代码库

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Contents

1 数论

1.1 快速求逆元

返回结果：

$$x^{-1}(mod)$$

使用条件：$x \in [0, mod)$ 并且 x 与 mod 互质。

```
long long inverse(const long long &x, const long long &mod) {
    if (x == 1) {
        return 1;
    } else {
        return (mod - mod / x) * inverse(mod % x, mod) % mod;
    }
}
```

1.2 扩展欧几里德算法

返回结果：

$$ax + by = gcd(a, b)$$

时间复杂度：$O(nlogn)$

```
void solve(const long long &a, const long long &b, long long &x, long long &y) {
    if (b == 0) {
        x = 1;
        y = 0;
    } else {
        solve(b, a % b, x, y);
        x -= a / b * y;
        std::swap(x, y);
    }
}
```

1.3 中国剩余定理

返回结果：

$$x \equiv r_i(mod\ p_i)\ (0 \leq i < n)$$

使用条件：p_i 无需两两互质
时间复杂度：$O(nlogn)$

```
bool solve(int n, std::pair<long long, long long> input[], std::pair<long long, long long> &output)
    output = std::make_pair(1, 1);
    for (int i = 0; i < n; ++i) {
        long long number, useless;
        euclid(output.second, input[i].second, number, useless);
        long long divisor = std::__gcd(output.second, input[i].second);
        if ((input[i].first - output.first) % divisor) {
            return false;
        }
        number *= (input[i].first - output.first) / divisor;
        fix(number, input[i].second);
        output.first += output.second * number;
        output.second *= input[i].second / divisor;
        fix(output.first, output.second);
    }
    return true;
}
```

1.4 Miller Rabin 素数测试

```
const int BASE[12] = {2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37};

bool check(const long long &prime, const long long &base) {
    long long number = prime - 1;
    for (; ~number & 1; number >>= 1);
    long long result = power_mod(base, number, prime);
    for (; number != prime - 1 && result != 1 && result != prime - 1; number <<= 1) {
        result = multiply_mod(result, result, prime);
    }
    return result == prime - 1 || (number & 1) == 1;
}

bool miller_rabin(const long long &number) {
    if (number < 2) {
        return false;
    }
    if (number < 4) {
        return true;
    }
    if (~number & 1) {
        return false;
    }
    for (int i = 0; i < 12 && BASE[i] < number; ++i) {
        if (!check(number, BASE[i])) {
            return false;
        }
    }
    return true;
}
```

1.5 Pollard Rho 大数分解

时间复杂度：$O(n^{1/4})$

```
long long pollard_rho(const long long &number, const long long &seed) {
    long long x = rand() % (number - 1) + 1, y = x;
    for (int head = 1, tail = 2; ; ) {
        x = multiply_mod(x, x, number);
        x = add_mod(x, seed, number);
        if (x == y) {
            return number;
        }
        long long answer = std::__gcd(abs(x - y), number);
        if (answer > 1 && answer < number) {
            return answer;
        }
        if (++head == tail) {
            y = x;
            tail <<= 1;
        }
    }
}

void factorize(const long long &number, std::vector<long long> &divisor) {
    if (number > 1) {
        if (miller_rabin(number)) {
            divisor.push_back(number);
```

```
        } else {
            long long factor = number;
            for (; factor >= number; factor = pollard_rho(number, rand() % (number - 1) + 1));
            factorize(number / factor, divisor);
            factorize(factor, divisor);
        }
    }
}
```

1.6 快速数论变换

返回结果：

$$c_i = \sum_{0 \le j \le i} a_j \cdot b_{i-j}(mod)\ (0 \le i < n)$$

使用说明：$magic$ 是 mod 的原根
时间复杂度：$O(nlogn)$

```
void solve(long long number[], int length, int type) {
        for (int i = 1, j = 0; i < length - 1; ++i) {
                for (int k = length; j ^= k >>= 1, ~j & k; );
                if (i < j) {
                        std::swap(number[i], number[j]);
                }
        }
        long long unit_p0;
        for (int turn = 0; (1 << turn) < length; ++turn) {
                int step = 1 << turn, step2 = step << 1;
                if (type == 1) {
                        unit_p0 = power_mod(MAGIC, (MOD - 1) / step2, MOD);
                } else {
                        unit_p0 = power_mod(MAGIC, MOD - 1 - (MOD - 1) / step2, MOD);
                }
                for (int i = 0; i < length; i += step2) {
                        long long unit = 1;
                        for (int j = 0; j < step; ++j) {
                                long long &number1 = number[i + j + step];
                                long long &number2 = number[i + j];
                                long long delta = unit * number1 % MOD;
                                number1 = (number2 - delta + MOD) % MOD;
                                number2 = (number2 + delta) % MOD;
                                unit = unit * unit_p0 % MOD;
                        }
                }
        }
}

void multiply() {
        for (; lowbit(length) != length; ++length);
        solve(number1, length, 1);
        solve(number2, length, 1);
        for (int i = 0; i < length; ++i) {
                number[i] = number1[i] * number2[i] % MOD;
        }
        solve(number, length, -1);
        for (int i = 0; i < length; ++i) {
                answer[i] = number[i] * power_mod(length, MOD - 2, MOD) % MOD;
        }
}
```

1.7 原根

1.8 离散对数

1.9 离散平方根

1.10 佩尔方程求解

1.11 牛顿迭代法

1.12 直线下整点个数

返回结果：

$$\sum_{0\le i<n} \lfloor \frac{a+b\cdot i}{m} \rfloor$$

使用条件：$n, m > 0$，$a, b \ge 0$
时间复杂度：$O(nlogn)$

```
long long solve(const long long &n, const long long &a, const long long &b, const long long &m) {
    if (b == 0) {
        return n * (a / m);
    }
    if (a >= m) {
        return n * (a / m) + solve(n, a % m, b, m);
    }
    if (b >= m) {
        return (n - 1) * n / 2 * (b / m) + solve(n, a, b % m, m);
    }
    return solve((a + b * n) / m, (a + b * n) % m, m, b);
}
```

