

CP Algorithms Handbook

Stanisław Fiedler

October 17, 2025

Contents

1	Sorting and Searching	2
1.1	Quick Sort	2
1.2	Merge Sort	2
2	Dynamic Programming	2
2.1	State representation	2
2.1.1	All subsets	2
3	Graph Algorithms	3
3.1	Shortest Path	3
3.1.1	Dijkstra	3
3.1.2	Belman-Ford	3
3.1.3	Floyd–Warshal	3
3.2	Union Find	4
3.3	Path through all edges	4
3.4	Topo Sort	5
3.5	Flows and Cuts	6
3.5.1	Maximum Flow	6
3.5.2	Minimum Cut	7
3.5.3	Maximum Matching	7
3.6	2SAT	7
4	Range Queries	9
4.1	Segment trees	9
4.1.1	Point-Range Trees	9
4.1.2	Range-Range Trees	10
4.2	Max Subarray Sum	11
5	Tree Algorithms	11
5.1	Binary Liftng	11
5.2	Tree Traversal	12
5.3	LCA	12
6	String Algorithms	12
6.1	Trie	12
6.2	Pattern Finding	12
6.2.1	KMP	12
6.2.2	Hashing	13
6.3	Palindormes	14
7	Mathematics	14
7.1	Fermat’s Theorem	14
7.2	Fast Fibonacci	14
8	Geometry	15
8.1	Point Location Test	15
9	Other Algorithms	15

1 Sorting and Searching

1.1 Quick Sort

```
1 void qwik_sort(int p, int q, int tab[]){
2     int a = p, b = q;
3     int m = tab[(p+q)/2];
4
5     while(a <= b){
6         while(m > tab[a])
7             a++;
8         while(m < tab[b])
9             b--;
10        if(a <= b){
11            swap(tab[a], tab[b]);
12            a++;
13            b--;
14        }
15    }
16    if(b > p)
17        qwik_sort(p, b, tab);
18    if(a < q)
19        qwik_sort(a, q, tab);
20 }
```

1.2 Merge Sort

```
1 void merge(int left, int mid, int right, int t[]){
2     int a = left, b = mid;
3     int i = left;
4     while(a < mid && b < right)
5         tab[i++] = (t[a] < t[b] ? t[a++] : t[b++]);
6     while(a < mid)
7         tab[i++] = t[a++];
8     while(b < right)
9         tab[i++] = t[b++];
10    for(int k = left; k < right; k++)
11        t[k] = tab[k];
12 }
13
14 void mergesort(int left, int right, int t[]){
15     if(left+1 != right){
16         int m = (left+right)/2;
17         mergesort(left, m, t);
18         mergesort(m, right, t);
19         merge(left, m, right, t);
20     }
21 }
```

2 Dynamic Programming

2.1 State representation

2.1.1 All subsets

This way you can generate all subsets in order ready for DP.

```
1     int sub = whole_set;
2     while(sub > 0){
3
4         sub = (sub-1)&whole_set;
5     }
```

3 Graph Algorithms

3.1 Shortest Path

3.1.1 Dijkstra

```
1 priority_queue<pair<long long int ,int>> q;
2 dist[1] = 0;
3 q.push({0, 1});
4 while(!q.empty()){
5     int a = q.top().second;
6     q.pop();
7     if(vis[a]) continue;
8     vis[a] = true;
9     for(auto v : adj[a]){
10         int b = v.first;
11         int w = v.second;
12         if(dist[b] > dist[a] + w){
13             dist[b] = dist[a] + w;
14             q.push({-dist[b], b});
15         }
16     }
17 }
```

3.1.2 Belman-Ford

```
1 dist[1] = 0;
2 for(int i = 1; i <= n-1; i++){
3     for(auto e : edges){
4         int a, b, w;
5         tie(a, b ,w) = e;
6         if(dist[b] > dist[a]+w){
7             par[b] = a;
8             dist[b] = dist[a]+w;
9         }
10    }
11 }
12 for(auto e : edges){
13     int a, b, w;
14     tie(a, b ,w) = e;
15     if(dist[b] > dist[a]+w){
16         found = true;
17         node = b;
18         par[b] = a;
19         dist[b] = dist[a]+w;
20 }
```

