

ACM ICPC Code Notebook

UofT Blue 2018

November 4, 2018

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Templates

C++

```
1 #include <bits/stdc++.h>
2
3 using namespace std;
4
5 #define ll long long int
6 #define inf 0x3f3f3f3f
7 #define pb push_back
8 #define mk make_pair
9 #define mt make_tuple
10 #define fi first
11 #define se second
12 #define ii pair<int, int>
13 #define all(x) (x).begin(), (x).end()
14 #define N 1000007 // 10e6 + 7
15
16 const double PI = acos(-1.0);
17
18
19 int main(int argc, char const *argv[]) {
20     //ios::sync_with_stdio(false);
21
22     return 0;
23 }
```

Java

```
1 import java.io.BufferedReader;
2 import java.io.Closeable;
3 import java.io.IOException;
4 import java.io.InputStreamReader;
5 import java.io.PrintWriter;
6 import java.util.StringTokenizer;
7 import java.math.*;
8 import java.text.*;
9 import java.util.*;
10
11 public class Icpc {
12
13     public static void main(String... args) throws Exception {
14         FastScan sc = new FastScan(new BufferedReader(new
15             InputStreamReader(System.in)));
16         PrintWriter pw = new PrintWriter(System.out);
17
18         sc.close();
19         pw.close();
20         System.exit(0);
21     }
22
23     static class FastScan implements Closeable {
24         private BufferedReader br;
25         private StringTokenizer tk;
26
27         public FastScan(BufferedReader br) {
28             this.br = br;
29         }
30
31         public int in() throws NumberFormatException, IOException
32         {
33             return Integer.parseInt(next());
34         }
35
36         public long ln() throws NumberFormatException, IOException
37         {
38             return Long.parseLong(next());
39         }
40     }
41 }
```

```

38     }
39
40     public double db() throws NumberFormatException ,
        IOException {
41         return Double.parseDouble(next());
42     }
43
44     @Override
45     public void close() throws IOException {
46         tk = null;
47         br.close();
48     }
49
50     public String next() throws IOException {
51         while (tk == null || !tk.hasMoreTokens()) {
52             String line = br.readLine();
53             if (line == null)
54                 return null;
55             tk = new StringTokenizer(line);
56         }
57         return tk.nextToken();
58     }
59 }
60 }

```

Algorithms

Graphs

AP & Bridges

```
1 int dfs(int u, int p){
2     dfs_num[u] = dfs_low[u] = ++dfs_counter;
3     for(auto v : adjList[u]){
4         if(dfs_num[v]==0){
5             dfs(v, u);
6             if(dfs_low[v] >= dfs_num[u]){
7                 articulation[u]=true;
8             }
9             if(dfs_low[v] > dfs_num[u])
10                bridge = true;
11            dfs_low[u] = min(dfs_low[u], dfs_low[v]);
12        } else if(v!=p)
13            dfs_low[u] = min(dfs_low[u], dfs_num[v]);
14    }
15 }
16
17 int main(){
18     memset(dfs_num, 0, sizeof(dfs_num));
19     memset(dfs_low, 0, sizeof(dfs_low));
20     bridge=false;
21     dfs_counter=0;
22     dfs(0, -1);
23     for(int i = 0; i < N; ++i)
24         if(dfs_num[i]==0)
25             bridge=true;
26     puts(bridge ? "Yes" : "No");
27     return 0;
28 }
```

Centroid Decomposition

Centroid Decomposition

```
1 #include <bits/stdc++.h>
2 #define MAXN 100100
3 typedef long long ll;
4
5 using namespace std;
```

```
6
7 int n, sz[MAXN];
8 bool deleted[MAXN], vis[MAXN];
9 char ch[MAXN];
10 vector<int> g[MAXN];
11
12 void dfs(int x, int p){
13     if(vis[x]) return;
14     vis[x] = true;
15     sz[x] = 1;
16     for(auto i : g[x]){
17         if(i == p || deleted[i]) continue;
18         dfs(i, x);
19         sz[x] += sz[i];
20     }
21     //cout << x << " " << sz[x] << "\n";
22 }
23
24 int findCentroid(int x){
25     memset(vis, 0, sizeof(vis));
26     dfs(x, -1);
27     int p = -1, c = sz[x] / 2;
28     while(true){
29         bool found = false;
30         for(auto i : g[x]){
31             if(!deleted[i] && i != p && sz[i] > c){
32                 found = true;
33                 p = x;
34                 x = i;
35                 break;
36             }
37         }
38         if(!found) return x;
39     }
40 }
41
42 void decomp(int x, char c){
43     int cen = findCentroid(x);
44     ch[cen] = c;
45     deleted[cen] = true;
46     for(auto i : g[cen]){
47         if(deleted[i]) continue;
48         decomp(i, c + 1);
49     }
50 }
```

```

49     }
50 }
51
52 int main(){
53     #ifndef ONLINE_JUDGE
54         freopen("input.txt", "r", stdin);
55     #endif
56     ios_base::sync_with_stdio(false);
57     cin.tie(NULL);
58     memset(deleted, 0, sizeof(deleted));
59     cin >> n;
60     for(int i = 0; i < n - 1; i++){
61         int a, b;
62         cin >> a >> b;
63         g[a].push_back(b);
64         g[b].push_back(a);
65     }
66     //cout << findCentroid(1);
67     decomp(1, 'A');
68     for(int i = 1; i <= n; i++){
69         cout << ch[i] << " ";
70     }
71 }

```

Centroid Decomposition (Eoin)

```

1 void fill_sz(int u, int p){
2     sz[u] = 1;
3     for(int v : adjList[u]){
4         if(v==p || mkd[v])
5             continue;
6         fill_sz(v, u);
7         sz[u] += sz[v];
8     }
9 }
10
11 int get_centroid(int u, int n, int p){
12     for(int v : adjList[u]){
13         if(v==p || mkd[v])
14             continue;
15         if(sz[v] > n/2)
16             return get_centroid(v, n, u);
17     }
18     return u;
19 }
20
21 int decomp(int u){
22     fill_sz(u, -1);
23     int cent = get_centroid(u, sz[u], -1);
24     mkd[cent] = true;
25     for(int v : adjList[cent]){
26         if(mkd[v])
27             continue;
28         int r = decomp(v);
29         centP[r] = cent;