2 数值

2.1 高斯消元

2.2 快速傅立叶变换

返回结果：

$$c_i = \sum_{0\le j\le i} a_j \cdot b_{i-j} \ (0 \le i < n)$$

时间复杂度：$O(nlogn)$

```
void solve(Complex number[], int length, int type) {
    for (int i = 1, j = 0; i < length - 1; ++i) {
        for (int k = length; j ^= k >>= 1, ~j & k; );
        if (i < j) {
            std::swap(number[i], number[j]);
        }
    }
    Complex unit_p0;
    for (int turn = 0; (1 << turn) < length; ++turn) {
        int step = 1 << turn, step2 = step << 1;
        double p0 = PI / step * type;
        sincos(p0, &unit_p0.imag(), &unit_p0.real());
        for (int i = 0; i < length; i += step2) {
            Complex unit = 1;
            for (int j = 0; j < step; ++j) {
                Complex &number1 = number[i + j + step];
```

```
                Complex &number2 = number[i + j];
                Complex delta = unit * number1;
                number1 = number2 - delta;
                number2 = number2 + delta;
                unit = unit * unit_p0;
            }
        }
    }
}

void multiply() {
    for (; lowbit(length) != length; ++length);
    solve(number1, length, 1);
    solve(number2, length, 1);
    for (int i = 0; i < length; ++i) {
        number[i] = number1[i] * number2[i];
    }
    solve(number, length, -1);
    for (int i = 0; i < length; ++i) {
        answer[i] = (int)(number[i].real() / length + 0.5);
    }
}
```

2.3 单纯形法求解线性规划

返回结果：

$$max\{c_{1\times m} \cdot x_{m\times 1} \mid x_{m\times 1} \geq 0_{m\times 1}, a_{n\times m} \cdot x_{m\times 1} \leq b_{n\times 1}\}$$

```
std::vector<double> solve(const std::vector<std::vector<double> > &a,
                        const std::vector<double> &b, const std::vector<double> &c) {
    int n = (int)a.size(), m = (int)a[0].size() + 1;
    std::vector<std::vector<double> > value(n + 2, std::vector<double>(m + 1));
    std::vector<int> index(n + m);
    int r = n, s = m - 1;
    for (int i = 0; i < n + m; ++i) {
        index[i] = i;
    }
    for (int i = 0; i < n; ++i) {
        for (int j = 0; j < m - 1; ++j) {
            value[i][j] = -a[i][j];
        }
        value[i][m - 1] = 1;
        value[i][m] = b[i];
        if (value[r][m] > value[i][m]) {
            r = i;
        }
    }
    for (int j = 0; j < m - 1; ++j) {
        value[n][j] = c[j];
    }
    value[n + 1][m - 1] = -1;
    for (double number; ; ) {
        if (r < n) {
            std::swap(index[s], index[r + m]);
            value[r][s] = 1 / value[r][s];
            for (int j = 0; j <= m; ++j) {
                if (j != s) {
                    value[r][j] *= -value[r][s];
```

```
                }
            }
            for (int i = 0; i <= n + 1; ++i) {
                if (i != r) {
                    for (int j = 0; j <= m; ++j) {
                        if (j != s) {
                            value[i][j] += value[r][j] * value[i][s];
                        }
                    }
                    value[i][s] *= value[r][s];
                }
            }
        }
        r = s = -1;
        for (int j = 0; j < m; ++j) {
            if (s < 0 || index[s] > index[j]) {
                if (value[n + 1][j] > eps || value[n + 1][j] > -eps && value[n][j] > eps) {
                    s = j;
                }
            }
        }
        if (s < 0) {
            break;
        }
        for (int i = 0; i < n; ++i) {
            if (value[i][s] < -eps) {
                if (r < 0
                    || (number = value[r][m] / value[r][s] - value[i][m] / value[i][s]) < -eps
                    || number < eps && index[r + m] > index[i + m]) {
                     r = i;
                }
            }
        }
        if (r < 0) {
            //    Solution is unbounded.
            return std::vector<double>();
        }
    }
    if (value[n + 1][m] < -eps) {
        //    No solution.
        return std::vector<double>();
    }
    std::vector<double> answer(m - 1);
    for (int i = m; i < n + m; ++i) {
        if (index[i] < m - 1) {
            answer[index[i]] = value[i - m][m];
        }
    }
    return answer;
}
```

2.4 自适应辛普森

```
double area(const double &left, const double &right) {
    double mid = (left + right) / 2;
    return (right - left) * (calc(left) + 4 * calc(mid) + calc(right)) / 6;
}
```

```cpp
double simpson(const double &left, const double &right, const double &eps, const double &area_sum) {
    double mid = (left + right) / 2;
    double area_left = area(left, mid);
    double area_right = area(mid, right);
    double area_total = area_left + area_right;
    if (std::abs(area_total - area_sum) < 15 * eps) {
        return area_total + (area_total - area_sum) / 15;
    }
    return simpson(left, mid, eps / 2, area_left) + simpson(mid, right, eps / 2, area_right);
}

double simpson(const double &left, const double &right, const double &eps) {
    return simpson(left, right, eps, area(left, right));
}
```

