

Competitive Programming Reference

First, solve the problem. Then, write the code.

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Coding Resources

C++

1.1.1 Decimal Precision

```
// rounds up the decimal number
cout << setprecision(N) << n << endl;
// specify N fixed number of decimals
cout << fixed << setprecision(N) << n << endl;
```

1.1.2 IO Optimization

```
int main() {
    ios_base::sync_with_stdio(0);
    cin.tie(0);
}
```

1.1.3 Int To Binary

```
#include <bits/stdc++.h>
using namespace std;
typedef long long int lli;

lli bitsInInt(lli n) { // clz = count leading zeroes
    return sizeof(n) * 8 - __builtin_clzll(n);
}
```

```
vector<bool> intToBitsArray(lli n) {
    n = abs(n);
    if (!n) return {};
    int length = bitsInInt(n), lastPos = length - 1;
    vector<bool> v(length);
    for (lli i = lastPos, j = 0; i > -1LL; i--, j++)
        ↪ v[j] = (n >> i) & 1LL;
    return v;
}
```

```
int main() {
    vector<bool> ans = intToBitsArray(8LL);
    for (auto a : ans) cout << a << " ";
    cout << endl;
    return 0;
}
```

1.1.4 Map Value To Int

```
// val = value
typedef string Val;
unordered_map<Val, int> intForVal;
unordered_map<int, Val> valForInt;
int mapId = 0;

int Map(Val val) {
    valForInt[mapId] = val;
    return intForVal.count(val) ? intForVal[val] :
        ↪ intForVal[val] = mapId++;
}

int IMap(int val) {
```

```
    return valForInt[val];
}
```

```
void initMapping() {
    mapId = 0;
    intForVal.clear();
    valForInt.clear();
}
```

1.1.5 Permutations

```
typedef vector<int> T; // typedef string T;
vector<T> permutations(T v) {
    vector<vector<int>> ans;
    sort(v.begin(), v.end());
    do
        ans.push_back(v);
    while (next_permutation(v.begin(), v.end()));
    return ans;
}
```

1.1.6 Print Vector

```
void printv(vector<int> v) {
    if (v.size() == 0) {
        cout << "[]" << endl;
        return;
    }
    cout << "[" << v[0];
    for (int i = 1; i < v.size(); i++) {
        cout << ", " << v[i];
    }
    cout << "]" << endl;
}
```

1.1.7 Priority Queue Of Object

```
struct Object {
    char first;
    int second;
};

int main() {
    auto cmp = [](const Object& a,
                  const Object& b) {
        return a.second > b.second;
    };
    priority_queue<Object, vector<Object>,
                  decltype(cmp)>
        pq(cmp);
    vector<Object> v = {
        {'c', 3}, {'a', 1}, {'b', 2}};
    sort(v.begin(), v.end(), cmp);
    return 0;
}
```

1.1.8 Random

```
int random(int min, int max) {
    return min + rand() % (max - min + 1);
}
```

```
}
```

```
int main() {
    srand(time(0));
    // code
}
```

1.1.9 Read Line

```
// when reading lines, don't mix 'cin' with
// 'getline' just use getline and split
string input() {
    string ans;
    // cin >> ws; // eats all whitespaces.
    getline(cin, ans);
    return ans;
}
```

1.1.10 Sort Pair

```
pair<int, int> p;
sort(p.begin(), p.end());
// sorts array on the basis of the first element
```

1.1.11 Sort Vector Of Object

```
struct Object {
    char first;
    int second;
};

bool cmp(const Object& a, const Object& b) {
    return a.second > b.second;
}
```

```
int main() {
    vector<Object> v = {
        {'c', 3}, {'a', 1}, {'b', 2}};
    sort(v.begin(), v.end(), cmp);
    printv(v);
    return 0;
}
```

1.1.12 Split String

```
vector<string> split(string str, char token) {
    stringstream test(str);
    string seg;
    vector<string> seglist;
    while (getline(test, seg, token))
        seglist.push_back(seg);
    return seglist;
}
```

1.1.13 Typedef

```
typedef TYPE ALIAS;
// example:
typedef int T;
```

1.2 Python

1.2.1 Combinations

```
import itertools
# from arr choose k = > combinations(arr, k)
print(list(itertools.combinations([1, 2, 3], 3)))
```

1.2.2 Fast IO

```
from sys import stdin, stdout

N = 10
# Reads N chars from stdin (it counts '\n' as char)
stdin.read(N)
# Reads until '\n' or EOF
line = stdin.readline()
# Reads all lines in stdin until EOF
lines = stdin.readlines()
# Writes a string to stdout, it doesn't add '\n'
stdout.write(line)
# Writes a list of strings to stdout
stdout.writelines(lines)
# Reads numbers separated by space in a line
numbers = list(map(int, stdin.readline().split()))
```

1.2.3 Permutations

```
import itertools
print(list(itertools.permutations([1, 2, 3])))
```

1.2.4 Random

```
import random
# Initialize the random number generator.
random.seed(None)
# Returns a random integer N such that a <= N <= b.
random.randint(a, b)
# Returns a random integer N such that 0 <= N < b
random.randrange(b)
# Returns a random integer N such that a <= N < b.
random.randrange(a, b)
# Returns and integer with k random bits.
random.getrandbits(k)
# shuffles a list
random.shuffle(li)
```

1.2.5 Sort List

```
li = ['a', 'c', 'b']
# sorts inplace in descending order
li.sort(reverse=True)
# returns sorted list ascending order
ol = sorted(li)
```