```

```

30     }
31     return cent;
32 }

```

Network Flow

Dinic's Blocking flow

```

1 /**
2     e-maxx's flow
3     Dinic algorithm
4     Complexity  $O(V^2 * E)$  OR  $O(V \sqrt{E})$  for bipartite graphs!
5 */
6
7
8 struct edge {
9     int a, b, cap, flow;
10 };
11
12 int nodes, s, t, d[N], ptr[N], q[N]; // NEED TO set n (
13                                     // max of nodes), s source, t sink
14 vector<edge> e;
15 vector<int> g[N];
16
17 void add_edge(int a, int b, int cap) {
18     edge e1 = { a, b, cap, 0 };
19     edge e2 = { b, a, 0, 0 };
20     g[a].push_back((int) e.size());
21     e.push_back(e1);
22     g[b].push_back((int) e.size());
23     e.push_back(e2);
24 }
25
26 bool bfs() {
27     int qh=0, qt=0;
28     q[qt++] = s;
29     memset(d, -1, nodes * sizeof d[0]);
30     d[s] = 0;
31     while (qh < qt && d[t] == -1) {
32         int v = q[qh++];
33         for (size_t i=0; i<g[v].size(); ++i) {
34             int id = g[v][i],
35                 to = e[id].b;
36             if (d[to] == -1 && e[id].flow < e[id].cap) {
37                 q[qt++] = to;
38                 d[to] = d[v] + 1;
39             }
40         }
41     }
42     return d[t] != -1;
43 }
44
45 int dfs(int v, int flow) {
46     if (!flow) return 0;
47     if (v == t) return flow;

```

```

47     for (; ptr[v]<(int)g[v].size(); ++ptr[v]) {
48         int id = g[v][ptr[v]],
49             to = e[id].b;
50         if (d[to] != d[v] + 1) continue;
51         int pushed = dfs (to, min (flow, e[id].cap - e[id].flow));
52         if (pushed) {
53             e[id].flow += pushed;
54             e[id ^ 1].flow -= pushed;
55             return pushed;
56         }
57     }
58     return 0;
59 }
60
61 int dinic() {
62     int flow = 0;
63     for (;;) {
64         if (!bfs()) break;
65         memset (ptr, 0, nodes * sizeof ptr[0]);
66         while (int pushed = dfs (s, inf))
67             flow += pushed;
68     }
69     return flow;
70 }

```

Edmond Karp

```

1 void aug(int u, int minE){
2     if(u==S){ f=minE; return; }
3     if(p[u]!=u){
4         aug(p[u], min(minE, res[p[u]][u]));
5         res[p[u]][u]-=f;
6         res[u][p[u]]+=f;
7     }
8 }
9
10 int main(){
11     int mf=0;
12     for(;;){
13         f=0; //Global
14         for(int i = 0; i < N; i++)
15             dist[i]=INF, p[i]=i;
16         dist[S]=0;
17         queue<int> q; q.push(S);
18         while(!q.empty()){
19             int u = q.front(); q.pop();
20             if(u==T) break;
21             for(int i = 0; i < N; i++)
22                 if(res[u][i] > 0 && dist[i]==INF)
23                     dist[i]=dist[u]+1, p[i]=u, q.push(i);
24         }
25         aug(T, INF);
26         if(f==0) break;
27         mf+=f;
28     }

```

```

29     vector<ii> used;
30     for(int i = 0; i < N; i++)
31         for(int j = 0; j < N; j++)
32             if(graph[i][j] > 0 && res[i][j] < graph[i][j])
33                 used.push_back(make_pair(i, j));
34 }

```

Ford Fulkerson 1

```

1 int ff(int u, int minE){
2     if(u==T)
3         return minE;
4     vis[u]=true;
5     for(auto i : adjList[u]){
6         if(!vis[i] && res[u][i] > 0){
7             if(int f = ff(i, min(minE, res[u][i]))){
8                 res[u][i] -= f;
9                 res[i][u] += f;
10                return f;
11            }
12        }
13    }
14    return 0;
15 }
16
17 int main(){
18     int mf = 0;
19     while(1){
20         memset(vis, 0, sizeof(vis));
21         int f = ff(S, INF);
22         if(f==0)
23             break;
24         mf+=f;
25     }
26     printf("%d\n", mf);
27 }

```

Ford Fulkerson 2

```

1 #include <bits/stdc++.h>
2 #define MAXN 3000
3 typedef long long ll;
4
5 using namespace std;
6
7 int n;
8 int g[MAXN][MAXN], rg[MAXN][MAXN], parent[MAXN];
9
10 bool bfs(int source, int sink){
11     bool visited[MAXN];
12     memset(visited, 0, sizeof(visited));
13     queue<int> q;
14     q.push(source);
15     visited[source] = true;
16     parent[source] = -1;

```



```

17     while(!q.empty()){
18         int i = q.front();
19         q.pop();
20         for(int j = 0; j < MAXN; j++){
21             if(!visited[j] && rg[i][j] > 0){
22                 q.push(j);
23                 parent[j] = i;
24                 visited[j] = true;
25             }
26         }
27     }
28     return visited[sink];
29 }
30
31 int maxFlow(int source, int sink){
32     for(int i = 0; i < MAXN; i++){
33         for(int j = 0; j < MAXN; j++){
34             rg[i][j] = g[i][j];
35         }
36     }
37     int max_flow = 0;
38     while(bfs(source, sink)){
39         int path_flow = 99999999;
40         for(int i = sink; i != source; i = parent[i]){
41             int j = parent[i];
42             path_flow = min(path_flow, rg[j][i]);
43         }
44         for(int i = sink; i != source; i = parent[i]){
45             int j = parent[i];
46             rg[j][i] -= path_flow;
47             rg[i][j] += path_flow;
48         }
49         max_flow += path_flow;
50     }
51     return max_flow;
52 }
53
54 int main(){
55     #ifndef ONLINE_JUDGE
56         freopen("input.txt", "r", stdin);
57     #endif
58     ios_base::sync_with_stdio(false);
59     for(int i = 0; i < MAXN; i++){
60         for(int j = 0; j < MAXN; j++){
61             rg[i][j] = g[i][j] = 0;
62         }
63     }
64 }

```

Lowest Common Ancestor

Lowest Common Ancestor (Using RMQ)

```

1  /*
2   * H[u] is first visit of u

```

```

3   * E[x] is vertex at time x
4   * L[x] is depth at time x
5   */
6 void vis(int u, int d){
7     H[u]=vind;
8     E[vind] = u;
9     L[vind++] = d;
10    for(auto i : adjList[u]){
11        if(H[i]!=-1)
12            continue;
13        vis(i,d+1);
14        E[vind] = u;
15        L[vind++] = d;
16    }
17 }
18
19 int LCA(int u, int v){
20     if(H[u] > H[v]){
21         int t = u;
22         u = v;
23         v = t;
24     }
25     //run some range min query on L
26     //between H[u] and H[v]
27     int ind = rmq(H[u],H[v]);
28     return E[ind];
29 }
30
31 int dist(int u, int v){
32     int a = H[u];
33     int b = H[v];
34     int ind = LCA(u,v);
35     return abs(L[H[ind]]-L[a])
36            + abs(L[H[ind]]-L[b]);
37 }