2.5 多项式方程求解

2.6 最小二乘法

3 数据结构

3.1 平衡的二叉查找树

3.1.1 Treap

```cpp
class Node {
public:
    Node *child[2];
    int key;
    int size, priority;

    Node(Node *left, Node *right, int key) : key(key), size(1), priority(rand()) {
        child[0] = left;
        child[1] = right;
    }

    void update() {
        size = child[0]->size + 1 + child[1]->size;
    }
};

Node *null;

void rotate(Node *&x, int dir) {
    Node *y = x->child[dir];
    x->child[dir] = y->child[dir ^ 1];
    y->child[dir ^ 1] = x;
    x->update();
    y->update();
    x = y;
}

void insert(Node *&x, int key) {
    if (x == null) {
        x = new Node(null, null, key);
    } else {
        insert(x->child[key > x->key], key);
        if (x->child[key > x->key]->priority < x->priority) {
```

```
            rotate(x, key > x->key);
        }
        x->update();
    }
}

void remove(Node *&x, int key) {
    if (x->key != key) {
        remove(x->child[key > x->key], key);
    } else if (x->child[0] == null && x->child[1] == null) {
        x = null;
        return;
    } else {
        int dir = x->child[0]->priority > x->child[1]->priority;
        rotate(x, dir);
        remove(x->child[dir ^ 1], key);
    }
    x->update();
}

void build() {
    null = new Node(NULL, NULL, 0);
    null->child[0] = null->child[1] = null;
    null->size = 0;
    null->priority = RAND_MAX;
}
```

3.1.2 Splay

3.2 坚固的数据结构

3.2.1 坚固的线段树

```
class Node {
public:
    Node *left, *right;
    int value;

    Node(Node *left, Node *right, int value) : left(left), right(right), value(value) {}

    Node* modify(int l, int r, int ql, int qr, int value);
    int query(int l, int r, int qx);
};

Node* null;

Node* Node::modify(int l, int r, int ql, int qr, int value) {
    if (qr < l || r < ql) {
        return this;
    }
    if (ql <= l && r <= qr) {
        return new Node(this->left, this->right, this->value + value);
    }
    int mid = l + r >> 1;
    return new Node(this->left->modify(l, mid, ql, qr, value),
                    this->right->modify(mid + 1, r, ql, qr, value),
                    this->value);
}
```

```cpp
int Node::query(int l, int r, int qx) {
    if (qx < l || r < qx) {
        return 0;
    }
    if (qx <= l && r <= qx) {
        return this->value;
    }
    int mid = l + r >> 1;
    return this->left->query(l, mid, qx)
         + this->right->query(mid + 1, r, qx)
         + this->value;
}

void build() {
    null = new Node(NULL, NULL, 0);
    null->left = null->right = null;
}
```

3.2.2 坚固的平衡树

3.2.3 坚固的字符串

3.2.4 坚固的左偏树

3.3 树上的魔术师

3.3.1 轻重树链剖分

```cpp
int father[N], height[N], size[N], son[N], top[N], pos[N], data[N];

void build(int root) {
    std::vector<int> queue;
    father[root] = -1;
    height[root] = 0;
    queue.push_back(root);
    for (int head = 0; head < (int)queue.size(); ++head) {
        int x = queue[head];
        for (int i = 0; i < (int)edge[x].size(); ++i) {
            int y = edge[x][i];
            if (y != father[x]) {
                father[y] = x;
                height[y] = height[x] + 1;
                queue.push_back(y);
            }
        }
    }
    for (int index = n - 1; index >= 0; --index) {
        int x = queue[index];
        size[x] = 1;
        son[x] = -1;
        for (int i = 0; i < (int)edge[x].size(); ++i) {
            int y = edge[x][i];
            if (y != father[x]) {
                size[x] += size[y];
                if (son[x] == -1 || size[son[x]] < size[y]) {
                    son[x] = y;
                }
            }
```

```
        }
    }
    std::fill(top, top + n, 0);
    int counter = 0;
    for (int index = 0; index < n; ++index) {
        int x = queue[index];
        if (top[x] == 0) {
            for (int y = x; y != -1; y = son[y]) {
                top[y] = x;
                pos[y] = ++counter;
                data[counter] = value[y];
            }
        }
    }
    build(1, 1, n);
}

void solve(int x, int y) {
    while (true) {
        if (top[x] == top[y]) {
            if (x == y) {
                solve(1, 1, n, pos[x], pos[x]);
            } else {
                if (height[x] < height[y]) {
                    solve(1, 1, n, pos[x], pos[y]);
                } else {
                    solve(1, 1, n, pos[y], pos[x]);
                }
            }
            break;
        }
        if (height[top[x]] > height[top[y]]) {
            solve(1, 1, n, pos[top[x]], pos[x]);
            x = father[top[x]];
        } else {
            solve(1, 1, n, pos[top[y]], pos[y]);
            y = father[top[y]];
        }
    }
}
```

3.3.2 Link Cut Tree

3.3.3 AAA Tree

3.4 k-d 树

4 图论

4.1 强连通分量

4.2 双连通分量

4.2.1 点双连通分量

4.2.2 边双连通分量

4.3 2-SAT 问题

4.4 二分图最大匹配

4.4.1 Hungary 算法

时间复杂度：$O(V \cdot E)$

```
int n, m, stamp;
int match[N], visit[N];

bool dfs(int x) {
    for (int i = 0; i < (int)edge[x].size(); ++i) {
        int y = edge[x][i];
        if (visit[y] != stamp) {
            visit[y] = stamp;
            if (match[y] == -1 || dfs(match[y])) {
                match[y] = x;
                return true;
            }
        }
    }
    return false;
}

int solve() {
    std::fill(match, match + m, -1);
    int answer = 0;
    for (int i = 0; i < n; ++i) {
        stamp++;
        answer += dfs(i);
    }
    return answer;
}
```