1.2.6 Sort List Of Object

```
class MyObject :
    def __init__(self, first, second, third):
        self.first = first
        self.second = second
        self.third = third

li = [MyObject('b', 3, 1), MyObject('a', 3, 2),
      ↪ MyObject('b', 3, 3)]
# returns list sorted by first then by second then by
↪ third in increasing order
ol = sorted(li, key = lambda x: (x.first, x.second,
    ↪ x.third), reverse=False)
# sorts inplace by first then by second then by third
↪ in increasing order
li.sort(key = lambda x: (x.first, x.second, x.third),
    ↪ reverse=False)
```

2 Data Structures

2.1 Graphs

2.1.1 UnionFind

```
struct UnionFind {
    vector<int> dad, size;
    int n;
    UnionFind(int N=0) : n(N), dad(N), size(N, 1) {
        while (N-->0) dad[N] = N;
    }

    int root(int u) {
        if (dad[u] == u) return u;
        return dad[u] = root(dad[u]);
    }

    bool areConnected(int u, int v) {
        return root(u) == root(v);
    }

    void join(int u, int v) {
        int Ru = root(u), Rv = root(v);
        if (Ru == Rv) return;
        --n, dad[Ru] = Rv;
        size[Rv] += size[Ru];
    }

    int getSize(int u) {
        return size[root(u)];
    }

    int numberOfSets() {
        return n;
    }
};
```

2.2 Ranges

2.2.1 BIT

```
typedef long long int T;
T neutro = 0;
vector<T> bit;

void initVars(int n) {
    bit.assign(++n, neutro);
}

T F(T a, T b) {
    return a + b;
    // return a * b;
}
// Inverse of F
T I(T a, T b) {
    return a - b;
    // return a / b;
}
// O(N)
void build() {
    for (int i = 1; i < bit.size(); i++) {
        int j = i + (i & -i);
        if (j < bit.size()) bit[j] = F(bit[j], bit[i]);
    }
}
// O(lg(N))
void update(int i, T val) {
    for (i++; i < bit.size(); i += i & -i) bit[i] =
        ↪ F(bit[i], val);
}
// O(lg(N))
T query(int i) {
    T ans = neutro;
    for (i++; i; i -= i & -i) ans = F(ans, bit[i]);
    return ans;
}
// O(lg(N)), [l, r]
T query(int l, int r) {
    return I(query(r), query(--l));
}

void setValAt(T val, int i) {
    bit[++i] = val;
}
```

2.2.2 BIT Range Update

```
typedef long long int T;
T neutro = 0;
vector<T> bit1, bit2;

void initVars(int n) {
    bit1.assign(++n, neutro);
    bit2 = bit1;
}
// O(lg(N))
void update(vector<T> &bit, int i, T val) {
```

```

    for (i++; i < bit.size(); i += i & -i) bit[i] +=
        ↪ val;
}
// O(lg(N)), [l, r]
void update(int l, int r, T val) {
    update(bit1, l, val);
    update(bit1, r + 1, -val);
    update(bit2, r + 1, val * r);
    update(bit2, l, -val * (l - 1));
}
// O(lg(N))
T query(vector<T> &bit, int i) {
    T ans = neutro;
    for (i++; i; i -= i & -i) ans += bit[i];
    return ans;
}
// O(lg(N))
T query(int i) {
    return query(bit1, i) * i + query(bit2, i);
}
// O(lg(N)), [l, r]
T query(int l, int r) {
    return query(r) - query(l - 1);
}

```

2.2.3 Interval Tree

2.2.4 Segment Tree

```

// st = segment tree. st[1] = root;
// neutro = operation neutral value
// e.g. for sum is 0, for multiplication
// is 1, for gcd is 0, for min is INF, etc.
typedef int T;
T neutro = 0;
int N;
vector<T> st;

void initVars(int n) {
    st.assign(2 * (N = n), neutro);
}

T F(T a, T b) {
    return a + b;
    // return __gcd(a, b);
    // return a * b;
    // return min(a, b);
}
// O(2N)
void build() {
    for (int i = N - 1; i > 0; i--) st[i] = F(st[i <<
        ↪ 1], st[i << 1 | 1]);
}
// O(lg(2N))
void update(int i, T val) {
    for (st[i += N] = val; i > 1; i >>= 1) st[i >> 1] =
        ↪ F(st[i], st[i ^ 1]);
}

```

```

}
// O(3N), [l, r]
void update(int l, int r, T val) {
    for (l += N, r += N; l <= r; l++) st[l] = val;
    build();
}
// O(lg(2N)), [l, r]
T query(int l, int r) {
    T ans = neutro;
    for (l += N, r += N; l <= r; l >>= 1, r >>= 1) {
        if (l & 1) ans = F(ans, st[l++]);
        if (~r & 1) ans = F(ans, st[r--]);
    }
    return ans;
}

void setValAt(T val, int i) {
    st[i + N] = val;
}

