a.y-b.y)
      *(a.y-b.y) + .0);
    if (dist < mindist)
        mindist = dist, ansa = a.id, ansb = b.id;
}

void rec (int l, int r) {
    if (r - l <= 3) {
        for (int i=l; i<=r; ++i)
            for (int j=i+1; j<=r; ++j)
                upd_ans (a[i], a[j]);
        sort (a+l, a+r+1, &cmp_y);
        return;
    }

    int m = (l + r) >> 1;
    int midx = a[m].x;
    rec (l, m), rec (m+1, r);
    static pt t[MAXN];
    merge (a+l, a+m+1, a+m+1, a+r+1, t, &cmp_y);
    copy (t, t+r-l+1, a+l);

    int tsz = 0;
    for (int i=l; i<=r; ++i)
        if (abs (a[i].x - midx) < mindist) {
            for (int j=tsz-1; j>=0 && a[i].y - t[j].y <
              mindist; --j)
                upd_ans (a[i], t[j]);
            t[tsz++] = a[i];
        }
}

sort (a, a+n, &cmp_x);
mindist = 1E20;
rec (0, n-1);
```

Convex Hull

```
vector<vec> monotone_chain_ch(vector<vec> P){
    sort(P.begin(), P.end());

    vector<vec> L, U;
    for(auto p : P){
        while(L.size() >= 2 && L[L.size() - 2].cross(L.
          back(), p) < 0)
            L.pop_back();

        L.push_back(p);
    }

    reverse(P.begin(), P.end());
    for(auto p : P){
        while(U.size() >= 2 && U[U.size() - 2].cross(U.
          back(), p) < 0)
            U.pop_back();

        U.push_back(p);
    }

    L.pop_back(), U.pop_back();

    L.reserve(L.size() + U.size());
    L.insert(L.end(), U.begin(), U.end());

    return L;
}
```

Check point inside polygon

```
bool below(const vector<vec> &vet, vec p){
    auto it = lower_bound(vet.begin(), vet.end(), p);
    if(it == vet.end()) return false;
    if(it == vet.begin()) return *it == p;
    return prev(it)->cross(*it, p) <= 0;
}

bool above(const vector<vec> &vet, vec p){
    auto it = lower_bound(vet.begin(), vet.end(), p);
    if(it == vet.end()) return false;
    if(it == vet.begin()) return *it == p;
    return prev(it)->cross(*it, p) >= 0;
}

// lowerhull, upperhull and point, borders included
bool inside_poly(const vector<vec> &lo, const vector<vec
  > &hi, vec p){
    return below(hi, p) && above(lo, p);
```

```
}
```

Check point inside polygon without lower/upper hull

```
// borders included
// must not have 3 colinear consecutive points
bool inside_poly(const vector<vec> &v, vec p){
    if(v[0].ccw(v[1], p) < 0) return false;
    if(v[0].ccw(v.back(), p) > 0) return 0;
    if(v[0].ccw(v.back(), p) == 0)
        return v[0].dot(p, v.back()) >= 0
            && v.back().dot(p, v[0]) >= 0;

    int L = 1, R = (int)v.size() - 1, ans = 1;

    while(L <= R){
        int mid = (L+R)/2;
        if(v[0].ccw(v[mid], p) >= 0) ans = mid, L = mid
          +1;
        else R = mid-1;
    }

    return v[ans].ccw(v[(ans+1)%v.size()], p) >= 0;
}
```

Minkowski sum

```
vector<vec> mk(const vector<vec>&a,const vector<vec>&b){
    int i = 0, j = 0;
    for(int k = 0; k < (int)a.size(); k++)if(a[k] <a[i])
        i = k;
    for(int k = 0; k < (int)b.size(); k++)if(b[k] <b[j])
        j = k;

