

Contents

| | |
|---|-----------|
| 1 Basic | 1 |
| 1.1 vimrc | 1 |
| 1.2 Fast Integer Input | 1 |
| 1.3 Big Integer | 1 |
| 2 Flow | 3 |
| 2.1 Dinic's algorithm | 3 |
| 2.2 Min cost Max flow | 3 |
| 2.3 Maximum bipartite matching | 3 |
| 2.4 Maximum weighted bipartite matching | 4 |
| 3 Math | 4 |
| 3.1 FFT | 4 |
| 3.2 Miller-Rabin | 4 |
| 3.3 Pollard's Rho | 4 |
| 3.4 μ function | 5 |
| 3.5 Extend GCD | 5 |
| 3.6 Matrix | 5 |
| 4 Graph | 5 |
| 4.1 Strongly connected components | 5 |
| 4.2 Heavy-Light Decomposition | 5 |
| 4.3 Centroid Decomposition | 6 |
| 4.4 Bi-connected component | 6 |
| 4.5 2-Satisfiability | 6 |
| 5 Data Structures | 7 |
| 5.1 Dark Magic | 7 |
| 5.2 Treap | 7 |
| 5.3 Persistent Disjoint Set | 7 |
| 5.4 Leftlist Tree | 7 |
| 6 Geometry | 8 |
| 6.1 Points | 8 |
| 6.2 Segment Intersection | 8 |
| 6.3 Line Intersection | 8 |
| 6.4 Circle Intersection | 8 |
| 6.5 Convex Hull | 8 |
| 6.6 Rotating Caliper | 8 |
| 6.7 Closest Pair | 9 |
| 7 String | 9 |
| 7.1 KMP | 9 |
| 7.2 Suffix Array | 9 |
| 7.3 Z algorithm | 9 |
| 7.4 Manacher's algorithm | 9 |
| 7.5 Rolling hash primes | 10 |
| 8 Dynamic Programming | 10 |
| 8.1 Linear convex hull optimization | 10 |
| 8.2 Divide and conquer optimization | 10 |

1 Basic

1.1 vimrc

```
syn on
se ai nu ru mouse=a
se cin et ts=4 sw=4 sts=4
so $VIMRUNTIME/mswin.vim
colo desert
se gfn=Monospace\ 15
execute pathogen#infect()
```

1.2 Fast Integer Input

```
#define getchar gtx

inline int gtx() {
    const int N = 1048576;
    static char buffer[N];
    static char *p = buffer, *end = buffer;
    if (p == end) {
        if ((end = buffer + fread(buffer, 1, N, stdin)) ==
            buffer) return EOF;
        p = buffer;
    }
    return *p++;
}

template <typename T>
inline bool rit(T& x) {
    char __c = 0; bool flag = false;
    while (__c = getchar(), (__c < '0' && __c != '-') ||
           __c > '9') if (__c == -1) return false;
    __c == '-' ? (flag = true, x = 0) : (x = __c - '0');
    while (__c = getchar(), __c >= '0' && __c <= '9') x =
        x * 10 + __c - '0';
    if (flag) x = -x;
    return true;
}

template <typename T, typename ...Args>
inline bool rit(T& x, Args& ...args) { return rit(x) &&
    rit(args...); }
```

1.3 Big Integer

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

struct Int {
    static const int inf = 1e9;
    std::vector<int> dig;
    bool sgn;
    Int() {
        dig.push_back(0);
        sgn = true;
    }
    Int(int n) {
        sgn = n >= 0;
        while (n) {
            dig.push_back(n % 10);
            n /= 10;
        }
        if (dig.size() == 0) dig.push_back(0);
    }
    Int(std::string s) {
        int i = 0; sgn = true;
        if (s[i] == '-') sgn = false, ++i;
        for (; i < s.length(); ++i) dig.push_back(s[i] - '0');
        reverse(dig.begin(), dig.end());
        if (dig.size() == 1 && dig[0] == '0') sgn = true;
    }
    Int(const std::vector<int>& d, const bool& s = true) {
        dig = std::vector<int>(d.begin(), d.end());
        sgn = s;
    }
};
```

```

}
Int(const Int& n) {
    sgn = n.sgn;
    dig = n.dig;
}
bool operator<(const Int& rhs) const {
    if (sgn && !rhs.sgn) return true;
    if (!sgn && rhs.sgn) return false;
    if (!sgn && !rhs.sgn) return Int(dig) > Int(rhs.dig);
    if (dig.size() < rhs.dig.size()) return true;
    if (dig.size() > rhs.dig.size()) return false;
    for (int i = dig.size() - 1; i >= 0; --i) {
        if (dig[i] != rhs.dig[i]) return dig[i] < rhs.dig[i];
    }
    return false;
}
bool operator==(const Int& rhs) const {
    if (sgn != rhs.sgn) return false;
    return dig == rhs.dig;
}
bool operator>(const Int& rhs) const {
    return !(*this < rhs) && !(*this == rhs);
}
bool operator<(const int& n) const {
    return *this < Int(n);
}
bool operator>(const int& n) const {
    return *this > Int(n);
}
bool operator==(const int& n) const {
    return *this == Int(n);
}
Int operator-() const {
    return Int(dig, !sgn);
}
Int operator+(const Int& rhs) const {
    bool res = true;
    if (!sgn && !rhs.sgn) res = false;
    else if (!sgn && rhs.sgn) return rhs - (*this);
    else if (sgn && !rhs.sgn) return *this - -rhs;
    std::vector<int> v1 = dig, v2 = rhs.dig;
    if (v2.size() > v1.size()) swap(v1, v2);
    int car = 0;
    std::vector<int> nvec;
    for (int i = 0; i < v2.size(); ++i) {
        int k = v1[i] + v2[i] + car;
        nvec.push_back(k % 10);
        car = k / 10;
    }
    for (int i = v2.size(); i < v1.size(); ++i) {
        int k = v1[i] + car;
        nvec.push_back(k % 10);
        car = k / 10;
    }
    return Int(nvec, res);
}
Int operator-(const Int& rhs) const {
    if (*this < rhs) {
        std::vector<int> nvec = (rhs - *this).dig;
        return Int(nvec, false);
    }
    if (*this == rhs) return Int(0);
    std::vector<int> v1 = dig, v2 = rhs.dig;
    std::vector<int> nvec;
    for (int i = 0; i < v2.size(); ++i) {
        int k = v1[i] - v2[i];
        if (k < 0) {
            for (int j = i + 1; j < v1.size(); ++j) if (v1[j] > 0) {
                --v1[j]; k += 10;
                break;
            }
        }
        nvec.push_back(k);
    }
    int rind = v1.size() - 1;
    while (rind >= v2.size() && v1[rind] == 0) --rind;
    for (int i = v2.size(); i <= rind; ++i) {
        nvec.push_back(v1[i]);
    }
}

```

