Code Template for ACM-ICPC

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Contents

1 Template

1.1 Starter Code

```cpp
#pragma GCC optimize("O3,unroll-loops")
#pragma GCC target("avx2,bmi,bmi2,lzcnt,popcnt")
#include <bits/stdc++.h>
using namespace std;

#define ll long long
#define f first
#define s second
#define all(x) (x).begin(), (x).end()
#define sz(x) (int)(x).size()

template<typename A, typename B> ostream&
    operator<<(ostream &os, const pair<A, B> &p) {
    return os << '(' << p.f << ", " << p.s << ')'; }
template<typename T_container, typename T = typename
    enable_if<!is_same<T_container, string>::value,
    typename T_container::value_type>::type> ostream&
    operator<<(ostream &os, const T_container &v) { os
    << '{'; string sep; for (const T &x : v) os << sep
    << x, sep = ", "; return os << '}'; }
void dbg_out() { cerr << endl; }
template<typename Head, typename... Tail> void
    dbg_out(Head H, Tail... T) { cerr << ' ' << H;
    dbg_out(T...); }

#ifdef LOCAL
#define dbg(...) cerr << "(" << #__VA_ARGS__ << "):",
    dbg_out(__VA_ARGS__)
#else
#define dbg(...)
#endif

int main() {
    ios::sync_with_stdio(false);
    cin.tie(nullptr);
#ifdef LOCAL
    freopen("input.txt", "r", stdin);
    freopen("output.txt", "w", stdout);
    freopen("error.txt", "w", stderr);
#endif
    return 0;
}
```

1.2 Script

```sh
# alias cprun="/home/cprun.sh"
PROG_NAME=$1
OUT_NAME="${PROG_NAME%.*}"
g++ -std=c++17 -DLOCAL $PROG_NAME -o $OUT_NAME.out
if [[ $? == 0 ]]; then
    ./$OUT_NAME.out
fi
```

1.3 Vim

```
set nocp
filetype plugin indent on
set number
set relativenumber
syntax on
colorscheme ron
let mapleader = " "
set tabstop=4
set shiftwidth=4
set softtabstop=4
set autoindent
set expandtab
if has('persistent_undo')
    set undodir=$HOME/.vim/undo
    set undofile
endif
set ignorecase
set smartcase
set incsearch
nnoremap <leader>t :term<CR>
inoremap { {}<Esc>ha
inoremap ( ()<Esc>ha
inoremap [ []<Esc>ha
inoremap " ""<Esc>ha
inoremap ' ''<Esc>ha
inoremap ` ``<Esc>ha
```

Sublime

```
{
"cmd" : ["g++ -std=c++14 $file_name -o $file_base_name
    && timeout 4s
    ./$file_base_name<inputf.in>outputf.in"],
"selector" : "source.c",
"shell": true,
"working_dir" : "$file_path"
}
```

2 Number Theory

2.1 Chinese Remainder Theorem

```cpp
ll mod_inv(ll c, ll m) {
    ll m0 = m;
    ll y = 0, x = 1;
    if (m == 1) return 0;

    while (c > 1){
        ll q = c / m;
        ll t = m;
        m = c % m;
        c = t;
        t = y;
        y = x - q * y;
        x = t;
    }
    if (x < 0) x += m0;
    return x;
}

ll CRT(vector<pair<ll,ll>> congru) {
    ll M = 1;
    for (auto var : congru) {
        M *= var.second;
    }
    ll solution = 0;
    for (auto var : congru) {
```

```
        ll a_i = var.first;
        ll M_i = M / var.second;
        ll N_i = mod_inv(M_i, var.second);
        solution = (solution + a_i * (M_i % M) * N_i) %
            M;
    }
    return solution;
}
```

2.2 Extended Euclidean Algorithm

```
ll ex_gcd(ll a, ll b, ll& x, ll& y) {
    if (b == 0) {
        x = 1;
        y = 0;
        return a;
    }
    ll x1, y1;
    ll d = ex_gcd(b, a % b, x1, y1);
    x = y1;
    y = x1 - y1 * (a / b);
    return d;
}
```

2.3 Mod Inverse

```
ll mod_inv(ll c, ll m){
    ll m0 = m;
    ll y = 0, x = 1;
    if (m == 1) return 0;
    while (c > 1){
        ll q = c / m, t = m;
        m = c % m;
        c = t;
        t = y;
        y = x - q * y;
        x = t;
    }
    if (x < 0) x += m0;
    return x;
}
```

2.4 Phi Function

```
vector<ll> phi_1_to_n(ll n) {
    vector<ll> phi(n + 1);
    for (ll i = 0; i <= n; i++)
        phi[i] = i;

    for (ll i = 2; i <= n; i++) {
        if (phi[i] == i) {
            for (ll j = i; j <= n; j += i)
                phi[j] -= phi[j] / i;
        }
    }
    return phi;
}
```

2.5 Linear Diophantine Equations

```
// Diophantine equation : x0*a + y0*b = c
bool diophantine_solution(ll a, ll b, ll c, ll &x0, ll
    &y0, ll &g) {
    g = gcd(abs(a), abs(b), x0, y0);
    if (c % g) return false;

    x0 *= c / g;
    y0 *= c / g;
    if (a < 0) x0 = -x0;
    if (b < 0) y0 = -y0;
    return true;
}
```