    vector<vec> c;
    c.reserve(a.size() + b.size());
    for(int k = 0; k < int(a.size()+b.size()); k++){
        vec pt{a[i] + b[j]};
        if((int)c.size() >= 2
         && c[c.size()-2].ccw(c.back(), pt) == 0)
            c.pop_back();
        c.push_back(pt);
        int q = i+1, w = j+1;
        if(q == int(a.size())) q = 0;
        if(w == int(b.size())) w = 0;
        if(c.back().ccw(a[i]+b[w], a[q]+b[j]) < 0) i = q;
        else j = w;
    }
    c.shrink_to_fit();

    return c;
}
```

Miscellaneous

LIS

```
multiset<int> S;
for(int i = 0; i < n; i++){
    auto it = S.upper_bound(a[i]); // low for inc
    if(it != S.end()) S.erase(it);
    S.insert(a[i]);
}
ans = S.size();
```

DSU rollback

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

struct DSU{
    vector<int> sz, p, change;
    vector<tuple<int, int, int>> modifications;
    vector<size_t> saves;
    bool bipartite;

    DSU(int n): sz(n+1, 1), p(n+1), change(n+1),
      bipartite(true){
        iota(p.begin(), p.end(), 0);
    }

    void add_edge(int u, int v){
        if(!bipartite) return;
        int must_change = get_colour(u) == get_colour(v);
        int a = rep(u), b = rep(v);
        if(sz[a] < sz[b]) swap(a, b);
        if(a != b){
            p[b] = a;
            modifications.emplace_back(b, change[b],
              bipartite);
            change[b] ^= must_change;
            sz[a] += sz[b];
        }
        else if(must_change){
            modifications.emplace_back(0, change[0],
              bipartite);
            bipartite = false;
        }
    }

    int rep(int u){
        return p[u] == u ? u : rep(p[u]);
    }

    int get_colour(int u){
        if(p[u] == u) return change[u];
        return change[u] ^ get_colour(p[u]);
    }

    void reset(){
        modifications.clear();
        saves.clear();
        iota(p.begin(), p.end(), 0);
        fill(sz.begin(), sz.end(), 1);
        fill(change.begin(), change.end(), 0);
        bipartite = true;
    }

    void rollback(){
        int u = get<0>(modifications.back());
        tie(ignore, change[u], bipartite) = modifications
          .back();
        sz[ p[u] ] -= sz[u];
        p[u] = u;
        modifications.pop_back();
    }

    void reload(){
        while(modifications.size() > saves.back())
            rollback();
        saves.pop_back();
    }

    void save(){
        saves.push_back(modifications.size());
```

```
    }
};

const int N = 100005;
const int B = 318;

int n, m, q;
int x[N], y[N], l[N], r[N], ans[N];

vector<int> qu[N];

int brute(int lef, int rig, DSU &s){
    s.save();
    for(int i = lef; i <= rig; i++)
        s.add_edge(x[i], y[i]);
    int ret = s.bipartite;
    s.reload();
    return ret;
}

int main(){

    scanf("%d %d %d", &n, &m, &q);

    for(int i = 1; i <= m; i++)
        scanf("%d %d", x+i, y+i);

    DSU s(n);
    for(int i = 0; i < q; i++){
        scanf("%d %d", l+i, r+i);
        if(r[i] - l[i] <= B + 10)
            ans[i] = brute(l[i], r[i], s);
        else qu[l[i] / B].push_back(i);
    }

    for(int i = 0; i <= m / B; i++){
        sort(qu[i].begin(), qu[i].end(),[](int a, int b){
            return r[a] < r[b];
        });
        s.reset();

        int R = (i+1)*B-1;

        for(int id : qu[i]){
            while(R < r[id]) ++R, s.add_edge(x[R], y[R]);
            s.save();
            for(int k = l[id]; k < (i+1)*B; k++)
                s.add_edge(x[k], y[k]);
            ans[id] = s.bipartite;
            s.reload();
        }
    }

    for(int i = 0; i < q; i++)
        printf("%s\n",ans[i] ? "Possible":"Impossible");
}
```