```

return Int(nvec);
}
Int operator*(const Int& rhs) const {
    if (sgn && !rhs.sgn || !sgn && rhs.sgn) return -(Int(dig, true) * Int(rhs.dig, true));
    if (*this == 0) return Int();
    if (rhs == 0) return Int();
    std::vector<int> v1 = dig, v2 = rhs.dig;
    if (v1.size() < v2.size()) swap(v1, v2);
    std::vector<int> res(v1.size() * v2.size(), 0);
    for (int i = 0; i < v2.size(); ++i) {
        int car = 0;
        for (int j = 0; j < v1.size(); ++j) {
            int k = car + v1[j] * v2[i];
            res[j + i] += k % 10;
            car = k / 10;
        }
    }
    int car = 0;
    for (int i = 0; i < res.size(); ++i) {
        int k = car + res[i];
        res[i] = k % 10;
        car = k / 10;
    }
    while (car) {
        res.push_back(car % 10);
        car /= 10;
    }
    int ind = res.size() - 1;
    while (ind >= 0 && res[ind] == 0) --ind;
    std::vector<int> nvec;
    for (int i = 0; i <= ind; ++i) nvec.push_back(res[i]);
    return Int(nvec);
}
Int operator+(const int& n) const {
    return *this + Int(n);
}
Int operator-(const int& n) const {
    return *this - Int(n);
}
Int& operator+=(const Int& n) {
    *this = (*this + n);
    return *this;
}
Int& operator-=(const Int& n) {
    *this = (*this - n);
    return *this;
}
Int& operator+=(const int& n) {
    *this += Int(n);
    return *this;
}
Int& operator-=(const int& n) {
    *this -= Int(n);
    return *this;
}
Int& operator*=(const Int& n) {
    *this = *this * n;
    return *this;
}
Int& operator*=(const int& n) {
    *this *= Int(n);
    return *this;
}
Int& operator++(int) {
    *this += 1;
    return *this;
}
Int& operator--(int) {
    *this -= 1;
    return *this;
}
friend std::istream& operator>>(std::istream& in, Int& n) {
    std::string s; in >> s;
    n = Int(s);
    return in;
}
friend std::ostream& operator<<(std::ostream& out, const Int& n) {
    if (!n.sgn) out << "-";
}

```

```

    for (int i = n.dig.size() - 1; i >= 0; --i) out <<
        n.dig[i];
    return out;
}
};

```

2 Flow

2.1 Dinic's algorithm

```

struct Dinic {
    int n, s, t;
    vector<int> level;
    struct Edge {
        int to, rev, cap;
        Edge() {}
        Edge(int a, int b, int c): to(a), cap(b), rev(c) {}
    };
    vector<Edge> G[maxn];
    bool bfs() {
        level.assign(n, -1);
        level[s] = 0;
        queue<int> que; que.push(s);
        while (que.size()) {
            int tmp = que.front(); que.pop();
            for (auto e : G[tmp]) {
                if (e.cap > 0 && level[e.to] == -1) {
                    level[e.to] = level[tmp] + 1;
                    que.push(e.to);
                }
            }
        }
        return level[t] != -1;
    }
    int flow(int now, int low) {
        if (now == t) return low;
        int ret = 0;
        for (auto &e : G[now]) {
            if (e.cap > 0 && level[e.to] == level[now] + 1) {
                int tmp = flow(e.to, min(e.cap, low - ret));
                e.cap -= tmp; G[e.to][e.rev].cap += tmp;
                ret += tmp;
            }
        }
        if (ret == 0) level[now] = -1;
        return ret;
    }
    Dinic(int _n, int _s, int _t): n(_n), s(_s), t(_t) {
        fill(G, G + maxn, vector<Edge>());
    }
    void add_edge(int a, int b, int c) {
        G[a].push_back(Edge(b, c, G[b].size()));
        G[b].push_back(Edge(a, 0, G[a].size() - 1));
    }
    int maxflow() {
        int ret = 0;
        while (bfs()) ret += flow(s, inf);
        return ret;
    }
};

```

2.2 Min cost Max flow