```

2.2.5 Segment Tree Lazy Propagation

```

// st = segment tree, st[1] = root, H = height of d
// u = updates, d = delayed updates
// neutro = operation neutral val
// e.g. for sum is 0, for multiplication
// is 1, for gcd is 0, for min is INF, etc.
typedef int T;
T neutro = 0;
int N, H;
vector<T> st, d;
vector<bool> u;

void initVars(T n) {
    u.assign(N = n, 0);
    st.assign(2 * n, neutro);
    d = vector<T>(n);
    H = sizeof(int) * 8 - __builtin_clz(n);
}

T F(T a, T b) {
    return a + b;
    // return __gcd(a, b);
    // return a * b;
    // return min(a, b);
}

void apply(int i, T val, int k) {
    st[i] = val * k; // sum
    // st[i] = val; // min, max, gcd
    // st[i] = pow(a, k); // multiplication
    if (i < N) d[i] = val, u[i] = 1;
}

void calc(int i) {
    if (!u[i]) st[i] = F(st[i << 1], st[i << 1 | 1]);
}
// O(2N)
void build() {

```

```

    for (int i = N - 1; i > 0; i--) calc(i);
}
// O(lg(N))
void build(int p) {
    while (p > 1) p >>= 1, calc(p);
}
// O(lg(N))
void push(int p) {
    for (int s = H, k = 1 << (H - 1); s > 0; s--, k >>=
        1) {
        int i = p >> s;
        if (u[i]) {
            apply(i << 1, d[i], k);
            apply(i << 1 | 1, d[i], k);
            u[i] = 0, d[i] = neutro;
        }
    }
}
// O(lg(N)), [l, r]
void update(int l, int r, T val) {
    push(l += N);
    push(r += N);
    int ll = l, rr = r, k = 1;
    for (; l <= r; l >>= 1, r >>= 1, k <<= 1) {
        if (l & 1) apply(l++, val, k);
        if (~r & 1) apply(r--, val, k);
    }
    build(ll);
    build(rr);
}
// O(lg(2N)), [l, r]
T query(int l, int r) {
    push(l += N);
    push(r += N);
    T ans = neutro;
    for (; l <= r; l >>= 1, r >>= 1) {
        if (l & 1) ans = F(ans, st[l++]);
        if (~r & 1) ans = F(ans, st[r--]);
    }
    return ans;
}

void setValAt(T val, int i) {
    st[i + N] = val;
}

```

2.2.6 Sparse Table

```

// st = sparse table, Arith = Arithmetic
typedef int T;
int neutro = 0;
vector<vector<T>> st;

T F(T a, T b) {
    // return min(a, b);
    return __gcd(a, b);
    // return a + b; // Arith
    // return a * b; // Arith
}

```

```

// O(NlgN)
void build(vector<T> &arr) {
    st.assign(ceil(log2(arr.size())),
        vector<T>(arr.size()));
    st[0] = arr;
    for (int i = 1; (1 << i) <= arr.size(); i++)
        for (int j = 0; j + (1 << i) <= arr.size(); j++)
            st[i][j] = F(st[i - 1][j], st[i - 1][j + (1 <<
                i - 1)]);
}
// O(1)
T query(int L, int R) {
    int i = log2(R - L + 1);
    return F(st[i][L], st[i][R + 1 - (1 << i)]);
}
// O(lgN)
T queryArith(int L, int R) {
    T ans = neutro;
    while (true) {
        int k = log2(R - L + 1);
        ans = F(ans, st[k][L]);
        L += 1 << k;
        if (L > R) break;
    }
    return ans;
}

```

2.3 Strings

2.3.1 Trie

```

// wpt = number of words passing through
// w = number of words ending in the node
// c = character
struct Trie {
    struct Node {
        // for lexicographical order use 'map'
        // map<char, Node*> ch;
        unordered_map<char, Node*> ch;
        int w = 0, wpt = 0;
    };

    Node *root = new Node();
    // O(STR.SIZE)
    void insert(string str) {
        Node *curr = root;
        for (auto &c : str) {
            curr->wpt++;
            if (!curr->ch.count(c)) curr->ch[c] = new
                Node();
            curr = curr->ch[c];
        }
        curr->wpt++;
        curr->w++;
    }

    Node *find(string &str) {
        Node *curr = root;
        for (auto &c : str) {

```

```

    if (!curr->ch.count(c)) return nullptr;
    curr = curr->ch[c];
}
return curr;
}
// number of words with given prefix O(N)
int prefixCount(string prefix) {
    Node *node = find(prefix);
    return node ? node->wpt : 0;
}
// number of words matching str O(N)
int strCount(string str) {
    Node *node = find(str);
    return node ? node->w : 0;
}

void getWords(Node *curr, vector<string> &words,
    ↪ string &word) {
    if (!curr) return;
    if (curr->w) words.push_back(word);
    for (auto &c : curr->ch) {
        getWords(c.second, words, word += c.first);
        word.pop_back();
    }
}
// O(N)
vector<string> getWords() {
    vector<string> words;
    string word = "";
    getWords(root, words, word);
    return words;
}
// O(N)
vector<string> getWordsByPrefix(string prefix) {
    vector<string> words;
    getWords(find(prefix), words, prefix);
}

bool remove(Node *curr, string &str, int &i) {
    if (i == str.size()) {
        curr->wpt--;
        return curr->w ? !(curr->w = 0) : 0;
    }
    int c = str[i];
    if (!curr->ch.count(c)) return false;
    if (remove(curr->ch[c], str, ++i)) {
        if (!curr->ch[c]->wpt) curr->wpt--,
            ↪ curr->ch.erase(c);
        return true;
    }
    return false;
}
// O(STR.SIZE)
int remove(string str) {
    int i = 0;
    return remove(root, str, i);
}
};