3.1.3 Floyd–Warshal

```
1 long long int dist[SIZE][SIZE] {};
2 for(int i = 0; i <= n; i++){
3     for(int k = 0; k <= n; k++){
4         dist[i][k] = __INT64_MAX__/2;
5     }
6 }
7 for(int i = 1; i <= n; i++){
8     dist[i][i] = 0;
9     for(auto v : adj[i]){
10         int b = v.first;
11         long long int w = v.second;
12         dist[i][b] = min(w, dist[i][b]);
13         dist[b][i] = min(w, dist[i][b]);
14     }
15 }
16
17 for(int k = 1; k <= n; k++){
18     for(int i = 1; i <= n; i++){
19         for(int j = 1; j <= n; j++){
20             dist[i][j] = min(dist[i][j], dist[i][k] + dist[k][j]);
21         }
22     }
23 }
```

3.2 Union Find

```
1 int s_size[MX];
2 int link[MX];
3
4 int max_size = 0;
5 int num;
6
7 int find(int x){
8     while(x != link[x])
9         x = link[x];
10    return x;
11 }
12
13 bool same(int a, int b){
14     return find(a) == find(b);
15 }
16
17 void unite(int a, int b){
18     a = find(a);
19     b = find(b);
20     if(s_size[a] < s_size[b])
21         swap(a, b);
22     s_size[a] += s_size[b];
23     max_size = max(max_size, s_size[a]);
24     link[b] = a;
25     num--;
26 }
27
28 int main(){
29     for(int i = 0; i < MX; i++){
30         s_size[i] = 1;
31         link[i] = i;
32     }
33
34     int n, m;
35     cin >> n >> m;
36     num = n;
37     for(int i = 0; i < m; i++){
38         int a, b;
39         cin >> a >> b;
40         if(!same(a, b))
41             unite(a, b);
42         cout << num << " " << max_size << endl;
43     }
44     return 0;
45 }
```

3.3 Path through all edges

```
1 set <int> adj[MX];
2
3 bool vis[MX];
4
5 void zero(){
6     for(int i = 0; i < MX; i++)
7         vis[i] = false;
8 }
9
10 int dfs1(int a){
11     int ret = 0;
12     vis[a] = true;
13     for(int b : adj[a]){
14         ret += 1;
15         if(!vis[b])
16             ret += dfs1(b);
17     }
18     return ret;
19 }
20
21 int main(){
22     int n, m;
23     cin >> n >> m;
```

```

24     for(int i = 0; i < m; i++){
25         int a, b;
26         cin >> a >> b;
27         adj[a].insert(b);
28         adj[b].insert(a);
29     }
30
31     zero();
32     if(dfs1(1)/2 != m){
33         cout << "IMPOSSIBLE";
34         return 0;
35     }
36
37     for(int i = 1; i <= n; i++){
38         if(adj[i].size() & 1){
39             cout << "IMPOSSIBLE";
40             return 0;
41         }
42     }
43
44     vector<int> ans;
45
46     stack<int> s;
47     s.push(1);
48     while(!s.empty()){
49         int a = s.top();
50         if(adj[a].size() == 0){
51             ans.push_back(a);
52             s.pop();
53         }
54         else{
55             int b = *adj[a].begin();
56             adj[a].erase(adj[a].begin());
57             adj[b].erase(a);
58             s.push(b);
59         }
60     }
61
62     for(int a : ans)
63         cout << a << " ";
64
65
66     return 0;
67 }

