

CodeBook for Competitive Programming

MIST_EaglesExpr

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1 Useful Tips

Big Integer C++ _int128_t

C++ FastIO

```
ios::sync_with_stdio(false); cin.tie(nullptr);
```

Python FastIO

```
import sys;
input = sys.stdin.readline
```

Integer - Binary Conversion in C++

```
bitset<size>(val).to_string();
stoi(str, nullptr, base);
```

Input From File

```
freopen("input.txt", "r", stdin);
```

Python Array Input

```
list(map(int, input().split()))
```

Vim Setup

```
" install xclip, vim-gtk3
set nocompatible
set nocp ai bs=2 hls ic is lbr
ls=2 mouse=a nu ru sc scs
smd so=3 sw=2 ts=2 rnu
filetype plugin indent on
syn on
map gA m'ggVG"+y'
inoremap {<CR> {<CR>}<Esc>ko
nnoremap = mzgg=G'z
vnoremap <C-k> :s/^s*zs\\/\ /<CR>:nohl<CR>
nnoremap <C-k> :s/^s*zs\\/\ /<CR>:nohl<CR>
vnoremap <C-l> :s/^s*zs\\/\ //<CR>:nohl<CR>
nnoremap <C-l> :s/^s*zs\\/\ //<CR>:nohl<CR>
autocmd FileType cpp map <F9> :
w<CR> :!clear; g++ % -DONPC
-o %:r && ./%:r<CR>
" autocmd FileType cpp map <F9>
:w<CR> :!clear; g++ % -o %<
&& gnome-terminal -- ./%<<CR>
>
```

2 Formula

2.1 Area Formula

Rectangle $Area = length * width$

Square $Area = Side * Side$

Triangle $Area = \frac{1}{2} * length * width$

Circle $Area = \pi * radius^2$

Parallelogram $Area = base * height$

Pyramid Base $Area = \frac{1}{2} * base * slantHeight$

Polygon

a $Area = \frac{1}{2} |\sum_{n=1}^{n-1} (x_i y_{i+1})|$

b (Pick's formula) $Area = a + \frac{b}{2} - 1$ (for int coordinates). Here a = int points inside polygon and b = int points outside polygon.

2.2 Perimeter Formulas

Rectangle $Perimeter = 2 * (length + width)$

Square $Perimeter = 4 * side$

Triangle $Perimeter = 4 * side$

Circle $Perimeter = 2 * \pi * radius$

2.3 Volume Formula

Cube $Volume = side^3$

Rect Prism $Volume = length * width * height$

Cylinder $Volume = \pi * radius^2 * height$

Sphere $Volume = \frac{4}{3} * \pi * radius^3$

Pyramid $Volume = \frac{1}{3} * baseArea * height$

2.4 Surface Area Formula

Cube $SurfaceArea = 6 * side^2$

Rectangle Prism $SurfaceArea = 2 * (length * width + length * height + width * height)$

Cylinder $SurfaceArea = 2 * \pi * radius * (radius + height)$

Sphere $SurfaceArea = 4 * \pi * radius^2$

Pyramid $SurfaceArea = basearea + \frac{1}{2} * perimeterOfBase * slantHeight$

2.5 Triangles

Side Lengths a, b, c

Semi Perimeter $p = \frac{a+b+c}{2}$

Area $A = \sqrt{p(p-a)(p-b)(p-c)}$

Circumstance $R = \frac{abc}{4A}$

In Radius $r = \frac{A}{p}$

2.6 Summation Of Series

- $c^k + c^{k+1} + \dots + c^n = c^{n+1} - c^k$
- $1 + 2 + 3 + \dots + n = \frac{n(n+1)}{2}$
- $1^2 + 2^2 + 3^2 + \dots + n^2 = \frac{n(n+1)(2n+1)}{6}$
- $1^3 + 2^3 + 3^3 + \dots + n^3 = \left(\frac{n(n+1)}{2}\right)^2$

2.7 Miscellaneous

- $2^{100} = 2^{50} * 2^{50}$
- $\begin{bmatrix} F_n \\ F_{n-1} \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix}^{n-1} \begin{bmatrix} F_1 \\ F_0 \end{bmatrix}$
- $\log n! = \log 1 + \log 2 + \dots + \log n$
- $\gcd(a, b) = \gcd(a - b, b)$
- Number of occurrence of a prime number p in $n!$ is $\lfloor \frac{n}{p} \rfloor + \lfloor \frac{n}{p^2} \rfloor + \lfloor \frac{n}{p^3} \rfloor + \dots + 0$
- Formula of Catalan number is $\binom{2n}{n} - \binom{2n}{n-1}$
- Number of divisors of $p^x q^y$ where p and q are prime is $(x+1) * (y+1)$
- Sum of divisors of $p^x q^y$ where p and q are prime is $(1+p+p^2+\dots+p^x)(1+q+q^2+\dots+q^y)$
- Divisibility rules for a number
 - 3 The sum of its digits is divisible by 3.
 - 4 Last two digits form a number that is divisible by 4.
 - 5 The number ends in 0 or 5.
 - 6 Divisible by both 2 and 3.
 - 7 A rule for 7 is to double the last digit, subtract it from the rest of the number, and check if the result is divisible by 7. Repeat if necessary.
 - 8 Last three digits form a number divisible by 8.
 - 9 Sum of its digits is divisible by 9
 - 11 Difference between the sum of digits of odd places and even places is divisible by 11.
- Derangement Number
 n person put their hat in a box. How many way they can collect hat such that no one get their own hat - $D_n = (n-1)D_{n-2} + (n-1)D_{n-1}$
- Golden Ratio $\Phi = (\frac{1+\sqrt{5}}{2}) \approx 1.618034$
- n th Fibonacci number $F_n = \frac{\Phi^n - (1-\Phi)^n}{\sqrt{5}}$
- Stars and Bars
 Number of solutions of $x_1 + x_2 + x_3 + \dots + x_k = n$ is $\binom{n+k-1}{k-1}$ where $x_i > 0$ and $\binom{n+k-1}{k-1}$ where $x_i \geq 0$

3 Graph Theory

All about graph.