```

Lowest Common Ancestor (Using Binary Lifting)

```

1 #include <bits/stdc++.h>
2 #define MAXN 100100
3 typedef long long ll;
4
5 using namespace std;
6
7 int n, m, s[MAXN], depth[MAXN], anc[MAXN][40];
8 vector<int> g[MAXN];
9 bool vis[MAXN];
10
11 int dfs(int x, int d, int p){
12     vis[x] = true;
13     depth[x] = d;
14     s[x] = 1;
15     anc[x][0] = p;
16     for(int i = 1; pow(2, i) <= d; i++){
17         anc[x][i] = anc[anc[x][i-1]][i-1];

```

```

18     }
19     for(int i = 0; i < g[x].size(); i++){
20         if(vis[g[x][i]]) continue;
21         s[x] += dfs(g[x][i], d + 1, x);
22     }
23
24     return s[x];
25 }
26
27 int walk(int x, int d){
28     int i = 0;
29     while(d){
30         if(d & 1) x = anc[x][i];
31         d /= 2;
32         i++;
33     }
34     //cout << "\n";
35     return x;
36 }
37
38 int lca(int x, int y){
39     //cout << x<<y;
40
41     if(depth[x] < depth[y]) y = walk(y, depth[y] - depth[x]);
42     if(depth[x] > depth[y]) x = walk(x, depth[x] - depth[y]);
43     //cout << x<<y;
44     if(x == y) return x;
45     for(int i = 30; i >= 0; i--){
46         if(depth[x] >= pow(2, i) && anc[x][i] != anc[y][i]){
47             return lca(anc[x][i], anc[y][i]);
48         }
49     }
50     return anc[x][0];
51 }
52
53 int main(){
54     ios_base::sync_with_stdio(false);
55     cin >> n;
56     for(int i = 0; i < n - 1; i++){
57         int a, b;
58         cin >> a >> b;
59         g[a].push_back(b);
60         g[b].push_back(a);
61     }
62     dfs(1, 0, -1);
63     cin >> m;
64     for(int i = 0; i < m; i++){
65         int a, b;
66         cin >> a >> b;
67         if(depth[a] > depth[b]) swap(a, b);
68         if(a == b) cout << n;
69         else{
70             int l = lca(a, b);
71             int d = -2 * depth[l] + depth[a] + depth[b];
72             if(d % 2) cout << "0";

```

```

73         else{
74             if(depth[a] == depth[b]) cout << s[1] - s[walk(b,
75                 d / 2 - 1)] - s[walk(a, d / 2 - 1)];
76             else cout << s[walk(b, d / 2)] - s[walk(b, d / 2 -
77                 1)];
78         }
79         cout << "\n";
80     }
81 }

```

Minimum Spanning Tree (Kruskal's)

```

1 struct edge {
2     int x,y,w;
3     bool operator < (edge e) const {
4         return w < e.w;
5     }
6 };
7
8 int main(){
9     vector<edge> eList; //Input
10    for(int i = 0; i < N; i++)// Set up UFDS
11        p[i]=i;
12    vector<ii> treeList;
13    sort(eList.begin(), eList.end());
14    int cost = 0;
15    int sz=N;
16    int u,v,w;
17    for(const auto &i : eList){
18        v=i.x; u=i.y; w=i.w;
19        if(!connected(u,v)){
20            join(u,v);
21            treeList.push_back({min(u,v), max(u,v)});
22            sz--;
23            cost+=w;
24        }
25    }
26    if(sz!=1)
27        puts("Impossible");
28 }

```

Strongly Connected Components (Tarjan's)

```

1 typedef pair<int, int> ii;
2
3 int N,M;
4 vector<int> adjList[MXN];
5 int dfs_num[MXN], dfs_low[MXN];
6 bool vis[MXN];
7 stack<int> scc;
8 int dfsCounter=1;
9 int sccIdx=1;

```

```

10
11 map<int, int> sccMap;
12
13 void tarjans(int u){
14     scc.push(u);
15     vis[u]=true;
16
17     dfs_low[u]=dfs_num[u]=dfsCounter++;
18
19     for(int i = 0; i < adjList[u].size(); i++){
20         int v = adjList[u][i];
21         if(dfs_num[v]==0){
22             tarjans(v);
23             dfs_low[u]=min(dfs_low[u], dfs_low[v]);
24         } else if(vis[v]){
25             dfs_low[u]=min(dfs_low[u], dfs_num[v]);
26         }
27     }
28     if(dfs_low[u]==dfs_num[u]){
29         while(1){
30             int v = scc.top(); scc.pop();
31             sccMap[v]=sccIdx;
32             vis[v]=false;
33             if(v==u)
34                 break;
35         }
36         sccIdx++;
37     }
38 }

```

Bipartite Check

```

1 int n;
2 vector<vector<int>> adj;
3
4 vector<int> side(n, -1);
5 bool is_bipartite = true;
6 queue<int> q;
7 for (int st = 0; st < n; ++st) {
8     if (side[st] == -1) {
9         q.push(st);
10        side[st] = 0;
11        while (!q.empty()) {
12            int v = q.front();
13            q.pop();
14            for (int u : adj[v]) {
15                if (side[u] == -1) {
16                    side[u] = side[v] ^ 1;
17                    q.push(u);
18                } else {
19                    is_bipartite &= side[u] != side[v];
20                }
21            }
22        }
23    }
24 }

```

```

24 }
25
26 cout << (is_bipartite ? "YES" : "NO") << endl;

```

Dijkstras

```

1 #include <bits/stdc++.h>
2 #include <utility>
3 #define MAXN 505
4
5 using namespace std;
6
7 typedef long long ll;
8 typedef pair<int, int> ii;
9 int n;
10
11 vector<pair<int, int> > g[MAXN];
12 int dist[MAXN];
13
14 void dijkstra(int x){
15     for(int i = 0; i < n; i++){
16         dist[i] = 99999999;
17     }
18     priority_queue<pair<int, int>, vector<pair<int, int> >, greater<
19         pair<int, int> > > pq;
20     pq.push({0, x});
21     dist[x] = 0;
22     while(!pq.empty()){
23         pair<int, int> v = pq.top();
24         pq.pop();
25         for(int i = 0; i < g[v.second].size(); i++){
26             pair<int, int> u = g[v.second][i];
27             if(dist[v.second] + u.second < dist[u.first])
28                 pq.push({dist[v.second] + u.second, u.first});
29         }
30     }
31
32 int main(){
33     #ifndef ONLINE_JUDGE
34         freopen("input.txt", "r", stdin);
35     #endif
36     ios_base::sync_with_stdio(false);
37     //cin >> n;
38 }