```

3.4 Topo Sort

```

1  int n, m;
2  stack<int> res;
3  vector<int> g[100007];
4  int vis[100007];
5  bool imp = false;
6
7  void dfs(int n){
8      vis[n] = 1;
9      for(int v : g[n]){
10         if(vis[v] == 0)
11             dfs(v);
12         else if(vis[v] == 1)
13             imp = true;
14     }
15     vis[n] = 2;
16     res.push(n);
17 }
18
19 int main(){
20     cin >> n >> m;
21     for(int i = 0 ; i < m; i++){
22         int a, b;
23         cin >> a >> b;
24         g[a].push_back(b);
25     }
26

```

```

27     for(int i = 1; i <= n; i++){
28         if(vis[i] == 0){
29             dfs(i);
30         }
31     }
32
33     if(!imp){
34         while(!res.empty()){
35             cout << res.top() << " ";
36             res.pop();
37         }
38     }
39     else{
40         cout << "IMPOSSIBLE";
41     }
42
43     return 0;
44 }

```

3.5 Flows and Cuts

All problems in this section can be solved using the same basic algorithm defined in 3.5.1.

3.5.1 Maximum Flow

This implementation of Ford-Fulkerson algorithm (known as Edmonds-Karp algorithm) uses BFS to check if it's possible to expand the flow through the graph and assign depths from the source. Later it uses DFS to expand the flow.

```

1 ll flow[MX][MX];
2 ll used[MX][MX];
3
4 vector<int> adj[MX];
5 vector<int> radj[MX];
6
7 bool vis[MX];
8
9 bool bfs(int s, int lvl[], const int n){
10     queue<int> q;
11     q.push(s);
12     lvl[s] = 1;
13     while(!q.empty()){
14         int p = q.front();
15         q.pop();
16         for(int v : adj[p]){
17             if(lvl[v] == 0 and flow[p][v] - used[p][v] > 0){
18                 lvl[v] = lvl[p]+1;
19                 q.push(v);
20             }
21         }
22         for(int v : radj[p]){
23             if(lvl[v] == 0 and used[v][p] > 0){
24                 lvl[v] = lvl[p]+1;
25                 q.push(v);
26             }
27         }
28     }
29     return lvl[n] > 0;
30 }
31
32 int dfs(int x, ll val, const int lvl[], const int n){
33     vis[x] = true;
34     if(x == n){
35         return val;
36     }
37     for(int v : adj[x]){
38         if(lvl[v] == lvl[x]+1 and flow[x][v] - used[x][v] > 0 and !vis[v]){
39             int r = dfs(v, min(val, flow[x][v]-used[x][v]), lvl, n);
40             if(r > 0){
41                 used[x][v] += r;
42                 return r;
43             }
44         }
45     }
46 }

```

```

45     }
46     for(int v : radj[x]){
47         if(lvl[v] == lvl[x]+1 and used[v][x] > 0 and !vis[v]){
48             int r = dfs(v, min(val, used[v][x]), lvl, n);
49             if(r > 0){
50                 used[v][x] -= r;
51                 return r;
52             }
53         }
54     }
55     return 0;
56 }

```

To find the flow:

```

1     long long int res = 0;
2
3     while(bfs(1, lvl, n)){
4         res += dfs(1, __INT_MAX__, lvl, n);
5         for(int i = 0 ; i < MX; i++){
6             vis[i] = false;
7             lvl[i] = 0;
8         }
9     }

```

3.5.2 Minimum Cut

To find Minimum Cut in a graph we need to find the Maximum Flow and check which edges connect two created disjoint sets of nodes. This modification to finds them:

```

1     long long int res = 0;
2
3     while(bfs(1, lvl, n)){
4         res += dfs(1, __INT_MAX__, lvl, n);
5         for(int i = 0 ; i < MX; i++){
6             vis[i] = false;
7             lvl[i] = 0;
8         }
9     }
10    cout << res << endl;
11    for(int i = 0 ; i < MX; i++){
12        vis[i] = false;
13        lvl[i] = 0;
14    }
15
16    bfs(1, lvl, n);
17    for(int a = 1; a <= n; a++){
18        if(lvl[a] > 0){
19            for(int b : adj[a]){
20                if(lvl[b] == 0){
21                    cout << a << " " << b << endl;
22                }
23            }
24        }
25    }