3.1 BFS

```
void bfs(int start, int target = -1) {
    queue<int> q;
    q.push(start);
    vis[start] = true;
    while (!q.empty()) {
        int u = q.front();
        q.pop();
        for (int i : adj[u]) {
            if (!vis[i]) {
                vis[i] = true;
                q.push(i);
            }
        }
    }
}
```

3.2 DFS

```
map<int, vector<int>>> adj;
map<int, int> visited, parent, level, color;

void dfs(int start)
{
    visited[start]=1;
    for (auto child : adj[start])
    {
        if (!visited[child])
        {
            dfs(child);
        }
    }
    visited[start]=2;
}
```

3.3 Dijkstra Algorithm

```
void Dijkstra(int start) {
    // vector<pair<int, int>> adj[N];
    priority_queue<pair<int, int>>, greater<pair<int, int>>> pq;
    pq.push({0, start});
    while (!pq.empty()) {
        auto it = pq.top();
        pq.pop();
        int wt = it.first;
        int u = it.second;
        if (vis[u])
            continue;
        vis[u] = 1;
        for (pair<int, int> i : adj[u]) {
            int adjWt = i.second;
            int adjNode = i.first;
            if (dist[adjNode] > wt + adjWt)
            {
                dist[adjNode] = wt + adjWt;
            }
        }
    }
}
```

```

        pq.push({dist[adjNode],
                adjNode});
    }
}
}
}

```

3.4 Bellman Ford

```

vector<int> dist;
vector<int> parent;
vector<vector<pair<int, int>>> adj;
// resize the vectors from main
function
void bellmanFord(int num_of_nd, int
    src) {
    dist[src] = 0;
    for (int step = 0; step < num_of_nd;
        step++) {
        for (int i = 1; i <= num_of_nd; i
            ++){
            for (auto it : adj[i]) {
                int u = i;
                int v = it.first;
                int wt = it.second;
                if (dist[u] != inf &&
                    ((dist[u] + wt) < dist[v])
                ) {
                    if (step == num_of_nd - 1) {
                        cout << "Negative cycle
                            found\n ";
                        return;
                    }
                    dist[v] = dist[u] + wt;
                    parent[v] = u;
                }
            }
        }
    }
    for (int i = 1; i <= num_of_nd; i++)
        cout << dist[i] << " ";
    cout << endl;
}

```

3.5 Floyd Warshall Algorithm

```

typedef double T;
typedef vector<T> VT;
typedef vector<VT> VVT;
typedef vector<int> VI;
typedef vector<VI> VVI;
bool FloydWarshall(VVT &w, VVI &prev)
{
    int n = w.size();
    prev = VVI(n, VI(n, -1));
    for (int k = 0; k < n; k++) {
        for (int i = 0; i < n; i++) {
            for (int j = 0; j < n; j++) {
                if (w[i][j] > w[i][k] + w[k][j]) {
                    w[i][j] = w[i][k] + w[k][j];
                    prev[i][j] = k;
                }
            }
        }
    }
}

```

```

    }
}
for (int i = 0; i < n; i++)
    if (w[i][i] < 0)
        return false;
return true;
}

```

3.6 Kruskal Algorithm (MST)

```

vector<pair<int, pair<int, int>>>
    Kruskal(vector<pair<int, pair<int,
        int>>> &edges, int n) {
    sort(edges.begin(), edges.end());
    vector<pair<int, pair<int, int>>>
        ans;
    DisjointSet D(n);
    for (auto it : edges) {
        if (D.findUPar(it.second.first) !=
            D.findUPar(it.second.second))
        {
            ans.push_back({it.first, {it.
                second.first, it.second.
                second}});
            D.unionBySize(it.second.first,
                it.second.second);
        }
    }
    return ans;
}

```

3.7 Prims Algorithm (MST)

```

void Prims(int start) {
    // map<int, vector<pair<int, int>>>
    adj, ans;
    priority_queue<pair<int, pair<int,
        int>>, vector<pair<int, pair<int,
        int>>>, greater<pair<int, pair
        <int, int>>>> pq;
    pq.push({0, {start, -1}});
    while (!pq.empty()) {
        auto it = pq.top();
        pq.pop();
        int wt = it.first;
        int u = it.second.first;
        int v = it.second.second;
        if (vis[u]) continue;
        vis[u] = 1;
        if (v != -1) ans[u].push_back({v,
            wt});
        for (pair<int, int> i : adj[u]) {
            int adjWt = i.second;
            int adjNode = i.first;
            if (!vis[adjNode]) pq.push({
                adjWt, {adjNode, u}});
        }
    }
}