```

Find Cycles

```

1 int n;
2 vector<vector<int>> adj;
3 vector<char> color;
4 vector<int> parent;
5 int cycle_start, cycle_end; // In O(M)

```

```

6
7 bool dfs(int v) {
8     color[v] = 1;
9     for (int u : adj[v]) {
10         if (color[u] == 0) {
11             parent[u] = v;
12             if (dfs(u))
13                 return true;
14         } else if (color[u] == 1) {
15             cycle_end = v;
16             cycle_start = u;
17             return true;
18         }
19     }
20     color[v] = 2;
21     return false;
22 }
23
24 void find_cycle() {
25     color.assign(n, 0);
26     parent.assign(n, -1);
27     cycle_start = -1;
28
29     for (int v = 0; v < n; v++) {
30         if (dfs(v))
31             break;
32     }
33
34     if (cycle_start == -1) {
35         cout << "Acyclic" << endl;
36     } else {
37         vector<int> cycle;
38         cycle.push_back(cycle_start);
39         for (int v = cycle_end; v != cycle_start; v = parent[v])
40             cycle.push_back(v);
41         cycle.push_back(cycle_start);
42         reverse(cycle.begin(), cycle.end());
43
44         cout << "Cycle_found:_" ;
45         for (int v : cycle)
46             cout << v << "_";
47         cout << endl;
48     }
49 }

```

Arrays

Longest Increasing Subsequence

```

1 int ls[MX_N];
2 int L[MX_N];
3 int I[MX_N];
4
5 void nlogn(){

```

```

6     for(int i = 1; i < N+1; ++i)
7         I[i]=INF;
8     I[0] = -INF;
9     int mx = 1;
10    for(int i = 0; i < N; ++i){
11        int ind = lower_bound(I, I+N+1, ls[i]) - I;
12        I[ind] = ls[i];
13        L[i] = ind;
14        mx = max(mx, ind);
15    }
16    int prv = INF;
17    vector<int> out;
18    for(int i = N-1; i >= 0; --i){
19        if(ls[i] < prv && L[i]==mx){
20            out.push_back(ls[i]);
21            prv = ls[i];
22            mx--;
23        }
24    }
25 }

```

Data Structures

Fenwick Tree

```
1 int tree[MXN];
2 int N;
3 int lsOne(int i){ return i&(-i); }
4 void update(int k,int v){
5     for(; k<MXN; k+=lsOne(k))
6         tree[k]+=v;
7 }
8 int query(int k){
9     int cnt=0;
10    for(; k; k-=lsOne(k)){
11        cnt+=tree[k];
12    }
13    return cnt;
14 }
```

Segment Trees

Segment Tree Lazy

```
1 typedef long long ll;
2 typedef pair<int, int> ii;
3 const int INF = 0x3f3f3f3f;
4 const double PI = acos(-1.0);
5
6 struct SegT {
7     vector<ll> seg, lazy;
8     int n;
9
10    SegT () {}
11
12    SegT (int n) {
13        this->n = n;
14        seg.resize(4*n + 1);
15        lazy.resize(4*n + 1);
16    }
17
18    void prop (int r, int i, int j) {
19
20        seg[r] += lazy[r] * (j-i+1);
21    }
```

```
22        if (i != j) {
23            lazy[2*r] += lazy[r];
24            lazy[2*r + 1] += lazy[r];
25        }
26
27        lazy[r] = 0;
28    }
29
30    int a, b;
31    ll update (int r, int i, int j, ll val) {
32        prop (r, i, j);
33        if (j < a or i > b) return 0LL;
34
35        if (i >= a and j <= b) {
36            lazy[r] += val;
37            prop (r, i, j);
38            return seg[r];
39        } else {
40            int mid = (i + j)/2;
41            ll L = update (2*r, i, mid, val);
42            ll R = update (2*r + 1, mid + 1, j, val);
43            return L + R;
44        }
45    }
46
47    ll update (int l, int r, ll val) {
48        a = l; b = r;
49        return update (1, 0, n - 1, val);
50    }
51
52    ll query (int l, int r) {
53        return update (1, r, 0);
54    }
55
56 };
```

Segment Tree (Eoin)

```
1 int tree[MXN*4];
2 int a[MXN];
3 int N;
4
5 void construct(int p, int L, int R){
```

```

6      if(L==R){
7          tree[p] = a[L];
8          return;
9      }
10     if(R<L)
11         return;
12     int md = (L+R)/2;
13     construct(2*p,L,md);
14     construct(2*p+1,md+1,R);
15     tree[p] = min(tree[2*p], tree[2*p+1]);
16 }
17
18 void update(int p, int L, int R, int ind, int v){
19     if(L==R){
20         a[ind] = v;
21         tree[p] = v;
22         return;
23     }
24     int md = (L+R)/2;
25     if(ind <= md)
26         update(2*p,L,md,ind,v);
27     else
28         update(2*p+1,md+1,R,ind,v);
29     tree[p] = min(tree[2*p], tree[2*p+1]);
30 }
31
32 int rmq(int p, int L, int R, int l, int r){
33     if(r < L || l > R)
34         return INF;
35     if(l>=L && r<=R)
36         return tree[p];
37     int md = (l+r)/2;
38     return min(rmq(2*p,L,R,l,md), rmq(2*p+1,L,R,md+1,r));
39 }

```

Iterative Segment Tree

```

1  int t[2*N], n; // When debugging, the prob is most likely that you have
    multiple n's. need this one here!
2
3  int query(int l, int r){ // This r is exclusive!
4      int ans=0;
5      for(l+=n, r+=n; l<r; l>>=1, r>>=1){
6          if(l&1)ans+=t[l++];
7          if(r&1)ans+=t[--r];
8      }
9      return ans;
10 }
11
12 void update(int p, int v){
13     for(t[p+=n]+=v; p>1; p>>=1){
14         t[p>>1]=t[p]+t[p^1];
15     }
16 }

```

Sparse Table

```

1  inline int rmq(int u, int v){
2      if(u > v)
3          return -2000000000;
4      int k=(int) floor(log2((double)(v-u+1)));
5      if(r[mtable[u][k]]>
6          r[mtable[v-(1<<k)+1][k]])
7          return mtable[u][k];
8      return mtable[v-(1<<k)+1][k];
9  }
10
11 for(int i = 0; i < N; i++)
12     mtable[i][0] = i;
13 for(int j = 1; (1 << j) <= N; j++)
14     for(int i = 0; i + (1<<j)-1 < N; ++i)
15         if(r[mtable[i][j-1]]
16             >r[mtable[i+(1<<(j-1))][j-1]])
17             mtable[i][j]= mtable[i][j-1];
18         else
19             mtable[i][j]=mtable[i+(1<<(j-1))][j-1];