```

3.5.3 Maximum Matching

3.6 2SAT

Given logical formula in the conjunctive normal form:

$$(a_1 \vee b_1) \wedge (a_2 \vee b_2) \wedge \dots \wedge (a_n \vee b_n)$$

we can eliminate disjunction by repacing each $(a_i \vee b_i)$ element with pair:

$$\neg a_i \rightarrow b_i \wedge \neg b_i \rightarrow a_i$$

```

1 vector<int> adj[MX];
2 vector<int> Tadj[MX];
3 stack<int> scc_stack;
4
5 int scc[MX];
6
7 bool vis[MX];
8 int scc_val[MX];
9
10 int not_node(int a){
11     if(!(a&1))
12         return a+1;
13     else
14         return a-1;
15 }
16
17 void dfs1(int a){
18     vis[a] = true;
19     for(int b : adj[a]){
20         if(!vis[b])
21             dfs1(b);
22     }
23     scc_stack.push(a);
24 }
25
26 void dfs2(int a, int scc_n){
27     vis[a] = true;
28     for(int b : Tadj[a]){
29         if(!vis[b])
30             dfs2(b, scc_n);
31     }
32     scc[a] = scc_n;
33 }
34
35 void zero(){
36     for(int i = 0 ; i < MX; i++)
37         vis[i] = false;
38 }
39
40 int main(){
41     int n, m;
42     cin >> n >> m;
43     for(int i = 0 ; i < n; i++){
44         char op;
45         int a, b;
46         cin >> op >> a;
47         if(op == '+'){
48             a *= 2;
49         }
50         else{
51             a *= 2;
52             a++;
53         }
54         cin >> op >> b;
55         if(op == '+'){
56             b *= 2;
57         }
58         else{
59             b *= 2;
60             b++;
61         }
62         Tadj[a].push_back(not_node(b));
63         Tadj[b].push_back(not_node(a));
64         adj[not_node(b)].push_back(a);
65         adj[not_node(a)].push_back(b);
66     }
67
68     for(int i = 1 ; i <= 2*m+1; i++){
69         if(!vis[i])
70             dfs1(i);
71     }
72
73     zero();

```



```

74     int scc_n = 1;
75     while(!scc_stack.empty()){
76         int a = scc_stack.top();
77         scc_stack.pop();
78         if(scc[a] == 0){
79             dfs2(a, scc_n);
80             scc_n++;
81         }
82     }
83
84     for(int i = 2; i <= m*2; i+=2){
85         if(scc[i] == scc[i+1]){
86             cout << "IMPOSSIBLE" << endl;
87             return 0;
88         }
89     }
90     // 1 - false; 2 - true;
91     for(int i = 2; i <= 2*m; i+=2){
92         int a = scc[i];
93         int b = scc[i+1];
94         if(scc_val[a] != 0){
95             scc_val[b] = (scc_val[a] == 1 ? 2 : 1);
96         }
97         if(scc_val[b] != 0){
98             scc_val[a] = (scc_val[b] == 1 ? 2 : 1);
99         }
100        if(a < b){
101            scc_val[a] = 1;
102            scc_val[b] = 2;
103        }
104        else{
105            scc_val[a] = 2;
106            scc_val[b] = 1;
107        }
108    }
109
110    for(int i = 2; i <= m*2; i+=2)
111        cout << (scc_val[scc[i]] == 2 ? "+" : "-") << " ";
112
113    return 0;
114 }

```

4 Range Queries

4.1 Segment trees

BASE size table:

a	$2 \cdot 10^5$	$5 \cdot 10^5$	10^6
$\log_2 a$	18	19	20

4.1.1 Point-Range Trees

```

1  int sal[2*BASE];
2
3  void add(int p, int val){
4      p += BASE;
5      sal[p] += val;
6      while(p > 0){
7          p >>= 1;
8          sal[p] = sal[2*p] + sal[2*p+1];
9      }
10 }
11
12 int query(int p, int q){
13     int ret = 0;
14     p += BASE - 1;
15     q += BASE + 1;
16     while(p >> 1 != q >> 1){
17         if(not(p & 1)){