Buildings

```
// count the number of circular arrays
// of size m, with elements on range
// [1, c**(x*x)]

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

#define debug(x) cerr << fixed << #x << " = " << x <<
  endl;

#define ll long long

const int MOD = 1e9 + 7;
const int MAX = 1e5 + 5;
int dp[MAX];

inline int add(int a, int b) {
  a += b;
  if(a >= MOD) {
    a -= MOD;
  }
  return a;
}

inline int sub(int a, int b) {
  a -= b;
  if(0 > a) {
    a += MOD;
  }
  return a;
}

inline int mult(int a, int b) {
  return (1LL * a * b) % MOD;
}

int f_exp(int x, int exp) {
  if(exp == 0) {
    return 1;
  }
  else if(exp & 1) {
    return mult(x, f_exp(x, exp - 1));
  }
  return f_exp(mult(x, x), exp / 2);
}

inline int inv(int x) {
  return f_exp(x, MOD - 2);
}

int main()
{
  ios::sync_with_stdio(false);
  cin.tie(NULL); cout.tie(NULL);

  int n, m, c;
  cin >> n >> m >> c;

  int x = f_exp(c, n * n);
  int ans = f_exp(x, m);
  for(int i = 1; i <= m; i++) {
    if(m % i == 0) {
      int y = f_exp(x, i);
      for(int j = 1; j < i; j++) {
        if(i % j == 0) {
          y = sub(y, mult(j, dp[j]));
        }
      }
      dp[i] = mult(y, inv(i));
      ans = sub(ans, mult(i - 1, dp[i]));
    }
  }

  cout << ans << '\n';

  return 0;
}
```

Rand

```
cout << RAND_MAX << endl;
mt19937 rng(chrono::steady_clock::now().time_since_epoch
  ().count());
vector<int> permutation(N);

iota(permutation.begin(), permutation.end(), 0);

shuffle(permutation.begin(), permutation.end(), rng);

iota(permutation.begin(), permutation.end(), 0);

for(int i = 1; i < N; i++){
    swap(permutation[i], permutation[
      uniform_int_distribution<int>(0, i)(rng)]);
}
```

Klondike

```
// minimum number of moves to make
// all elements equal
// move: change a segment of equal value
// elements to any value

int v[305];
int dp[305][305];
int rec[305][305];

int f(int l, int r){
  if(r == l) return 1;
  if(r < l) return 0;
  if(dp[l][r] != -1) return dp[l][r];
  int ans = f(l+1, r) + 1;
  for(int i = l+1; i <= r; i++)
    if(v[i] == v[l])
      ans = min(ans, f(l, i - 1) + f(i+1, r));


  return dp[l][r] = ans;
}

int main() {
  int n, m;
  memset(dp, -1, sizeof dp);
  scanf("%d %d",&n , &m);
  for(int i = 0; i < n; i++){
    scanf("%d",v+i);
    if(i && v[i] == v[i-1]){
      i--;
      n--;
    }
  }
  printf("%d\n",f(0, n-1) - 1);
  // printf("%d\n",rec[0][n-1] );
  // printf("%d\n",rec[1][n-1] );
  // printf("%d\n",rec[2][n-3] );
}
```

Hilbert Order

```
// maybe use B = n / sqrt(q)
inline int64_t hilbertOrder(int x, int y, int pow = 21,
  int rotate = 0) {
    if(pow == 0) return 0;
    int hpow = 1 << (pow-1);
    int seg = (x < hpow) ? (
        (y < hpow) ? 0 : 3
    ) : (
        (y < hpow) ? 1 : 2
    );
    seg = (seg + rotate) & 3;
    const int rotateDelta[4] = {3, 0, 0, 1};
    int nx = x & (x ^ hpow), ny = y & (y ^ hpow);
    int nrot = (rotate + rotateDelta[seg]) & 3;
    int64_t subSquareSize = int64_t(1) << (2*pow - 2);
    int64_t ans = seg * subSquareSize;
    int64_t add = hilbertOrder(nx, ny, pow-1, nrot);
    ans += (seg == 1 || seg == 2) ? add : (subSquareSize
       - add - 1);
    return ans;
}
```