```

3.8 Strongly Connected Components

```

vector<bool> visited; // keeps track
                      // of which vertices are already
                      // visited

// runs depth first search starting at
// vertex v.
// each visited vertex is appended to
// the output vector when dfs leaves
// it.
void dfs(int v, vector<vector<int>>
        const &adj, vector<int> &output) {
    visited[v] = true;
    for (auto u : adj[v])
        if (!visited[u])
            dfs(u, adj, output);
    output.push_back(v);
}

// input: adj -- adjacency list of G
// output: components -- the strongly
//         connected components in G
// output: adj_cond -- adjacency list
//         of G^SCC (by root vertices)
void scc(vector<vector<int>> const &
        adj, vector<vector<int>> &
        components, vector<vector<int>> &
        adj_cond) {
    int n = adj.size();
    components.clear(), adj_cond.clear();

    vector<int> order; // will be a
                      // sorted list of G's vertices by
                      // exit time

    visited.assign(n, false);

    // first series of depth first
    // searches
    for (int i = 0; i < n; i++)
        if (!visited[i])
            dfs(i, adj, order);

    // create adjacency list of G^T
    vector<vector<int>> adj_rev(n);
    for (int v = 0; v < n; v++)
        for (int u : adj[v])
            adj_rev[u].push_back(v);

    visited.assign(n, false);
    reverse(order.begin(), order.end());

    vector<int> roots(n, 0); // gives
                          // the root vertex of a vertex's
                          // SCC

    // second series of depth first
    // searches
    for (auto v : order)
        if (!visited[v]) {
            std::vector<int> component;
            dfs(v, adj_rev, component);
            components.push_back(component);

```

```

            int root = *min_element(begin(
                component), end(component));
            for (auto u : component)
                roots[u] = root;
        }

    // add edges to condensation graph
    adj_cond.assign(n, {});
    for (int v = 0; v < n; v++)
        for (auto u : adj[v])
            if (roots[v] != roots[u])
                adj_cond[roots[v]].push_back(
                    roots[u]);
}

```

3.9 LCA

```

struct LCA {
    vector<int> height, euler, first,
        segtree, parent;
    vector<bool> visited;
    vector<vector<int>> jump;

    int n;

    LCA(vector<vector<int>> &adj, int
        root = 0) {
        n = adj.size();
        height.resize(n);
        first.resize(n);
        parent.resize(n);
        euler.reserve(n * 2);
        visited.assign(n, false);
        dfs(adj, root);
        int m = euler.size();
        segtree.resize(m * 4);
        build(1, 0, m - 1);

        jump.resize(n, vector<int>(32, -1));

        for (int i = 0; i < n; i++) {
            jump[i][0] = parent[i];
        }

        for (int j = 1; j < 20; j++) {
            for (int i = 0; i < n; i++) {
                int mid = jump[i][j-1];
                if (mid != -1) jump[i][j] =
                    jump[mid][j-1];
            }
        }
    }

    void dfs(vector<vector<int>> &adj,
        int node, int h = 0) {
        visited[node] = true;
        height[node] = h;
        first[node] = euler.size();
        euler.push_back(node);
        for (auto to : adj[node]) {
            if (!visited[to]) {
                parent[to] = node;
                dfs(adj, to, h + 1);
            }
        }
    }
}

```

```

        euler.push_back(node);
    }
}

void build(int node, int b, int e) {
    if (b == e) {
        segtree[node] = euler[b];
    } else {
        int mid = (b + e) / 2;
        build(node << 1, b, mid);
        build(node << 1 | 1, mid + 1, e);
        ;
        int l = segtree[node << 1], r =
            segtree[node << 1 | 1];
        segtree[node] = (height[l] <
            height[r]) ? l : r;
    }
}

int query(int node, int b, int e,
    int L, int R) {
    if (b > R || e < L)
        return -1;
    if (b >= L && e <= R)
        return segtree[node];
    int mid = (b + e) >> 1;

    int left = query(node << 1, b, mid,
        L, R);
    int right = query(node << 1 | 1,
        mid + 1, e, L, R);
    if (left == -1)
        return right;
    if (right == -1)
        return left;
    return height[left] < height[right]
        ? left : right;
}

int lca(int u, int v) {
    int left = first[u], right = first
        [v];
    if (left > right)
        swap(left, right);
    return query(1, 0, euler.size() -
        1, left, right);
}

int kthParent(int u, int k) {
    for(int i=0; i<19; i++) {
        if(k & (1LL<<i)) u = jump[u]
            [i];
    }
    return u;
}
};

```

3.10 Max Flow

```

const int N = 505;
int capacity[N][N];
int vis[N], p[N];
int n, m;

```

```

int bfs(int s, int t) {
    memset(vis, 0, sizeof vis);
    queue<int> qu;
    qu.push(s);
    vis[s] = 1;
    while (!qu.empty()) {
        int u = qu.front();
        qu.pop();
        for (int i = 0; i <= n + m + 2; i
            ++){
            if (capacity[u][i] > 0 && !vis[i]
                ) {
                p[i] = u;
                vis[i] = 1;
                qu.push(i);
            }
        }
    }
    return vis[t] == 1;
}

int maxflow(int s, int t) {
    int cnt = 0;
    while (bfs(s, t)) {
        int cur = t;
        while (cur != s) {
            int prev = p[cur];
            capacity[prev][cur] -= 1;
            capacity[cur][prev] += 1;
            cur = prev;
        }
        cnt++;
    }
    return cnt;
}

```

4 Data Structures

Different Data Structures.