```

```

18         ret += sal[p+1];
19     }
20     if(q&1){
21         ret += sal[q-1];
22     }
23     p >>= 1;
24     q >>= 1;
25 }
26 return ret;
27 }

```

4.1.2 Range-Range Trees

1. range ADD insert, range MAX value query

```

1 void max_add(int a, int b, int val, int k=1, int x=0, int y=BASE-1){
2     if(a <= x and y <= b){
3         max_tree[k][1] += val;
4         return;
5     }
6     max_tree[2*k][1] += max_tree[k][1];
7     max_tree[2*k+1][1] += max_tree[k][1];
8     max_tree[k][0] += max_tree[k][1];
9     max_tree[k][1] = 0;
10
11     int d = (x+y)/2;
12     if(a <= d){
13         max_add(a, b, val, 2*k, x, d);
14     }
15     if(b > d){
16         max_add(a, b, val, 2*k+1, d+1, y);
17     }
18     max_tree[k][0] = max(max_tree[2*k+1][0] + max_tree[2*k+1][1], max_tree[2*k][0]
19         + max_tree[2*k][1]);
20 }

```

```

1 ll max_query(int a, int b, int k=1, int x=0, int y=BASE-1){
2     if(a <= x and y <= b){
3         return max_tree[k][0] + max_tree[k][1];
4     }
5     max_tree[2*k][1] += max_tree[k][1];
6     max_tree[2*k+1][1] += max_tree[k][1];
7     max_tree[k][0] += max_tree[k][1];
8     max_tree[k][1] = 0;
9     int d = (x+y)/2;
10    ll ret = -INF;
11    if(a <= d){
12        ret = max(ret, max_query(a, b, 2*k, x, d));
13    }
14    if(b > d){
15        ret = max(ret, max_query(a, b, 2*k+1, d+1, y));
16    }
17    return ret;
18 }

```

2. range ADD insert, range SUM query

```

1 void sum_add(int a, int b, int val, int k=1, int x=0, int y=BASE-1){
2     if(a <= x and y <= b){
3         sum_tree[k][1] += val;
4         return;
5     }
6     sum_tree[2*k][1] += sum_tree[k][1];
7     sum_tree[2*k+1][1] += sum_tree[k][1];
8     sum_tree[k][0] += sum_tree[k][1]*(y-x+1);
9     sum_tree[k][1] = 0;
10    int d = (x+y)/2;
11    if(a <= d){
12        int w = (d <= b ? d : b)+1;
13        w -= (x <= a ? a : x);
14        sum_tree[k][0] += val*(w);
15        sum_add(a, b, val, 2*k, x, d);
16    }

```

```

17     if(b > d){
18         int w = (y <= b ? y : b)+1;
19         w -= (d+1 <= a ? a : d+1);
20         sum_tree[k][0] += val*(w);
21         sum_add(a, b, val, 2*k+1, d+1, y);
22     }
23 }

1 ll sum_query(int a, int b, int k=1, int x=0, int y=BASE-1){
2     if(a <= x and y <= b){
3         return sum_tree[k][0] + sum_tree[k][1]*(y-x+1);
4     }
5     sum_tree[2*k][1] += sum_tree[k][1];
6     sum_tree[2*k+1][1] += sum_tree[k][1];
7     sum_tree[k][0] += sum_tree[k][1]*(y-x+1);
8     sum_tree[k][1] = 0;
9     int d = (x+y)/2;
10    ll ret = 0;
11    if(a <= d){
12        ret += sum_query(a, b, 2*k, x, d);
13    }
14    if(b > d){
15        ret += sum_query(a, b, 2*k+1, d+1, y);
16    }
17    return ret;
18 }
19 int sal[2*BASE];