4.4.2 Hopcroft Karp 算法

时间复杂度：$O(\sqrt{V} \cdot E)$

```
int matchx[N], matchy[N], level[N];

bool dfs(int x) {
    for (int i = 0; i < (int)edge[x].size(); ++i) {
        int y = edge[x][i];
```

```
        int w = matchy[y];
        if (w == -1 || level[x] + 1 == level[w] && dfs(w)) {
            matchx[x] = y;
            matchy[y] = x;
            return true;
        }
    }
    level[x] = -1;
    return false;
}

int solve() {
    std::fill(matchx, matchx + n, -1);
    std::fill(matchy, matchy + m, -1);
    for (int answer = 0; ; ) {
        std::vector<int> queue;
        for (int i = 0; i < n; ++i) {
            if (matchx[i] == -1) {
                level[i] = 0;
                queue.push_back(i);
            } else {
                level[i] = -1;
            }
        }
        for (int head = 0; head < (int)queue.size(); ++head) {
            int x = queue[head];
            for (int i = 0; i < (int)edge[x].size(); ++i) {
                int y = edge[x][i];
                int w = matchy[y];
                if (w != -1 && level[w] < 0) {
                    level[w] = level[x] + 1;
                    queue.push_back(w);
                }
            }
        }
        int delta = 0;
        for (int i = 0; i < n; ++i) {
            if (matchx[i] == -1 && dfs(i)) {
                delta++;
            }
        }
        if (delta == 0) {
            return answer;
        } else {
            answer += delta;
        }
    }
}
```

4.5 二分图最大权匹配

4.5.1 KM 算法

时间复杂度：$O(V^3)$

```
int labelx[N], labely[N], match[N], slack[N];
bool visitx[N], visity[N];

bool dfs(int x) {
```

```cpp
    visitx[x] = true;
    for (int y = 0; y < n; ++y) {
        if (visity[y]) {
            continue;
        }
        int delta = labelx[x] + labely[y] - graph[x][y];
        if (delta == 0) {
            visity[y] = true;
            if (match[y] == -1 || dfs(match[y])) {
                match[y] = x;
                return true;
            }
        } else {
            slack[y] = std::min(slack[y], delta);
        }
    }
    return false;
}

int solve() {
    for (int i = 0; i < n; ++i) {
        match[i] = -1;
        labelx[i] = INT_MIN;
        labely[i] = 0;
        for (int j = 0; j < n; ++j) {
            labelx[i] = std::max(labelx[i], graph[i][j]);
        }
    }
    for (int i = 0; i < n; ++i) {
        while (true) {
            std::fill(visitx, visitx + n, 0);
            std::fill(visity, visity + n, 0);
            for (int j = 0; j < n; ++j) {
                slack[j] = INT_MAX;
            }
            if (dfs(i)) {
                break;
            }
            int delta = INT_MAX;
            for (int j = 0; j < n; ++j) {
                if (!visity[j]) {
                    delta = std::min(delta, slack[j]);
                }
            }
            for (int j = 0; j < n; ++j) {
                if (visitx[j]) {
                    labelx[j] -= delta;
                }
                if (visity[j]) {
                    labely[j] += delta;
                } else {
                    slack[j] -= delta;
                }
            }
        }
    }
    int answer = 0;
    for (int i = 0; i < n; ++i) {
```

```
        answer += graph[match[i]][i];
    }
    return answer;
}
```

4.5.2 扩展 KM 算法

4.6 最大流

时间复杂度：$O(V^2 \cdot E)$

```
struct EdgeList {
    int size;
    int last[N];
    int succ[M], other[M], flow[M];
    void clear(int n) {
        size = 0;
        fill(last, last + n, -1);
    }
    void add(int x, int y, int c) {
        succ[size] = last[x];
        last[x] = size;
        other[size] = y;
        flow[size++] = c;
    }
} e;

int n, source, target;
int dist[N], curr[N];

void add(int x, int y, int c) {
    e.add(x, y, c);
    e.add(y, x, 0);
}

bool relabel() {
    std::vector<int> queue;
    for (int i = 0; i < n; ++i) {
        curr[i] = e.last[i];
        dist[i] = -1;
    }
    queue.push_back(target);
    dist[target] = 0;
    for (int head = 0; head < (int)queue.size(); ++head) {
        int x = queue[head];
        for (int i = e.last[x]; ~i; i = e.succ[i]) {
            int y = e.other[i];
            if (e.flow[i ^ 1] && dist[y] == -1) {
                dist[y] = dist[x] + 1;
                queue.push_back(y);
            }
        }
    }
    return ~dist[source];
}

int dfs(int x, int answer) {
    if (x == target) {
        return answer;
```

```
    }
    int delta = answer;
    for (int &i = curr[x]; ~i; i = e.succ[i]) {
        int y = e.other[i];
        if (e.flow[i] && dist[x] == dist[y] + 1) {
            int number = dfs(y, std::min(e.flow[i], delta));
            e.flow[i] -= number;
            e.flow[i ^ 1] += number;
            delta -= number;
        }
        if (delta == 0) {
            break;
        }
    }
    return answer - delta;
}

int solve() {
    int answer = 0;
    while (relabel()) {
        answer += dfs(source, INT_MAX));
    }
    return answer;
}
```

4.7 最小费用最大流

4.7.1 稀疏图

时间复杂度：$O(V \cdot E^2)$

```
struct EdgeList {
    int size;
    int last[N];
    int succ[M], other[M], flow[M], cost[M];
    void clear(int n) {
        size = 0;
        std::fill(last, last + n, -1);
    }
    void add(int x, int y, int c, int w) {
        succ[size] = last[x];
        last[x] = size;
        other[size] = y;
        flow[size] = c;
        cost[size++] = w;
    }
} e;

int n, source, target;
int prev[N];

void add(int x, int y, int c, int w) {
    e.add(x, y, c, w);
    e.add(y, x, 0, -w);
}

bool augment() {
    static int dist[N], occur[N];
    std::vector<int> queue;
```

```
    std::fill(dist, dist + n, INT_MAX);
    std::fill(occur, occur + n, 0);
    dist[source] = 0;
    occur[source] = true;
    queue.push_back(source);
    for (int head = 0; head < (int)queue.size(); ++head) {
        int x = queue[head];
        for (int i = e.last[x]; ~i; i = e.succ[i]) {
            int y = e.other[i];
            if (e.flow[i] && dist[y] > dist[x] + e.cost[i]) {
                dist[y] = dist[x] + e.cost[i];
                prev[y] = i;
                if (!occur[y]) {
                    occur[y] = true;
                    queue.push_back(y);
                }
            }
        }
        occur[x] = false;
    }
    return dist[target] < INT_MAX;
}

std::pair<int, int> solve() {
    std::pair<int, int> answer = std::make_pair(0, 0);
    while (augment()) {
        int number = INT_MAX;
        for (int i = target; i != source; i = e.other[prev[i] ^ 1]) {
            number = std::min(number, e.flow[prev[i]]);
        }
        answer.first += number;
        for (int i = target; i != source; i = e.other[prev[i] ^ 1]) {
            e.flow[prev[i]] -= number;
            e.flow[prev[i] ^ 1] += number;
            answer.second += number * e.cost[prev[i]];
        }
    }
    return answer;
}
```