```

struct MincostMaxflow {
    struct Edge {
        int to, rev, cap, w;
        Edge() {}
        Edge(int a, int b, int c, int d): to(a), cap(b), w(
            c), rev(d) {}
    };
    int n, s, t;
    vector<int> p, id, d;
    bitset<maxn> inque;
    vector<Edge> G[maxn];
    pair<int, int> spfa() {
        p.assign(n, -1);
    }
};

```

```

d.assign(n, inf);
id.assign(n, -1);
d[s] = 0; p[s] = s;
queue<int> que; que.push(s); inque[s] = true;
while (que.size()) {
    int tmp = que.front(); que.pop();
    inque[tmp] = false;
    int i = 0;
    for (auto e : G[tmp]) {
        if (e.cap > 0 && d[e.to] > d[tmp] + e.w) {
            d[e.to] = d[tmp] + e.w;
            p[e.to] = tmp;
            id[e.to] = i;
            if (!inque[e.to]) que.push(e.to), inque[e.to]
                = true;
        }
        ++i;
    }
}
if (d[t] == inf) return make_pair(-1, -1);
int a = inf;
for (int i = t; i != s; i = p[i]) {
    a = min(a, G[p[i]][id[i]].cap);
}
for (int i = t; i != s; i = p[i]) {
    Edge &e = G[p[i]][id[i]];
    e.cap -= a; G[e.to][e.rev].cap += a;
}
return make_pair(a, d[t]);
}
MincostMaxflow(int _n, int _s, int _t): n(_n), s(_s),
    t(_t) {
    fill(G, G + maxn, vector<Edge>());
}
void add_edge(int a, int b, int cap, int w) {
    G[a].push_back(Edge(b, cap, w, (int)G[b].size()));
    G[b].push_back(Edge(a, 0, -w, (int)G[a].size() - 1)
    );
}
pair<int, int> maxflow() {
    int mxf = 0, mnc = 0;
    while (true) {
        pair<int, int> res = spfa();
        if (res.first == -1) break;
        mxf += res.first; mnc += res.first * res.second;
    }
    return make_pair(mxf, mnc);
}
};

```

2.3 Maximum bipartite matching

```

struct MaximumMatching {
    vector<int> G[maxn], mt;
    int n;
    bitset<maxn> v;
    MaximumMatching(int n): n(n) {
        fill(G, G + maxn, vector<int>());
        v.reset();
    }
    void add_edge(int a, int b) {
        G[a].push_back(b);
    }
    bool dfs(int now) {
        v[now] = true;
        for (int u : G[now]) {
            if (mt[u] == -1 || !v[mt[u]] && dfs(mt[u])) {
                mt[u] = now;
                return true;
            }
        }
        return false;
    }
    int solve() {
        mt.assign(n, -1);
        int ret = 0;
        for (int i = 0; i < n; ++i) {
            memset(v, false, sizeof(v));
            if (dfs(i)) ++ret;
        }
    }
};

```

```

    return ret;
}
};

```

2.4 Maximum weighted bipartite matching

```

struct Hungarian {
    vector<int> lx, ly, match;
    vector<vector<int>> w;
    int n;
    bitset<maxn> s, t;
    bool dfs(int now) {
        s[now] = true;
        for (int i = 0; i < n; ++i) {
            if (lx[now] + ly[i] == w[now][i] && !t[i]) {
                t[i] = true;
                if (match[i] == -1 || dfs(match[i])) {
                    match[i] = now;
                    return true;
                }
            }
        }
        return false;
    }
    void relabel() {
        int a = inf;
        for (int i = 0; i < n; ++i) if (s[i]) {
            for (int j = 0; j < n; ++j) if (!t[j]) {
                a = min(a, lx[i] + ly[j] - w[i][j]);
            }
        }
        for (int i = 0; i < n; ++i) {
            if (s[i]) lx[i] -= a;
            if (t[i]) ly[i] += a;
        }
    }
    Hungarian(int n): n(n) {
        w.assign(n, vector<int>());
        for (int i = 0; i < n; ++i) w[i].assign(n, 0);
        lx.assign(n, 0); ly.assign(n, 0);
        match.assign(n, -1);
    }
    void add_edge(int a, int b, int c) {
        w[a][b] = c;
    }
    int solve() {
        for (int i = 0; i < n; ++i) for (int j = 0; j < n; ++j) lx[i] = max(lx[i], w[i][j]);
        for (int i = 0; i < n; ++i) {
            while (true) {
                s.reset(); t.reset();
                if (dfs(i)) break;
                else relabel();
            }
        }
        int ans = 0;
        for (int i = 0; i < n; ++i) ans += w[match[i]][i];
        return ans;
    }
};

```

3 Math

3.1 FFT

```

const double pi = acos(-1);
const complex<double> I(0, 1);
complex<double> omega[maxn + 1];

void prefft() {
    for (int i = 0; i <= maxn; ++i) omega[i] = exp(i * 2
        * pi / maxn * I);
}

void fft(vector<complex<double>>& a, int n, bool inv=
    false) {
    int basic = maxn / n;

```

```

    int theta = basic;
    for (int m = n; m >= 2; m >>= 1) {
        int h = m >> 1;
        for (int i = 0; i < h; ++i) {
            complex<double> w = omega[inv ? maxn - (i * theta
                % maxn) : i * theta % maxn];
            for (int j = i; j < n; j += m) {
                int k = j + h;
                complex<double> x = a[j] - a[k];
                a[j] += a[k];
                a[k] = w * x;
            }
        }
        theta = (theta * 2) % maxn;
    }
    int i = 0;
    for (int j = 1; j < n - 1; ++j) {
        for (int k = n >> 1; k > (i ^= k); k >>= 1);
        if (j < i) swap(a[i], a[j]);
    }
    if (inv) for (int i = 0; i < n; ++i) a[i] /= (double)
        n;
}

void invfft(vector<complex<double>>& a, int n) {
    fft(a, n, true);
}

```

3.2 Miller-Rabin