```

4.2 Max Subarray Sum

```

1 ll ssum[2*BASE];
2 ll prfx[2*BASE];
3 ll sufx[2*BASE];
4 ll tsum[2*BASE];
5
6 void insert(int val, int p){
7     p+=BASE;
8     ssum[p] = val;
9     prfx[p] = val;
10    sufx[p] = val;
11    tsum[p] = val;
12    int l, r;
13    while(p){
14        p >>= 1;
15        l = 2*p;
16        r = 2*p+1;
17        tsum[p] = tsum[l] + tsum[r];
18        prfx[p] = max(prfx[l], tsum[l] + prfx[r]);
19        sufx[p] = max(sufx[l] + tsum[r], sufx[r]);
20        ssum[p] = max(sufx[l] + prfx[r], max(ssum[l], ssum[r]));
21    }
22 }

```

5 Tree Algorithms

5.1 Binary Lifting

```

1 int main(){
2     int n, q;
3     cin >> n >> q;
4     boss[1][0] = 0;
5     for(int i = 2; i <= n; i++){
6         cin >> boss[i][0];
7     }
8     for(int i = 1; i < LOG_MX; i++){
9         for(int emp = 1; emp <= MX; emp++){
10            boss[emp][i] = boss[boss[emp][i-1]][i-1];
11        }
12    }

```

5.2 Tree Traversal

```
1 vector <int> adj[MX];
2 int subtree[MX];
3 int flat[MX];
4 int vals[MX];
5
6 int idx = 1;
7 int dfs(int a, int p){
8     flat[a] = idx;
9     idx++;
10    for(int b : adj[a]){
11        if(b == p)
12            continue;
13        subtree[a] += dfs(b, a)+1;
14    }
15    return subtree[a];
16 }
```

5.3 LCA

LCA can be found using binary lifting or by building a segment tree build on pre- and postorder.

6 String Algorithms

6.1 Trie

```
1 int trie[TMX][30];
2 bool stop[TMX];
3 int next_node = 1;
4 int dp[MX];
5
6 void insert(string s){
7     int idx = 0;
8     for(char c : s){
9         if(trie[idx][c-'a'] == 0){
10             trie[idx][c-'a'] = next_node;
11             next_node ++;
12         }
13         idx = trie[idx][c-'a'];
14     }
15     stop[idx] = true;
16 }
17
18 int main(){
19     string text;
20     int n;
21     cin >> text >> n;
22     for(int i = 0; i < n; i++){
23         string s;
24         cin >> s;
25         insert(s);
26     }
```

6.2 Pattern Finding

6.2.1 KMP

```
1 int pi[MX];
2
3 int main(){
4     string text, pattern;
5     cin >> text >> pattern;
6     string s = pattern + "+" + text;
7     for(int i = 1; i < s.size(); i++){
8         int j = pi[i-1];
9         while(j > 0 and s[i] != s[j])
10             j = pi[j-1];
11         if(s[i] == s[j])
12             j++;
13     }
```

```

13     pi[i] = j;
14 }
15
16 int res = 0;
17 for(int i = 0; i < s.size(); i++){
18     if(pi[i] == pattern.size())
19         res++;
20 }
21
22 cout << res;
23 return 0;

```

6.2.2 Hashing

```

1  const int MOD = 1e9+9;
2  const int P = 9973;
3  const int MX = 1e6+7;
4
5  ll ppow[MX];
6  ll pfx_hash[MX];
7
8  int res = 0;
9
10 int main(){
11     string s, pattern;
12     cin >> s >> pattern;
13     ppow[0] = 1;
14     for(int i = 1 ; i < MX; i++){
15         ppow[i] = (ppow[i-1]*P)%MOD;
16     }
17
18     ll pattern_hash = 0;
19     for(int i = 0; i < pattern.size(); i++){
20         pattern_hash = (pattern_hash + (pattern[i]-'a'+1)*ppow[i])%MOD;
21     }
22
23     for(int i = 0; i < s.size(); i++){
24         pfx_hash[i+1] = (pfx_hash[i] + (s[i]-'a'+1)*ppow[i])%MOD;
25     }
26
27     for(int i = 0; i+pattern.size()-1 < s.size(); i++){
28         int a = i, b = i+pattern.size();
29         ll sub_hash = pfx_hash[b] - pfx_hash[a]+MOD;
30         sub_hash %= MOD;
31         if(sub_hash == (pattern_hash*ppow[a])%MOD){
32             res++;
33         }
34     }
35     cout << res << endl;
36     return 0;