```

2.4 Trees

2.4.1 Treap

3 Graphs

3.1 Articulation Points And Bridges

```

// APB = articulation points and bridges
// ap = Articulation Point
// br = bridges, p = parent
// disc = discovery time
// low = lowTime, ch = children
typedef pair<int, int> Edge;
int Time;
vector<vector<int>> ady;
vector<int> disc, low, ap;
vector<Edge> br;

void initVars(int N) {
    ady.assign(N, vector<int>());
}

int dfsAPB(int u, int p) {
    int ch = 0;
    low[u] = disc[u] = ++Time;
    for (int &v : ady[u]) {
        if (v == p) continue;
        if (!disc[v]) {
            ch++, dfsAPB(v, u);
            if (disc[u] <= low[v]) ap[u]++;
            if (disc[u] < low[v]) br.push_back({u, v});
            low[u] = min(low[u], low[v]);
        } else
            low[u] = min(low[u], disc[v]);
    }
    return ch;
}
// O(N)
void APB() {
    br.clear();
    ap = low = disc = vector<int>(ady.size());
    Time = 0;
    for (int u = 0; u < ady.size(); u++)
        if (!disc[u]) ap[u] = dfsAPB(u, u) > 1;
}

void addEdge(int u, int v) {
    ady[u].push_back(v);
    ady[v].push_back(u);
}

// comp = component
int compId;
vector<vector<int>> ady;

```



```

vector<int> getComp;

void initVars(int N) {
    ady.assign(N, vector<int>());
    getComp.assign(N, -1);
    compId = 0;
}

void dfsCC(int u, vector<int> &comp) {
    if (getComp[u] > -1) return;
    getComp[u] = compId;
    comp.push_back(u);
    for (auto &v : ady[u]) dfsCC(v, comp);
}

// O(N)
vector<vector<int>> connectedComponents() {
    vector<vector<int>> comps;
    for (int u = 0; u < ady.size(); u++) {
        vector<int> comp;
        dfsCC(u, comp);
        if (!comp.empty()) comps.push_back(comp),
        ↪ compId++;
    }
    return comps;
}

void addEdge(int u, int v) {
    ady[u].push_back(v);
    ady[v].push_back(u);
}

```

3.3 Cycles

3.3.1 Get All Simple Cycles

3.3.2 Get Some Cycles

```

// at least detects one cycle per component
vector<vector<int>> ady, cycles;
vector<int> vis, cycle;
bool flag = false, isDirected = false;
int root = -1;

void initVars(int N) {
    ady.assign(N, vector<int>());
    vis.assign(N, 0);
    cycles.clear();
    root = -1, flag = false;
}

bool hasCycle(int u, int prev) {
    vis[u] = 1;
    for (auto &v : ady[u]) {
        if (v == u || vis[v] == 2 || (!isDirected && v ==
        ↪ prev)) continue;
        if (flag) {
            if (!vis[v]) hasCycle(v, u);

```

```

        continue;
    }
    if (vis[v] || hasCycle(v, u)) {
        if (root == -1) root = v, flag = true;
        cycle.push_back(u);
        if (root == u) flag = false, root = -1,
        ↪ cycles.push_back(cycle), cycle.clear();
    }
}
vis[u] = 2;
return flag;
}

// O(N)
bool hasCycle() {
    for (int u = 0; u < ady.size(); u++)
        if (!vis[u]) cycle.clear(), hasCycle(u, -1);
    return cycles.size() > 0;
}

void addEdge(int u, int v) {
    ady[u].push_back(v);
    if (!isDirected) ady[v].push_back(u);
}

```

3.3.3 Has Cycle

```

vector<vector<int>> ady;
vector<int> vis;
bool isDirected = false;

void initVars(int N) {
    ady.assign(N, vector<int>());
    vis.assign(N, 0);
}

bool hasCycle(int u, int prev) {
    vis[u] = 1;
    for (auto &v : ady[u])
        if (v != u && vis[v] != 2 && (isDirected || v !=
        ↪ prev) && (vis[v] || hasCycle(v, u))) return
        ↪ true;
    vis[u] = 2;
    return false;
}

// O(N)
bool hasCycle() {
    for (int u = 0; u < ady.size(); u++)
        if (!vis[u] && hasCycle(u, -1)) return true;
}

void addEdge(int u, int v) {
    ady[u].push_back(v);
    if (!isDirected) ady[v].push_back(u);
}

```

3.4 Flood Fill

```
int n, m, oldColor = 0, color = 1;
vector<vector<int>>> mat;

vector<vector<int>>> movs = {{1, 0}, {0, 1}, {-1, 0},
    ↪ {0, -1}};

void floodFill(int i, int j) {
    if (i >= mat.size() || i < 0 || j >= mat[i].size()
    ↪ || j < 0 || mat[i][j] != oldColor) return;
    mat[i][j] = color;
    for (auto move : movs) floodFill(i + move[1], j +
    ↪ move[0]);
}

void floodFill() {
    for (int i = 0; i < n; i++)
        for (int j = 0; j < m; j++)
            if (mat[i][j] == oldColor) floodFill(i, j);
}
```