```

// n < 4759123141    chk = [2, 7, 61]
// n < 1122004669633 chk = [2, 13, 23, 1662803]
// n < 2^64          chk = [2, 325, 9375, 28178, 450775,
//                        9780504, 1795265022]

long long fpow(long long a, long long n, long long mod)
{
    long long ret = 1LL;
    for (; n; n >>= 1) {
        if (n & 1) ret = (__int128)ret * (__int128)a % mod;
        a = (__int128)a * (__int128)a % mod;
    }
    return ret;
}

bool check(long long a, long long u, long long n, int t)
{
    a = fpow(a, u, n);
    if (a == 0) return true;
    if (a == 1 || a == n - 1) return true;
    for (int i = 0; i < t; ++i) {
        a = (__int128)a * (__int128)a % n;
        if (a == 1) return false;
        if (a == n - 1) return true;
    }
    return false;
}

bool is_prime(long long n) {
    if (n < 2) return false;
    if (n % 2 == 0) return n == 2;
    long long u = n - 1; int t = 0;
    for (; u & 1; u >>= 1, ++t);
    for (long long i : chk) {
        if (!check(i, u, n, t)) return false;
    }
    return true;
}

```

3.3 Pollard's Rho

```

long long f(long long x, long long mod) {
    return add(mul(x, x, mod), 1, mod);
}

long long pollard_rho(long long n) {
    if (n % 2 == 0) return 2;
    while (true) {
        long long y = 2, x = rand() % (n - 1) + 1, res = 1;
        for (int sz = 2; res == 1; sz <= 1) {
            for (int i = 0; i < sz && res <= 1; ++i) {

```

```

    x = f(x, n);
    res = __gcd(abs(x - y), n);
}
y = x;
}
if (res && res != n) return res;
}
}

```

3.4 μ function

```

int mu[maxn], pi[maxn];
vector<int> prime;

void sieve() {
    mu[1] = pi[1] = 1;
    for (int i = 2; i < maxn; ++i) {
        if (!pi[i]) {
            pi[i] = i;
            prime.push_back(i);
            mu[i] = -1;
        }
        for (int j = 0; i * prime[j] < maxn; ++j) {
            pi[i * prime[j]] = prime[j];
            mu[i * prime[j]] = -mu[i];
            if (i % prime[j] == 0) {
                mu[i * prime[j]] = 0;
                break;
            }
        }
    }
}

```

3.5 Extend GCD

```

template <typename T> tuple<T, T, T> extgcd(T a, T b) {
    if (!b) return make_tuple(a, 1, 0);
    T d, x, y;
    tie(d, x, y) = extgcd(b, a % b);
    return make_tuple(d, y, x - (a / b) * y);
}

```

3.6 Matrix

```

template <typename T> class Matrix {
public:
    int n, m, mod;
    vector<vector<T>> mat;
    Matrix(int n, int m, int mod=0, bool I=false): n(n), m(m), mod(mod) {
        mat.resize(n);
        for (int i = 0; i < n; ++i) mat[i].resize(m);
        if (!I) return;
        for (int i = 0; i < n; ++i) mat[i][i] = 1;
    }
    Matrix operator+(const Matrix& rhs) const {
        Matrix ret(n, m, mod);
        for (int i = 0; i < n; ++i) {
            for (int j = 0; j < m; ++j) {
                ret.mat[i][j] = mat[i][j] + rhs.mat[i][j];
                if (mod) ret.mat[i][j] %= mod;
            }
        }
        return ret;
    }
    Matrix operator-(const Matrix& rhs) const {
        Matrix ret(n, m, mod);
        for (int i = 0; i < n; ++i) {
            for (int j = 0; j < m; ++j) {
                ret.mat[i][j] = mat[i][j] - rhs.mat[i][j];
                if (mod) {
                    ret.mat[i][j] %= mod;
                    ret.mat[i][j] += mod;
                    ret.mat[i][j] %= mod;
                }
            }
        }
    }
}

```

```

    }
    return ret;
}
Matrix operator*(const Matrix& rhs) const {
    Matrix ret(n, rhs.m, mod);
    for (int i = 0; i < n; ++i) {
        for (int j = 0; j < rhs.m; ++j) {
            for (int k = 0; k < m; ++k) {
                if (mod) ret.mat[i][j] = (ret.mat[i][j] +
                    mat[i][k] * rhs.mat[k][j] % mod) % mod;
                else ret.mat[i][j] += mat[i][k] * rhs.mat[k][j];
            }
        }
    }
    return ret;
}
};

```

4 Graph

4.1 Strongly connected components

```

struct SCC {
    vector<int> G[maxn], R[maxn], topo;
    int n, nsc;
    vector<int> scc, sz;
    bitset<maxn> v;
    void dfs(int now) {
        v[now] = true;
        for (int u : G[now]) if (!v[u]) {
            dfs(u);
        }
        topo.push_back(now);
    }
    void rdfs(int now) {
        v[now] = true;
        scc[now] = nsc;
        ++sz[nsc];
        for (int u : R[now]) if (!v[u]) {
            rdfs(u);
        }
    }
    SCC(): {}
    SCC(int n): n(n) {
        scc.assign(n, 0); sz.assign(n, 0);
    }
    void add_edge(int a, int b) {
        G[a].push_back(b);
        R[b].push_back(a);
    }
    void solve() {
        v.reset();
        for (int i = 0; i < n; ++i) if (!v[i]) dfs(i);
        reverse(topo.begin(), topo.end());
        v.reset();
        for (int i : topo) if (!v[i]) {
            ++nsc;
            rdfs(i);
        }
    }
};

```

4.2 Heavy-Light Decomposition