4.1 Segment Tree

```

constexpr int N = 100005;
int arr[N], seg[N];

void build(int ind, int low, int high)
{
    if (low == high) {
        seg[ind] = arr[low];
        return;
    }
    int mid = (low + high) / 2;
    build(2 * ind + 1, low, mid);
    build(2 * ind + 2, mid + 1, high);
    seg[ind] = seg[2 * ind + 1] + seg[2
        * ind + 2];
}

int query(int ind, int low, int high,
    int l, int r) {
    if (low >= l && high <= r) return
        seg[ind];
    if (low > r || high < l) return 0;
}

```

```

    int mid = (low + high) / 2;
    int left = query(2 * ind + 1, low,
                    mid, 1, r);
    int right = query(2 * ind + 2, mid +
                     1, high, 1, r);
    return left + right;
}
void update(int ind, int low, int high
           , int node, int val) {
    if (low == high) {
        seg[ind] = val;
        return;
    }
    int mid = (low + high) / 2;
    if (low <= node && node <= mid)
        update(2 * ind + 1, low, mid,
              node, val);
    else update(2 * ind + 2, mid + 1,
              high, node, val);
    seg[ind] = seg[2 * ind + 1] + seg[2
    * ind + 2];
}

```

4.2 Segment Tree Lazy

```

const int N = 1e5 + 5;
int arr[N], seg[N << 2], lz[N << 2];

void pull(int node, int l, int r) {
    seg[node] = seg[node << 1] + seg[
    node << 1 | 1];
}

void push(int node, int l, int r) {
    int mid = (l + r) >> 1;
    lz[node << 1] += lz[node];
    seg[node << 1] += lz[node] * (mid -
    1 + 1);
    lz[node << 1 | 1] += lz[node];
    seg[node << 1 | 1] += lz[node] * (r
    - mid);
    lz[node] = 0;
}

void build(int node, int l, int r) {
    if(l == r) {
        seg[node] = arr[l];
        lz[node] = 0;
        return;
    }
    int mid = (l + r) >> 1;
    build(node << 1, l, mid);
    build(node << 1 | 1, mid + 1, r);
    pull(node, l, r);
}

void update(int node, int l, int r,
           int ql, int qr, int val) {
    if(qr < l || r < ql) return;
    if(ql <= l && r <= qr) {
        seg[node] += val;
        lz[node] += val;
        return;
    }
}

```

```

push(node, l, r);

int mid = (l + r) >> 1;
update(node << 1, l, mid, ql, qr,
      val);
update(node << 1 | 1, mid + 1, r, ql
      , qr, val);

pull(node, l, r);
}

int query(int node, int l, int r, int
         ql, int qr) {
    if(qr < l || r < ql) return 0;
    if(ql <= l && r <= qr) return seg[
    node];

    push(node, l, r);

    int mid = (l + r) >> 1;
    return query(node << 1, l, mid, ql,
                qr) + query(node << 1 | 1, mid +
                1, r, ql, qr);
}

```

4.3 Fenwick Tree

```

int fenwick[N];

void update(int ind, int val) {
    while (ind < N) {
        fenwick[ind] += val;
        ind += ind & -ind;
    }
}

int query(int ind) {
    int sum = 0;
    while (ind > 0) {
        sum += fenwick[ind];
        ind -= ind & -ind;
    }
    return sum;
}

```

4.4 Disjoint Set

```

class DisjointSet {
    vector<int> parent, sz;

public:
    DisjointSet(int n) {
        sz.resize(n + 1);
        parent.resize(n + 2);
        for (int i = 1; i <= n; i++)
            parent[i] = i, sz[i] = 1;
    }

    int findUPar(int u) { return parent[
    u] == u ? u : parent[u] =
    findUPar(parent[u]); }

    void unionBySize(int u, int v) {
        int a = findUPar(u);
        int b = findUPar(v);
        if (sz[a] < sz[b]) swap(a, b);
    }
}

```

```

        if (a != b) {
            parent[b] = a;
            sz[a] += sz[b];
        }
    }
};

4.5 TRIE

const int N = 26;
class Node {
public:
    int EoW;
    Node* child[N];
    Node() {
        EoW = 0;
        for (int i = 0; i < N; i++) child[i] = NULL;
    }
};

void insert(Node* node, string s) {
    for (size_t i = 0; i < s.size(); i++) {
        int r = s[i] - 'A';
        if (node->child[r] == NULL) node->child[r] = new Node();
        node = node->child[r];
    }
    node->EoW += 1;
}

int search(Node* node, string s) {
    for (size_t i = 0; i < s.size(); i++) {
        int r = s[i] - 'A';
        if (node->child[r] == NULL) return 0;
    }
    return node->EoW;
}

void print(Node* node, string s = "") {
    {
        if (node->EoW) cout << s << "\n";
        for (int i = 0; i < N; i++) {
            if (node->child[i] != NULL) {
                char c = i + 'A';
                print(node->child[i], s + c);
            }
        }
    }
}

bool isChild(Node* node) {
    for (int i = 0; i < N; i++)
        if (node->child[i] != NULL) return true;
    return false;
}

bool isJunc(Node* node) {
    int cnt = 0;
    for (int i = 0; i < N; i++) {
        if (node->child[i] != NULL) cnt++;
    }
}

```

```

    }
    if (cnt > 1) return true;
    return false;
}

int trie_delete(Node* node, string s, int k = 0) {
    if (node == NULL) return 0;
    if (k == (int)s.size()) {
        if (node->EoW == 0) return 0;
        if (isChild(node)) {
            node->EoW = 0;
            return 0;
        }
        return 1;
    }
    int r = s[k] - 'A';
    int d = trie_delete(node->child[r], s, k + 1);
    int j = isJunc(node);
    if (d) delete node->child[r];
    if (j) return 0;
    return d;
}

void delete_trie(Node* node) {
    for (int i = 0; i < 15; i++) {
        if (node->child[i] != NULL)
            delete_trie(node->child[i]);
    }
    delete node;
}

```

4.6 Ordered Set

```

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

template <typename T> using o_set =
    tree<T, null_type, less<T>,
        rb_tree_tag,
        tree_order_statistics_node_update
    >;
// o_set<int> st;
// *(st.find_by_order(index))
// st.order_of_key(value)

```

4.7 Mo's Algorithm

```

void remove(int idx);
void add(int idx);
int get_answer();

int block_size = 700;

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

```



```

        return r < 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;
}

```

5 Algorithms

All about algorithms.