3.5 Flow

3.5.1 Max Flow Dinic

```
// cap[a][b] = Capacity from a to b
// flow[a][b] = flow occupied from a to b
// level[a] = level in graph of node a
typedef int T;
vector<int> level;
vector<vector<int>>> ady;
unordered_map<int, unordered_map<int, T>>> cap, flow;

void initVars(int N) {
    ady.assign(N, vector<int>());
    cap.clear();
    flow.clear();
}

bool levelGraph(int s, int t) {
    level = vector<int>(ady.size());
    level[s] = 1;
    queue<int> q;
    q.push(s);
    while (!q.empty()) {
        int u = q.front();
        q.pop();
        for (int &v : ady[u]) {
            if (!level[v] && flow[u][v] < cap[u][v]) {
                q.push(v);
                level[v] = level[u] + 1;
            }
        }
    }
    return level[t];
}

T blockingFlow(int u, int t, T currPathMaxFlow) {
    if (u == t) return currPathMaxFlow;
```

```
    for (int v : ady[u]) {
        T capleft = cap[u][v] - flow[u][v];
        if ((level[v] == (level[u] + 1)) && (capleft > 0))
            ↪ {
                T pathMaxFlow = blockingFlow(v, t,
                ↪ min(currPathMaxFlow, capleft));
                if (pathMaxFlow > 0) {
                    flow[u][v] += pathMaxFlow;
                    flow[v][u] -= pathMaxFlow;
                    return pathMaxFlow;
                }
            }
    }
    return 0;
}
// O(E * V^2)
T dinicMaxFlow(int s, int t) {
    if (s == t) return -1;
    T maxFlow = 0;
    while (levelGraph(s, t))
        while (T flow = blockingFlow(s, t, 1 << 30))
            ↪ maxFlow += flow;
    return maxFlow;
}

void addEdge(int u, int v, T capacity) {
    cap[u][v] = capacity;
    ady[u].push_back(v);
}
```

3.5.2 Maximum Bipartite Matching

```
#include "Max Flow Dinic.cpp"
void addEdge(int u, int v) {
    cap[u][v] = 1;
    ady[u].push_back(v);
}

int main() {
    int n, s = 0, t = 1;
    cin >> n;
    initVars(n);
    while (n--) {
        int u, v;
        cin >> u >> v;
        addEdge(u += 2, v += 2);
        addEdge(s, u);
        addEdge(v, t);
    }
    cout << dinicMaxFlow(s, t) << endl;
    return 0;
}
```

3.6 Is Bipartite

```
vector<vector<int>>> ady;

void initVars(int N) {
```

```

    ady.assign(N, vector<int>());
}
// O(N)
bool isBipartite() {
    vector<int> color(ady.size(), -1);
    for (int s = 0; s < ady.size(); s++) {
        if (color[s] > -1) continue;
        color[s] = 0;
        queue<int> q;
        q.push(s);
        while (!q.empty()) {
            int u = q.front();
            q.pop();
            for (int &v : ady[u]) {
                if (color[v] < 0) q.push(v), color[v] =
                    ↪ !color[u];
                if (color[v] == color[u]) return false;
            }
        }
    }
    return true;
}

```

3.7 LCA

```

// st = sparse table
typedef pair<int, int> T;
int neutro = 0;
vector<vector<T>> st;

vector<int> first;
vector<T> tour;
vector<vector<int>> ady;

void initVars(int N) {
    ady.assign(N, vector<int>());
}

T F(T a, T b) {
    return a.first < b.first ? a : b;
}

void build() {
    st.assign(ceil(log2(tour.size()))),
    ↪ vector<T>(tour.size()));
    st[0] = tour;
    for (int i = 1; (1 << i) <= tour.size(); i++)
        for (int j = 0; j + (1 << i) <= tour.size(); j++)
            ↪ st[i][j] = F(st[i - 1][j], st[i - 1][j + (1 <<
            ↪ (i - 1))]);
}

void eulerTour(int u, int p, int h) {
    first[u] = tour.size();
    tour.push_back({h, u});
    for (int v : ady[u])
        if (v != p) {
            eulerTour(v, u, h + 1);
            tour.push_back({h, u});
        }
    }

```

```

    }
}

void preprocess() {
    tour.clear();
    first.assign(ady.size(), -1);
    eulerTour(0, 0, 0);
    build();
}
// O(1)
int lca(int u, int v) {
    int l = min(first[u], first[v]);
    int r = max(first[u], first[v]);
    int i = log2(r - l + 1);
    return F(st[i][l], st[i][r + 1 - (1 << i)]).second;
}

void addEdge(int u, int v) {
    ady[u].push_back(v);
    ady[v].push_back(u);
}

```

3.8 MST Kruskal

```

// N = number of nodes, Wedge = Weighted Edge
#include "../Data Structures/Graphs/UnionFind.cpp"
typedef int T;
typedef pair<int, int> Edge;
typedef pair<T, Edge> Wedge;
vector<Wedge> Wedges;
vector<Wedge> mst;
UnionFind uf(0);

void initVars(int N) {
    mst.clear();
    Wedges.clear();
    uf = UnionFind(N);
}

T kruskal() {
    T cost = 0;
    sort(Wedges.begin(), Wedges.end());
    // reverse(Wedges.begin(), Wedges.end());
    for (Wedge &wedge : Wedges) {
        int u = wedge.second.first, v =
            ↪ wedge.second.second;
        if (!uf.areConnected(u, v)) uf.join(u, v),
            ↪ mst.push_back(wedge), cost += wedge.first;
    }
    return cost;
}

void addEdge(int u, int v, T w) {
    Wedges.push_back({w, {u, v}});
}