Modular Factorial

```
// Compute (1*2*...*(p-1)*1*(p+1)*(p+2)*..*n) % p
// in O(p*lg(n))

int factmod(int n, int p){
    int ans = 1;
    while(n > 1){
        for(int i = 2; i <= n % p; i++)
            ans = (ans * i) % p;
        n /= p;
        if(n % 2) ans = p - ans;
    }
    return ans % p;
}

int fac_pow(int n, int p){
    int ans = 0;
    while(n) n /= p, ans += n;
    return ans;
}

int C(int n, int k, int p){
    if(fac_pow(n, p) > fac_pow(n-k, p) + fac_pow(k, p))
        return 0;
    int tmp = factmod(k, p) * factmod(n-k, p);
    return (f_exp(tmp, p-2, p) * factmod(n, p)) % p;
}
```

Enumeration all submasks of a bitmask

```
// loop through all submask of a given bitmask
// it does not include mask 0
for(int sub = mask; sub; sub = (sub-1)&mask){

}
```

Slope Trick

```
///By woqja125, contest: Codeforces Round #371 (Div. 1),
   problem: (C) Sonya and Problem Wihtout a Legend,
  Accepted, #

#include<stdio.h>
#include<queue>

int main()
{
    int n, t;
    long long ans = 0;
    std::priority_queue<int> Q;
    scanf("%d%d", &n, &t);
    Q.push(t);
    for(int i=1; i<n; i++)
    {
        scanf("%d", &t); t-=i;
```

```
        Q.push(t);
        if(Q.top() > t)
        {
            ans += Q.top() - t;
            Q.pop();
            Q.push(t);
        }
    }
    printf("%lld", ans);
    return 0;
}
```

Fast IO

```
#define pc(x) putchar_unlocked(x)
#define gc(x) getchar_unlocked(x)

inline void scan_int(int &x){
    register int c = gc();
    x = 0;
    int neg = 0;
    for(; ((c < '0' || c > '9') && c != '-'); c = gc());
    if(c == '-'){
        neg = 1;
        c = gc();
    }
    for(; c >= '0' && c <= '9'; c = gc())
        x = (x << 1) + (x << 3) + c - '0';
    if(neg) x = -x;
}

inline void print_int(int n){
    int rev = 0, count = 0, neg;
    if(n == 0){
        pc('0');
        return;
    }
    if(n < 0) n = -n, neg = 1;
    while(n % 10 == 0) count++, n /= 10;
    for(rev = 0; n != 0; n /= 10)
        rev = (rev << 3) + (rev << 1) + n % 10;
    if(neg) pc('-');
    while(rev != 0) pc(rev % 10 + '0'), rev /= 10;
    while(count--) pc('0');
    pc('\n');
}

inline void print_string(char *str){
    while(*str) pc(*str++);
    pc('\n');
}
```

Knapsack Bounded with Cost

```
// menor custo para conseguir peso ate M usando N tipos
  diferentes de elementos, sendo que o i-esimo elemento
  pode ser usado b[i] vezes, tem peso w[i] e custo c[i]
// O(N * M)

int b[N], w[N], c[N];
MinQueue Q[M]
int d[M] //d[i] = custo minimo para conseguir peso i

for(int i = 0; i <= M; i++) d[i] = i ? oo : 0;
for(int i = 0; i < N; i++){
    for(int j = 0; j < w[i]; j++)
        Q[j].clear();
    for(int j = 0; j <= M; j++){
        q = Q[j % w[i]];
        if(q.size() >= q) q.pop();
        q.add(c[i]);
        q.push(d[j]);
        d[j] = q.getmin();
    }
}
```