5.1 Monotonic Stack (Immediate Large)

```

for (int i = n - 1; i >= 0; i--) {
    while (!stk.empty() && v[i] >= v[stk
        .top()]) stk.pop();
    ind[i] = stk.empty() ? -1 : stk.top
        ();
    stk.push(i);
}
// 3 1 5 4 10
// 2 2 4 4 -1

```

5.2 Kadane's Algorithm

```

int maxSubArraySum(vector<int> &a) {
    int size = a.size();
    int maxTill = INT_MIN, maxEnd = 0;
    for (int i = 0; i < size; i++) {
        maxEnd = maxEnd + a[i];

```

```

        if (maxTill < maxEnd) maxTill =
            maxEnd;
        if (maxEnd < 0) maxEnd = 0;
    }
    return maxTill;
}

```

5.3 2D Prefix Sum

```

pref[i][j] = a[i][j] + pref[i - 1][j]
    + pref[i][j - 1] - pref[i - 1][j -
        1];
Sum of region = pref[row2 + 1][col2 +
    1] - pref[row2 + 1][col1] - pref[
    row1][col2 + 1] + pref[row1][col1
    ];

```

5.4 2D Convex Hull

```

struct pt {
    double x, y;
    bool operator == (pt const& t)
        const {
            return x == t.x && y == t.y;
        }
};

int orientation(pt a, pt b, pt c) {
    double v = a.x*(b.y-c.y)+b.x*(c.y-
        a.y)+c.x*(a.y-b.y);
    if (v < 0) return -1; // clockwise
    if (v > 0) return +1; // counter-
        clockwise
    return 0;
}

bool cw(pt a, pt b, pt c, bool
    include_collinear) {
    int o = orientation(a, b, c);
    return o < 0 || (include_collinear
        && o == 0);
}

bool collinear(pt a, pt b, pt c) {
    return orientation(a, b, c) == 0;
}

void convex_hull(vector<pt>& a, bool
    include_collinear = false) {
    pt p0 = *min_element(a.begin(), a.
        end(), [](pt a, pt b) {
        return make_pair(a.y, a.x) <
            make_pair(b.y, b.x);
        });
    sort(a.begin(), a.end(), [&p0](
        const pt& a, const pt& b) {
        int o = orientation(p0, a, b);
        if (o == 0)
            return (p0.x-a.x)*(p0.x-a.
                x) + (p0.y-a.y)*(p0.y-
                a.y)
                < (p0.x-b.x)*(p0.x-b.x
                ) + (p0.y-b.y)*(p0
                .y-b.y);
        return o < 0;
    });
}

```

```

});
if (include_collinear) {
    int i = (int)a.size()-1;
    while (i >= 0 && collinear(p0,
        a[i], a.back())) i--;
    reverse(a.begin()+i+1, a.end());
}

vector<pt> st;
for (int i = 0; i < (int)a.size();
    i++) {
    while (st.size() > 1 && !cw(st
        [st.size()-2], st.back(),
        a[i], include_collinear))
        st.pop_back();
    st.push_back(a[i]);
}

if (include_collinear == false &&
    st.size() == 2 && st[0] == st
    [1])
    st.pop_back();

a = st;
}

```

6 Number Theory

All about math.

6.1 nCr

```

int inverseMod(int a, int m) { return
    power(a, m - 2); }

int nCr(int n, int r, int m = mod){
    if(r==0) return 1;
    if(r>n) return 0;
    return (fact[n] * inverseMod((fact[
        r] * fact[n-r]) % m , m)) % m;
}

```

6.2 Power

```

int power(int base, int n, int m = mod
) {
    if (n == 0) return 1;
    if (n & 1) {
        int x = power(base, n / 2);
        return ((x * x) % m * base) % m;
    }
    else {
        int x = power(base, n / 2);
        return (x * x) % m;
    }
}

```

6.3 Miller Rabin

```

using u64 = uint64_t;
using u128 = __uint128_t;

```

```

u64 binpower(u64 base, u64 e, u64 mod)
{
    u64 result = 1;
    base %= mod;
    while (e) {
        if (e & 1) result = (u128)result *
            base % mod;
        base = (u128)base * base % mod;
        e >>= 1;
    }
    return result;
}

```

```

bool check_composite(u64 n, u64 a, u64
    d, int s) {
    u64 x = binpower(a, d, n);
    if (x == 1 || x == n - 1) return
        false;
    for (int r = 1; r < s; r++) {
        x = (u128)x * x % n;
        if (x == n - 1) return false;
    }
    return true;
};

```

```

bool MillerRabin(u64 n, int iter = 5)
{ // returns true if n is
    probably prime, else returns false
    .
    if (n < 4) return n == 2 || n == 3;
    int s = 0;
    u64 d = n - 1;
    while ((d & 1) == 0) {
        d >>= 1;
        s++;
    }

    for (int i = 0; i < iter; i++) {
        int a = 2 + rand() % (n - 3);
        if (check_composite(n, a, d, s))
            return false;
    }
    return true;
}