2.6 Sieve

```
const int MXN = 1e7 + 1;
int spf[MXN];
vector<int> primes;

void init() {
    iota(spf, spf + MXN, 0);
    spf[0] = -1, spf[1] = 1;
    for(int i = 2; i * 1LL * i < MXN; i++) {
        if(spf[i] == i) {
            if(i * 1LL * i < MXN) {
                for(int j = i * i; j < MXN; j += i) {
                    if(spf[j] == j) spf[j] = i;
                }
            }
        }
    }
    primes.push_back(2);
    for(int i = 3; i < MXN; i += 2) {
        if(spf[i] == i) primes.push_back(i);
    }
}

bool is_prime(int n) {
    return (n == 1? false: spf[n] == n);
}
```

2.7 Pollard Rho

```
long long pollards_p_minus_1(long long n) {
    int B = 10;
    long long g = 1;
    while (B <= 1000000 && g < n) {
        long long a = 2 + rand() % (n - 3);
        g = gcd(a, n);
        if (g > 1)
            return g;

        // compute a^M
        for (int p : primes) {
            if (p >= B)
                continue;
            long long p_power = 1;
            while (p_power * p <= B)
                p_power *= p;
            a = power(a, p_power, n);

            g = gcd(a - 1, n);
            if (g > 1 && g < n)
```

```
            return g;
        }
        B *= 2;
    }
    return 1;
}
```

3 Range Query

3.1 Segment Tree

```
template<typename I>
class SegTree {
public:
    int n;
    vector<I> info;

    SegTree(int _n) {
        n = _n;
        info = vector<I>(4 * n + 1);
    }

    SegTree(const vector<I> &init) :
        SegTree(init.size()) {
        function<void(int, int, int)> build = [&](int
            p, int l, int r) -> void {
            if(l == r) {
                info[p] = init[l];
                return;
            }
            int m = l + (r - l) / 2;
            build(2 * p + 1, l, m);
            build(2 * p + 2, m + 1, r);
            pull(p);
        };
        build(0, 0, n - 1);
    }

    void pull(int p) {
        info[p] = info[2 * p + 1] + info[2 * p + 2];
    }

    void modify(int p, int l, int r, int x, const I& v)
        {
        if(r == l) {
            info[p] = v;
            return;
        }

        int m = l + (r - l) / 2;
        if(x <= m) {
            modify(2 * p + 1, l, m, x, v);
        } else {
            modify(2 * p + 2, m + 1, r, x, v);
        }
        pull(p);
    }

    void modify(int p, const I& v) {
        modify(0, 0, n - 1, p, v);
    }

    I rangeQuery(int p, int l, int r, int x, int y) {
        if(y < l or r < x) {
            return I();
        }

        if(x <= l and r <= y) {
            return info[p];
        }

        int m = l + (r - l) / 2;
        return rangeQuery(2 * p + 1, l, m, x, y) +
            rangeQuery(2 * p + 2, m + 1, r, x, y);
    }

    I rangeQuery(int l, int r) {
        return rangeQuery(0, 0, n - 1, l, r);
    }
};

class Sum {
public:
    long long x = 0;
    int index = -1;

    Sum() {}

    Sum(long long _x) {
        x = _x;
    }

    Sum(long long _x, int _index) {
        x = _x;
        index = _index;
    }

};

Sum operator+(const Sum &lf, const Sum &rt) {
    return Sum(lf.x + rt.x);
}

class Solution {
public:
    long long numberOfPairs(vector<int>& nums1,
        vector<int>& nums2, int diff) {
        const int n = (int)nums1.size();
        SegTree<Sum> st(1e5 + 2);
        int shift = 1e4;
        long long ans = 0;
        for(int i = 0; i < n; i++) {
            int lf = nums1[i] - nums2[i] + 2 * shift;
            ans += st.rangeQuery(0, lf + diff).x;
            int val = st.rangeQuery(lf, lf).x;
            st.modify(lf, Sum(val + 1));
        }
        return ans;
    }
};
```