4.7.2 稠密图

时间复杂度：$O(V \cdot E^2)$

```
struct EdgeList {
    int size;
    int last[N];
    int succ[M], other[M], flow[M], cost[M];
    void clear(int n) {
        size = 0;
        std::fill(last, last + n, -1);
    }
    void add(int x, int y, int c, int w) {
        succ[size] = last[x];
        last[x] = size;
        other[size] = y;
        flow[size] = c;
        cost[size++] = w;
```

```
    }
} e;

int n, source, target, flow, cost;
int slack[N], dist[N];
bool visit[N];

void add(int x, int y, int c, int w) {
    e.add(x, y, c, w);
    e.add(y, x, 0, -w);
}

bool relabel() {
    int delta = INT_MAX;
    for (int i = 0; i < n; ++i) {
        if (!visit[i]) {
            delta = std::min(delta, slack[i]);
        }
        slack[i] = INT_MAX;
    }
    if (delta == INT_MAX) {
        return true;
    }
    for (int i = 0; i < n; ++i) {
        if (visit[i]) {
            dist[i] += delta;
        }
    }
    return false;
}

int dfs(int x, int answer) {
    if (x == target) {
        flow += answer;
        cost += answer * (dist[source] - dist[target]);
        return answer;
    }
    visit[x] = true;
    int delta = answer;
    for (int i = e.last[x]; ~i; i = e.succ[i]) {
        int y = e.other[i];
        if (e.flow[i] > 0 && !visit[y]) {
            if (dist[y] + e.cost[i] == dist[x]) {
                int number = dfs(y, std::min(e.flow[i], delta));
                e.flow[i] -= number;
                e.flow[i ^ 1] += number;
                delta -= number;
                if (delta == 0) {
                    dist[x] = INT_MIN;
                    return answer;
                }
            } else {
                slack[y] = std::min(slack[y], dist[y] + e.cost[i] - dist[x]);
            }
        }
    }
    return answer - delta;
}
```

```cpp
std::pair<int, int> solve() {
    flow = cost = 0;
    std::fill(dist, dist + n, 0);
    do {
        do {
            fill(visit, visit + n, 0);
        } while (dfs(source, INT_MAX));
    } while (!relabel());
    return std::make_pair(flow, cost);
}
```

4.8 一般图最大匹配

时间复杂度：$O(V^3)$

```cpp
int match[N], belong[N], next[N], mark[N], visit[N];
std::vector<int> queue;

int find(int x) {
    if (belong[x] != x) {
        belong[x] = find(belong[x]);
    }
    return belong[x];
}

void merge(int x, int y) {
    x = find(x);
    y = find(y);
    if (x != y) {
        belong[x] = y;
    }
}

int lca(int x, int y) {
    static int stamp = 0;
    stamp++;
    while (true) {
        if (x != -1) {
            x = find(x);
            if (visit[x] == stamp) {
                return x;
            }
            visit[x] = stamp;
            if (match[x] != -1) {
                x = next[match[x]];
            } else {
                x = -1;
            }
        }
        std::swap(x, y);
    }
}

void group(int a, int p) {
    while (a != p) {
        int b = match[a], c = next[b];
        if (find(c) != p) {
```

```
            next[c] = b;
        }
        if (mark[b] == 2) {
            mark[b] = 1;
            queue.push_back(b);
        }
        if (mark[c] == 2) {
            mark[c] = 1;
            queue.push_back(c);
        }
        merge(a, b);
        merge(b, c);
        a = c;
    }
}

void augment(int source) {
    queue.clear();
    for (int i = 0; i < n; ++i) {
        next[i] = visit[i] = -1;
        belong[i] = i;
        mark[i] = 0;
    }
    mark[source] = 1;
    queue.push_back(source);
    for (int head = 0; head < (int)queue.size() && match[source] == -1; ++head) {
        int x = queue[head];
        for (int i = 0; i < (int)edge[x].size(); ++i) {
            int y = edge[x][i];
            if (match[x] == y || find(x) == find(y) || mark[y] == 2) {
                continue;
            }
            if (mark[y] == 1) {
                int r = lca(x, y);
                if (find(x) != r) {
                    next[x] = y;
                }
                if (find(y) != r) {
                    next[y] = x;
                }
                group(x, r);
                group(y, r);
            } else if (match[y] == -1) {
                next[y] = x;
                for (int u = y; u != -1; ) {
                    int v = next[u];
                    int mv = match[v];
                    match[v] = u;
                    match[u] = v;
                    u = mv;
                }
                break;
            } else {
                next[y] = x;
                mark[y] = 2;
                mark[match[y]] = 1;
                queue.push_back(match[y]);
            }
```

```
        }
    }
}

int solve() {
    std::fill(match, match + n, -1);
    for (int i = 0; i < n; ++i) {
        if (match[i] == -1) {
            augment(i);
        }
    }
    int answer = 0;
    for (int i = 0; i < n; ++i) {
        answer += (match[i] != -1);
    }
    return answer;
}
```