```

6.4 Sieve

```

const int N = 1e7 + 3;
vector<int> primes;
int notprime[N];

void sieve() {
    primes.push_back(2);
    for (int i = 4; i < N; i += 2) {
        notprime[i] = true;
    }
    for (int i = 3; i < N; i += 2) {
        if (!notprime[i]) {
            primes.push_back(i);
            for (int j = i * i; j < N; j +=
                2 * i) {
                notprime[j] = true;
            }
        }
    }
}

```

```

    }
}

```

6.5 Bitset Sieve

```

const int sieve_size = 10000006;
bitset<sieve_size> sieve;

void Sieve() {
    sieve.flip();
    int finalBit = sqrt(sieve.size()) + 1;
    for (int i = 2; i < finalBit; ++i) {
        if (sieve.test(i))
            for (int j = 2 * i; j < sieve_size; j += i) sieve.reset(j);
    }
}

```

6.6 Segmented Sieve

Need Sieve() from 6.4

```

void segmentedSieve(int L, int R) {
    bool isPrime[R - L + 1];
    for (int i = 0; i <= R - L + 1; i++)
        isPrime[i] = true;
    if (L == 1) isPrime[0] = false;
    for (int i = 0; primes[i] * primes[i] <= R; i++) {
        int curPrime = primes[i];
        int base = curPrime * curPrime;
        if (base < L) {
            base = ((L + curPrime - 1) / curPrime) * curPrime;
        }
        for (int j = base; j <= R; j += curPrime) isPrime[j - L] = false;
    }
    for (int i = 0; i <= R - L; i++) {
        if (isPrime[i] == true) cout << L + i << '\n';
    }
    cout << '\n';
}

```

6.7 Divisors

```

constexpr int N = 1000005;

int Prime[N + 4], kk;
bool notPrime[N + 5];
void SieveOf() {
    notPrime[1] = true;
    Prime[kk++] = 2;
    for (int i = 4; i <= N; i += 2)
        notPrime[i] = true;
    for (int i = 3; i <= N; i += 2) {
        if (!notPrime[i]) {
            Prime[kk++] = i;
            for (int j = i * i; j <= N; j += 2 * i) notPrime[j] = true;
        }
    }
}

```

```

    }
}
}

```

```

void Divisors(int n) {
    int sum = 1, total = 1;
    int mnP = INT_MAX, mxP = INT_MIN,
        cntP = 0, totalP = 0;
    for (int i = 0; i <= N && Prime[i] * Prime[i] <= n; i++) {
        if (n % Prime[i] == 0) {
            mnP = min(mnP, Prime[i]);
            mxP = max(mxP, Prime[i]);
            int k = 0;
            cntP++;
            while (n % Prime[i] == 0) {
                k++;
                n /= Prime[i];
            }

            sum *= (k + 1); // NOD
            totalP += k;
            int s = 0, p = 1;
            while (k-- >= 0) {
                s += p;
                p *= Prime[i];
            };
            total *= s; // SOD
        }
    }
    if (n > 1) {
        cntP++, totalP++;
        sum *= 2;
        total *= (1 + n);
        mnP = min(mnP, n);
        mxP = max(mxP, n);
    }
    cout << mnP << " " << mxP << " " <<
        cntP << " " << totalP << " " <<
        sum << " " << total << "\n";
}

```

6.8 Euler's Totient Phi Function

```

const int N = 5000005;
int phi[N];
unsigned long long phiSum[N];
void phiCalc() {
    for (int i = 2; i < N; i++) phi[i] = i;
    for (int i = 2; i < N; i++) {
        if (phi[i] == i) {
            for (int j = i; j < N; j += i) {
                phi[j] -= phi[j] / i;
            }
        }
    }
    for (int i = 2; i < N; i++) {
        phiSum[i] = (unsigned long long)
            phi[i] * (unsigned long long)
            phi[i] + phiSum[i - 1];
    }
}

```

6.9 Log a base b

```
int logab (int a, int b){
    return log2(a) / log2(b);
}
```

6.10 Count 1's from 0 to n

```
int cntOnes(int n) {
    int cnt = 0;
    for(int i=1; i<=n; i<=1) {
        int x = (n + 1) / (i << 1);
        cnt += x * i;
        if((n + 1) % i && n & i) cnt += (n
            + 1) % i;
    }
    return cnt;
}
```