3.2 Lazy Segement Tree

```
template<typename I, typename T>
class LazySegTree {
public:
    int n;
    vector<I> info;
    vector<T> tag;
```

```
LazySegTree(int _n) {
    n = _n;
    info = vector<I>(4 * n + 1);
    tag = vector<T>(4 * n + 1);
}

LazySegTree(const vector<I> &init) :
     LazySegTree(init.size()) {
    function<void(int, int, int)> build = [&](int
         p, int l, int r) -> void {
        if(r == l) {
            info[p] = init[l];
            return;
        }
        int m = l + (r - l) / 2;
        build(2 * p + 1, l, m);
        build(2 * p + 2, m + 1, r);
        pull(p);
    };
    build(0, 0, n - 1);
}

void pull(int p) {
    info[p] = info[2 * p + 1] + info[2 * p + 2];
}

void apply(int p, const T &v) {
    info[p].apply(v);
    tag[p].apply(v);
}

void push(int p) {
    apply(2 * p + 1, tag[p]);
    apply(2 * p + 2, tag[p]);
    tag[p] = T();
}

void modify(int p, int l, int r, int x, const I &v)
     {
    if(r == l) {
        info[p] = v;
        return;
    }

    int m = l + (r - l) / 2;
    push(p);
    if(x <= m) {
        modify(2 * p + 1, l, m, x, v);
    } else {
        modify(2 * p + 2, m + 1, r, x, v);
    }
    pull(p);
}

void modify(int p, const I &v) {
    modify(0, 0, n - 1, p, v);
}

I rangeQuery(int p, int l, int r, int x, int y) {
    if(y < l or r < x) {
        return I();
    }

    if(x <= l and r <= y) {
        return info[p];
    }
        int m = l + (r - l) / 2;
        push(p);
        return rangeQuery(2 * p + 1, l, m, x, y) +
            rangeQuery(2 * p + 2, m + 1, r, x, y);
    }

    I rangeQuery(int l, int r) {
        return rangeQuery(0, 0, n - 1, l, r);
    }

    void rangeApply(int p, int l, int r, int x, int y,
         const T &v) {
        if(y < l or r < x) {
            return;
        }

        if(x <= l and r <= y) {
            apply(p, v);
            return;
        }

        int m = l + (r - l) / 2;
        push(p);
        rangeApply(2 * p + 1, l, m, x, y, v);
        rangeApply(2 * p + 2, m + 1, r, x, y, v);
        pull(p);
    }

    void rangeApply(int l, int r, const T &v) {
        return rangeApply(0, 0, n - 1, l, r, v);
    }
};

class Tag {
public:
    long long x = 0;

    Tag() {}

    Tag(long long _x) {
        x = _x;
    }

    void apply(const Tag &t) {
        x += t.x;
    }
};

class Sum {
public:
    long long x = 0;
    int index = -1;

    Sum() {}

    Sum(long long _x) {
        x = _x;
    }

    Sum(long long _x, int _index) {
        x = _x;
        index = _index;
    }

    void apply(const Tag &t) {
        x += t.x;
    }
```

```
};

Sum operator+(const Sum &lf, const Sum &rt) {
    return Sum(lf.x + rt.x);
}

class Solution {
public:
    string shiftingLetters(string s,
         vector<vector<int>>& shifts) {
        const int n = (int)s.size();
        LazySegTree<Sum, Tag> st(n);
        for(const auto& v: shifts) {
            st.rangeApply(v[0], v[1], Tag(v[2]? +1: -1));
        }
        for(int i = 0; i < n; i++) {
            int val = st.rangeQuery(i, i).x;
            s[i] = (((s[i] - 'a' + val) % 26 + 26) % 26)
                +'a';
        }
        return s;
    }
};
```

3.3 Fenwick Tree

```
template<typename T>
class BIT {
public:
    vector<T> bit;
    int n;

    BIT() {
        n = 0;
    }

    BIT(int _n) {
        n = _n;
        bit.assign(n, 0);
    }

    void inc(int idx, T val) {
        assert(0 <= idx and idx < n);
        for(int i = idx + 1; i <= n; i += (i & -i))
            bit[i - 1] += val;
    }

    T query(int idx) {
        assert(0 <= idx and idx < n);
        T res = 0;
        for(int i = idx + 1; i > 0; i -= (i & -i))
            res += bit[i - 1];
        return res;
    }

    T at(int idx) {
        assert(0 <= idx and idx < n);
        return query(idx) - (idx - 1 >= 0? query(idx -
            1): 0);
    }

    T at(int l, int r) {
        assert(0 <= l and l <= r and r < n);
        return query(r) - (l - 1 >= 0? query(l - 1): 0);
    }
};

template<typename T>
class FT {
public:
    BIT<T> f1, f2;
    int n;

    FT() {
        n = 0;
    }

    FT(int _n) {
        n = _n;
        f1 = f2 = BIT<T>(_n + 1);
    }

    void inc(int idx, T val){
        assert(0 <= idx and idx < n);
        inc(idx, idx, val);
    }

    void inc(int l, int r, T val) {
        assert(0 <= l and l <= r and r < n);
        f1.inc(l, val);
        f1.inc(r + 1, -val);
        f2.inc(l, val * (l - 1));
        f2.inc(r + 1, -val * r);
    }

    T query(int idx) {
        assert(0 <= idx and idx < n);
        return f1.query(idx) * idx - f2.query(idx);
    }

    T at(int idx) {
        assert(0 <= idx and idx < n);
        return query(idx) - (idx - 1 >= 0? query(idx -
            1): 0);
    }

    T at(int l, int r) {
        assert(0 <= l and l <= r and r < n);
        return query(r) - (l - 1 >= 0? query(l - 1): 0);
    }
};
```

3.4 Sparse Table

```
template<typename T>
class RMQ {
public:
    vector<vector<T>> st;
    function<T(T, T)> op;
    int n, m;

    RMQ(const vector<T>& a, function<T(T, T)> _op) {
        n = (int)a.size(); m = __lg(n) + 1; //
            ceil(log(r - l + 1))
        st = vector<vector<T>>(n, vector<T>(m));
        op = _op;
        int p = 1;
        for(int j = 0; j < m; j++) {
            for(int i = 0; i + p - 1 < n; i++) {
                if(j == 0) st[i][j] = a[i];
```

```
            else st[i][j] = op(st[i][j - 1], st[i +
                (p >> 1)][j - 1]);
        }
        p *= 2;
    }
}

T query(int l, int r) {
    int sz = __lg(r - l + 1); // floor(log(r - l +
        1))
    return op(st[l][sz], st[r + 1 - (1 << sz)][sz]);
}
}; // RMQ<int> rmq(arr, [](int x, int y) -> int {
    return min(x, y); });
```