```

struct HeavyLightDecomp {
    vector<int> G[maxn];
    vector<int> tin, top, dep, maxson, sz, p;
    int n, t;
    void dfs(int now, int fa, int d) {
        dep[now] = d;
        maxson[now] = -1;
        sz[now] = 1;
        p[now] = fa;
        for (int u : G[now]) if (u != fa) {
            dfs(u, now, d + 1);
        }
    }
}

```

```

    sz[now] += sz[u];
    if (maxson[now] == -1 || sz[u] > sz[maxson[now]])
        maxson[now] = u;
}
void link(int now, int tp) {
    top[now] = tp;
    tin[now] = ++t;
    if (maxson[now] == -1) return;
    link(maxson[now], tp);
    for (int u : G[now]) if (u != p[now]) {
        if (u == maxson[now]) continue;
        link(u, u);
    }
}
HeavyLightDecomp(int n): n(n) {
    t = 0;
    tin.assign(n, 0); top.assign(n, 0); dep.assign(n, 0);
    maxson.assign(n, 0); sz.assign(n, 0); p.assign(n, 0);
}
void add_edge(int a, int b) {
    G[a].push_back(b);
    G[b].push_back(a);
}
void build() {
    dfs(0, -1, 0);
    link(0, 0);
}
int lca(int a, int b) {
    int ta = top[a], tb = top[b];
    while (ta != tb) {
        if (dep[ta] < dep[tb]) {
            swap(ta, tb); swap(a, b);
        }
        a = p[ta]; ta = top[a];
    }
    if (a == b) return a;
    return dep[a] < dep[b] ? a : b;
}
vector<pair<int, int>> get_path(int a, int b) {
    int ta = top[a], tb = top[b];
    vector<pair<int, int>> ret;
    while (ta != tb) {
        if (dep[ta] < dep[tb]) {
            swap(ta, tb); swap(a, b);
        }
        ret.push_back(make_pair(tin[ta], tin[a]));
        a = p[ta]; ta = top[a];
    }
    ret.push_back(make_pair(min(tin[a], tin[b]), max(
tin[a], tin[b])));
    return ret;
}
};

```

4.3 Centroid Decomposition

```

vector<pair<int, int>> G[maxn];
int sz[maxn], mx[maxn];
bool v[maxn];
vector<int> vtx;

void get_center(int now) {
    v[now] = true; vtx.push_back(now);
    sz[now] = 1; mx[now] = 0;
    for (int u : G[now]) if (!v[u]) {
        get_center(u);
        mx[now] = max(mx[now], sz[u]);
        sz[now] += sz[u];
    }
}

void get_dis(int now, int d, int len) {
    dis[d][now] = cnt;
    v[now] = true;
    for (auto u : G[now]) if (!v[u.first]) {
        get_dis(u, d, len + u.second);
    }
}

```

```

}

void dfs(int now, int fa, int d) {
    get_center(now);
    int c = -1;
    for (int i : vtx) {
        if (max(mx[i], (int)vtx.size() - sz[i]) <= (int)vtx
.size() / 2) c = i;
        v[i] = false;
    }
    get_dis(c, d, 0);
    for (int i : vtx) v[i] = false;
    v[c] = true; vtx.clear();
    dep[c] = d; p[c] = fa;
    for (auto u : G[c]) if (u.first != fa && !v[u.first])
        dfs(u.first, c, d + 1);
}
}

```

4.4 Bi-connected component

```

int tin[maxn], low[maxn], t, bccsz;
stack<int> st;
vector<int> bcc[maxn];

void dfs(int now, int fa) {
    tin[now] = ++t; low[now] = tin[now];
    st.push(now);
    for (int u : G[now]) if (u != fa) {
        if (!tin[u]) {
            dfs(u, now);
            low[now] = min(low[now], low[u]);
            if (low[u] >= tin[now]) {
                int v;
                ++bccsz;
                do {
                    v = st.top(); st.pop();
                    bcc[bccsz].push_back(v);
                } while (v != u);
                bcc[bccsz].push_back(now);
            }
        } else {
            low[now] = min(low[now], tin[u]);
        }
    }
}
}

```

4.5 2-Satisfiability

```

struct TwoSat {
    vector<int> G[maxn << 1];
    bitset<maxn << 1> v;
    vector<int> s;
    int c;
    bool dfs(int now) {
        if (v[now ^ 1]) return false;
        if (v[now]) return true;
        v[now] = true;
        s[c++] = now;
        for (int u : G[now]) if (!dfs(u)) return false;
        return true;
    }
    TwoSat() {
        s.assign(maxn << 1, 0);
        v.reset();
    }
    void add_edge(int a, int b) {
        G[a].push_back(b);
    }
    bool solve() {
        for (int i = 0; i < maxn << 1; i += 2) {
            if (!v[i] && !v[i + 1]) {
                c = 0;
                if (!dfs(i)) {
                    while (c) v[s[--c]] = false;
                    if (!dfs(i + 1)) return false;
                }
            }
        }
    }
}

```