```

Union Find

```

1  /**
2      Union find algorithm
3      Complexity O(log n) for Join or Find.
4  */
5
6  int pai[N];
7
8  void init(int n){
9      for(int i=1; i<=n; i++){
10         pai[i]=i;
11     }
12 }
13
14 int find(int i){
15     if(pai[i]==i) return i;
16     return pai[i]=find(pai[i]);
17 }
18
19 int join(int a, int b){
20     a=find(a);
21     b=find(b);
22     pai[a]=pai[b];
23 }

```

Strings

KMP

KMP

```
1  /*
2      border = proper prefix that is suffix
3      p[i] = length of longest border of prefix of length i, s[0...i-1]
4  */
5
6  typedef long long ll;
7  typedef pair<int, int> ii;
8  const int INF = 0x3f3f3f3f;
9  const double PI = acos(-1.0);
10
11 const int N = 1e6 + 6;
12 int pi[N];
13 string p, t;
14
15 void pre () {
16     p += '#';
17
18     pi[0] = pi[1] = 0;
19     for (int i = 2; i <= (int)p.size(); i++) {
20         pi[i] = pi[i-1];
21
22         while (pi[i] > 0 and p[pi[i]] != p[i-1])
23             pi[i] = pi[pi[i]];
24
25         if (p[pi[i]] == p[i-1])
26             pi[i]++;
27     }
28 }
29
30 void report (int at) {
31
32 }
33
34 void KMP () {
35     pre ();
36
37     int k = 0;
38     int m = p.size() - 1;
```

```
39
40     for (int i = 0; i < (int)t.size(); i++) {
41         while (k > 0 and p[k] != t[i])
42             k = pi[k];
43
44         if (p[k] == t[i])
45             k++;
46         if (k == m)
47             report (i - m + 1);
48     }
49 }
50
51 int main (void) {
52     ios_base::sync_with_stdio(false);
53
54     return 0;
55 }
56
```

KMP (Eoin)

```
1 vector<int> buildFailure(string s){
2     vector<int> T(n+1,0);
3     T[0]=-1;
4     int j = 0;
5     for(int i = 1; i < s.size();++i){
6         if(s[i]==s[j]){
7             T[i]=T[j];
8             j++;
9         } else{
10            T[i] = j;
11            j = T[j];
12            while(j >= 0 && s[i]!=s[j])
13                j = T[j];
14            j++;
15        }
16    }
17    T[s.size()] = j;
18    return T;
19 }
20 vector<int> search(string W, string S){
21     auto T=buildFailure(W);
22     vector<int> p;
```

```

23     int k = 0;
24     int j = 0;
25     while(j < S.size()){
26         if(W[k]==S[j]){
27             k++; j++;
28             if(k==W.size()){
29                 p.push_back(j-k);
30                 k = T[k];
31             }
32         }else{
33             k = T[k];
34             if(k < 0)
35                 j+=1, k+=1;
36         }
37     }
38     return p;
39 }

```

Rabin Karp

```

1  // Looks for a pattern s in text t in O(n+m) time.
2  // Returns where the occurrences are
3
4  vector<int> rabin_karp(string const& s, string const& t) {
5      const int p = 31;
6      const int m = 1e9 + 9;
7      int S = s.size(), T = t.size();
8
9      vector<long long> p_pow(max(S, T));
10     p_pow[0] = 1;
11     for (int i = 1; i < (int)p_pow.size(); i++)
12         p_pow[i] = (p_pow[i-1] * p) % m;
13
14     vector<long long> h(T + 1, 0);
15     for (int i = 0; i < T; i++)
16         h[i+1] = (h[i] + (t[i] - 'a' + 1) * p_pow[i]) % m;
17     long long h_s = 0;
18     for (int i = 0; i < S; i++)
19         h_s = (h_s + (s[i] - 'a' + 1) * p_pow[i]) % m;
20
21     vector<int> occurrences;
22     for (int i = 0; i + S - 1 < T; i++) {
23         long long cur_h = (h[i+S] + m - h[i]) % m;
24         if (cur_h == h_s * p_pow[i] % m)
25             occurrences.push_back(i);
26     }
27     return occurrences;
28 }

```

Suffix Array

```

1 void countingSort(int k){
2     int i, sum, maxi=max(300,N);

```

```

3     memset(c,0,sizeof(c));
4     for(i = 0; i < N; i++)
5         c[i+k < N ? RA[i+k] : 0]++;
6     for(i=sum=0; i < maxi; i++){
7         int t = c[i];
8         c[i]=sum;
9         sum+=t;
10    }
11    for(i = 0; i < N; i++)
12        tempSA[c[SA[i]+k < N
13            ? RA[SA[i]+k]: 0]++] = SA[i];
14    for(i=0; i < N; i++)
15        SA[i]=tempSA[i];
16 }
17
18 int main(){
19     for(int i = 0; i < N; i++)
20         SA[i]=i, RA[i]=input[i];
21     int r;
22     for(int k = 1; k < N; k <= 1){
23         countingSort(k);
24         countingSort(0);
25         tempRA[SA[0]]=r=0;
26         for(int i = 1; i < N; i++){
27             tempRA[SA[i]]
28                 =(RA[SA[i]]==RA[SA[i-1]]
29                 && RA[SA[i]+k]==RA[SA[i-1]+k]
30                 ? r:++r);
31         }
32         for(int i = 0; i < N; i++)
33             RA[i]=tempRA[i];
34     }
35     return 0;
36 }

```

Manacher's algorithm for longest palindromic substring

```

1  /* Manacher's algorithm O(N), time and memory, algorithm to find
2  * longest palindromic substring
3  *
4  * Transform initial string t into s,
5  * putting separators between characters
6  *
7  * Build vector p[], where p[i] is the length of the
8  * palindrome centered at s[i]
9  *
10 * Works for both, odd and even length
11 * s: # a # b # a #                # a # a #
12 * p: 0 1 0 3 0 1 0                0 1 2 1 0
13 *
14 * p built in O(N) using the fact that elements can be symmetric
15 * given some center and p[center]:

```



```

16  * If we are in i and center c, i_mirror = c - (i - c), if p[i_mirror]
17  * fits in center + p[center], p[i] is p[i_mirror], else we need to
18  * check real value of p[i]
19  * If we call the border center + p[center], r. Its easy to see
20  * r is only increased, achieving the O(N) time complexity
21  *
22  * Longest palindromic substring is the maximum element in p
23  *
24  */
25
26 typedef long long ll;
27 typedef pair<int, int> ii;
28 const int INF = 0x3f3f3f3f;
29 const double PI = acos(-1.0);
30
31 const int N = 1e6 + 5;
32 int p[2*N + 2];
33
34 int main (void) {
35     ios_base::sync_with_stdio(false);
36
37     string s, t;    cin >> t;
38     s += "#";
39     for (auto c : t) {
40         s += c;
41         s += '#';
42     }
43
44     int n = s.size();
45     int c = 0, r = 0;
46     for (int i = 0; i < n; i++) {
47         int i_mirror = c - (i - c);
48
49         if (i <= r)
50             p[i] = min (p[i_mirror], r - i);
51         else
52             p[i] = 0;
53
54         while (i - 1 - p[i] >= 0 and i + 1 + p[i] < n and s[i + 1 - p[i]] == s[i + 1 + p[i]]) {
55             p[i]++;
56         }
57
58         if (i + p[i] > r) {
59             c = i;
60             r = i + p[i];
61         }
62     }
63
64     int len = 0, center = 0;
65     for (int i = 0; i < n; i++)
66         if (p[i] > len) {
67             len = p[i];
68             center = i;
69         }

```

```

70
71     /* not tested */
72     string res;
73     for (int i = 0; i < n; i++)
74         if (i >= center - len and i <= center + len and s[i] != '#')
75             res += s[i];
76
77     /* */
78
79     cout << len << endl;
80     cout << res << endl;
81
82     return 0;
83 }

```

Z function

```

1  /*          {0, if i = 0
2  z[i] = {length longest common prefix of s and s[i...n-1]
3  */
4
5  typedef long long ll;
6  typedef pair<int, int> ii;
7  const int INF = 0x3f3f3f3f;
8  const double PI = acos(-1.0);
9
10 const int N = 2e5 + 5;
11 string s;
12 int z[N];
13
14 void go () {
15     int l = 0, r = 0;
16     int n = s.size();
17     memset (z, 0, sizeof z);
18
19     for (int i = 1; i < n; i++) {
20         if (i <= r)
21             z[i] = min (z[i-l], r - i + 1);
22         while (z[i] + i < n and s[z[i] + i] == s[i + z[i]])
23             z[i]++;
24         if (r < i + z[i] - 1) {
25             l = i;
26             r = i + z[i] - 1;
27         }
28     }
29 }

```

Hash

```

1  typedef long long ll;
2  typedef pair <ll, ll> ii;
3
4  ll md (ll x, ll mod) {

```

```

5         x %= mod;
6         if (x < 0)
7             return x + mod;
8         return x;
9     }
10
11 struct Hash {
12     const ll base = 31;
13     ll mod, *h, *pot;
14     string s;
15
16     Hash () {}
17
18     void build (string s, ll mod) { // O(n)
19         this->mod = mod;
20         this->s = s;
21         h = new ll [s.size() + 2];
22         pot = new ll [s.size() + 2];
23
24         h[0] = s[0] - 'a';
25         for (int i = 1; i < (int)s.size(); i++)
26             h[i] = (h[i-1]*base + s[i] - 'a')%mod;
27
28         pot[0] = 1LL;
29         for (int i = 1; i < (int)s.size(); i++)
30             pot[i] = (pot[i-1] * base)%mod;
31     }
32
33     ll query (int l, int r) { // O(1)
34         ll R = h[r], L = 0;
35
36         if (l)
37             L = (h[l-1] * pot[r - l + 1])%mod;
38
39         return md (R - L, mod);
40     }
41 } h[2];
42
43 // returns if s[i, i + ilen - 1] is lexicographically smaller than s[j, j
44 // + jlen - 1]
45 // not tested if ilen != jlen
46 bool comp (string &s, int i, int ilen, int j, int jlen) {
47     int bot = 0, top = min (ilen, jlen) - 1;
48     int id = -1;
49
50     while (bot <= top) {
51         int mid = (bot + top)>>1;
52
53         ii pi = ii(h[0].query(i, i + mid), h[1].query(i, i + mid))
54             ;
55         ii pj = ii(h[0].query(j, j + mid), h[1].query(j, j + mid))
56             ;
57         if (pi == pj) {
58             bot = mid + 1;

```

```

57             id = mid;
58         } else {
59             top = mid - 1;
60         }
61     }
62
63     if (id == min (ilen, jlen) - 1) {
64         if (ilen != jlen)
65             return ilen < jlen;
66         return i < j;
67     }
68
69     return s[i + id + 1] < s[j + id + 1];
70 }
71
72 const ll mod[2] = {1000000007, 1000000009};

```

Geometry

Convex Hull

Convex Hull

```
1 // Implementation of Andrew's monotone chain 2D convex hull algorithm.
2 // Asymptotic complexity:  $O(n \log n)$ .
3
4 typedef double coord_t; // coordinate type
5 typedef double coord2_t; // must be big enough to hold  $2 \cdot \max(|\text{coordinate}|)^2$ 
6
7 struct Point {
8     coord_t x, y;
9     Point() {}
10    Point(coord_t xx, coord_t yy){
11        x=xx, y=yy;
12    }
13    bool operator <(const Point &p) const {
14        return x < p.x || (x == p.x && y < p.y);
15    }
16 };
17
18 // 2D cross product of OA and OB vectors, i.e. z-component of their 3D
19 // cross product.
20 // Returns a positive value, if OAB makes a counter-clockwise turn,
21 // negative for clockwise turn, and zero if the points are collinear.
22 coord2_t cross(const Point &O, const Point &A, const Point &B){
23     return (A.x - O.x) * (B.y - O.y) - (A.y - O.y) * (B.x - O.x);
24 }
25
26 // Returns a list of points on the convex hull in counter-clockwise order.
27 // Note: the last point in the returned list is the same as the first one.
28 vector<Point> convex_hull(vector<Point> P){
29     size_t n = P.size(), k = 0;
30     if (n <= 3) return P;
31     vector<Point> H(2*n);
32
33     // Sort points lexicographically
34     sort(P.begin(), P.end());
35
36     // Build lower hull
37     for (size_t i = 0; i < n; ++i) {
```

```
37         while (k >= 2 && cross(H[k-2], H[k-1], P[i]) <= 0) k--; //
38         // Remove the last "=" if you want to get max points in
39         // the hull
40         H[k++] = P[i];
41     }
42
43     // Build upper hull
44     for (size_t i = n-1, t = k+1; i > 0; --i) {
45         while (k >= t && cross(H[k-2], H[k-1], P[i-1]) <= 0) k--;
46         // Remove the last "=" if you want to get max points
47         // in the hull
48         H[k++] = P[i-1];
49     }
50
51     H.resize(k-1);
52     return H;
53 }
54
55 /*
56  * Note that this is using double. Its better to use long long because
57  * double might be TLE!
58 */
```