3.5 Centroid Decomposition

```
const int maxn = 200010;
int n;
vector<int> adj[maxn];
int subtree_size[maxn];

int get_subtree_size(int node, int par = -1) {
    int &res = subtree_size[node];
    res = 1;
    for (int i : adj[node]) {
        if (i == par) continue;
        res += get_subtree_size(i, node);
    }
    return res;

}

int get_centroid(int node, int par = -1) {
    for (int i : adj[node]) {
        if (i == par) continue;
        if (subtree_size[i] * 2 > n) { return
            get_centroid(i, node); }
    }
    return node;
}

int main() {
    cin >> n;
    for (int i = 0; i < n - 1; i++) {
    int a, b; cin >> a >> b;
        a--; b--;
        adj[a].push_back(b);
        adj[b].push_back(a);

    }
    get_subtree_size(0);
    cout << get_centroid(0) + 1 << endl;
}
```

3.6 Heavy Light Decomposition

```
template <class T, int V>
class HeavyLight {
  int parent[V], heavy[V], depth[V];
  int root[V], treePos[V];
  SegmentTree<T> tree;

  template <class G>
  int dfs(const G& graph, int v) {
    int size = 1, maxSubtree = 0;
    for (int u : graph[v]) if (u != parent[v]) {
      parent[u] = v;
      depth[u] = depth[v] + 1;
      int subtree = dfs(graph, u);
      if (subtree > maxSubtree) heavy[v] = u,
          maxSubtree = subtree;
      size += subtree;
    }
    return size;
  }

  template <class BinaryOperation>
  void processPath(int u, int v, BinaryOperation op) {
    for (; root[u] != root[v]; v = parent[root[v]]) {
      if (depth[root[u]] > depth[root[v]]) swap(u, v);
      op(treePos[root[v]], treePos[v] + 1);
    }
    if (depth[u] > depth[v]) swap(u, v);
    op(treePos[u], treePos[v] + 1);
  }

public:
  template <class G>
  void init(const G& graph) {
    int n = graph.size();
    fill_n(heavy, n, -1);
    parent[0] = -1;
    depth[0] = 0;
    dfs(graph, 0);
    for (int i = 0, currentPos = 0; i < n; ++i)
      if (parent[i] == -1 || heavy[parent[i]] != i)
        for (int j = i; j != -1; j = heavy[j]) {
          root[j] = i;
          treePos[j] = currentPos++;
        }
    tree.init(n);
  }

  void set(int v, const T& value) {
    tree.set(treePos[v], value);
  }

  void modifyPath(int u, int v, const T& value) {
    processPath(u, v, [this, &value](int l, int r) {
        tree.modify(l, r, value); });
  }

  T queryPath(int u, int v) {
    T res = T();
    processPath(u, v, [this, &res](int l, int r) {
        res.add(tree.query(l, r)); });
    return res;
  }
};
```

3.7 Mo's Algorithm

```
void remove(idx); // TODO: remove value at idx from
    data structure
void add(idx);   // TODO: add value at idx from data
    structure
```

```
int get_answer(); // TODO: extract the current answer
    of the data structure

int block_size;

struct Query {
    int l, r, idx;
    bool operator<(Query other) const
    {
        return make_pair(l / block_size, r) <
               make_pair(other.l / block_size, other.r);
    }
};

vector<int> mo_s_algorithm(vector<Query> queries) {
    vector<int> answers(queries.size());
    sort(queries.begin(), queries.end());

    // TODO: initialize data structure

    int cur_l = 0;
    int cur_r = -1;
    // invariant: data structure will always reflect
        the range [cur_l, cur_r]
    for (Query q : queries) {
        while (cur_l > q.l) {
            cur_l--;
            add(cur_l);
        }
        while (cur_r < q.r) {
            cur_r++;
            add(cur_r);
        }
        while (cur_l < q.l) {
            remove(cur_l);
            cur_l++;
        }
        while (cur_r > q.r) {
            remove(cur_r);
            cur_r--;
        }
        answers[q.idx] = get_answer();
    }
    return answers;
}
```

4 String

4.1 Hashing

```
// long long mod0 = 1000000007, mod1 = 987654347;
// long long p0 = 31, p1 = 37;
long long mod0 = 127657753, mod1 = 987654319;
long long p0 = 137, p1 = 277;
vector<array<long long, 2>> pw;
vector<array<long long, 2>> ipw;

long long h(char c) {
    return c; // return c - 'a' + 1;
}

long long binpow(long long a, long long b, long long m)
    {
    a %= m;
    long long res = 1;
    while(b > 0) {
        if(b & 1) res = (res * a) % m;
        a = (a * a) % m;
        b >>= 1;
    }
    return res;
}

long long inv(long long a, long long m) {
    // a is prime and a mod m != 0
    // a ^ m      === a     (mod m)
    // a ^ (m - 2) === a ^ -1 (mod m)
    return binpow(a, m - 2, m);
}

// Till the limit i.e. [0, limit]
void init(int limit) {
    if(pw.empty()) pw.push_back({1, 1});
    while(pw.size() < limit + 1) {
        pw.push_back({
            (pw.back()[0] * p0) % mod0,
            (pw.back()[1] * p1) % mod1
        });
    }
    if(ipw.empty()) {
        ipw.push_back({1, 1});
        ipw.push_back({
            inv(p0, mod0),
            inv(p1, mod1)
        });
    }
    while(ipw.size() < limit + 1) {
        ipw.push_back({
            (ipw.back()[0] * ipw[1][0]) % mod0,
            (ipw.back()[1] * ipw[1][1]) % mod1
        });
    }
}

class Hashing {
public:
    vector<array<long long, 2>> pre;
    int n;

    Hashing(string s) {
        init((int)s.size() + 1);
        if(s.size() == 0) return;
        pre.push_back({(h(s[0]) * pw[0][0]) % mod0,
             (h(s[0]) * pw[0][1]) % mod1});
        for(int i = 1; i < (int)s.size(); i++) {
            pre.push_back({
                (pre[i - 1][0] + h(s[i]) * pw[i][0]) %
                    mod0,
                (pre[i - 1][1] + h(s[i]) * pw[i][1]) %
                    mod1
            });
        }
        n = (int)s.size();
    }

    array<long long, 2> get_hash(int l, int r) {
        assert(0 <= l and l <= r and r < n);
        array<long long, 2> hs;
        hs[0] = pre[r][0] - (l - 1 >= 0? pre[l - 1][0]:
            0) + mod0;
        hs[1] = pre[r][1] - (l - 1 >= 0? pre[l - 1][1]:
            0) + mod1;
```

```
        hs[0] = (hs[0] * ipw[l][0]) % mod0;
        hs[1] = (hs[1] * ipw[l][1]) % mod1;
        return hs;
    }

    array<long long, 2> get_hash() {
        return get_hash(0, n - 1);
    }
};
```