LCA <O(nlgn), O(1)>

```
int start[N], dfs_time;
int tour[2*N], id[2*N];

void dfs(int u){
    start[u] = dfs_time;
    id[dfs_time] = u;
    tour[dfs_time++] = start[u];
    for(int v : g[u]){
        dfs(v);
        id[dfs_time] = u;
        tour[dfs_time++] = start[u];
    }
}

int LCA(int u, int v){
    if(start[u] > start[v]) swap(u, v);
    return id[min(tour[k]for k in [start[u],start[v]])];
}
```

Burnside's Lemma

Let $(G, \oplus)$ be a finite group that acts on a set X. It should hold that $e_g * x = x$ and $g_1 * (g_2 * x) = (g_1 \oplus g_2) * x, \forall x \in X, g_1, g_2 \in G$. For each $g \in G$ let $X^g = \{x \in X \mid g * x = x\}$. The number of orbits its given by:

$$| X/G | = \frac{1}{|G|} \sum_{g \in G} |X^g|$$

Wilson's Theorem

$(n-1)! = -1 \mod n \iff n$ is prime

Fibonacci

- $F_{n-1}F_{n+1} - F_n^2 = (-1)^n$
- $F_{n+k} = F_k F_{n+1} + F_{k-1} F_n$
- $GCD(F_n, F_m) = F_{GCD(n,m)}$
- $F_n = \frac{(\frac{1+\sqrt{5}}{2})^n - (\frac{1-\sqrt{5}}{2})^n}{\sqrt{5}}$

Kirchhoff's Theorem

Laplacian matrix is $L = D - A$, where D is a diagonal matrix with vertex degrees on the diagonals and A is adjacency matrix.

The number of spanning trees is any cofactor of L. i-th cofactor is determinant of the matrix gotten by removing i-th row and column of L.

Multigraphs

In $D[i][i]$ all loops are excluded. $A[i][j]$ = number of edges from i to j.

Directed multigraphs

$D[i][i]$ = indegree of i minus the number of loops at i. $A[i][j]$ = number of edges from i to j.

The number of oriented spanning trees rooted at a vertex i is the determinant of the matrix gotten by removing the ith row and column of L.

Edge coloring

Data: A graph G
Result: A proper coloring c of the edges of G
Let U := E(G);
while $U \neq \emptyset$ **do**
  Let (u,v) be any edge in U;
  Let F[1:k] be a maximal fan of u starting at F[1]=v;
  Let c be a color that is free on u and d be a color that is free on F[k];
  Invert the cd_u path;
  Let $w \in V(G)$ be such that $w \in F, F' = [F[1]...w]$ is a fan and d is free on w;
  Rotate F' and set c(u,w)=d;
  U := U - (u,v);
end

Notes

When we repeat something and each time we have probability p to succeed then the expected number or tries is $\frac{1}{p}$, till we succeed.

Small to large

Trick in statement If k sets are given you should note that the amount of different set sizes is $O(\sqrt{s})$ where s is total size of those sets. And no more than $\sqrt{s}$ sets have size greater than $\sqrt{s}$. For example, a path to the root in Aho-Corasick through suffix links will have at most $O(\sqrt{s})$ vertices.

gcd on subsegment, we have at most $\log(a_i)$ different values in $\{\gcd(a_j, a_{j+1}, ..., a_i)$ for $j < i\}$.

From static set to expandable. To insert, create a new set with the new element. While there are two sets with same size, merge them. There will be at most $\log(n)$ disjoints sets.

Matrix exponentiation optimization. Save binary power of A_{nxn} and answer q queries $b = A^m x$ in $O((n^3 + qn^2)log(m))$.

Ternary search on integers into binary search, comparing f(mid) and f(mid+1), binary search on derivative

Dynamic offline set For each element we will wind segment of time $[a, b]$ such that element is present in the set during this whole segment. Now we can come up with recursive procedure which handles $[l, r]$ time segment considering that all elements such that $[l, r] \subset [a, b]$ are already included into the set. Now, keeping this invariant we recursively go into $[l, m]$ and $[m + 1, r]$ subsegments. Finally when we come into segment of length 1.

$a > b \implies a \mod b < \frac{a}{2}$