4.9 无向图全局最小割

时间复杂度：$O(V^3)$
注意事项：处理重边时，应该对边权累加

```
int node[N], dist[N];
bool visit[N];

int solve(int n) {
    int answer = INT_MAX;
    for (int i = 0; i < n; ++i) {
        node[i] = i;
    }
    while (n > 1) {
        int max = 1;
        for (int i = 0; i < n; ++i) {
            dist[node[i]] = graph[node[0]][node[i]];
            if (dist[node[i]] > dist[node[max]]) {
                max = i;
            }
        }
        int prev = 0;
        memset(visit, 0, sizeof(visit));
        visit[node[0]] = true;
        for (int i = 1; i < n; ++i) {
            if (i == n - 1) {
                answer = std::min(answer, dist[node[max]]);
                for (int k = 0; k < n; ++k) {
                    graph[node[k]][node[prev]] = (graph[node[prev]][node[k]] += graph[node[k]][node[
                }
                node[max] = node[--n];
            }
            visit[node[max]] = true;
            prev = max;
            max = -1;
            for (int j = 1; j < n; ++j) {
                if (!visit[node[j]]) {
                    dist[node[j]] += graph[node[prev]][node[j]];
                    if (max == -1 || dist[node[max]] < dist[node[j]]) {
                        max = j;
```

```
                }
            }
        }
    }
    return answer;
}
```

4.10 最小树形图

4.11 有根树的同构

时间复杂度：$O(VlogV)$

```
const unsigned long long MAGIC = 4423;

unsigned long long magic[N];
std::pair<unsigned long long, int> hash[N];

void solve(int root) {
    magic[0] = 1;
    for (int i = 1; i <= n; ++i) {
        magic[i] = magic[i - 1] * MAGIC;
    }
    std::vector<int> queue;
    queue.push_back(root);
    for (int head = 0; head < (int)queue.size(); ++head) {
        int x = queue[head];
        for (int i = 0; i < (int)son[x].size(); ++i) {
            int y = son[x][i];
            queue.push_back(y);
        }
    }
    for (int index = n - 1; index >= 0; --index) {
        int x = queue[index];
        hash[x] = std::make_pair(0, 0);

        std::vector<std::pair<unsigned long long, int> > value;
        for (int i = 0; i < (int)son[x].size(); ++i) {
            int y = son[x][i];
            value.push_back(hash[y]);
        }
        std::sort(value.begin(), value.end());

        hash[x].first = hash[x].first * magic[1] + 37;
        hash[x].second++;
        for (int i = 0; i < (int)value.size(); ++i) {
            hash[x].first = hash[x].first * magic[value[i].second] + value[i].first;
            hash[x].second += value[i].second;
        }
        hash[x].first = hash[x].first * magic[1] + 41;
        hash[x].second++;
    }
}
```

4.12 度限制生成树

4.13 弦图相关

4.13.1 弦图的判定

4.13.2 弦图的团数

4.14 哈密尔顿回路（ORE 性质的图）

ORE 性质：

$$\forall x, y \in V \wedge (x, y) \notin E \ \ s.t. \ \ deg_x + deg_y \geq n$$

返回结果：从顶点 1 出发的一个哈密尔顿回路
使用条件：$n \geq 3$

```
int left[N], right[N], next[N], last[N];

void cover(int x) {
    left[right[x]] = left[x];
    right[left[x]] = right[x];
}

int adjacent(int x) {
    for (int i = right[0]; i <= n; i = right[i]) {
        if (graph[x][i]) {
            return i;
        }
    }
    return 0;
}

std::vector<int> solve() {
    for (int i = 1; i <= n; ++i) {
        left[i] = i - 1;
        right[i] = i + 1;
    }
    int head, tail;
    for (int i = 2; i <= n; ++i) {
        if (graph[1][i]) {
            head = 1;
            tail = i;
            cover(head);
            cover(tail);
            next[head] = tail;
            break;
        }
    }
    while (true) {
        int x;
        while (x = adjacent(head)) {
            next[x] = head;
            head = x;
            cover(head);
        }
        while (x = adjacent(tail)) {
            next[tail] = x;
            tail = x;
            cover(tail);
        }
```

```
        if (!graph[head][tail]) {
            for (int i = head, j; i != tail; i = next[i]) {
                if (graph[head][next[i]] && graph[tail][i]) {
                    for (j = head; j != i; j = next[j]) {
                        last[next[j]] = j;
                    }
                    j = next[head];
                    next[head] = next[i];
                    next[tail] = i;
                    tail = j;
                    for (j = i; j != head; j = last[j]) {
                        next[j] = last[j];
                    }
                    break;
                }
            }
        }
        next[tail] = head;
        if (right[0] > n) {
            break;
        }
        for (int i = head; i != tail; i = next[i]) {
            if (adjacent(i)) {
                head = next[i];
                tail = i;
                next[tail] = 0;
                break;
            }
        }
    }
    std::vector<int> answer;
    for (int i = head; ; i = next[i]) {
        if (i == 1) {
            answer.push_back(i);
            for (int j = next[i]; j != i; j = next[j]) {
                answer.push_back(j);
            }
            answer.push_back(i);
            break;
        }
        if (i == tail) {
            break;
        }
    }
    return answer;
}
```

5 字符串

5.1 模式匹配

5.1.1 KMP 算法

```
void build(char *pattern) {
    int length = (int)strlen(pattern + 1);
    fail[0] = -1;
    for (int i = 1, j; i <= length; ++i) {
```

```
        for (j = fail[i - 1]; j != -1 && pattern[i] != pattern[j + 1]; j = fail[j]);
        fail[i] = j + 1;
    }
}

void solve(char *text, char *pattern) {
    int length = (int)strlen(text + 1);
    for (int i = 1, j; i <= length; ++i) {
        for (j = match[i - 1]; j != -1 && text[i] != pattern[j + 1]; j = fail[j]);
        match[i] = j + 1;
    }
}
```