4.2 KMP

```
vector<int> prefix_function(string s) {
    int n = (int)s.length();
    vector<int> pi(n);
    for (int i = 1; i < n; i++) {
        int j = pi[i-1];
        while (j > 0 && s[i] != s[j])
            j = pi[j-1];
        if (s[i] == s[j])
            j++;
        pi[i] = j;
    }
    return pi;
}
```

4.3 Z Function

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

4.4 String Trie

```
class Node {
public:
    static const int N = (1 << 8); // 256
    bool is_leaf;
    int next[N];
    int count;

    Node() {
        is_leaf = false;
        count = 0;
        memset(next, -1, sizeof next);
    }
};

class Trie {
public:
    vector<Node> root;

    Trie() {
        root.emplace_back(); // insert a object
    }

    void insert(string word) {
        int i = 0;
        for (char c: word) {
            if (root[i].next[c] == -1) {
                root[i].next[c] = root.size();
                root.emplace_back();
            }
            i = root[i].next[c];
        }
        root[i].is_leaf = true;
    }

    bool search(string word) {
        int i = 0;
        for (char c: word) {
            if (root[i].next[c] == -1) {
                return false;
            }
            i = root[i].next[c];
        }
        return root[i].is_leaf;
    }

    bool startsWith(string prefix) {
        int i = 0;
        for (char c: prefix) {
            if (root[i].next[c] == -1) {
                return false;
            }
            i = root[i].next[c];
        }
        return true;
    }
};
```

4.5 XOR Trie

```
class Trie {
private:
    static const int N = 2;

    class Node {
    public:
        int next[N];
        bool leaf;

        Node() {
            memset(next, -1, sizeof next);
            leaf = false;
        }
    };
public:
    vector<Node> root;

    Trie() {
        root = vector<Node>(1);
    }

    void insert(int num) {
        int v = 0;
```

```
        for(int i = 30; i >= 0; i--) {
            int c = ((1 << i) & num) > 0;
            if(root[v].next[c] == -1) {
                root[v].next[c] = (int)root.size();
                root.emplace_back();
            }
            v = root[v].next[c];
        }
        root[v].leaf = true;
    }

    int query(int num) {
        int v = 0, res = 0;
        for(int i = 30; i >= 0; i--) {
            int sb = ((1 << i) & num), c = 1;
            if(sb > 0) c = 0;
            if(root[v].next[c] != -1) res += (1 << i);
            else c ^= 1;
            v = root[v].next[c];
        }
        return res;
    }

};

class Solution {
public:
    int findMaximumXOR(vector<int>& a) { // pair
        const int n = (int)a.size();
        Trie t;
        for(int i = 0; i < n; i++) t.insert(a[i]);
        int ans = INT_MIN;
        for(int i = 0; i < n; i++) ans = max(ans,
            t.query(a[i]));
        return ans;
    }
};
```

4.6 Robin Karp

```
vector<int> rabin_karp(string const& s, string const&
    t) {
    const int p = 31;
    const int m = 1e9 + 9;
    int S = s.size(), T = t.size();

    vector<long long> p_pow(max(S, T));
    p_pow[0] = 1;
    for (int i = 1; i < (int)p_pow.size(); i++)
        p_pow[i] = (p_pow[i-1] * p) % m;

    vector<long long> h(T + 1, 0);
    for (int i = 0; i < T; i++)
        h[i+1] = (h[i] + (t[i] - 'a' + 1) * p_pow[i]) %
            m;
    long long h_s = 0;
    for (int i = 0; i < S; i++)
        h_s = (h_s + (s[i] - 'a' + 1) * p_pow[i]) % m;

    vector<int> occurences;
    for (int i = 0; i + S - 1 < T; i++) {
        long long cur_h = (h[i+S] + m - h[i]) % m;
        if (cur_h == h_s * p_pow[i] % m)
            occurences.push_back(i);
    }
    return occurences;
}
```

4.7 Manacher

```
vector<int> manacher_odd(string s) {
    int n = s.size();
    s = "$" + s + "^";
    vector<int> p(n + 2);
    int l = 1, r = 1;
    for(int i = 1; i <= n; i++) {
        p[i] = max(0, min(r - i, p[l + (r - i)]));
        while(s[i - p[i]] == s[i + p[i]]) {
            p[i]++;
        }
        if(i + p[i] > r) {
            l = i - p[i], r = i + p[i];
        }
    }
    return vector<int>(begin(p) + 1, end(p) - 1);
}
```