```

3.9 MST Prim

```
// st = spanning tree, p = parent
// vis = visited, dist = distance
typedef int T;
typedef pair<int, int> Edge;
typedef pair<T, Edge> Wedge;
typedef pair<T, int> DistNode;
int MAXN = 20001, INF = 1 << 30;
vector<vector<int>>> ady;
unordered_map<int, unordered_map<int, T>> weight;
vector<int> p, vis;
vector<T> dist;
vector<vector<Wedge>> msts;

void initVars(int N) {
    ady.assign(N, vector<int>());
    p.assign(N, 0);
    vis.assign(N, 0);
    dist.assign(N, INF);
    weight.clear();
    msts.clear();
}

T prim(int s) {
    vector<Wedge> mst;
    vector<set<Edge>::iterator> pos(ady.size());
    vector<T> dist(ady.size(), INF);
    set<Edge> q;
    T cost = dist[s] = 0;
    q.insert({0, s});
    while (q.size()) {
        int u = q.begin()->second;
        q.erase(q.begin());
        vis[u] = 1, cost += dist[u];
        mst.push_back({dist[u], {p[u], u}});
        for (int &v : ady[u]) {
            T w = weight[u][v];
            if (!vis[v] && w < dist[v]) {
                if (dist[v] != INF) q.erase(pos[v]);
                pos[v] = q.insert({dist[v] = w, v}).first;
            }
        }
    }
    msts.push_back(vector<Wedge>(mst.begin() + 1,
        ↪ mst.end()));
    return cost;
}

T primLazy(int s) {
    vector<Wedge> mst;
    vector<set<Edge>::iterator> pos(ady.size());
    vector<T> dist(ady.size(), INF);
    priority_queue<DistNode, vector<DistNode>,
        ↪ greater<DistNode>> q;
    T cost = dist[s] = 0;
    q.push({0, s});
    while (q.size()) {
        pair<int, int> aux = q.top();
```

```
        int u = aux.second;
        q.pop();
        if (dist[u] < aux.first) continue;
        vis[u] = 1, cost += dist[u];
        mst.push_back({dist[u], {p[u], u}});
        for (int &v : ady[u]) {
            T w = weight[u][v];
            if (!vis[v] && w < dist[v]) q.push({dist[v] = w,
                ↪ v});
        }
    }
    msts.push_back(vector<Wedge>(mst.begin() + 1,
        ↪ mst.end()));
    return cost;
}

// O(V + E * log(V))
T prim() {
    T cost = 0;
    map<int, T> q;
    for (int i = 0; i < ady.size(); i++)
        if (!vis[i]) cost += prim(i);
    return cost;
}

void addEdge(int u, int v, T w) {
    ady[u].push_back(v);
    weight[u][v] = w;
    ady[v].push_back(u);
    weight[v][u] = w;
}
```

3.10 ShortestPaths

3.10.1 Bellman Ford

```
// N = number of nodes
// returns {} if there is a negative weight cycle
typedef int T;
int MAXN = 20001, N, INF = 1 << 30, isDirected = true;
vector<vector<int>>> ady;
unordered_map<int, unordered_map<int, T>> weight;

void initVars(int N) {
    ady.assign(N, vector<int>());
    weight.clear();
}

// O(V * E)
vector<T> bellmanFord(int s) {
    vector<T> dist(ady.size(), INF);
    dist[s] = 0;
    for (int i = 1; i <= ady.size(); i++)
        for (int u = 0; u < ady.size(); u++)
            for (auto &v : ady[u]) {
                T w = weight[u][v];
                if (dist[u] != INF && dist[u] + w < dist[v]) {
                    if (i == ady.size()) return {};
                    dist[v] = dist[u] + w;
                }
            }
    return dist;
}
```

```

}

void addEdge(int u, int v, T w) {
    ady[u].push_back(v);
    weight[u][v] = w;
    if (isDirected) return;
    ady[v].push_back(u);
    weight[v][u] = w;
}

```

3.10.2 Dijkstra

```

typedef int T;
typedef pair<T, int> DistNode;
int MAXN = 20001, INF = 1 << 30, isDirected = false;
vector<vector<int>>> ady;
unordered_map<int, unordered_map<int, T>> weight;

void initVars(int N) {
    ady.assign(N, vector<int>());
    weight.clear();
}

// O(E * log(V))
vector<int> dijkstra(int s) {
    vector<set<DistNode>::iterator> pos(ady.size());
    vector<T> dist(ady.size(), INF);
    set<DistNode> q;
    q.insert({0, s}), dist[s] = 0;
    while (q.size()) {
        int u = q.begin()->second;
        q.erase(q.begin());
        for (int &v : ady[u]) {
            T w = weight[u][v];
            if (dist[u] + w < dist[v]) {
                if (dist[v] != INF) q.erase(pos[v]);
                pos[v] = q.insert({dist[v] = dist[u] + w,
                    ↪ v}).first;
            }
        }
    }
    return dist;
}

vector<int> dijkstraLazy(int s) {
    vector<int> dist(ady.size(), INF);
    priority_queue<DistNode, vector<DistNode>,
        ↪ greater<DistNode>> q;
    q.push({0, s}), dist[s] = 0;
    while (q.size()) {
        DistNode top = q.top(); q.pop();
        int u = top.second;
        if (dist[u] < top.first) continue;
        for (int &v : ady[u]) {
            T w = weight[u][v];
            if (dist[u] + w < dist[v]) q.push({dist[v] =
                ↪ dist[u] + w, v});
        }
    }
    return dist;
}