5.1.2 扩展 KMP 算法

5.1.3 AC 自动机

5.2 后缀三姐妹

5.2.1 后缀数组

5.2.2 后缀自动机

```
class Node {
public:
    Node *child[256], *parent;
    int length;

    Node(int length = 0) : parent(NULL), length(length) {
        memset(child, NULL, sizeof(child));
    }

    Node* extend(Node *start, int token) {
        Node *p = this;
        Node *np = new Node(length + 1);
        for (; p && !p->child[token]; p = p->parent) {
            p->child[token] = np;
        }
        if (!p) {
            np->parent = start;
        } else {
            Node *q = p->child[token];
            if (p->length + 1 == q->length) {
                np->parent = q;
            } else {
                Node *nq = new Node(p->length + 1);
                memcpy(nq->child, q->child, sizeof(q->child));
                nq->parent = q->parent;
                np->parent = q->parent = nq;
                for (; p && p->child[token] == q; p = p->parent) {
                    p->child[token] = nq;
                }
            }
        }
        return np;
    }
};
```

5.3 回文三兄弟

5.3.1 Manacher 算法

```
void manacher(char *text, int length) {
    palindrome[0] = 1;
    for (int i = 1, j = 0; i < length; ++i) {
        if (j + palindrome[j] <= i) {
            palindrome[i] = 0;
        } else {
            palindrome[i] = std::min(palindrome[(j << 1) - i], j + palindrome[j] - i);
        }
        while (i - palindrome[i] >= 0 && i + palindrome[i] < length
                && text[i - palindrome[i]] == text[i + palindrome[i]]) {
            palindrome[i]++;
        }
        if (i + palindrome[i] > j + palindrome[j]) {
            j = i;
        }
    }
}
```

5.3.2 回文树

```
class Node {
public:
    Node *child[256], *fail;
    int length;

    Node(int length) : fail(NULL), length(length) {
        memset(child, NULL, sizeof(child));
    }
};

int size;
int text[N];
Node *odd, *even;

Node* match(Node *now) {
    for (; text[size - now->length - 1] != text[size]; now = now->fail);
    return now;
}

bool extend(Node *&last, int token) {
    text[++size] = token;
    Node *now = last;
    now = match(now);
    if (now->child[token]) {
        last = now->child[token];
        return false;
    }
    last = now->child[token] = new Node(now->length + 2);
    if (now == odd) {
        last->fail = even;
    } else {
        now = match(now->fail);
        last->fail = now->child[token];
    }
    return true;
```

```
}

void build() {
    text[size = 0] = -1;
    even = new Node(0), odd = new Node(-1);
    even->fail = odd;
}
```

5.4 循环串最小表示

```
int solve(char *text, int length) {
    int i = 0, j = 1, delta = 0;
    while (i < length && j < length && delta < length) {
        char tokeni = text[(i + delta) % length];
        char tokenj = text[(j + delta) % length];
        if (tokeni == tokenj) {
            delta++;
        } else {
            if (tokeni > tokenj) {
                i += delta + 1;
            } else {
                j += delta + 1;
            }
            if (i == j) {
                j++;
            }
            delta = 0;
        }
    }
    return std::min(i, j);
}
```

6 计算几何

6.1 二维基础

6.1.1 点类

6.1.2 凸包

```
std::vector<Point> convex_hull(std::vector<Point> point) {
    if ((int)point.size() < 3) {
        return point;
    }
    std::sort(point.begin(), point.end());
    std::vector<Point> convex;
    {
        std::vector<Point> stack;
        for (int i = 0; i < (int)point.size(); ++i) {
            while ((int)stack.size() >= 2 &&
                    sgn(det(stack[(int)stack.size() - 2], stack.back(), point[i])) <= 0) {
                stack.pop_back());
            }
            stack.push_back(point[i]);
        }
        for (int i = 0; i < (int)stack.size(); ++i) {
            convex.push_back(stack[i]);
        }
```

```
    }
    {
        std::vector<Point> stack;
        for (int i = (int)point.size() - 1; i >= 0; --i) {
            while ((int)stack.size() >= 2 &&
                    sgn(det(stack[(int)stack.size() - 2], stack.back(), point[i])) <= 0) {
                stack.pop_back());
            }
            stack.push_back(point[i]);
        }
        for (int i = 1; i < (int)stack.size() - 1; ++i) {
            convex.push_back(stack[i]);
        }
    }
    return convex;
}
```

6.1.3 半平面交

6.2 三维基础

6.2.1 点类

6.2.2 凸包

6.2.3 绕轴旋转

6.3 多边形

6.3.1 判断点在多边形内部

```
bool point_on_line(const Point &p, const Point &a, const Point &b) {
    return sgn(det(p, a, b)) == 0 && sgn(dot(p, a, b)) <= 0;
}

bool point_in_polygon(const Point &p, const std::vector<Point> &polygon) {
    int counter = 0;
    for (int i = 0; i < (int)polygon.size(); ++i) {
        Point a = polygon[i], b = polygon[(i + 1) % (int)polygon.size()];
        if (point_on_line(p, a, b)) {
            //    Point on the boundary are excluded.
            return false;
        }
        int x = sgn(det(a, p, b));
        int y = sgn(a.y - p.y);
        int z = sgn(b.y - p.y);
        counter += (x > 0 && y <= 0 && z > 0);
        counter -= (x < 0 && z <= 0 && y > 0);
    }
    return counter;
}
```