5 Graph

5.1 DSU

```
class UnionFind {
    private:
        vector<ll> p, rank, setSize;
        ll numSets;
    public:
        UnionFind(ll N){
            p.assign(N, 0);
            for(ll i = 0; i < N; i++){
                p[i] = i;
            }
            rank.assign(N, 0);
            setSize.assign(N, 1);
            numSets = N;
        }

        ll findSet(ll i){
            if(p[i] == i) return i;
            else return p[i] = findSet(p[i]);
        }

        bool isSameSet(ll i, ll j){
            return findSet(i) == findSet(j);
        }

        ll sizeOfSet(ll i){
            return setSize[findSet(i)];
        }

        ll numDisjointSets(){
            return numSets;
        }

        void unionSet(ll i, ll j){
            if(isSameSet(i,j)) return;

            ll x = findSet(i);
            ll y = findSet(j);
```

```
            if(rank[x] > rank[y]) swap(x,y);
            p[x] = y;

            if (rank[x] == rank[y]) rank[y]++;
            setSize[y] += setSize[x];
            numSets--;
        }
};
```

5.2 Bridges

```
int n; // number of nodes
vector<vector<int>> adj; // adjacency list of graph

vector<bool> visited;
vector<int> tin, low;
int timer;

void dfs(int v, int p = -1) {
    visited[v] = true;
    tin[v] = low[v] = timer++;
    for (int to : adj[v]) {
        if (to == p) continue;
        if (visited[to]) {
            low[v] = min(low[v], tin[to]);
        } else {
            dfs(to, v);
            low[v] = min(low[v], low[to]);
            if (low[to] > tin[v])
                IS_BRIDGE(v, to);
        }
    }
}

void find_bridges() {
    timer = 0;
    visited.assign(n, false);
    tin.assign(n, -1);
    low.assign(n, -1);
    for (int i = 0; i < n; ++i) {
        if (!visited[i])
            dfs(i);
    }
}
```

5.3 Bridges Online

```
vector<int> par, dsu_2ecc, dsu_cc, dsu_cc_size;
int bridges;
int lca_iteration;
vector<int> last_visit;

void init(int n) {
    par.resize(n);
    dsu_2ecc.resize(n);
    dsu_cc.resize(n);
    dsu_cc_size.resize(n);
    lca_iteration = 0;
    last_visit.assign(n, 0);
    for (int i=0; i<n; ++i) {
        dsu_2ecc[i] = i;
        dsu_cc[i] = i;
        dsu_cc_size[i] = 1;
        par[i] = -1;
    }
    bridges = 0;
}

int find_2ecc(int v) {
    if (v == -1)
        return -1;
    return dsu_2ecc[v] == v ? v : dsu_2ecc[v] =
        find_2ecc(dsu_2ecc[v]);
}

int find_cc(int v) {
    v = find_2ecc(v);
    return dsu_cc[v] == v ? v : dsu_cc[v] =
        find_cc(dsu_cc[v]);
}

void make_root(int v) {
    v = find_2ecc(v);
    int root = v;
    int child = -1;
    while (v != -1) {
        int p = find_2ecc(par[v]);
        par[v] = child;
        dsu_cc[v] = root;
        child = v;
        v = p;
    }
    dsu_cc_size[root] = dsu_cc_size[child];
}

void merge_path (int a, int b) {
    ++lca_iteration;
    vector<int> path_a, path_b;
    int lca = -1;
    while (lca == -1) {
        if (a != -1) {
            a = find_2ecc(a);
            path_a.push_back(a);
            if (last_visit[a] == lca_iteration){
                lca = a;
                break;
                }
            last_visit[a] = lca_iteration;
            a = par[a];
        }
        if (b != -1) {
            b = find_2ecc(b);
            path_b.push_back(b);
            if (last_visit[b] == lca_iteration){
                lca = b;
                break;
                }
            last_visit[b] = lca_iteration;
            b = par[b];
        }

    }

    for (int v : path_a) {
        dsu_2ecc[v] = lca;
        if (v == lca)
            break;
        --bridges;
    }
    for (int v : path_b) {
```

```
        dsu_2ecc[v] = lca;
        if (v == lca)
            break;
        --bridges;
    }
}

void add_edge(int a, int b) {
    a = find_2ecc(a);
    b = find_2ecc(b);
    if (a == b)
        return;

    int ca = find_cc(a);
    int cb = find_cc(b);

    if (ca != cb) {
        ++bridges;
        if (dsu_cc_size[ca] > dsu_cc_size[cb]) {
            swap(a, b);
            swap(ca, cb);
        }
        make_root(a);
        par[a] = dsu_cc[a] = b;
        dsu_cc_size[cb] += dsu_cc_size[a];
    } else {
        merge_path(a, b);
    }
}
```