```

    }
  }
  return true;
}
};

```

5 Data Structures

5.1 Dark Magic

```

#include <bits/stdc++.h>
#include <bits/extc++.h>
#include <ext/rope>
using namespace __gnu_pbds;
using namespace __gnu_cxx;
#include <ext/pb_ds/assoc_container.hpp>
typedef tree<int, null_type, std::less<int>,
    rb_tree_tag, tree_order_statistics_node_update>
    tree_set;
typedef cc_hash_table<int, int> umap;
typedef priority_queue<int> heap;

int main() {
    // rb tree
    tree_set s;
    s.insert(71); s.insert(22);
    assert(*s.find_by_order(0) == 22); assert(*s.
        find_by_order(1) == 71);
    assert(s.order_of_key(22) == 0); assert(s.
        order_of_key(71) == 1);
    s.erase(22);
    assert(*s.find_by_order(0) == 71); assert(s.
        order_of_key(71) == 0);
    // mergable heap
    heap a, b; a.join(b);
    // persistant
    rope<char> r[2];
    r[1] = r[0];
    std::string st = "abc";
    r[1].insert(0, st.c_str());
    r[1].erase(1, 1);
    std::cout << r[1].substr(0, 2) << std::endl;
    return 0;
}

```

5.2 Treap

```

namespace Treap {
    struct Node {
        int val, pri, sz;
        Node *lc, *rc;
        Node(T v): pri(rand()), val(v) {
            lc = rc = nullptr;
            sz = 1;
        }
        void pull() {
            sz = size(lc) + size(rc) + 1;
        }
    };
    inline int size(Node* t) {
        return t ? t->sz : 0;
    }
    Node *merge(Node *a, Node *b) {
        if (!a || !b) return a ? a : b;
        if (a->pri > b->pri) {
            a->rc = merge(a->rc, b);
            a->pull();
            return a;
        } else {
            b->lc = merge(a, b->lc);
            b->pull();
            return b;
        }
    }
    void split(Node *t, int k, Node *&a, Node *&b) {
        if (!t) { a = b = nullptr; return; }

```

```

        if (t->val <= k) {
            a = t;
            split(t->rc, k, a->rc, b);
            a->pull();
        } else {
            b = t;
            split(t->lc, k, a, b->lc);
            b->pull();
        }
    }
    int kth(Node *t, int k) {
        if (size(t->lc) + 1 == k) return t->val;
        if (size(t->lc) + 1 > k) return kth(t->lc, k);
        return kth(t->rc, k - size(t->lc) - 1);
    }
    void clear(Node *t) {
        if (!t) return;
        if (t->lc) clear(t->lc);
        if (t->rc) clear(t->rc);
        delete t;
    }
}

```

5.3 Persistant Disjoint Set

```

struct DisjointSet {
    int p[maxn], sz[maxn], n;
    vector<pair<int*, int>> h;
    vector<int> sp;
    void init(int size) {
        n = size;
        for (int i = 0; i < n; ++i) p[i] = i, sz[i] = 1;
        sp.clear(); h.clear();
    }
    void assign(int *k, int v) {
        h.push_back(make_pair(k, *k));
        *k = v;
    }
    void save() {
        sp.push_back(h.size());
    }
    void undo() {
        int last = sp.back(); sp.pop_back();
        while (h.size() != last) {
            pair<int*, int> pi = h.back(); h.pop_back();
            *pi.first = pi.second;
        }
    }
    int find(int x) {
        if (x == p[x]) return x;
        return p[x] = find(p[x]);
    }
    void merge(int x, int y) {
        x = find(x); y = find(y);
        if (x == y) return;
        if (sz[x] < sz[y]) swap(x, y);
        assign(&sz[x], sz[x] + sz[y]);
        assign(&p[y], x);
    }
};

```

5.4 Leftlist Tree

```

namespace LeftlistTree {
    struct Node {
        T val;
        int s;
        Node *lc, *rc;
        Node(T v): val(v) {
            lc = rc = nullptr;
            s = 1;
        }
    };
    inline int rank(Node* t) {
        return t ? t->s : 0;
    }
    Node *merge(Node *a, Node *b) {
        if (!a || !b) return a ? a : b;

```



```

    if (a->val < b->val) swap(a, b);
    a->rc = merge(a->rc, b);
    if (rank(a->lc) < rank(a->rc)) swap(a->lc, a->rc);
    a->s = rank(a->rc) + 1;
    return a;
}
void clear(Node *t) {
    if (!t) return;
    if (t->lc) clear(t->lc);
    if (t->rc) clear(t->rc);
    delete t;
}
}

```

6 Geometry

6.1 Points

```

using type = int;

struct pt {
    type x, y;
    pt(): x(0), y(0) {}
    pt(type x, type y): x(x), y(y) {}
    pt operator+(const pt& a) const { return pt(x + a.x,
        y + a.y); }
    pt operator-(const pt& a) const { return pt(x - a.x,
        y - a.y); }
    pt operator*(const type& t) const { return pt(x * t,
        y * t); }
    pt operator/(const type& t) const { return pt(x / t,
        y / t); }
    type operator*(const pt& a) const { return x * a.x +
        y * a.y; }
    type operator^(const pt& a) const { return x * a.y -
        y * a.x; }
    bool operator<(const pt& a) const { return x == a.x ?
        y < a.y : x < a.x; }
    bool operator>(const pt& a) const { return x == a.x ?
        y > a.y : x > a.x; }
    bool operator==(const pt& a) const { return x == a.x
        && y == a.y; }
    bool operator!=(const pt& a) const { return x != a.x
        || y != a.y; }
};

```

6.2 Segment Intersection