6.3.2 旋转卡壳

6.3.3 动态凸包

6.3.4 点到凸包的切线

6.3.5 直线与凸包的交点

6.3.6 凸多边形的交集

6.3.7 凸多边形内的最大圆

6.4 圆

6.4.1 圆类

6.4.2 圆的交集

6.4.3 最小覆盖圆

6.4.4 最小覆盖球

6.4.5 判断圆存在交集

6.4.6 圆与多边形的交集

6.5 三角形

6.5.1 三角形的内心

6.5.2 三角形的外心

6.5.3 三角形的垂心

6.6 黑暗科技

6.6.1 平面图形的转动惯量

6.6.2 平面区域处理

6.6.3 Vonoroi 图

7 其他

7.1 某年某月某日是星期几

```
int solve(int year, int month, int day) {
    int answer;
    if (month == 1 || month == 2) {
        month += 12;
        year--;
    }
    if ((year < 1752) || (year == 1752 && month < 9) || (year == 1752 && month == 9 && day < 3)) {
        answer = (day + 2 * month + 3 * (month + 1) / 5 + year + year / 4 + 5) % 7;
    } else {
        answer = (day + 2 * month + 3 * (month + 1) / 5 + year + year / 4 - year / 100 + year / 400)
    }
    return answer;
}
```

7.2 动态规划

7.3 搜索

7.3.1 Dancing Links X

8 Java

8.1 基础模板

```java
import java.io.*;
import java.util.*;
import java.math.*;

public class Main {
    public static void main(String[] args) {
        InputStream inputStream = System.in;
        OutputStream outputStream = System.out;
        InputReader in = new InputReader(inputStream);
        PrintWriter out = new PrintWriter(outputStream);
        Task solver = new Task();
        solver.solve(0, in, out);
        out.close();
    }
}

class Task {
    public void solve(int testNumber, InputReader in, PrintWriter out) {

    }
}

class InputReader {
    public BufferedReader reader;
    public StringTokenizer tokenizer;

    public InputReader(InputStream stream) {
        reader = new BufferedReader(new InputStreamReader(stream), 32768);
        tokenizer = null;
    }

    public String next() {
        while (tokenizer == null || !tokenizer.hasMoreTokens()) {
            try {
                tokenizer = new StringTokenizer(reader.readLine());
            } catch (IOException e) {
                throw new RuntimeException(e);
            }
        }
        return tokenizer.nextToken();
    }

    public int nextInt() {
        return Integer.parseInt(next());
    }

    public long nextLong() {
        return Long.parseLong(next());
```

```
    }
}
```

8.2 BigInteger

8.3 BigDecimal

9 数学

9.1 常用积分表

9.2 常用数学公式

9.2.1 求和公式

1. $\sum_{k=1}^{n}(2k-1)^2 = \frac{n(4n^2-1)}{3}$
2. $\sum_{k=1}^{n} k^3 = [\frac{n(n+1)}{2}]^2$
3. $\sum_{k=1}^{n}(2k-1)^3 = n^2(2n^2-1)$
4. $\sum_{k=1}^{n} k^4 = \frac{n(n+1)(2n+1)(3n^2+3n-1)}{30}$
5. $\sum_{k=1}^{n} k^5 = \frac{n^2(n+1)^2(2n^2+2n-1)}{12}$
6. $\sum_{k=1}^{n} k(k+1) = \frac{n(n+1)(n+2)}{3}$
7. $\sum_{k=1}^{n} k(k+1)(k+2) = \frac{n(n+1)(n+2)(n+3)}{4}$
8. $\sum_{k=1}^{n} k(k+1)(k+2)(k+3) = \frac{n(n+1)(n+2)(n+3)(n+4)}{5}$

9.2.2 斐波那契数列

1. $fib_0 = 0, fib_1 = 1, fib_n = fib_{n-1} + fib_{n-2}$
2. $fib_{n+2} \cdot fib_n - fib_{n+1}^2 = (-1)^{n+1}$
3. $fib_{-n} = (-1)^{n-1} fib_n$
4. $fib_{n+k} = fib_k \cdot fib_{n+1} + fib_{k-1} \cdot fib_n$
5. $gcd(fib_m, fib_n) = fib_{gcd(m,n)}$
6. $fib_m | fib_n^2 \Leftrightarrow n fib_n | m$

9.2.3 错排公式

1. $D_n = (n-1)(D_{n-2} - D_{n-1})$
2. $D_n = n! \cdot (1 - \frac{1}{1!} + \frac{1}{2!} - \frac{1}{3!} + \ldots + \frac{(-1)^n}{n!})$

9.3 平面几何公式

9.3.1 三角形

1. 半周长

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

2. 面积

$$S = \frac{a \cdot H_a}{2} = \frac{ab \cdot sinC}{2} = \sqrt{p(p-a)(p-b)(p-c)}$$

3. 中线

$$M_a = \frac{\sqrt{2(b^2+c^2)-a^2}}{2} = \frac{\sqrt{b^2+c^2+2bc\cdot cosA}}{2}$$

4. 角平分线

$$T_a = \frac{\sqrt{bc\cdot[(b+c)^2-a^2]}}{b+c} = \frac{2bc}{b+c}cos\frac{A}{2}$$

5. 高线

$$H_a = bsinC = csinB = \sqrt{b^2-(\frac{a^2+b^2-c^2}{2a})^2}$$

6. 内切圆半径

$$r = \frac{S}{p} = \frac{arcsin\frac{B}{2}\cdot sin\frac{C}{2}}{sin\frac{B+C}{2}} = 4R\cdot sin\frac{A}{2}sin\frac{B}{2}sin\frac{C}{2}$$
$$= \sqrt{\frac{(p-a)(p-b)(p-c)}{p}} = p\cdot tan\frac{A}{2}tan\frac{B}{2}tan\frac{C}{2}$$

7. 外接圆半径

$$R = \frac{abc}{4S} = \frac{a}{2sinA} = \frac{b}{2sinB} = \frac{c}{2sinC}$$

9.3.2 四边形

9.3.3 正 n 边形

9.3.4 圆

9.3.5 棱柱

9.3.6 棱锥

9.3.7 棱台

9.3.8 圆柱

9.3.9 圆锥

9.3.10 圆台

9.4 常用数表

9.4.1 梅森数