5.4 Articulation Points

```
int n; // number of nodes
vector<vector<int>> adj; // adjacency list of graph

vector<bool> visited;
vector<int> tin, low;
int timer;

void dfs(int v, int p = -1) {
    visited[v] = true;
    tin[v] = low[v] = timer++;
    int children=0;
    for (int to : adj[v]) {
        if (to == p) continue;
        if (visited[to]) {
            low[v] = min(low[v], tin[to]);
        } else {
            dfs(to, v);
            low[v] = min(low[v], low[to]);
            if (low[to] >= tin[v] && p!=-1)
                IS_CUTPOINT(v);
            ++children;
        }
    }
    if(p == -1 && children > 1)
        IS_CUTPOINT(v);
}

void find_cutpoints() {
    timer = 0;
    visited.assign(n, false);
    tin.assign(n, -1);
    low.assign(n, -1);
    for (int i = 0; i < n; ++i) {
        if (!visited[i])
            dfs (i);
    }
}
```

5.5 Kosaraju(SCC)

```
vector<vector<int>> adj, adj_rev;
vector<bool> used;
vector<int> order, component;

void dfs1(int v) {
    used[v] = true;
    for (auto u : adj[v])
        if (!used[u])
            dfs1(u);
    order.push_back(v);
}

void dfs2(int v) {
    used[v] = true;
    component.push_back(v);
    for (auto u : adj_rev[v])
        if (!used[u])
            dfs2(u);
}

int main() {
    int n;
    // ... read n ...
    for (;;) {
        int a, b;
        // ... read next directed edge (a,b) ...
        adj[a].push_back(b);
        adj_rev[b].push_back(a);
    }
    used.assign(n, false);
    for (int i = 0; i < n; i++)
        if (!used[i])
            dfs1(i);
    used.assign(n, false);
    reverse(order.begin(), order.end());
    for (auto v : order)
        if (!used[v]) {
            dfs2 (v);
            // ... processing next component ...
            component.clear();
        }
}
```

5.6 Binary Lifting

```
int n, l;
vector<vector<int>> adj;

int timer;
vector<int> tin, tout;
vector<vector<int>> up;

void dfs(int v, int p) {
    tin[v] = ++timer;
    up[v][0] = p;
    for (int i = 1; i <= l; ++i)
```

```
        up[v][i] = up[up[v][i-1]][i-1];

    for (int u : adj[v]) {
        if (u != p)
            dfs(u, v);
    }

    tout[v] = ++timer;
}

bool is_ancestor(int u, int v) {
    return tin[u] <= tin[v] && tout[u] >= tout[v];
}

int lca(int u, int v) {
    if (is_ancestor(u, v))
        return u;
    if (is_ancestor(v, u))
        return v;
    for (int i = l; i >= 0; --i) {
        if (!is_ancestor(up[u][i], v))
            u = up[u][i];
    }
    return up[u][0];
}

void preprocess(int root) {
    tin.resize(n);
    tout.resize(n);
    timer = 0;
    l = ceil(log2(n));
    up.assign(n, vector<int>(l + 1));
    dfs(root, root);
}
```

6 DP

6.1 DnC

```
int m, n;
vector<long long> dp_before(n), dp_cur(n);

long long C(int i, int j);

// compute dp_cur[l], ... dp_cur[r] (inclusive)
void compute(int l, int r, int optl, int optr) {
    if (l > r)
        return;

    int mid = (l + r) >> 1;
    pair<long long, int> best = {LLONG_MAX, -1};

    for (int k = optl; k <= min(mid, optr); k++) {
        best = min(best, {(k ? dp_before[k - 1] : 0) +
            C(k, mid), k});
    }

    dp_cur[mid] = best.first;
    int opt = best.second;

    compute(l, mid - 1, optl, opt);
    compute(mid + 1, r, opt, optr);
}

int solve() {
    for (int i = 0; i < n; i++)
        dp_before[i] = C(0, i);

    for (int i = 1; i < m; i++) {
        compute(0, n - 1, 0, n - 1);
        dp_before = dp_cur;
    }

    return dp_before[n - 1];
}
```

6.2 Knuth's Optimization

```
int solve() {
    int N;
    ... // read N and input
    int dp[N][N], opt[N][N];

    auto C = [&](int i, int j) {
        ... // Implement cost function C.
    };

    for (int i = 0; i < N; i++) {
        opt[i][i] = i;
        ... // Initialize dp[i][i] according to the
            problem
    }

    for (int i = N-2; i >= 0; i--) {
        for (int j = i+1; j < N; j++) {
            int mn = INT_MAX;
            int cost = C(i, j);
            for (int k = opt[i][j-1]; k <= min(j-1,
                opt[i+1][j]); k++) {
                if (mn >= dp[i][k] + dp[k+1][j] + cost) {
                    opt[i][j] = k;
                    mn = dp[i][k] + dp[k+1][j] + cost;
                }
            }
            dp[i][j] = mn;
        }
    }

    cout << dp[0][N-1] << endl;
}
```

6.3 Parquet Problem

```
int n, m;
vector<vector<long long>> dp;

void calc (int x = 0, int y = 0, int mask = 0, int
    next_mask = 0) {
    if (x == n)
        return;
    if (y >= m)
        dp[x+1][next_mask] += dp[x][mask];
    else {
        int my_mask = 1 << y;
        if (mask & my_mask)
            calc (x, y+1, mask, next_mask);
        else {
            calc (x, y+1, mask, next_mask | my_mask);
```

```
            if (y+1 < m && ! (mask & my_mask) && ! (mask
                & (my_mask << 1)))
                calc (x, y+2, mask, next_mask);
        }
    }
}


int main() {
    cin >> n >> m;
    dp.resize (n+1, vector<long long> (1<<m));
    dp[0][0] = 1;
    for (int x=0; x<n; ++x)
        for (int mask=0; mask<(1<<m); ++mask)
            calc (x, 0, mask, 0);

    cout << dp[n][0];
}
```