```

```

}

void addEdge(int u, int v, T w) {
    ady[u].push_back(v);
    weight[u][v] = w;
    if (isDirected) return;
    ady[v].push_back(u);
    weight[v][u] = w;
}

```

3.11 Strongly Connected Components

```

// tv = top value from stack
// sccs = strongly connected components
// scc = strongly connected component
// disc = discovery time
// low = low time
// s = stack
// top = top index of the stack
int Time, top;
vector<vector<int>>> ady, sccs;
vector<int> disc, low, s;

void initVars(int N) {
    ady.assign(N, vector<int>());
}

void dfsSCCS(int u) {
    if (disc[u]) return;
    low[u] = disc[u] = ++Time;
    s[++top] = u;
    for (int &v : ady[u]) dfsSCCS(v), low[u] =
        ↪ min(low[u], low[v]);
    if (disc[u] == low[u]) {
        vector<int> scc;
        while (true) {
            int tv = s[top--];
            scc.push_back(tv);
            low[tv] = ady.size();
            if (tv == u) break;
        }
        sccs.push_back(scc);
    }
}

// O(N)
void SCCS() {
    s = low = disc = vector<int>(ady.size());
    Time = 0, top = -1, sccs.clear();
    for (int u = 0; u < ady.size(); u++) dfsSCCS(u);
}

void addEdge(int u, int v) {
    ady[u].push_back(v);
}

```

3.12 Topological Sort

```

// vis = visited
vector<vector<int>>> ady;

```

```
vector<int> vis, toposorted;

void initVars(int N) {
    ady.assign(N, vector<int>());
    vis.assign(N, 0);
    toposorted.clear();
}
// returns false if there is a cycle
bool toposort(int u) {
    vis[u] = 1;
    for (auto &v : ady[u]) {
        if (v == u || vis[v] == 2) continue;
        if (vis[v] == 1 || !toposort(v)) return false;
    }
    vis[u] = 2;
    toposorted.push_back(u);
    return true;
}
// O(N)
bool toposort() {
    vis.clear();
    for (int u = 0; u < ady.size(); u++)
        if (!vis[u] && !toposort(u)) return false;
    return true;
}
```

4 Maths

4.1 Number Theory

4.1.1 Divisibility Criterion

```
def divisorCriteria(n, lim):
    results = []
    tenElevated = 1
    for i in range(lim):
        # remainder = pow(10, i, n)
        remainder = tenElevated % n
        negremainder = remainder - n
        if (remainder <= abs(negremainder)):
            results.append(remainder)
        else:
            results.append(negremainder)
        tenElevated *= 10
    return results

def testDivisibility(dividend, divisor,
    ↪ divisor_criteria):
    dividend = str(dividend)
    addition = 0
    dividendSize = len(dividend)
    i = dividendSize - 1
    j = 0
    while j < dividendSize:
        addition += int(dividend[i]) *
            ↪ divisor_criteria[j]
        i -= 1
        j += 1
```

```
return addition % divisor == 0
```

```
if __name__ == '__main__':
    dividend, divisor = map(int, input().split())
    divisor_criteria = divisorCriteria(divisor,
        ↪ len(str(dividend)))
    print(divisor_criteria)
    print(testDivisibility(dividend, divisor,
        ↪ divisor_criteria))
```

4.1.2 Extended Euclidean

```
// gcd(a, b) = ax + by
vector<long long int> extendedGCD(
    long long int a, long long int b) {
    if (a > 0LL && b == 0LL) {
        return {a, 1LL, 0LL};
    }
    long long int x = 1LL, y = 0LL, prevx = 0LL,
        prevy = 1LL, q, remainder;
    while (true) {
        q = a / b;
        remainder = a - b * q;
        if (remainder == 0LL) break;
        a = b;
        b = remainder;
        x = x - prevx * q;
        swap(x, prevx);
        y = y - prevy * q;
        swap(y, prevy);
    }
    // gcd = b, x = prevx, y = prevy
    return {b, prevx, prevy};
}
```

4.1.3 GCD

```
int gcd(int a, int b) {
    return !b ? a : gcd(b, a % b);
}

int gcdI(int a, int b) {
    while (b) {
        a %= b;
        swap(a, b);
    }
    return a;
}
```

4.1.4 LCM

```
int lcm(int a, int b) {
    int c = gcd(a, b);
    return c ? a / c * b : 0;
}
```

4.1.5 Prime Check Miller Rabin

```
from random import randrange

def is_prime(p):
    k = 100
    if p == 2 or p == 3:
        return True
    if (p & 1) == 0 or p == 1:
        return False
    phi = p - 1
    d = phi
    r = 0
    while (d & 1) == 0:
        d = int(d >> 1)
        r += 1
    for i in range(k):
        a = randrange(2, p - 2)
        exp = pow(a, d, p)
        if exp == 1 or exp == p - 1:
            continue
        flag = False
        for j in range(r - 1):
            exp = pow(exp, 2, p)
            if exp == 1:
                return False
            if exp == p - 1:
                flag = True
                break
        if flag:
            continue
        else:
            return False
    return True
```

4.1.6 Prime Sieve

```
vector<int> primeSieve(int n) {
    vector<int> sieve(n + 1);
    for (int i = 4; i <= n; i += 2) sieve[i] = 2;
    for (int i = 3; i * i <= n; i += 2)
        if (!sieve[i])
            for (int j = i * i; j <= n; j += 2 * i)
                if (!sieve[j]) sieve[j] = i;
    return sieve;
}
```