```

type orient(const pt& o, const pt& a, const pt& b) {
    type t = (a - o) ^ (b - o);
    return t / max(1, abs(t));
}

// if parallel and min(p1, p2) != max(q1, q2) and p1 !=
// p2 and q1 != q2 ==> segment
// else ==> point

bool intersect(const pt& p1, const pt& p2, const pt& q1
    , const pt& q2) {
    if (q1 == q2 && p1 == p2) return p1 == q1;
    if (q1 == q2) return ((p2 - q1) ^ (p1 - q1)) == 0 &&
        q1.x >= min(p1.x, p2.x) && q1.x <= max(p1.x, p2.x);
    if (p1 == p2) return ((q1 - p1) ^ (q2 - p1)) == 0 &&
        p1.x >= min(q1.x, q2.x) && p1.x <= max(q1.x, q2.x);
    int c = (p2 - p1) ^ (q2 - q1);
    if (c == 0) {
        if (orient(p1, p2, q1)) return false;
        return (p1 - q1) * (p2 - q1) <= 0 || (p1 - q2) * (
            p2 - q2) <= 0 || (q1 - p1) * (q2 - p1) <= 0 || (q1
            - p2) * (q2 - p2) <= 0;
    }
    return (orient(p1, p2, q1) * orient(p1, p2, q2) <= 0)
        && (orient(q1, q2, p1) * orient(q1, q2, p2) <= 0);
}

```

6.3 Line Intersection

```

pt intersection(const pt& p1, const pt& p2, const pt&
    p3, const pt& p4) {
    double f1 = (p2 - p1) ^ (q1 - p1);
    double f2 = (p2 - p1) ^ (p1 - q2);
    double f = f1 + f2;
    if (fabs(f) < eps) return pt(nan(""), nan(""));
    return q1 * (f2 / f) + q2 * (f1 / f);
}

```

6.4 Circle Intersection

```

vector<pt> circle_intersection(const pt& o1, const
    double& r1, const pt& o2, const double& r2) {
    double d2 = (o1 - o2) * (o1 - o2);
    double d = sqrt(d2);
    if (d > r1 + r2) return {};
    pt u = (o1 + o2) * 0.5 + (o1 - o2) * ((r2 * r2 - r1 *
        r1) / (2 * d2));
    double a = sqrt((r1 + r2 + d) * (r1 - r2 + d) * (r1 +
        r2 - d) * (-r1 + r2 + d));
    pt v = pt(o1.y - o2.y, -o1.x + o2.x) * a / (2 * d2);
    return { u + v, u - v };
}

```

6.5 Convex Hull

```

type cross(const pt& o, const pt& a, const pt& b) {
    return (a - o) ^ (b - o);
}

int rsd;

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

```

6.6 Rotating Caliper

```

void rotating_caliper(vector<pt> p) {
    vector<pt> ch = convex_hull(p);
    int tbz = ch.size();
    int lpr = 0, rpr = rsd;
    // ch[lpr], ch[rpr]
    while (lpr < rsd || rpr < tbz - 1) {
        if (lpr < rsd && rpr < tbz - 1) {
            pt rvt = ch[rpr + 1] - ch[rpr];
            pt lvt = ch[lpr + 1] - ch[lpr];
            if ((lvt ^ rvt) < 0) ++lpr;
            else ++rpr;
        }
        else if (lpr == rsd) ++rpr;
        else ++lpr;
        // ch[lpr], ch[rpr]
    }
}

```


6.7 Closest Pair

```
pt p[maxn];

double dis(const pt& a, const pt& b) {
    return sqrt((a - b) * (a - b));
}

double closest_pair(int l, int r) {
    if (l == r) return inf;
    if (r - l == 1) return dis(p[l], p[r]);
    int m = (l + r) >> 1;
    double d = min(closest_pair(l, m), closest_pair(m + 1, r));
    vector<int> vec;
    for (int i = m; i >= l && fabs(p[m].x - p[i].x) < d; --i) vec.push_back(i);
    for (int i = m + 1; i <= r && fabs(p[m].x - p[i].x) < d; ++i) vec.push_back(i);
    sort(vec.begin(), vec.end(), [=](const int& a, const int& b) { return p[a].y < p[b].y; });
    for (int i = 0; i < vec.size(); ++i) {
        for (int j = i + 1; j < vec.size() && fabs(p[vec[i]].y - p[vec[j]].y) < d; ++j) {
            d = min(d, dis(p[vec[i]], p[vec[j]]));
        }
    }
    return d;
}
```

7 String

7.1 KMP

```
int f[maxn];

int kmp(const string& a, const string& b) {
    f[0] = -1; f[1] = 0;
    for (int i = 1, j = 0; i < b.size() - 1; f[++i] = ++j) {
        if (b[i] == b[j]) f[i] = f[j];
        while (j != -1 && b[i] != b[j]) j = f[j];
    }
    for (int i = 0, j = 0; i - j + b.size() <= a.size(); ++i, ++j) {
        while (j != -1 && a[i] != b[j]) j = f[j];
        if (j == b.size() - 1) return i - j;
    }
    return -1;
}
```

7.2 Suffix Array