6.4 Convex Hull Optimization

```
deque<line> dq;
vector<int> ints(n);
iota(ints.begin(), ints.end(), 0);
auto cmp = [&dq](int idx, int x) { return
    dq[idx].intersectX(dq[idx + 1]) < x; };
dq.push_front({0, 0});
long long ans = 0;
for (int i = 1; i <= n; i++) {
    int idx = *lower_bound(ints.begin(), ints.begin() +
        dq.size() - 1, a[i].q, cmp);
    long long f = dq[idx].eval(rects[i].q) + rects[i].p
        * 1LL * rects[i].q - rects[i].a;
    ans = max(ans, f);
    line cur = {-rects[i].p, f};
    while (dq.size() >= 2 && cur.intersectX(dq[0]) >=
        dq[0].intersectX(dq[1]))
        dq.pop_front();
    dq.push_front(cur);
}
```

7 Miscellaneous

7.1 Matrix Expo

```
template<typename T>
class Matrix {
public:
    vector<vector<T>> mat;

    Matrix() {}

    Matrix(int _n, int _m, T init) {
        mat = vector<vector<T>>(_n, vector<T>(_m,
            init));
    }

    Matrix(const vector<vector<T>>& a) {
        mat = a;
    }

    void set(T init) {
        for(int i = 0; i < rows(); i++) {
            for(int j = 0; j < cols(); j++) {
                mat[i][j] = init;
            }
        }
    }

    int rows() const {
        return mat.size();
    }

    int cols() const {
        return mat[0].size();
    }

    Matrix operator*(const Matrix<T>& obj) const {
        assert(cols() == obj.rows());
        vector<vector<T>> res(rows(),
            vector<T>(obj.cols()));
        for(int r = 0; r < rows(); r++) {
            for(int c = 0; c < obj.cols(); c++) {
                for(int k = 0; k < cols(); k++) {
                    res[r][c] += mat[r][k] *
                        obj.mat[k][c];
                }
            }
        }
        return res;
    }

    vector<T>& operator[](int index) {
        return mat[index];
    }

};

template<typename T>
ostream& operator<<(ostream& os, Matrix<T>& mat) {
    int n = mat.rows(), m = mat.cols();
    for (int i = 0; i < n; i++) {
        for (int j = 0; j < m; j++) {
            os << mat[i][j] << " ";
        }
        os << endl;
    }
    return os;
}

template<typename T>
Matrix<T> power(Matrix<T> res, Matrix<T> a, long long
    b) {
    while(b > 0) {
        if(b & 1) res = a * res;
        a = a * a;
        b >>= 1;
    }
    return res;
}
```

7.2 Ordered Set

```
#include<ext/pb_ds/assoc_container.hpp>
#include<ext/pb_ds/tree_policy.hpp>
using namespace __gnu_pbds;
template<class T> using oset = tree<T, null_type,
    less<T>,
```

```
    rb_tree_tag,tree_order_statistics_node_update>;
// Declaration : oset<data_type> name; Fxn : insert,
    erase, upper_bound, lower_bound, find
// A.order_of_key(x): Number of items strictly smaller
    than k
// *A.find_by_order(k): K-th element in a set (counting
    from zero)
```

7.3 Number Theoretic Transform

```
const int MOD = 998244353; // prime modulo for NTT
const int PRIMITIVE_ROOT = 3; // primitive root of MOD

int power(int a, int b, int mod) {
    int res = 1;
    while (b > 0) {
        if (b & 1) res = (1LL * res * a) % mod;
        a = (1LL * a * a) % mod;
        b >>= 1;
    }
    return res % mod;
}

int inverse(int a, int mod) {
    return power(a, mod - 2, mod);
}

void ntt(vector<int>& a, bool invert) {
    int n = a.size();
    for (int i = 1, j = 0; i < n; i++) {
        int bit = n >> 1;
        while (j >= bit) {
            j -= bit;
            bit >>= 1;
        }
        j += bit;
        if (i < j) swap(a[i], a[j]);
    }
    for (int len = 2; len <= n; len <<= 1) {
        int wlen = invert ?
            inverse(power(PRIMITIVE_ROOT, (MOD - 1) /
            len, MOD), MOD) :
                        power(PRIMITIVE_ROOT, (MOD -
                            1) / len, 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 = (1LL * a[i + j +
                    len / 2] * w) % MOD;
                a[i + j] = (u + v) % MOD;
                a[i + j + len / 2] = (u - v + MOD) % MOD;
                w = (1LL * w * wlen) % MOD;
            }
        }
    }
    if (invert) {
        int n_inv = inverse(n, MOD);
        for (int i = 0; i < n; i++) {
            a[i] = (1LL * a[i] * n_inv) % MOD;
        }
    }
}

vector<int> multiply(vector<int> a, vector<int> b) {
    int n = 1, sz_a = a.size(), sz_b = b.size();
    while (n < sz_a + sz_b) n <<= 1;
    a.resize(n);
    b.resize(n);
    ntt(a, false);
    ntt(b, false);
    for (int i = 0; i < n; i++) {
        a[i] = (1LL * a[i] * b[i]) % MOD;
    }
    ntt(a, true);
    // added later (to fix the size)
    while((int)a.size() > sz_a + sz_b - 1) a.pop_back();
    return a;
}
```