Convex Hull (Eoin)

```
1 int main(){
2     for(int i = 0; i < N; i++){
3         perm[i]=i;
4     }
5     sort(perm, perm+N,
6         [](int a, int b){
7             const point &pa = V[a];
8             const point &pb = V[b];
9             if (real(pa) != real(pb))
10                 return real(pa) < real(pb);
11             return imag(pa) < imag(pb);
12         });
13     vector<int> L; vector<int> U;
14     for(int i = 0; i < N; i){
15         int t = L.size();
16         if (t >= 2 && !ccw(V[L[t-2]], V[L[t-1]], V[perm[i]]))
17             L.pop_back();
18         else
```

```

19         L.push_back(perm[i++]);
20     }
21     for(int i = N-1; i >=0;){
22         int t = U.size();
23         if(t >= 2 && !ccw(V[U[t-2]],V[U[t-1]],V[perm[i]]))
24             U.pop_back();
25         else
26             U.push_back(perm[i--]);
27     }
28     vector<int> hull;
29     for(int i = 0; i < L.size()-1; ++i)
30         hull.push_back(L[i]);
31     for(int i = 0; i < U.size()-1; ++i)
32         hull.push_back(U[i]);
33     return 0;
34 }

```

Geometry Functions

```

1  typedef complex<double> pt;
2  typedef complex<double> vec;
3  typedef vector<pt> pgon;
4  typedef struct { pt p,q; } lseg;
5  double cross(const vec& a, const vec &b){
6      return x(a)*y(b)-y(a)*x(b);
7  }
8  //cross product of (b-a) and (c-b), 0 is collinear
9  int orientation(const pt& a,
10     const pt& b, const pt& c){
11     double v = cross(b-a,c-b);
12     if(abs(v-0.0)<EPS)
13         return 0;
14     return v > 0 ? 1 : 2;
15 }
16 //Line segment intersection
17 bool intersects(const lseg& a, const lseg& b){
18     if(a.q == b.p || b.q == a.p)
19         return false;
20     if(orientation(a.p,a.q,b.p)
21        !=orientation(a.p,a.q,b.q)
22        && orientation(b.p,b.q,a.p)
23        != orientation(b.p,b.q,a.q))
24         return true;
25     return false;
26 }
27 //Area of polygon
28 double area(const pgon& p){
29     double area = 0.0;
30     for(int i = 1; i < p.size(); ++i)
31         area+=cross(p[i-1],p[i]);
32     return abs(area)/2.0;
33 }
34 //If a->b->c is a counterclockwise turn
35 double ccw(const point& a, const point& b,

```

```

36     const point& c){
37     if(a==b || b==c || a==c)
38         return false;
39     point relA = b-a;
40     point relC = b-c;
41     return cross(relA,relC) >= 0.0;
42 }
43 //Returns if point p is in the polygon poly
44 bool inPoly(const pgon& poly, const pt& p){
45     for(int i = 0; i < poly.size()-1; i++){
46         if(!ccw(poly[i],p,poly[i+1]))
47             return false;
48     }
49     return true;
50 }
51 //Distance from p to line (a,b)
52 double distToLine(const pt& p, const pt& a,
53     const pt &b){
54     vec ap = p-a;
55     vec ab = b-a;
56     double u = dot(ap,ab)/dot(ab,ab);
57     //Ignore for non-line segment
58     if(u < 0.0) //Closer to a
59         return abs(a-p);
60     if(u > 1.0) //Closer to b
61         return abs(b-p);
62     pt c = a+ab*u; // This is the point
63     return abs(c-p);
64 }

```

```

1  double area(vector<Point>v){ // Return the area of the convex hull in O
2      (n).
3      double ret=0.0;
4      int n=v.size();
5      for(int i=0; i<v.size(); i++){
6          ret+=v[i].x*(v[(i+1+n)%n].y-v[(i-1+n)%n].y);
7      }
8      return abs(ret/2);
9  }
10 double perimeter(vector<Point> v){ // Return the perimeter of the
11     convex hull in O(n).
12     double ans=0.0;
13     v.pb(v[0]);
14     for(int i=0; i<v.size()-1; i++){
15         ans+=sqrt((v[i].x-v[i+1].x)*(v[i].x-v[i+1].x)+(v[i].y-v[i
16             +1].y)*(v[i].y-v[i+1].y));
17     }
18     return ans;
19 }
19 Point rotate(Point c, Point po, double ang){ // Rotate po, around c by
20     ang.
21     /*
22      * C is the center of the rotation

```

```

22      * Po is the point to be rotated by ang in rad .
23      * Ang is the angle in radians to be rotated counter-clockwise.
24      */
25      Point p;
26      p.x=c.x+(po.x-c.x)*cos(ang)-(po.y-c.y)*sin(ang);
27      p.y=c.y+(po.x-c.x)*sin(ang)-(po.y-c.y)*cos(ang);
28      return p;
29  }

```

Math

Ternary Search

```
1 double ternary_search(double l, double r) {
2     double eps = 1e-9;           //set the error limit here
3     while (r - l > eps) {
4         double m1 = l + (r - l) / 3;
5         double m2 = r - (r - l) / 3;
6         double f1 = f(m1);        //evaluates the function at m1
7         double f2 = f(m2);        //evaluates the function at m2
8         if (f1 < f2)
9             l = m1;
10        else
11            r = m2;
12    }
13    return f(l);                  //return the maximum of f(x) in [l, r]
14 }
```

Miller Rabin primality test

```
1 void factor(ll x, ll& e, ll& k){
2     while(x%2LL==0LL){
3         x/=2LL;
4         ++e;
5     }
6     k = x;
7 }
8
9 //increase x for higher certainty, 5 works well
10 bool is_prime(ll n, int x){
11     if(n%2LL==0 || n==1LL)
12         return false;
13     if(n==2 || n==3 || n==5 || n==7)
14         return true;
15     ll e, k;
16     factor(n-1,e,k);
17     while(x-->0){
18         ll a = (rand())%(n-5LL) + 2LL;
19         ll p = mod_exp(a,k,n);
20         if(p==1LL || p==n-1LL)
21             continue;
22         bool all_fail = true;
23         for(int i = 0; i < e-1; ++i){
```

```
24             p = mod_exp(p, 2, n);
25             if(p==n-1LL){
26                 all_fail = false;
27                 break;
28             }
29         }
30         if(all_fail)
31             return false;
32     }
33     return true;
34 }
```