```
struct SuffixArray {
    int sa[maxn], tmp[2][maxn], c[maxn], _lcp[maxn], r[
        maxn], n;
    string s;
    SparseTable st;
    void suffixarray() {
        int* rank = tmp[0];
        int* nRank = tmp[1];
        int A = 128;
        for (int i = 0; i < A; ++i) c[i] = 0;
        for (int i = 0; i < s.length(); ++i) c[rank[i] = s[
            i]]++;
        for (int i = 1; i < A; ++i) c[i] += c[i - 1];
        for (int i = s.length() - 1; i >= 0; --i) sa[--c[s[
            i]]] = i;
        for (int n = 1; n < s.length(); n *= 2) {
            for (int i = 0; i < A; ++i) c[i] = 0;
            for (int i = 0; i < s.length(); ++i) c[rank[i
                ]]]++;
            for (int i = 1; i < A; ++i) c[i] += c[i - 1];
            int* sa2 = nRank;
            int r = 0;
```

```
        for (int i = s.length() - n; i < s.length(); ++i)
            sa2[r++] = i;
        for (int i = 0; i < s.length(); ++i) if (sa[i] >=
            n) sa2[r++] = sa[i] - n;
        for (int i = s.length() - 1; i >= 0; --i) sa[--c[
            rank[sa2[i]]]] = sa2[i];
        nRank[sa[0]] = r = 0;
        for (int i = 1; i < s.length(); ++i) {
            if (!(rank[sa[i - 1]] == rank[sa[i]] && sa[i -
                1] + n < s.length() && rank[sa[i - 1] + n] == rank[
                    sa[i] + n])) r++;
            nRank[sa[i]] = r;
        }
        swap(rank, nRank);
        if (r == s.length() - 1) break;
        A = r + 1;
    }
}

void solve() {
    suffixarray();
    for (int i = 0; i < n; ++i) r[sa[i]] = i;
    int ind = 0; _lcp[0] = 0;
    for (int i = 0; i < n; ++i) {
        if (!r[i]) { ind = 0; continue; }
        while (i + ind < n && s[i + ind] == s[sa[r[i] -
            1] + ind]) ++ind;
        _lcp[r[i]] = ind ? ind-- : 0;
    }
    st = SparseTable(n, _lcp);
}

int lcp(int L, int R) {
    if (L == R) return n - L - 1;
    L = r[L]; R = r[R];
    if (L > R) swap(L, R);
    ++L;
    return st.query(L, R);
}

SuffixArray(string s): s(s), n(s.length()) {}
SuffixArray() {}
};
```

7.3 Z algorithm

```
int z[maxn];

void z_function(const string& s) {
    memset(z, 0, sizeof(z));
    z[0] = (int)s.length();
    int l = 0, r = 0;
    for (int i = 1; i < s.length(); ++i) {
        z[i] = max(0, min(z[i - l], r - i + 1));
        while (i + z[i] < s.length() && s[z[i]] == s[i + z[
            i]]) {
            l = i; r = i + z[i];
            ++z[i];
        }
    }
}
```

7.4 Manacher's algorithm

```
int z[maxn];

int manacher(const string& s) {
    string t = ". ";
    for (int i = 0; i < s.length(); ++i) t += s[i], t +=
        ' ';
    int l = 0, r = 0;
    for (int i = 1; i < t.length(); ++i) {
        z[i] = (r > i ? min(z[2 * l - i], r - i) : 1);
        while (i - z[i] >= 0 && i + z[i] < t.length() && t[
            i - z[i]] == t[i + z[i]]) ++z[i];
        if (i + z[i] > r) r = i + z[i], l = i;
    }
    int ans = 0;
    for (int i = 1; i < t.length(); ++i) ans = max(ans, z[
        i] - 1);
    return ans;
}
```

```
|}
```

7.5 Rolling hash primes

```
const int mod[] = { 479001599, 433494437, 1073807359,
    1442968193, 715827883 };
const int p[] = { 101, 233, 457, 173, 211 }
```

8 Dynamic Programming

8.1 Linear convex hull optimization

```
struct ConvexHull {
    // Max convex hull
    deque<pair<int, int>> dq;
    bool check(const pair<int, int>& l1, const pair<int,
        int>& l2, int x) {
        // for min case, replace <= with >=
        return l1.first * x + l1.second <= l2.first * x +
            l2.second;
    }
    bool elim(const pair<int, int>& l1, const pair<int,
        int>& l2, const pair<int, int>& l) {
        return (double)(l1.second - l2.second) / (double)(
            l2.first - l1.first) <= (double)(l.second - l2.
            second) / (double)(l2.first - l.first);
    }
    int query(int x) {
        while (dq.size() >= 2 && check(dq[0], dq[1], x)) dq
            .pop_front();
        return dq.front().first * x + dq.front().second;
    }
    void add(int a, int b) {
        while (dq.size() >= 2 && elim(dq[dq.size() - 1], dq
            [dq.size() - 2], make_pair(a, b))) dq.pop_back();
        dq.push_back(make_pair(a, b));
    }
};
```

8.2 Divide and conquer optimization

```
int dp[maxk][maxn], f[maxk][maxn];

void go(int k, int l, int r, int fl, int fr) {
    if (l > r) return;
    int m = (l + r) >> 1;
    f[k][m] = -1;
    for (int i = fl; i <= min(m - 1, fr); ++i) {
        int t = dp[k - 1][i] + f(i + 1, m);
        if (t > dp[k][m]) {
            dp[k][m] = t;
            f[k][m] = i;
        }
    }
    go(k, l, m - 1, fl, f[k][m]);
    go(k, m + 1, r, f[k][m], fr);
}

void solve() {
    for (int i = 1; i <= k; ++i) go(i, 1, n, 0, n - 1);
}
```