5 Strings

5.1 KMP

```
// f = error function
// cf = create error function
// p = pattern
// t = text
// pos = positions where pattern is found in text
```

```
int MAXN = 1000000;
```

```
vector<int> f(MAXN + 1);

vector<int> kmp(string &p, string &t, int cf) {
    vector<int> pos;
    if (cf) f[0] = -1;
    for (int i = cf, j = 0; j < t.size(); i = f[i]) {
        while (i > -1 && p[i] != t[j]) i = f[i];
        i++, j++;
        if (cf) f[j] = i;
        if (!cf && i == p.size()) pos.push_back(j - i), i
            = f[i];
    }
    return pos;
}

vector<int> search(string &p, string &t) {
    kmp(p, p, -1); // create error function
    return kmp(p, t, 0); // search in text
}
```

5.2 Rabin Karp

```
class RollingHash {
public:
    vector<unsigned long long int> pow;
    vector<unsigned long long int> hash;
    unsigned long long int B;
    RollingHash(const string &text) : B(257) {
        int N = text.size();
        pow.resize(N + 1);
        hash.resize(N + 1);
        pow[0] = 1;
        hash[0] = 0;
        for (int i = 1; i <= N; ++i) {
            // in c++ an unsigned long long int is
            // automatically modulated by 2^64
            pow[i] = pow[i - 1] * B;
            hash[i] = hash[i - 1] * B + text[i - 1];
        }
    }

    unsigned long long int getWordHash() {
        return hash[hash.size() - 1];
    }

    unsigned long long int getSubstrHash(int begin, int
        ↪ end) {
        return hash[end] - hash[begin - 1] * pow[end -
            ↪ begin + 1];
    }

    int size() {
        return hash.size();
    }
};

vector<int> rabinKarp(RollingHash &rhStr, string
    ↪ &pattern) {
```



```

vector<int> positions;
RollingHash rhPattern(pattern);
unsigned long long int patternHash =
    ↪ rhPattern.getWordHash();
int windowSize = pattern.size(), end = windowSize;
for (int i = 1; end < rhStr.size(); i++) {
    if (patternHash == rhStr.getSubstrHash(i, end))
        ↪ positions.push_back(i);
    end = i + windowSize;
}
return positions;
}

```

6 Techniques

6.1 Binary Search

6.2 Multiple Queries

6.2.1 Mo

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

```
using namespace std;
```

```
// q = query
// qs = queries
```

```
struct Query {
    int l, r;
};
```

```
int N, M, blksize;
vector<Query> qs;
vector<int> arr;
```

```
void initVars() {
    qs = vector<Query>(M);
    arr = vector<int>(N);
}
```

```
bool cmp(Query &a, Query &b) {
    if (a.l == b.l) return a.r < b.r;
    return a.l / blksize < b.l / blksize;
}
```

```
void getResults() {
    blksize = (int)sqrt(N);
    sort(qs.begin(), qs.end(), cmp);
    int prevL = 0, prevR = -1;
    int sum = 0;
    for (auto &q : qs) {
        int L = q.l, R = q.r;
        while (prevL < L) {
            sum -= arr[prevL]; // problem specific
            prevL++;
        }
    }
}
```

```

while (prevL > L) {
    prevL--;
    sum += arr[prevL]; // problem specific
}
while (prevR < R) {
    prevR++;
    sum += arr[prevR]; // problem specific
}
while (prevR > R) {
    sum -= arr[prevR]; // problem specific
    prevR--;
}

cout << "sum[" << L << ", " << R
    << "]" << " = " << sum << endl;
}
}

```

```

int main() {
    arr = {1, 1, 2, 1, 3, 4, 5, 2, 8};
    N = arr.size();
    qs = {{0, 8}, {3, 5}};
    M = qs.size();
    getResults();
}

```

6.2.2 SQRT Decomposition

```
// sum of elements in range
#include <bits/stdc++.h>
```

```
using namespace std;
```

```
int N, blksize;
int MAXN = 100, MAXSQR = (int)sqrt(MAXN);
```

```
vector<int> arr(MAXN);
vector<int> blks(MAXSQR + 1);
```

```

void preprocess() {
    blksize = sqrt(N);
    for (int i = 0, j = 0; i < N; i++) {
        if (i == blksize * j) j++;
        blks[j - 1] += arr[i]; // problem specific
    }
}

```

```

// problem specific
void update(int i, int val) {
    blks[i / blksize] += val - arr[i];
    arr[i] = val;
}

```

```

int query(int l, int r) {
    int sum = 0;
    int lblk = l / blksize;
    if (l != blksize * lblk++)
        while (l < r && l != lblk * blksize) {
            sum += arr[l]; // problem specific
        }
}

```



```

        l++;
    }

    while (l + blksize <= r) {
        sum += blks[l / blksize]; // problem specific
        l += blksize;
    }
    while (l <= r) {
        sum += arr[l]; // problem specific
        l++;
    }
    return sum;
}

int main() {
    N = 10;
    arr = {1, 5, 2, 4, 6, 1, 3, 5, 7, 10};
    preprocess();
    for (int i = 0; i < blksize + 1; i++)
        cout << blks[i] << " ";
    // 8 11 15 10
    cout << endl;
    cout << query(3, 8) << " ";
    cout << query(1, 6) << " ";
    update(8, 0);
    cout << query(8, 8) << endl;
    // 26 21 0
    return 0;
}

```