6.11 Primes Upto 1e9

```
// credit: min_25
// takes 0.5s for n = 1e9
vector<int> sieve(const int N, const
    int Q = 17, const int L = 1 << 15)
{
    static const int rs[] = {1, 7, 11,
        13, 17, 19, 23, 29};
    struct P {
        P(int p) : p(p) {}
        int p; int pos[8];
    };
    auto approx_prime_count = [] (const
        int N) -> int {
        return N > 60184 ? N / (log(N) -
            1.1)
            : max(1., N / (
                log(N) -
                1.11)) + 1;
    };
    const int v = sqrt(N), vv = sqrt(v);
    vector<bool> isp(v + 1, true);
    for (int i = 2; i <= vv; ++i) if (
        isp[i]) {
        for (int j = i * i; j <= v; j += i
            ) isp[j] = false;
    }
    const int rsize = approx_prime_count
        (N + 30);
    vector<int> primes = {2, 3, 5}; int
        psize = 3;
    primes.resize(rsize);
    vector<P> sprimes; size_t pbeg = 0;
    int prod = 1;
    for (int p = 7; p <= v; ++p) {
        if (!isp[p]) continue;
        if (p <= Q) prod *= p, ++pbeg,
            primes[psize++] = p;
        auto pp = P(p);
        for (int t = 0; t < 8; ++t) {
            int j = (p <= Q) ? p : p * p;
```

```
            while (j % 30 != rs[t]) j += p
                << 1;
            pp.pos[t] = j / 30;
        }
        sprimes.push_back(pp);
    }
    vector<unsigned char> pre(prod, 0xFF
        );
    for (size_t pi = 0; pi < pbeg; ++pi)
        {
            auto pp = sprimes[pi]; const int p
                = pp.p;
            for (int t = 0; t < 8; ++t) {
                const unsigned char m = ~(1 << t
                    );
                for (int i = pp.pos[t]; i < prod
                    ; i += p) pre[i] &= m;
            }
        }
    const int block_size = (L + prod -
        1) / prod * prod;
    vector<unsigned char> block(
        block_size); unsigned char*
        pblock = block.data();
    const int M = (N + 29) / 30;
    for (int beg = 0; beg < M; beg +=
        block_size, pblock -= block_size
        ) {
        int end = min(M, beg + block_size)
            ;
        for (int i = beg; i < end; i +=
            prod) {
            copy(pre.begin(), pre.end(),
                pblock + i);
        }
        if (beg == 0) pblock[0] &= 0xFE;
        for (size_t pi = pbeg; pi <
            sprimes.size(); ++pi) {
            auto& pp = sprimes[pi];
            const int p = pp.p;
            for (int t = 0; t < 8; ++t) {
                int i = pp.pos[t]; const
                    unsigned char m = ~(1 << t
                        );
                for (; i < end; i += p) pblock
                    [i] &= m;
                pp.pos[t] = i;
            }
        }
        for (int i = beg; i < end; ++i) {
            for (int m = pblock[i]; m > 0; m
                &= m - 1) {
                primes[psize++] = i * 30 + rs[
                    __builtin_ctz(m)];
            }
        }
    }
    assert(psize <= rsize);
    while (psize > 0 && primes[psize -
        1] > N) --psize;
```

```

    primes.resize(psize);
    return primes;
}

```

6.12 Matrix Multiplication

```

const int mod = 1000000007;

vector<vector<i64>> multi(vector<
    vector<i64>> &m1, vector<vector<
    i64>> &m2) {
    int n = m1.size();
    vector<vector<i64>> res(n, vector<
    i64>(n, 0));
    for (int i = 0; i < n; i++) {
        for (int j = 0; j < n; j++) {
            for (int k = 0; k < n; k++) {
                res[i][j] = (res[i][j] + (m1[i]
                    ][k] * m2[k][j]) % mod) %
                    mod;
            }
        }
    }
    return res;
}

vector<vector<i64>> power(vector<
    vector<i64>> &base, int n, int m =
    mod) {
    int r = base.size();
    vector<vector<i64>> identity(r,
    vector<i64>(r));
    for (int i = 0; i < r; i++) {
        identity[i][i] = 1;
    }
    while (n > 0) {
        if (n % 2 == 1) {
            identity = multi(base, identity)
                ;
        }
        base = multi(base, base);
        n /= 2;
    }
    return identity;
}

```

6.13 Extended GCD

```

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

```

7 Dynamic Programming

7.1 LCS (Longest Common Subsequence)

```

string s, t;
vector<vector<int>> dp(3003, vector<
    int>(3003, -1));
vector<vector<int>> mark(3003, vector<
    int>(3003));

int f(int i, int j) {
    if (i < 0 || j < 0) return 0;
    if (dp[i][j] != -1) return dp[i][j];
    int res = 0;
    if (s[i] == t[j]) {
        mark[i][j] = 1;
        res = 1 + f(i - 1, j - 1);
    }
    else {
        int iC = f(i - 1, j);
        int jC = f(i, j - 1);
        if (iC > jC) mark[i][j] = 2;
        else mark[i][j] = 3;
        res = max(iC, jC);
    }
    return dp[i][j] = res;
}

void printWay(int i, int j) {
    if (i < 0 || j < 0) return;
    if (mark[i][j] == 1) printWay(i - 1,
        j - 1), cout << s[i];
    else if (mark[i][j] == 2) printWay(i
        - 1, j);
    else if (mark[i][j] == 3) printWay(i
        , j - 1);
}

```

7.2 LIS (Longest Increasing Subsequence)

```

void lis(vector<int> &v) {
    int n = v.size();
    vector<int> dp(n + 1, 1), hash(n);
    int mx = 1, lastInd = 0;
    for (int i = 0; i < n; i++) {
        hash[i] = i;
        for (int prev = 0; prev < i; prev
            ++){
            if (v[i] > v[prev] && 1 + dp[
                prev] > dp[i]) {
                dp[i] = 1 + dp[prev];
                hash[i] = prev;
            }
        }
        if (mx < dp[i]) {
            mx = dp[i];
            lastInd = i;
        }
    }
    vector<int> printSeq;
    printSeq.push_back(v[lastInd]);
}

```

```

while (hash[lastInd] != lastInd) {
    lastInd = hash[lastInd];
    printSeq.push_back(v[lastInd]);
}
reverse(printSeq.begin(), printSeq.
    end());
cout << mx << "\n";
for (int i : printSeq) cout << i <<
    " ";
cout << "\n";
}