```

6.3 Palindormes

Fiding longest palindromic substring.

```
1 int p[MX];
2
3 int main(){
4     string txt1, txt = "#";
5     cin >> txt1;
6     for(char c : txt1){
7         string s{c};
8         txt += s + "#";
9     }
10    txt = "^" + txt + "$";
11    int l = 1, r = 1;
12    for(int i = 1; i < txt.size(); i++){
13        p[i] = max(0, min(r-i, p[l+r-i]));
14        while(txt[i-p[i]] == txt[i+p[i]])
15            p[i]++;
16        if(i+p[i] > r){
17            l = i-p[i];
18            r = i+p[i];
19        }
20    }
21    int maxi = 0;
22    int imaxi;
23    for(int i = 0; i < txt.size(); i++){
24        if(p[i] > maxi){
25            maxi = p[i];
26            imaxi = i;
27        }
28    }
29    string res = txt.substr(imaxi-maxi+1, maxi*2-1);
30    for(auto c : res){
31        if(c != '#')
32            cout << c;
33    }
```

7 Mathematics

7.1 Fermat's Theorem

Modular inverse:

If m is prime, then: $x^{-1} \bmod m = x^{m-2} \bmod m$

$$x^{\varphi(m)} \bmod m = x^{k \bmod (m-1)} \bmod m$$

```
1 int exp(int a, int b, int MOD){
2     if(b == 0)
3         return 1;
4     if(b & 1){
5         return ((1ll)a * exp(a, b-1, MOD))%MOD;
6     }
7     ll tmp = exp(a, b/2, MOD);
8     return (tmp*tmp)%MOD;
9 }
```

7.2 Fast Fibonacci

```
1 void mul(ll a[][2], ll b[][2]){
2     ll res[2][2];
3     res[0][0] = a[0][0]*b[0][0] + a[0][1]*b[1][0];
4     res[0][1] = a[0][0]*b[0][1] + a[0][1]*b[1][1];
5     res[1][0] = a[1][0]*b[0][0] + a[1][1]*b[1][0];
6     res[1][1] = a[1][0]*b[0][1] + a[1][1]*b[1][1];
7 }
```

```

7
8     a[0][0] = res[0][0] % MOD;
9     a[0][1] = res[0][1] % MOD;
10    a[1][0] = res[1][0] % MOD;
11    a[1][1] = res[1][1] % MOD;
12 }
13
14 int main(){
15     ll n;
16     cin >> n;
17     ll m_pow[2][2] =
18         {{0, 1},
19          {1, 1}};
20     ll m[2][2] =
21         {{1, 0},
22          {0, 1}};
23
24     auto pow = bitset<64> (n);
25
26     for(int i = 0 ; i < 64; i++){
27         if(pow[i]){
28             mul(m,m_pow);
29         }
30         mul(m_pow, m_pow);
31     }
32
33     cout << m[0][1];
34
35     return 0;
36 }

```

8 Geometry

8.1 Point Location Test

```

1 // a, b line; c point
2 ll cross(pii a, pii b, pii c){
3     pii va, vb;
4     va.first = b.first-a.first;
5     va.second = b.second-a.second;
6     vb.first = c.first-b.first;
7     vb.second = c.second-b.second;
8     return (ll)va.first*vb.second - (ll)vb.first*va.second;
9 }
10
11 ll cros = cross(a, b, p);
12 if(cros > 0)
13     cout << "LEFT\n";
14 else if(cros == 0)
15     cout << "TOUCH\n";
16 else
17     cout << "RIGHT\n";
18 }

```

9 Other Algorithms