Fast fourier transform

```
1 /* emaxx implementation */
2 /* Multiplication with arbitrary modulus
3  * use ntt if mod is prime and can be written as 2**k * c + 1
4  * if not, use Chinese Remainder Theorem
5  * or transform A(x) = A1(x) + A2(x)*c decompose into A(x)/c and A(x)%c
6  * B(x) = B1(x) + B2(x)*c
7  * where c ~= sqrt(mod)
8  * A * B = A1*B1 + c*(A1*B2 + A2*B1) * c**2(A2*B2)
9  * with all values < sqrt(mod) subpolynomials have coefficients <
10  * mod * N after fft multiply decreasing changes of rounding error
11  */
12 const double PI=acos(-1);
13
14 typedef complex<double> base;
15
16 void fft (vector<base> & a, bool invert) {
17     int n=(int) a.size();
18     for (int i=1, j=0; i<n; ++i) {
19         int bit=n>>1;
20         for (;j>=bit; bit>>=1)
21             j-=bit;
22         j+=bit;
23         if(i<j)
24             swap(a[i],a[j]);
25     }
26     for (int len=2; len<=n; len<<=1) {
27         double ang = 2*PI/len * (invert ? -1 : 1);
28         base wlen(cos(ang), sin(ang));
```

```

29         for (int i=0; i<n; i+=len) {
30             base w(1);
31             for (int j=0; j<len/2; ++j) {
32                 base u=a[i+j], v=a[i+j+len/2]*w;
33                 a[i+j]=u+v;
34                 a[i+j+len/2]=u-v;
35                 w*=wlen;
36             }
37         }
38     }
39     if (invert)
40         for(int i=0;i<n;++i)
41             a[i]/=n;
42 }
43
44 // a, b => coefs to multiply, res => resulting coefs
45 // a[0], b[0], res[0] = coef x^0
46 // Doesnt work with negative coefs
47 void multiply (const vector<int> &a, const vector<int> &b, vector<int> &
48     res) {
49     vector<base> fa (a.begin(), a.end()), fb (b.begin(), b.end());
50     size_t n=1;
51     while (n<max(a.size(),b.size())) n<<=1;
52     fa.resize(n),fb.resize(n);
53     fft (fa,false);  fft (fb,false);
54     for (size_t i=0; i<n; ++i)
55         fa[i]*=fb[i];
56     fft (fa, true);
57     res.resize (n);
58     // avoid precision errors, mess up with negative values of coefs
59     for(size_t i=0; i<n; ++i)
60         res[i]=int(fa[i].real() + 0.5);
61 }

```

Matrix Exponentiation

```

1  typedef long long ll;
2  const int NMAT=2;
3  const int mod=1;
4
5  /* c=a*b */
6  void mu(ll a[][NMAT], ll b[][NMAT], ll c[][NMAT], int _n) {
7      for(int i=0;i<_n;i++)
8          for(int j=0;j<_n;j++) {
9              c[i][j]=0;
10             for(int h=0;h<_n;h++) {
11                 c[i][j]+=(a[i][h]*b[h][j])%mod;
12                 c[i][j]%=mod;
13             }
14         }
15 }
16 /*returns ans=mat^b*/
17 void power(ll ans[][NMAT], ll mat[][NMAT], ll b, int _n) {

```

```

18     ll tmp[NMAT][NMAT];
19     for(int i=0;i<_n;i++)
20         for (int j = 0; j<_n; j++)
21             ans[i][j]=i==j;
22
23     while(b) {
24         if(b&1) {
25             mu(ans, mat, tmp, _n);
26             for(int i=0;i<_n;i++)
27                 for (int j=0;j<_n;j++)
28                     ans[i][j]=tmp[i][j];
29         }
30         mu(mat, mat, tmp, _n);
31         for(int i=0;i<_n;i++)
32             for (int j=0;j<_n;j++)
33                 mat[i][j]=tmp[i][j];
34         b>>=1;
35     }

```

Math Tricks

```

1  ll fexp(ll a, int x, ll mod){ // Fast exponenciacion returns a^x
2      % mod
3      if (x==0)return 1ll;
4      if (x%2==0){
5          ll y=fexp(a, x/2, mod);
6          return (y*y)%mod;
7      }
8      return (a*fexp(a, x-1, mod))%mod;
9  }
10 ll divv(ll a, ll b, ll mod){ // Division with mod returns a/b % mod
11     return (a*fexp(b, mod-2, mod))%mod;
12 }
13
14 ll f[N];
15
16 ll fat(ll a, ll mod){ // Calculates factorial and stores in f %
17     mod
18     if (a<=1)return 1;
19     return f[a]?f[a]:(f[a]=(a*fat(a-1, mod))%mod);
20 }
21 ll choose(ll n, ll k, ll mod){ // Returns n choose k % mod
22     return divv(fat(n, mod), (fat(k, mod)*fat(n-k, mod))%mod, mod)%mod;
23 }
24
25 ll gcd(ll a, ll b){ // Greatest common divisor
26     return b?gcd(b, a%b):a;
27 }
28
29 ll lcm(ll a, ll b){ // Least common multiple
30     return (a*b)/gcd(a, b);

```

```

31 }
32
33
34 /* Fast factorization */
35
36 int p[N];
37
38 void start_fast(int MAX){ // Runs  $O(n \log(n))$  Needs to be called to
    use fast_fact or ammount_of_divisors.
39     for(int i=2; i<=MAX; i++){
40         if(p[i]==0){
41             for(int j=i; j<=MAX; j+=i){
42                 p[j]=i;
43             }
44         }
45     }
46 }
47
48 vector<int>fast_fact(int x){ // Fast factorization in  $O(\log^2(x))$ 
49     vector<int>ret;
50     while(x>1){
51         ret.pb(p[x]);
52         x/=p[x];
53     }
54     return ret;
55 }
56
57 int amount_of_divisors(int x){ // Calculate the ammount of divisors of a
    number in  $O(\log^2(x))$  assume already ran start_fast.
58     if(x==1)return 1;
59     vector<int>v=fast_fact(x);
60     int ret=1, curr=2;
61     for(int i=1; i<v.size(); i++){
62         if(v[i]==v[i-1])curr++;
63         else{
64             ret*=curr;
65             curr=2;
66         }
67     }
68     return ret*curr;
69 }

```

```

9
10
11 Burnsides Lemma
12 Let G be the finite group of operations we can perform on X
13 The number of orbits of X is the average of the number of fixed points for
    each g in G
14 G must be closed

```

Theorems

```

1 Picks theorem
2 Given a certain lattice polygon with non-zero area.
3
4 We denote its area by S, the number of points with integer coordinates
    lying strictly inside the polygon by I and the number of points lying
    on polygon sides by B.
5
6 Then, the Pick's formula states:
7
8  $S=I+B/2-1$ 

```