```

7.3 SOS (Sum Of Subsets)

```

void SOS (vector<int> &v) {
    const int BITS = log2(*max_element(v
        .begin(), v.end())) + 1;
    vector<int> freq(1 << BITS, 0);
    for (int mask : v) freq[mask]++;

    vector<vector<int>> dp(BITS + 1,
        vector<int> (1 << BITS, 0));
    for (int mask = 0; mask < 1 << BITS;
        mask++) {
        dp[0][mask] = freq[mask];
    }

    for (int bits = 1; bits <= BITS;
        bits++) {
        for (int mask = 0; mask < 1 <<
            BITS; mask++) {
            if ((mask & (1 << (bits - 1)))
                == 0) {
                dp[bits][mask] = dp[bits - 1][
                    mask];
            }
            else {
                int other_mask = mask - (1 <<
                    (bits - 1));
                dp[bits][mask] = dp[bits - 1][
                    mask] + dp[bits - 1][
                        other_mask];
            }
        }
    }

    for (int mask : v) cout << dp[BITS][
        mask] << '\n';
}

// dp[bits][mask] means left most '
// bits' of submasks can be differ
// for dp[1][11] 01, 00 are now allow
// because leftmost 1 bit can be
// differ. 10 and 11 are allowed.
// for traversing all the submask of a
// mask we can use
// submask = mask
// do {
// submask = (submask - 1) & mask
// } while (submask)

```

7.4 MCM (Matrix Chain Multipli- cation)

```

ans = min(ans, MCM(i, k) + MCM(k + 1,
    j) + v[i - 1] * v[k] * v[j]);

```

8 Strings

8.1 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;
}

vector<int> find_matches(string text,
    string pat) {
    int n = pat.length(), m = text.
        length();
    string s = pat + "$" + text;
    vector<int> pi = prefix_function(s
        ), ans;
    for (int i = n; i <= n + m; i++) {
        if (pi[i] == n) {
            ans.push_back(i - 2 * n);
        }
    }
    return ans;
}

```

8.2 Double Hashing

Need power() from 6.2

```

const int N = 1e6 + 9;
const int MOD1 = 127657753, MOD2 =
    987654319;
const int p1 = 137, p2 = 277;
int ip1, ip2;
pair<int, int> pw[N], ipw[N];
void prec() {
    pw[0] = {1, 1};
    for (int i = 1; i < N; i++) {
        pw[i].first = 1LL * pw[i - 1].
            first * p1 % MOD1;
        pw[i].second = 1LL * pw[i - 1].
            second * p2 % MOD2;
    }
    ip1 = power(p1, MOD1 - 2, MOD1);
    ip2 = power(p2, MOD2 - 2, MOD2);
    ipw[0] = {1, 1};
    for (int i = 1; i < N; i++) {
        ipw[i].first = 1LL * ipw[i - 1].
            first * ip1 % MOD1;
        ipw[i].second = 1LL * ipw[i - 1].
            second * ip2 % MOD2;
    }
}

```

```

}
struct Hashing {
    int n;
    string s; // 0 - indexed
    vector<pair<int, int>> hs; // 1 -
        indexed
    Hashing() {}
    Hashing(string _s) {
        n = _s.size();
        s = _s;
        hs.emplace_back(0, 0);
        for (int i = 0; i < n; i++) {
            pair<int, int> p;
            p.first = (hs[i].first + 1LL *
                pw[i].first * s[i] % MOD1) %
                MOD1;
            p.second = (hs[i].second + 1LL *
                pw[i].second * s[i] % MOD2)
                % MOD2;
            hs.push_back(p);
        }
    }
    pair<int, int> get_hash(int l, int r
        ) { // 1 - indexed
        assert(1 <= l && l <= r && r <= n)
            ;
        pair<int, int> ans;
        ans.first = (hs[r].first - hs[l -
            1].first + MOD1) * 1LL * ipw[l
            - 1].first % MOD1;
        ans.second = (hs[r].second - hs[l
            - 1].second + MOD2) * 1LL *
            ipw[l - 1].second % MOD2;
        return ans;
    }
    pair<int, int> get_hash() {
        return get_hash(1, n);
    }
};

```

8.3 Manacher's Algorithm

```

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);
}

```

```

vector<int> manacher(string s) {
    string t;
    for(auto c: s) t += string("#") +
        c;
    auto res = manacher_odd(t + "#");
    return vector<int>(begin(res) + 1,
        end(res) - 1);
}

// p[2 * i + (!odd)] - 1
// if r - l + 1 <= p[(r + l) / 2 + (r
    % 2 != l % 2)] is true then
    palindrome. Same parity means odd
    length.

```

9 Stress Testing

9.1 Bash Stress File

```

#!/usr/bin/env bash

g++ -g "$1".cpp -DONPC -o "$1"
g++ -g "$2".cpp -DONPC -o "$2"
g++ -g "$3".cpp -DONPC -o "$3"

for ((testNum=0; testNum<$4; testNum++))
do
    ./$3 > stdinput
    ./$2 < stdinput > outSlow
    ./$1 < stdinput > outWrong
    H1='md5sum outWrong'
    H2='md5sum outSlow'
    if !(cmp -s "outWrong" "outSlow")
    then
        echo "Error found!"
        echo "Input:"
        cat stdinput
        echo "Wrong Output:"
        cat outWrong
        echo "Slow Output:"
        cat outSlow
        exit
    fi
done
echo Passed $4 tests

```

```
# ./stress.sh wrong correct gen times
```

9.2 C++ Generator File

```

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

#define i64 long long
#define accuracy chrono::steady_clock
    ::now().time_since_epoch().count()

mt19937 rng(accuracy);

int rand(int l, int r) {
    uniform_int_distribution<int> ludo(l
        , r);
}

```

```
    return ludo(rng);  
}  
  
int main() {  
    srand(accuracy);  
    int t = 1;
```

```
    t = rand(1, 10), cout << t << '\n';  
    while (t--) {  
        // TODO  
    }  
}
```